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PROFESSIONAL PAPERS

OF THE

CORPS OF ROYAL ENGINEERS.

EDITED BY

CAPTAIN R. F. EDWARDS, R.E.

ROYAL ENGINEERS INSTITUTE

OCCASIONAL PAPERS.

VOL. XXIV.
1898.

Chatham:
PRINTED BY W. & J. MACKAY & CO., LTD., 176, HIGH STREET.
PUBLISHED BY THE ROYAL ENGINEERS INSTITUTE, CHATHAM.

AGENTS: W. & J. MACKAY & CO., LTD., CHATHAM.

1898.
Price, 10*s*. 6*d*. *net*.

LIST OF PLATES.

ERRATUM.

On *Plate* VIII., Paper V., *for* "1892" *read* "1792."

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PAPER I.

THE SELECTION, TESTING AND EMPLOYMENT OF CEMENT.

BY A. E. CAREY, ESQ., M.INST.C.E.

(*Fellow of the Chemical and Geological Societies*).

BEFORE dealing with the technical side of my subject, I may, perhaps, be pardoned if I refer briefly to the historical aspect of the question. In doing so, I cannot forbear from calling to your attention a fact which has, I think, entirely escaped notice. In the various developments and advances in scientific work which have been originated during Her Majesty's reign, no one, so far as I am aware, has recalled the fact that the manufacture of Portland cement is practically an art of the Victorian era. Considering the various applications of this material, and the fact that it has enabled works to be carried out which, without it, would have been impossible, or only practicable at an enormously enhanced cost, its inception may certainly be regarded as one of the industrial triumphs of Her Majesty's reign.

Portland cement is the product of English intelligence and perseverance. The profound and lucid mind of Smeaton first grasped the true significance of hydraulicity in cements, and the very name of Portland cement springs from a casual reference to the subject by him. He discovered that the partial fusion of bodies which are compounds of lime and clay gave hydraulic qualities, or the power of setting and hardening under water, to the resulting bodies, and that what Nature had done by random blendings in Roman and other cements could be systematically achieved by artificial means. In pondering upon the material which would be most suited for his purpose when about to build the Eddystone Lighthouse, chance threw in his way the means of experimenting with an Italian deposit called terra puzzuolana, coming from Civita Vecchia. A cargo of this volcanic material happened then, owing to a contractor's dispute, to lie at Plymouth. Smeaton instituted a long series of trials to ascertain the varying degrees of earthy matter present in the different limestones which he was able to obtain, and eventually fixed upon the Aberthaw lime as the most suited to his purpose. He clearly demonstrated that the hydraulic qualities of different samples depended upon the proportion of residuum remaining after dissolving the limestone from which they were made in acid. He then tested the hardening qualities of a number of mortars when immersed in water, and, in the end, determined on adopting Aberthaw lime mixed with puzzuolana. Now puzzuolana consists of about 44½ per cent. of silica, with 27 per cent. of alumina and oxide of iron, 9 per cent. of lime, and 4½ per cent. of magnesia. The Aberthaw limestone contains about 86 per cent. of carbonate of lime and 11 per cent. of clay. He said, in reviewing his investigations, "I did not doubt but to make a cement that would equal the best marketable Portland stone in solidity and durability." In another place he says, "I had no doubt of being able to unite the whole materials of my building into one solid mass of stone"—a foreshadowing of that great ideal of monolithic mass concrete towards which harbour practice is approaching more nearly year by year. The Eddystone Lighthouse has proved a monument of the prescience of the master mind of Smeaton, and of the skill with which his dispositions were made. The wearing away of the rock on which the lighthouse stood alone necessitated its being replaced by another structure after 123 years of storm and stress.

Little or no advance, so far as practical work is concerned, appears to have been made for many years after the publication of Smeaton's narrative in 1791. The patent of a builder named Aspdin, in 1824, describes somewhat closely the method of making Portland cement, but the dubious product of those days would seem, with good reason, to have been looked at askance by those engaged in actual work. The name of the great French chemist Vicat must not be forgotten as one of the pioneers in the artificial production of hydraulic cements, but apparently he got his clue from the researches of Smeaton. The honour of carrying forward the investigations which had almost come to a deadlock rests with a distinguished Royal Engineer, namely, General Sir Charles Pasley. In 1826, by command of the Duke of Wellington, he directed attention to this subject among the Royal Engineer officers in Chatham Dockyard. Apparently quite by chance, he blended and burnt some Medway clay with lime, and thus took a long stride towards modern practice. It was not, however, until the early forties that the manufacture of Portland cement truly commenced, almost simultaneously at the Swanscombe Works, now carried on by Messrs. J. B. White Bros., and the Northfleet Works of Messrs. Aspdin & Co. (now Messrs. Robins). The material was at first an extremely crude and uncertain one, and it is not difficult to account for the caution and suspicion with which it was first used, those responsible for the stability of their work being extremely shy of a material which was only in the state of inception. Another Royal Engineer officer of world-wide reputation, who was one of the pioneers in the *use* of Portland cement, still remains one of its strongest advocates. I refer to General Sir Andrew Clarke, who realized the latent capabilities of the material then struggling into use. In 1859, when the London Main Drainage Works commenced, the late Mr. John Grant boldly pinned his faith to the reliability of sound Portland cement, and the papers which he subsequently read at the Institution of Civil Engineers, in 1866 and 1871, on the testing of Portland cement, remained for many years the standard authorities on that subject. In the past 30 years the use of Portland cement has increased by leaps and bounds, until at this moment its production is a vast industry, which is no longer confined to the Thames and Medway districts, but is carried on in many different parts of England, to an enormous extent throughout the Continent, and to some extent in the United States. The United States do not produce more than one-half of their consumption. In India there are works at Madras, the cement being made from a shelly deposit, and in Australia various attempts to manufacture have been made, but, so far as I am aware, with indifferent success. In New Zealand there are two small factories, and there are one or two indifferently successful works in the South American continent.

As has been the case in other fields, the Germans, for a time, beat us on our ground, making a more finely ground and constant product. England is now, however, fast regaining the lead, which she should never have lost.

Portland cement is, in effect, a calcic silicate and aluminate. The degree of excellence of a given sample depends on the care and perfection of the blending of the materials, and the degree of vitrifaction to which they are subjected. Accuracy and skill in these operations result in chemical perfection, but it is essential that the clinker should be ground to an extreme degree of fineness, in order to bring about the mechanical condition which is essential to a satisfactory result in concrete making. In this district the manufacture of Portland cement is carried on in the following manner :—Chalk and river clay are blended in a washmill, being beaten into a liquid state with from 25 per cent. to 35 per cent. of water. The perfection of the blending of the raw materials at this stage is of the utmost importance, and in the best works a second, or finishing, mill is used after the materials have passed through the washmill. The calcimeter tests, at this stage, are of the utmost importance in order to ensure regularity and uniformity in the product. The proportion of carbonate of lime in the slurry varies from 72 to 75 ; if below 73 a low grade cement will result, and if above 76 a risky cement, from overliming, is almost certainly produced. The Dietrich calcimeter is an apparatus by which a given quantity of slurry or cement is treated with a given weight of hydrochloric acid in a graduated glass tube, and the carbonic acid gas given off displaces a column of mercury or distilled water from which the percentage of carbonate of lime may be worked out by tables. After being amalgamated in the washmill, the slurry is elevated or pumped to the wetmill stones, where it is ground to an extreme degree of fineness. About 8 per cent. on a sieve of 22,500 meshes per square inch is the best practice. If there is carelessness at this stage of the manufacture, the clinker is found full of minute particles of caustic lime, and when it is ground into cement, this caustic lime becomes hydrated, and slowly absorbs carbonic acid from the air. If overlimed cement is used, without being properly aerated, the concrete made from it will be blowy and unsatisfactory, and even if the caustic lime is sufficiently hydrated, there results an inert and soluble body instead of one chemically active. The next stage in the manufacture is the pumping of the liquid slurry on to the drying floor—arched chambers in connection with the kilns. The waste heat from one burning of a kiln is utilized for the drying of the succeeding charge of slurry, or slip, as it is termed, and when a kiln is drawn, this dried slip is loaded into it with the required proportion of coke for the next burning. Pure carbonate of lime contains about 56 per cent. of lime and 44 per cent. of carbonic acid, and in the burning of the dried slip the first effect is the expulsion of the carbonic acid, thus producing oxide of calcium or caustic lime. This change takes place at about 820° Fahrenheit. The next thing that happens is that the silica and lime gradually unite and form silicate of lime, up to a temperature of about 1,300° Fahrenheit. If the heat is too intense glass is produced. It is not uncommon to see it hanging in streamers from the bars of a cement kiln. I need hardly say that when this is the case to any considerable degree, the cement is burnt to death, and its chemical activity greatly reduced. There is a certain proportion of ferric oxide combined with the alumina of the clay, and this fuses at a lower temperature than the other bodies, and forms that blue black colour which is one indication of good clinker. The most perfect clinker has a greenish tinge upon its surface, and this is in all probability due to a trace of manganese in the clay. If the clay contains an excess of alumina, the silica compounds will be over-burnt before a true chemical combination of the lime, silica, and alumina is reached, and the result is an inert and feeble cement. What cement burners call "yellows" or "pinks" are the under-burnt clinker, which should be rigorously excluded from the crusher-house, as an under-burnt cement is most dangerous in use, owing to the blowing caused in the hydration of the caustic lime it contains. I recollect, in one instance, seeing the floor of a large warehouse, the walls of which were well built 18″ brickwork, with heavy iron cross ties, cracked, and in serrated ridges from end to end. This result was due to the use of an under-burnt cement in the concrete. After the clinker is burnt, it is drawn from the kiln, crushed and ground, and it is in the degree of fineness of grinding that there has been so marked an advance, even in the last ten years. The old specification of a residue of 10 per cent. on a 50 × 50 mesh sieve is now utterly out of date. It is the flour or unpalpable powder which is the really effective part of cement, not the nibs or coarse residue, which are of no greater advantage than a similar proportion of sand would be. It may be a startling statement, but nevertheless it is correct, that quite 8 cwt. in every ton of ordinary high-class cement, as supplied by the best makers, is entirely ineffective in cementitious qualities. The sieve most commonly adopted in the best specification of to-day is that of 5,000 meshes per square centimètre, which is equivalent to 32,257 meshes per square inch. Every particle of cement which will not pass through that sieve is of little or no use to you in making concrete. This is very easily demonstrated. Take the residue upon this mesh, and try to make a briquette with it, and you will find that it only coheres in a very feeble way, and forms a sort of loose paste. Another way of showing how important fine grinding is, is to make a comparative series of tests of the same sample of cement eliminating, the coarser parts by degrees. The following figures may, perhaps, be of interest to you. The temperature of the air and of the cement was 46° Fahrenheit, and the result was that obtained at 28 days, being the average of 6 briquettes in each case.

	Lbs. per square inch Tensile Breaking Strain.
Cement as ground, 9 per cent. residue on 50 × 50 mesh	220
do. with residue on 50 × 50 removed	304
do. do. 75 × 75 do.	311
do. do. 32,257 do.	360

I may just mention that the wire of which the extremely fine mesh sieves are made must, of course, for comparative purposes, be similar, as by varying the thickness of the wire the size of the holes in the sieve are correspondingly increased or diminished. The finest wire for sieves now in use is, I believe, ·0025 inch.

There are two guiding lights in Portland cement testing: one is the specific gravity of the cement, and the other is the fineness to which it is ground. Provided the cement is not adulterated, these data alone give you a very clear insight into its quality. If the cement is of a high specific gravity it must be well burnt. If a given cement has a specific gravity of not less than 3·1, and a fineness of 35 per cent. on a 32,000 mesh, you may use it for high-class work without waiting for the other usual tests, always providing, as I said before, that the cement is not adulterated. Until quite recently one of the standard conditions of testing cement has been the weight per striked bushel, and it has generally been specified at weights varying from 112 to 116 lbs. The test is fast dropping out of use, as it is of no practical value. By knocking or shaking the bushel measure you can increase the weight per bushel by 4 or 5 lbs. I remember an instance in which two people took the weight of the same sample of cement. One made it 115 lbs. to the bushel, and the other 130 lbs. The specific gravity is the true test, and this is best taken by a Schumann apparatus, which consists of a glass bulb with a glass tube fitting into it, having a graduated scale, which is filled with turpentine to a given level. A given weight of cement is introduced with great care, and the displacement of the turpentine indicates on the scale the specific gravity of the cement. In testing briquettes up to fracture under tensile strain, the apparatus now most commonly in use is the Holste or (as it is more commonly called) the Shot machine, shot being used for applying breaking weight. The old section of test of $1\frac{1}{2}'' \times 1\frac{1}{2}''$, giving $2\frac{1}{4}$ square inches in the neck of the briquette, is quite out of date. It involves an inconveniently large quantity of cement to manipulate with the rapidity necessary. A briquette of this size weighs about 2 lbs., whereas the 1″ briquette, which is now almost universally used, only weighs 5 ozs. In the making up of briquettes constant practice gives great skill, and an experienced briquette maker will, of course, obtain much better results than a beginner. Brass moulds are used, those of the best type admitting of the briquettes being taken out, when sufficiently hardened, without jarring. When sea water is used for making cement briquettes, they set more slowly than if fresh water were used, and give higher results, by about 15 per cent., at 7 days. They attain their maximum tensile strength at about 9 months, whereas fresh-water briquettes increase in tensile strength, at any rate for several years. It must not, however, be assumed from this that fresh water is preferable to salt water in actual work. In the majority of instances the very opposite is the case. In all probability the difference of effect due to the use of salt or fresh water is a physical difference rather than a chemical one. Crystallization and consequent hardening of the cement goes on for very long periods when sea water is used. The concrete so produced is probably a harder, denser, and more brittle material, standing a higher compressive strain, but fracturing more readily under tensile strain than if fresh water had been used. I shall have more particularly to refer to the question of the water of gauging for concrete work, as several points of the first interest hinge upon it.

The grouping of the potentially active compounds of Portland cement in concrete work is very obscure. According to Le Chatelier, the lime, silica, and alumina, which in effective combination are its active components, group themselves as tricalcic silicates and tricalcic aluminates. These three ingredients, in good samples of Portland cement, comprise 91 per cent. or 92 per cent. of the whole mass. About $60\frac{1}{2}$ or 61 per cent. of lime, $20\frac{1}{2}$ per cent. or 21 per cent. of silica, and about 9 per cent. of alumina are, on analysis, found in the best samples of Portland cement In addition to this, 3 or 4 per cent. of ferric oxide is found in combination with the alumina, and there is generally 1 to $1\frac{1}{2}$ per cent. of magnesia, about $\frac{3}{4}$ per cent. of sulphuric acid, and small quantities of potash and soda. The following has been given as the chemical formula for Portland cement:—3 (SiO_2, $3CaO$), Al_2O_3, $3CaO$, but this is a mere approximation, as it represents an excess of lime and a deficiency of silica. If alumina, with oxide of iron, is present to the extent of more than about 13 per cent., on burning the clinker the silica probably never gets a chance of combining really effectively, as the lime and the excess of alumina begin to pair and leave some of the silica more or less uncombined. The colour of the clinker is thus a good indication to the character of the cement, and in cement specifications power should always be retained for the cement inspector to visit the manufacturer's works at discretion. The best cement makers raise no difficulty as to this, which is a regular condition in the specifications of the Admiralty, and War and Colonial Offices. Should the lime be in an excess, some of the silica probably unites with it prematurely, thus robbing the resulting material of some portion of its effective constituents. An excess of lime causes a high tensile strain at 7 days, which, in many cases, is the only test which users really depend upon. This high short-term test is entirely fallacious, as it is not permanent. The use of more than 74 per cent. or 75 per cent. of carbonate of lime is disastrous to all concerned. If a considerable excess on this figure is used, the cement, when burnt and ground, contains a lot of caustic lime, the effect of which is a blowing in the finished work, unless the cement is sufficiently aerated to hydrate it off. In works in the sea a fresh crop of difficulties arises if an over-limed cement be adopted. To sum up the preliminary points which require special attention, they are as follows :—

(1). Specific gravity.

(2). Fineness of grinding.

(3). Either an analysis of the cement or some supervision at the works in order to insure a satisfactory burning of the raw materials.

(4.) The usual tensile tests.

During the last 10 years there has been great controversy as to the alleged chemical deterioration of concrete in sea water. One point has been incontestably proved—*i.e.*, that, with sound cement, and a well proportioned concrete, there is not a tittle of evidence of any period to the life of a concrete structure in the sea. Two serious failures occurred at Aberdeen—one in the foundations of the

South Breakwater, the other in the walls of a dry dock. The dock walls were built in a proportion of 1 cement, 3 sand, and respectively 3 and 4 parts of stones, not being faced with an impermeable rendering. The walls bulged and crumbled, and, on analysis, the percentage of magnesia in the disintegrated concrete was shown to be abnormally high. The theory of chemical degeneration was set up to account for this result. It was argued that concrete of the proportions used being porous, the hydraulic pressure, to which it was periodically subjected, had caused a flow of sea water through the mass of the wall, and this, it was supposed, must have set up some chemical dissolution. Mr. Pattison, Chemical Analyst for Northumberland, reported "that a chemical action between sea water and cement had actually taken place, that is, that the lime of the cement precipitates (as hydrate) the magnesia of the magnesium chloride and sulphate contained in sea water, with the consequent formation of calcium chloride and sulphate. If the cement is continually brought into contact throughout its substance with fresh portions of sea water, there will be a continued deposition of hydrate of magnesia and probably sulphate of lime, and removal of lime, necessarily resulting in the disintegration and destruction of the cement." As a result of this theory, for a time much alarm prevailed for the permanence of concrete works in the sea. Magnesia may, however, be added to cement in a very much larger percentage than that in any sample in the market, and its effect is simply that of a harmless diluent. In 1891 I instituted a series of experiments to show the effect of sulphuric acid in cement, and demonstrated that an addition of 5 per cent. to the water of gauging will bring down the strength at 7 days from 550 lbs. to 150, being a reduction of 73 per cent. Dr. Michaelis and some other specialist chemists now hold that porous concretes will disintegrate, especially under pressure in sea water. Sulphuric and hydrochloric acids are, they state, drawn away from the magnesium salts (the sulphates and chlorides) present in sea water; that they leave the magnesium base, combine with lime, for which they have more affinity, expand in crystallizing, and rupture the concrete. Whether this may be taken as a proved fact or no, it is certain that what Mr. Sandeman has well termed the "watertightness" of concrete is a most important, if not a vital, consideration. In a yard measure of gravel, from which the sand has been screened, $\frac{1}{3}$ is interstice, and the aggregates commonly used give a variation of from $\frac{1}{3}$ to $\frac{1}{2}$ of interstitial voids. Using cement of say 35 per cent. residue on a

32,000 mesh, coarse sand and shingle or small broken stone, the best proportions to ensure watertightness are :—

Cement.			Sand.			Shingle
1	...	...	1	...	..	$3\frac{1}{2}$
1	...	...	2	...	...	5
1	...	...	3	...	...	7

I may perhaps mention that a cubic yard of raw materials represents a trifle more than $\frac{5}{8}$ of a yard of finished concrete. The plan of punning or ramming concrete or dropping it from a height, as many contractors are fond of doing, is entirely a mistake. A little working as soon after deposition as possible, where a thin pavement is being laid, is an advantage, for it brings the liquid portions to the surface ; but, in massive work, the great point is to disturb the half-set concrete below the portion being deposited as little as is consistent with bringing the more liquid cement charged part of this to the surface of the work. At this point it may perhaps be well if I give you *in extenso* a cement specification, and I will therefore read to you the specification for the Portland cement used on the Hastings Harbour Works. These works I am now carrying out, but, although the specification is a complete and comprehensive one, it did not meet every eventuality.

Portland Cement.

"This shall be supplied from approved factories, and tested at the maker's works before being sent on. The Engineer or his representative may be present at the time of taking samples from the bulk cement, also when briquettes are gauged or broken, or during any operation necessary to prove its quality.

"Due notice shall be given by the Contractors to the Engineer of the date when consignments shall be ready for delivery, in order that he may take means to have all necessary tests carried out.

"The whole of the cement to be used on these works to be of a uniform dark grey colour, and free from all foreign constituents or adulterants, and comply with each and every one of the following conditions and tests :—

(*a*). "*Specific Gravity.*—Shall not be less than 3·1.

(*b*). "*Tensile Strength.*—Not less than 12 sample test briquettes of approved shape and of inch square or other approved section are to be made from the bulk of the different consignments, 8 being gauged neat, and 4 with 3 parts of normal sand. They shall be placed in sea water 24 hours after gauging, remaining thus steeped, and shall, at 3 and 7 days respectively, resist the following tensile strains applied in a machine to be approved by the Engineer.

Neat Cement.	Not less than an average of	Cement 1 part. Normal sand 3 parts.	Not less than an average of
Days.	Lbs. per sq. inch.	Days.	Lbs. per sq. inch.
3	180	7	130
7	400	—	—

"The rate at which the tensile strain shall be applied to be 100 lbs. in 10 seconds. Normal sand shall be quartz sand of approved quality, the whole of which passes through a sieve of 400 meshes per square inch, and the whole of which is retained on a sieve of 900 meshes per square inch.

(*c*). "*Over-liming.*—The Engineer or his representative may apply such tests with a view to determine any excess of lime as he considers necessary.

(*d*). "*Fineness.*—The cement shall be uniformly ground free from coarse clinker, and samples taken at random shall leave a residue by weight of not more than 5 per cent. in a sieve of 2,500 meshes per square inch, and of not more than 35 per cent. in a sieve of 32,000 meshes per square inch.

(*e*). "*Gauging.*—The proportionate quantity of water by weight used in gauging shall be correctly recorded, and also the temperature of the air, and that of the cement at the time of gauging. Observations of the time the cement takes in setting are also to be recorded."

I may now mention a matter which has, I believe, hitherto almost entirely escaped notice, namely, the effect of low sea temperatures in marine work. I was Resident Engineer on the Newhaven Harbour Works for seven years, and Hastings is only distant from Newhaven as the crow flies about 25 miles. The very first winter during which the Hastings Harbour Works were carried on brought to light a condition of affairs curiously different in the two localities. The works progressed in a perfectly normal way until the latter part of the month of October, when considerable losses of half-set concrete at the scar end of the works began, and the concrete was unusually slow in hardening. The specification tests were gone over again and again, but, barring the fact that the cement was extremely slow setting, due to very heavy burning, there was no characteristic to the door of which this condition of affairs could be laid. A series of new tests were then instituted, and samples of cement were, for this object, drawn from five of the principal makers. The result of these clearly demonstrated that the extreme cold of the sea was the cause of the effect produced. The temperature of the sea on several occasions ran down to 2 or 3 degrees above freezing, a result doubtless due to the enormous volume of extremely cold water flowing down from the North Sea into the English Channel. The Channel currents and those of the North Sea meet near Dungeness, immediately to the eastward of Hastings, and although I took no records, I have little doubt that the winter temperature of the sea at Newhaven is considerably higher than that at Hastings. Years ago I published a number of laboratory tests on the effect of extreme cold on briquettes, by which it was demonstrated that if briquettes are kept frozen, their properties remain dormant. An addition was made to the Hastings specification, requiring, when gauged with sea water drawn direct from the sea, setting properties sufficient to ensure resistance to the Vicat needle carrying $2\frac{1}{2}$ lbs. weight 25 minutes after gauging. It was also stipulated that balls of cement made with sea water, and plunged into sea water immediately after gauging, should not disintegrate. This, I may add, is an extremely searching test, and one well worth keeping in mind as a ready and quick guide to the grade of any particular sample of cement. It has fallen to my lot also to carry out harbour works under exactly opposite conditions to those I have detailed for Hastings. At the Harbour Works of La Guaira, in Venezuela, we were working within a few degrees of the line, and the effect of the warm sea water and high temperature was great rapidity in setting. You, as Royal Engineer officers, will have to carry out public works in every part of Her Majesty's dominions. You will therefore have to provide for every conceivable variety of condition. In tropical countries the great thing to remember is that concrete when setting must be kept constantly and thoroughly wet, otherwise the water of combination will evaporate before the proper chemical change has resulted. At La Guaira, when we were not being cannonaded by northers, the spray constantly beat over our work and kept it wet. For works in regions of extreme cold, my advice would be a careful preliminary record for as long a period as possible of the actual temperatures which may be expected, and, if these are extreme at all seasons of the year, that fact would certainly militate very greatly against the adoption of the system of mass concrete built *in situ*.

I propose now to briefly summarize the matters to be specially considered in applying concrete to foreshore works and structures in the sea. In dealing with the raw materials, I need hardly say that if you have a choice of stone you should take that which is least absorbent and friable, and which, at the same time, possesses the highest specific gravity. In structures in the open sea you have to match dead weight against moving force, and therefore weight per unit is a matter of primary importance. Crushed Guernsey granite, washed granite sand, and Portland cement in the proportions of 5, 2 and 1, give 3 days after gauging a weight of $142\frac{1}{2}$ lbs. per cubic foot. Concrete made of ordinary sea shingle and sand weighs almost exactly the same. You do not, however, get so perfect a key as with the sharp splintered edges of crushed granite, which is an ideal material for concrete work. At the Imperial Stone Company's Works at Greenwich a series of tests were made with washed crushed granite sand against unwashed samples, and the results were in favour of the washed sand to the extent of about 15 per cent. to 20 per cent. By washing you get rid of the fractural dust, which prevents the perfect adhesion of the rough surfaces. Another most important matter is the size of the stone which will give the best results. In this connection I may mention that there is a great variation in the size of the shingle along most foreshores. If you take shingle from the leeward side of a groyne, it is almost always much finer than that from the windward side, the action of the waves having the effect of riddling out and raking down the smaller material, which gets carried away to leeward. At Newhaven there were long foreshore walls to be built on both sides of the harbour, and the advantage of the use of the larger shingle on the western side was most marked. In the sea walls on the eastern side it was very difficult to prevent hair cracks. Tests of concrete girders which I had made demonstrated the superiority of the big shingle concrete incontestably. I should advise you, therefore, before drafting a specification, to take the percentage passing through respectively a $\frac{3}{4}$-inch, 1-inch and $1\frac{1}{4}$-inch mesh, and, on the result, adjust the proportion of cement in the mixture. I may, perhaps, mention that on the west side of Shoreham Harbour 25 per cent. of the shingle will pass through a $\frac{3}{4}$-inch mesh; on the eastern side the percentage is 40 per cent. On the western side of Newhaven Harbour 20 per cent. will pass through a $\frac{3}{4}$-inch mesh, and on the eastern side 55 per cent. Taking the 1-inch mesh, the proportions are:—

Shoreham ... 33 per cent. and 55 per cent. respectively.
Newhaven ... 60 per cent. and 70 per cent. respectively.

On Brighton beach 31 per cent. will pass through a $\frac{3}{4}$-inch mesh, and 90 per cent. a 1-inch mesh. You will thus see that in three localities, distant only a few miles apart, you have an enormous variation. If you can get irregular masses of stone, up to about $\frac{1}{2}$ cubic foot size, it is a capital plan to add them pellmell in the heart of the work, but keep them quite a foot away from the surface, as, if one of these stones gets loose, it may cause much mischief before the injury can be made good. I need hardly say that a perfectly smooth and dense skin is of the most vital importance in a structure in the sea. If you get cavities or irregularities in the surface of the work on which the seas break, air is compressed, and may produce dangerous forces within the structure itself. There have been instances in which waves beating on the weather side of a stone pier have started stones on the lee side, the compressed air acting with an almost explosive force, traversing the joints in the structure in following the line of least resistance and shaking or driving out blocks on the inner side. At Hastings we are putting in the foundation work up to low water level at $5\frac{1}{2}$ to 1, and the work above that level at 7 to 1.

With regard to the quantity of water; if you have a non-absorbent aggregate, my experience has been that 22 gallons per cubic yard of raw material will give the best results. I may add that this proportion is now being used on the Sunderland piers. Without a sufficiency of water you cannot bring to the surface the cement-charged portion of the mass, which will give you the tough, smooth skin which is so important. Take special care that the water to be used in making concrete is free from contamination, especially such as the silt, which is often brought down by rivers, or that of sewage contamination, which has to be guarded against where an outfall lies near your work. At Newhaven we built our foundation reef of sack blocks of 100 tons weight, and the mixing plant for making these was erected inside the River Ouse, which forms part of the harbour. For a considerable time the setting of these sacks was apparently capricious. In some cases they set in a perfectly normal manner, whereas in others after days or even weeks they cracked or broke up in a most unaccountable way. They were all made apparently under exactly similar conditions, but at last it dawned upon me that possibly the water, which was drawn direct from the river, might be the source of all our troubles. This proved to be the case, as when water was taken on the flood tide, and was, therefore, clear sea water, the difficulty ceased. There are several machines in the market for the mixing of concrete; that of the late Mr. Messent, of the Tyne, is an intermittent machine, a given quantity of materials being shaken in a box until blended. The Carey and Latham machine is of the continuous type, that is to say, the raw materials are continually fed into it, blended, and flow from it in a continuous stream either into wagons, direct into the work, or into hopper barges, if sack blocks are intended to be used. The most commonly used machine is that of the portable type. At Newhaven we had also a large fixed machine by which we were able to mix and deliver 100 tons of concrete in from 17 to 20 minutes. The maximum output of the portable machines now in use is 70 yards of concrete per hour, but, by multiplying the number of them, any required output may be attained. The sand and shingle, in the specified proportions, are lifted in dredger buckets, which take their supply from wooden hoppers alongside the machine. Tramway lines are laid so that these raw materials are shot direct into the hoppers. The cement is fed by an Archimedean screw, and a simple arrangement is to use an old railway brake van as a cement store, from which the cement is fed direct into the hopper feeding the screw. The centre shaft in the mixing cylinder acts also as a pipe through which water flows for incorporating the raw materials. The system has the advantage that by making openings for the water in any given proportionate length of the pipe the materials may be partly dry mixed and partly wet mixed in the cylinder to any required degree. A series of scrapers are fixed to the arms of this centre pipe, and they travel at a different speed to the mixing cylinder itself. The machine has been improved from time to time, as experience showed to be necessary, and the results of its use are certainly the production of more uniform concrete than hand mixing under ordinary conditions. The only thing the foreman has to see is that the machine is kept regularly fed, whereas by hand mixing you are entirely at the mercy of the foreman of works, who, if he scamps his job, may turn out bad or irregular work, for which you are very properly held responsible. Moreover, the temptation of a contractor is always to put in less cement than the proportion specified, whereas, by mechanical mixing, if the hopper is kept full, this is impossible. The cost of mixing by hand, at Newhaven, was 14½d. per cubic yard of raw materials; that by machine was 5½d. The labour on each 100-ton sack block was £5 5s. by hand; by machine £1 15s.

I may briefly refer to the methods of constructing breakwaters. One great charm about sea work is that no two places are alike, and you have to study and adapt your system to the locality you are at work upon. The foundation reef is the most difficult part of such structures. This should be carried a couple of feet above low water ordinary tides, to give a working plateau for the superstructure. The portion of the superstructure above high water level may require different treatment to the rest. Personally, I am an advocate of what is termed the monolithic system, that is, the system by which concrete in a soft or plastic condition is used, the aim being to produce a homogeneous structure, without joint or break from end to end. There are many distinguished advocates of the set block system, which is to be adopted at the great National Harbour about to be constructed at Dover. At Newhaven we built our foundation reef, which rested on the chalk bottom, in sack blocks of 100 tons weight, deposited from a 100-ton hopper barge. The superstructure was built in lengths of 40 feet, within a wooden framing. By carefully roughing the old work, so that the new concrete permeated its surface, the superstructure, as built, became a veritable monolith. The sack blocks were a trifle short, and there was a tendency for these to chafe on the weather side. Had they been 5 or 6 feet longer, the work would, probably, have cost less in construction. At La Guaira we had very severe conditions to contend with, the sea being hardly ever at rest, and storms of the hurricane type, at certain seasons of the year, frequent. The foundations were built in sack blocks, the maximum weight of which was 160 tons, and the upper tiers, which carried the work to about 10 feet below water level, weighed 130 tons each. A difficulty then presented itself. There was practically no tide, the tidal range being only about 15 inches, and when the depth of water in which the hopper barge would swim was reached, the system of depositing sack blocks became no longer admissible. The contractors suggested the depositing of sack blocks from travelling rocking depositors running on the surface of the finished work, and this system was ultimately adopted with complete success, the blocks, as used, being 70 tons in weight. When, by this system, the work reached water level, the cap of the entire structure was built in mass concrete. At its extremity the work is in 47 feet of water. At Hastings we are building the shoreward portion of our breakwaters on a soft sandstone rock, but this runs into silty mud with a substratum of stiff clay. The whole foundation is extremely broken and irregular. The system there adopted is that piles are driven to form a working stage, and up to about low water level freshly mixed concrete is deposited by means of skips into wooden framing fixed previously by divers. Upon the reef thus formed is built a mass concrete superstructure. At Sunderland Mr. Wake is building his foundations up to about low water level in sack blocks of 116, 75, and 52 tons weight. These blocks are laid and deposited with great accuracy to marks fixed by divers. The superstructure is built in four courses of set blocks, each averaging 43 tons weight, the outer blocks being faced with granite. Cross tie walls 42 feet 7 inches apart are built, and the intervening spaces filled in with mass concrete. This is an instance, therefore, of a compound structure, consisting partly of mass concrete, partly of sack blocks, the superstructure resting on a reef of sack blocks. With regard to the use of the set block system, it is obviously much more costly in plant than the rival system. Both systems have produced sound and permanent work, and they are about equally rapid. Doubtless the best system will in the long run win, but local conditions must always largely decide the issue.

Compound structures of concrete in conjunction with steel or iron have been in use for many years, and a large number of patents have been taken out. The Melan system of vaulting consists of small steel joists curved to the radius of the arch to be built, and about 3 feet apart, the intervening space being formed in concrete. The Monier system consists of a network of longitudinal and transverse iron ties bedded in concrete. A very exhaustive trial was instituted by the Austrian Engineers' and Architects' Association (which is a quasi-Government body), and the tests were comparative with those of masonry, brickwork, and ordinary concrete. The Monier system has been used in many important undertakings, especially in bridge work. I can only give an outline of the trials which the Austrian authorities instituted, omitting all the intermediate steps up to the maximum tests applied. Arches of 75 feet 6 inches span were tested, and the following was the breaking strains in their respective order :—

Brickwork ...	...	...	67·548 tons.
Stone ...	...	...	74·022 ,,
Concrete ...	...	...	83·275 ,,
Monier System	...	...	146·120 ,,

The loads were applied from one abutment up to the crown of the arch in each case. The Monier arch also had an advantage in that the percentage of increase from first fissure to its collapse was 86 per cent., whereas in the case of

Brickwork, it was only	...	59 per cent.
Stone ,, ,,	...	30 ,,
Concrete ,, ,,	...	31 ,,

These test arches had a rise of 15 feet $1\frac{1}{8}$ inches, and were 6 feet 6 inches wide. The masonry and brick arches had a radius of 54 feet $8\frac{1}{2}$ inches, thickness at crown 1 foot $11\frac{5}{8}$ inches, thickness at the haunches 3 feet $7\frac{1}{2}$ inches. Both were built in Portland cement mortar, 1 cement to 2·6 sand. The breaking loads were for the stone arch equal to 2 tons per lineal foot, or 709 lbs. per square foot ; for the brickwork 1·8 tons per lineal foot, or 638 lbs. per square foot. The concrete arch had the same rise and width, with a thickness throughout of 2 feet $3\frac{1}{2}$ inches. The proportions of the concrete were 1 in 2, 1 in 5, and 1 in 8 respectively, and the structure was allowed to stand 3 months before testing. The breaking load was equal to 2·2 tons per lineal foot, or 780 lbs. per square foot. In the case of the Monier arch the longitudinal rods were 0·55 inches diameter, the transverse rods 0·276 inches diameter, the mesh being $2\frac{1}{2}$ inches. The thickness of concrete at the crown was 1 foot $1\frac{3}{4}$ inches, at the haunches 1 foot $11\frac{5}{8}$ inches. The breaking load was 3·87 tons per lineal foot, or 1,344 lbs. per square foot. The widest spans of bridges which have been built on the Monier system, to my knowledge, are 39 and 40 mètres respectively, or about 130 feet. At the North-West German Trades and Industry Exhibition, at Bremen, in 1890, an arch of 40 mètres span, or 132 feet, was built experimentally. It had a width of 3 mètres, or about 10 feet, in the centre, widening out to 8 mètres, or about 26 feet, over the abutments. The thickness of the arch at the crown was 25 centimètres, or nearly 10 inches, and at the abutments 55 centimètres, or nearly 22 inches. There were flights of steps on both sides of the bridge.

The bridge was erected in 6 weeks, and the arch was built in 36 hours. After the exhibition was over the bridge was dismantled by cutting away the crown of the arch. At Wildegg, in Switzerland, there is a permanent bridge of 39 mètres span crossing a canal at an angle of 45°. It is 390 centimètres wide, or about 13 feet, and the thickness at the crown of the arch is only 17 centimètres, or nearly 7 inches, and at the abutments 25 centimètres, or nearly 10 inches. The bridge was tested with the maximum moving load of traffic, without any appreciable vibration or defection. The committee of the Austrian Association suggest, on theoretical grounds, the following proportions in bridges on the Monier system for railways and heavy roads, where the rise is not less than $\frac{1}{5}$ of the span :—

Span.		Thickness of Arch at Crown.		Maximum width of Arch at the Crown.
98′	...	3′ $7\frac{1}{2}$″	...	7′ $10\frac{1}{2}$″
131′	...	4′ 7″	...	9′ 10″
213′	...	7′ $2\frac{1}{2}$″	...	14′ 9″
262′ 6″	...	8′ $10\frac{1}{2}$″	...	18′ $6\frac{1}{2}$″
328′	...	11′ 2″	...	23′ 0″
395′	...	13′ $5\frac{1}{2}$″	...	28′ $2\frac{1}{2}$″

The foundations of the breakwaters in the Free Port at Copenhagen were formed by floating into position over the line of the work and then sinking concrete cylinders constructed upon the Monier system, and filling the same with concrete.

A material termed expanded metal is a good deal in evidence just now. It is a steel lathing made by piercing and stretching sheets of mild steel. For the purpose of covering ceilings, walls, etc., it is an extremely neat invention, as the cement, when plastered over its surface, is firmly keyed in the metallic latticework. A series of tests were instituted by Messrs. Fowler & Baker, who state that, for a 6 feet 6 inches span, the use of this material increased the strength of concrete slabs by 10 to 11 times. Expanded metal with cement or concrete also gives buildings a fire-proof and, to a large extent, a sound-proof casing. The reproductions of the new Eddystone Lighthouse, which were exhibited at the Naval Exhibition, and at a subsequent exhibition at Manchester, were built of this metal and coated with cement.

The next 10 years will probably mark greatly extended adaptations of cement for domestic and general purposes. I have little doubt that in numerous instances in which wood is now exclusively applied cements, either Portland or magnesian, will before long be used.

I remember it being credibly reported that the individual who addresses you was to be seen braving the battle and the breeze with a cement umbrella.

On Chadwell Heath there is a section of nearly a mile in length of concrete telegraph poles. Concrete boats and tramway sleepers have been in use for years past, and, in situations where the white ant or the teredo are to be encountered, such applications are well worth bearing in mind. For many domestic constructions cement and concrete are coming to the front. I need not refer to such things as tanks, chimney pots, sills, curbing, channelling, paving, etc. In lieu of brickwork for house building, in fire-proof constructions of all sorts, warehouse floors, magazines, and many other applications, concrete is gaining ground fast.

The use of cements, of which magnesia forms the base, in conjunction with sawdust, the combination taking the place of timber, is the revival of an old idea. The product is especially serviceable in such a country as the Argentine Republic, where native timber practically does not exist. In this department also there have been many patents with but little novelty. A new magnesian cement called "Petrifite" is now in the market, but I understand a similar material at a much lower price will very shortly be available. The possibilities these materials foreshadow open up a vista of revolution in building operations. We are fast approaching an Artificial Stone Age.

Your knowledge of fortification and military engineering will enable you to appreciate, and, I trust, take advantage of that which I have been able only to sketch in brief outline. In the hasty defence of many a tight place a few bags of cement and a little wire netting would have been invaluable. The distinguished force to which, I trust, you are destined to add fresh lustre, is not only concerned with the defence of a world-wide Empire, but has to learn the art of devoting infinite pains to apparently trivial matters. It is in the nice adjustment of means to end that such trivialities may change the old order of things.

PAPER II.

ON THE SANITARY METHODS OF DEALING WITH EPIDEMICS.

BY PROFESSOR J. LANE NOTTER, M.A., M.D.

THE prevention of epidemic diseases is the subject of my lecture this evening. It is one of first importance to the British Army, and inasmuch as foreign service in peace, as well as active service, is almost entirely in tropical and sub-tropical countries, I shall deal chiefly with the conditions met with in the tropics and with armies either on service in the field or at stations abroad.

At home recent legislation has given rules which are applicable not only to civil, but also to military life, and which are summed up in the three principles by which epidemics are controlled, namely, notification, isolation, and disinfection. The old system of quarantine against the invasion of cholera and other epidemic diseases has been replaced by the much more efficient methods of medical "observation."

There are two kinds of precautions which may be used against the introduction of epidemic diseases into England: first, if possible, to prevent the entrance of the contagion; and secondly, if the contagion be present, to annihilate as far as possible the circumstances which favour its spread. Subject to one qualification, which is not an important one, it may, I think, be accepted as certain that quarantine, conducted with extreme rigour and with the precision of a chemical experiment, will keep any epidemic disease out of every part of

Europe in which the extremely difficult conditions can be absolutely fulfilled. On the other hand, a quarantine which is ineffective is a mere irrational derangement of commerce; and a quarantine of a kind which ensures success is more easily imagined than realized.

Only in proportion as a community lives apart from the great highways and emporia of commerce, or is ready and able to treat its commerce as a subordinate political interest—only in such proportion can quarantine be made effectual for protecting it.

In proportion as these circumstances are reversed, it becomes impossible to reduce to practice the paper plausibilities of quarantine. The conditions which have to be fulfilled are conditions of natural seclusion, and fulfilment of such conditions by England would involve fundamental changes in the most established habits of the country. The whole tendency of English opinion and the basis of all recent legislation has been to look to measures of sanitary improvement as the best prophylactic against cholera and other epidemic diseases.

All our wars—and fighting has been the normal condition of the British Army during the last 40 years—have been in warm climates, and it is especially on active service that the effects of, and the difficulties of combating, epidemic diseases are greatest.

There is one important factor which meets us at the outset of our investigations—the distribution of disease. In like manner as there are *fauna* and *flora* proper to the tropics, so are there diseases. Each country has its destructive diseases, for disease, like plants and animals, can only flourish within certain geographical limits. In the tropic isothermic zone we have China, Malay, India, Afghanistan, Persia, Arabia, Abyssinia, the Soudan, and Ashanti. Within these limits of temperature the British Army has fought the campaigns of China, Abyssinia, Looshai, Ashanti, Malay, Duffa, Afghanistan, Egypt, and the Soudan. And within these limits are to be found the worst forms of malaria, cholera, yellow fever, dysentery, typhoid fever, typhus fever, and relapsing fever.

And as we merge into the sub-tropics we find the continued fevers giving place to intermittent. Now the geographical distribution of disease must be a most important element in service in the tropics; for, by knowing what to expect, we are in a certain measure forearmed. Take, for example, dysentery; by ensuring wholesome food, solid and liquid, we can remove all causes of irritation from within, and by proper clothing we can protect from without. Again, the matter of conservancy; by ensuring the absence of putrefaction from the camp or barracks, and the burning or proper disposal of excreta, we cut the ground away from the feet of cholera, enteric fever, and yellow fever.

Lastly, it must be borne in mind that all diseases, however trivial elsewhere, become serious in the tropics.

Much has been said and written with regard to the action of "climate" in tropical and sub-tropical countries.

Within a measurable limit as a primary factor it is nothing. A prolonged residence in a hot climate doubtless deteriorates the system. It is the duration of heat, and not the intensity, that is the determining cause of such deteriorations. The energy of the Anglo-Saxon who has been long resident in the tropics suffers; but as regards foreign service, the element of time is on the side of the British soldier, for the period of service is hardly long enough for him to be seriously affected. By proper selection of men, by reasonable food and clothing, climate may be relegated to a secondary place. And as regards the influence of "climate" as a direct etiological factor of cholera and enteric fever, such a causation is dangerous in practice as it is baseless in fact. Hygiene will deprive tropical climates of their lethal weapons—we can actually prevent the special diseases which cause so large a mortality in the tropics; and, if so, we have only the fact left that our men in the tropics are acting under a temperature which is not their best. We cannot, indeed, hope that the European soldier will become so adapted to the environment of the tropics as to raise his standard of health, but we can at any rate neutralize to a great extent, if not entirely, the effects of this rise of temperature of the environment.

I propose, in the first place, to indicate the steps to be taken to procure a healthy environment to the soldier on tropical service, and secondly, to briefly indicate the prevention of the chief diseases affecting hot regions. These diseases have certain features which strike the observer at once. First, they are eminently preventable; secondly, a large proportion of them are propagated by human intercourse; thirdly, in the absence of sanitary measures they are apt to take on an epidemic form; and lastly, all of them are due to a specific micro-organism.

The chief points which need careful attention, in order to procure a healthy environment to the soldier, are those connected with his clothing, food, barracks, conservancy of camp, etc. Time will not permit me to do more than very lightly touch on these points.

As regards clothing, let us consider what are the conditions to be carried out as regards the soldier's dress in hot climates. They are:—

1. To maintain an equable temperature, and thus to avoid all those diseases brought on by chill.

2. To reduce the absorption and conduction of heat, and thus to avoid a condition producing heat-stroke.

3. To ensure as much reduction of fatigue from mechanical work as possible, and so to lessen liability to heat-stroke.

Such being the purposes to be fulfilled, we find that cotton and wool may be considered, as regards their power of absorbing heat, equal; but in its less power of conducting heat, in its greater power of absorbing moisture and of maintaining an equable temperature round the body, in its better hygienic condition when clothes cannot be washed, and in its lesser power of absorbing contagious principles, flannel is immeasurably superior to cotton stuffs. The soldier in the tropics should wear next his skin textures of the nature of flannel; but whatever be the form of wool which is selected, the material should be of the best kind.

As regards absorption of heat, much more influence is exerted by colour than material, black absorbing most; then blue, red, green, yellow; and, finally, white least.

The best colour is grey or pale straw colour; in fact, some of the tints of khaki used in India answer exactly to the requisite colour for the tropics.

As regards "food," according to the environment a definite relation must exist between the amount and kind of food if we wish to obtain the best results. Proteids, fats, starches and salts must exist in certain proportions for the attainment of the best result, and the income of food results in an outcome of bodily movement and bodily heat.

The body must produce more heat in cold climates, and hence more starches and fats are consumed. In a hot climate a corresponding modification must be made.

The more nearly the diet is assimilated to the natives of the country in the substitution of fruits and farinaceous substances for oleaginous articles, the less will be the liability to a disordered digestion.

A large proportion of the digestive mortality in the tropics results from the habitual ingestion of a larger quantity of food—and that of a rich stimulating character—than the system requires; hence follows loss of appetite, not due to climate, but to repletion.

Nothing exercises so deleterious an effect on digestion as a monotonous diet. Loss of appetite is bound to arise. Mr. Stanley's observations on the best diet for soldiers during the Nile expedition are specially valuable as coming from an explorer in tropical lands. He insists that soldiers on tropical service need a frequent change of diet to keep them in good health. The horrible monotony of butcher's meat in India has much to do with the so-called climatic diseases.

And with respect to all food, care must be taken that it is not a source of disease. It will be noted how diseased food can give rise to bowel affections ; how food poisoned with typhoid and cholera can cause typhoid and cholera ; how food can introduce parasites into the system ; and how an insufficiently proportioned diet can cause scurvy.

It is thus seen that food can spread disease by being itself in a diseased condition ; by serving as a medium for specific germs ; by serving as a place of selection for special parasites, such as tape-worms, etc. The great rules are—(1), to thoroughly cook all meat and boil all fluids such as milk, water, etc. ; and (2) reject all food supplies whenever there is a doubt of their being fresh.

In barracks and cantonments let animal food be in part substituted by vegetable ; let the fats be diminished—the carbonaceous elements being furnished rather by the starches ; but in long marches and on active service animal food should resume its wonted proportions.

As regards the use of alcohol in tropical countries, there can be no question that men are better without it. Nothing is more inimical to the acclimatising process in tropical countries than the habitual use of alcohol. As regards allowing it on active service in the tropics, one should not pass into extremes. The daily issue of alcohol is to be condemned ; but there are occasions in which a ration of alcohol has proved of the greatest service. A man who systematically drinks will most assuredly break down sooner or later. But this is not an argument for total abstinence ; it is only an argument against habitual alcoholic poisoning. There should be no issue of rum, strong beer, or spirits in the tropics ; but, with advantage, light red wines, well diluted with water, might be used ; they form a most refreshing drink, and may act as a preservative against cholera and bowel complaints. On this point I may mention that Mr. Stanley recommends their use, as much as he warns against beer or spirits for an army in the tropics.

Alcohol, in any form, should not be issued either just before or during a march ; in camps and barracks it should not be taken until evening. Alcohol in the form of spirits or beer is contra-indicated in all cases where cholera, enteric fever, and other zymotic diseases are likely to occur. But alcohol in the shape of red wines is beneficial, both from the vegetable salts and from the tannin contained in them.

Water supply is a subject of the first magnitude. The water supply depends on the nature of the soil on which the troops are placed. Healthy geological soils have, as a rule, good water. Having selected and tested a water source, keep it carefully guarded from pollution ; if such a source be a river, let the water be drawn from the highest spot, and let all bathing and washing be below it. If the water be near a native village, examine its relations to the villagers. All water in stagnant pools should be avoided ; and in this particular especially warn the men on the line of march rather to rinse their mouths than to swallow such water, when none other is obtainable. Pure water has, if possible, to be supplied. We seem to have arrived at a possible solution of this difficulty at last by the use of Vaillard's sterilizer, which promises good results. On a smaller scale water may be purified by the Pasteur-Chamberland filter. The principle of this filter is to force the water through porcelain, porous enough to allow the passage of the liquid, but barring that of the minutest germs. For their action they require water pressure, and the process is slow but effective.

Tea, coffee, and cocoa should always be supplied in free quantity in hot climates. Cocoa possesses distinct nutrient properties in addition to the stimulating effects of tea and coffee. They all act on the nervous system, quickening the lagging powers and restoring exhausted nature. Coffee and tea, in addition, protect the system against malaria. Coffee and cocoa are especially indicated—(1), for early breakfast before marching; (2), for those on night guard. Tea is indicated for the line of march. In any malarial districts coffee and tea may be given for breakfast; otherwise chocolate or cocoa. A few precautions are necessary with regard to these beverages. Large quantities of strong tea are apt to cause acidity and dyspepsia, hence do not let the brew be too strong for the men's bottles ; in fact, all these drinks, when strong, retard digestion ; and digestion is ever apt to get wrong in hot climates.

Conservancy is especially needed in damp tropical climates. The dry earth system is the one which generally prevails in barracks and cantonments in India and the tropics generally—it is doubtful whether it is the best. At all events, its success or failure depends on local conditions of soil and place. Sand is useless; it is devoid of those micro-organisms which feed upon and destroy organic matter, and, disintegrating it, render it innocuous. On the other hand, loam affords us just that kind of soil which teems with organic life. It effects its purpose, if we place no hindrance in its way by using strong disinfectants. The greatest security will be attained when all excreta and organic filth are finally disposed of by fire in some form of cremator.

I need only add that the *locale* for all trenches and pits should be perfectly remote from the drinking-water source.

In treating of the subject of camps, we enter upon one of the most important elements in connection with the health of the soldier.

The factor of overcrowding comes into play with far greater force as regards its consequences in hot climates; the results of overcrowding in the shape of accumulated excreta from the skin, lungs, bowels, etc., will be acted upon by tropical heat.

The choice of site is naturally more important for permanent than for temporary camps; a bad site may be chosen to pass a single night in and then to be left next day without many ill effects; but this would not be the case as regards a permanent camp on the line of communication.

First, as regards unfavourable sites. The following, where possible, are to be avoided:—Valleys so narrow that the air stagnates; entrances to gorges; foot of hills with stagnant water at their base; half-dried beds of rivers; jungly ground on banks of rivers or lakes; ground immediately above marshes; fresh clearings, etc. In hot climates the banks of rivers, especially if the water is stagnant, and marsh lands, lands subject to periodical floodings, and especially if covered with mixed salt and fresh water, are particularly unhealthy.

On the contrary, the following constitute good sites:—All high and dry grounds; a porous subsoil not encumbered with vegetation, with a good fall for drainage, not receiving or retaining water from any higher ground, and the prevailing winds not blowing over a marsh, will afford the best sites.

As regards the geology and conformation of the features of any locality, the following are the chief points to be borne in mind:—

(1). The water supply. In favourable sites the water supply is, as a rule, good.

(2). The drainage. Good natural drainage is essential for the health of a camp. Dampness is by all means to be avoided. Dampness of soil adds immensely to the liability to camp diseases.

There should be no overcrowding of tents. The question of tentage allowance is not one of transport only. Against the large supply of tents, on the other hand, we have the hampering thereby of military movements. For troops, however, on the line of communications a large tent allowance is indicated. The most open order of camps in time of war gives a much smaller space per head than the most crowded conditions of civil life. Care should also be taken that the site of a permanent camp should be such that the air can freely circulate all over the camp.

As too many men aggregated in one space will infect the air, so will they infect the soil, and with this infection will appear dysentery and diarrhœa, and cholera and enteric fever when the specific element is added. Even when the greatest precautions are adopted, organic matters are thrown out in camps, and by intercourse pressed into the soil, and thus gradually the earth becomes infected. And in hot countries, under the conditions of heat and rainfall, the process becomes much more acute, especially where the soil itself does not possess any disinfecting power. Sandy soils, for example, act prejudiciously both by not disinfecting these organic matters and by their drying power, so that when clouds of sand are raised by the wind, these clouds carry particles of organic matter. The foregoing statement indicates what can be done in this case—first, to pitch the tents as widely apart as possible ; and secondly, move to fresh ground periodically.

The floor of a tent should never be excavated with a view to increase the space ; water is apt to lodge in the cavity ; the space is nearly always damp, and the occupants are exposed to ground-air emanations. Men should never sleep below the level of the ground, but, if possible, above it.

To prevent the subsoil beneath the tent becoming saturated with filth, tents should occasionally be shifted to fresh ground within the same lines, so as to expose the vacated sites to sun and air. It is well known that tents occupying the same ground for a lengthened period become unhealthy.

The German regulations order that the soil underneath the tents, if not clean and firm, should be dug to the depth of one foot and replaced by gravel, coal dust, etc., slightly watered, and covered by a few boards until hard and dry. In all cases the soil should be beaten down so as to render it less permeable, the surface scraped from time to time and replaced by clean gravel or ashes from wood fires.

In tropical countries night duties should be as limited as possible. When the variations of day and night temperature are great, disease is especially liable to arise. Lord Roberts has drawn attention to the injurious effects of night duty and sentry go, and explains the quicker onset of effects of age on the private soldier after 30 by the influence of sentry duties.

Exposure during guard and transition of temperature on passing from the hot air of the guard-room to the outside air are also causes of disease.

I propose now to offer a few brief remarks on the prevention of the more common forms of epidemic diseases to which military service in the tropics renders the soldier liable, and to indicate the most efficient means of keeping an army in health.

Enteric Fever.—This disease, as regards its frequency and diffusion, marks widely its difference from all other forms of disease. It knows no geographical limits, and its very universality and infectiveness make it one of peculiar interest to officers of the British army who, serving in various parts of the world, and under varying conditions of climate, have ever to contend against this disease, often assuming an epidemic form.

In India enteric fever is found under all conditions of diversity of climate, in very hot and very dry localities, in very cold stations in the hills, and in the plains, in different ratios in different regiments at one and the same time located in any given station, and in different ratios in different years under exactly the same conditions of climate. Climate cannot generate enteric fever no more than it can generate plants and animals. But although a tropical or sub-tropical climate has no influence as a primary exciting cause of enteric fever, yet when once the disease has originated the influence of climate will be shown in a higher death rate.

The mortality from enteric fever in hot climates is always higher than that in temperate ones. Nor is this to be wondered at; there is increased activity in any acute fever due to the diminished resistant power of the individual. It is evident that a man with enteric fever in a temperate climate will have a better chance than a man with enteric fever in a hot climate.

The undermining factors appear to be age and recent arrival in the country. The increased predisposition at an early age is now universally admitted; therefore, what is required is an army of older men to serve in the tropics. But there is a more important factor than age in predisposing to the disease; enteric fever most frequently attacks new arrivals, and with the present system of short service there undoubtedly is a much larger proportion of men serving in India under five years' service than formerly.

The immunity afforded by residence appears to be much more perfect in tropical and sub-tropical regions than in higher latitudes. The protection acquired through acclimatisation cannot be denied, though what influence of its own a tropical climate has in this respect is uncertain. The increased prevalence of enteric fever in India has, therefore, been accompanied by, and is possibly dependent on, an increase in the number of young and recently arrived soldiers.

An undoubted *rôle* in the causation of this disease is played by drinking water; both water and milk are excellent media for the preservation and growth of the enteric micro-organism. All water and milk should be boiled before use in hot climates.

As regards the prevention :—

(1). We must recognize the fact that enteric fever in tropical and sub-tropical climates is the same as at home. It is dependent on the same causes. The poison is reproduced in the patients suffering from the disease, and is conveyed by water or food which has been contaminated by them.

(2). To discover the first case is all-important. Hence men suffering from diarrhœa should always report themselves sick at once.

(3). To prevent the origin of the first case, warn the soldier against frequenting native villages and bazaars, and carefully scrutinize all food, whether liquid or solid, especially looking after the water supply and milk from native villages.

(4). Should the disease become epidemic, if in camp, the site should be changed at once, and a new one to windward substituted, subject to military considerations. And apart from this, striking camp and changing the ground should be periodically carried out.

In the actual dissemination of the disease, water has been repeatedly proved to play the most important part. Not only in this country, but abroad, various epidemics and groups of cases have been investigated, where a contamination of drinking water by sewage from drains or old cess-pits, and, by inference, with enteric excreta, has been proved to be connected with the outbreak and spread of the disease. Complete and instructive evidences as to the contamination of drinking water by enteric stools and wholesale infection by such water are afforded by the Maidstone and Lynn epidemics.

Further, milk plays an important *rôle* in the dissemination of enteric fever virus; such milk epidemics, where milk had directly, or by the vessels containing it, been brought into contact with sewage polluted water, have been numerously recorded. Although it is true that, in the greater number of epidemics of enteric fever, the cases are due to specifically contaminated water or milk, it is not safe to overlook other possible modes of the spread of this disease.

In India and other countries where dry systems of conservancy are in force, a possible danger exists in the dislodgment of dried and imperfectly buried excreta from the soil, and their diffusion as dust by winds. If specifically infective, few persons who have knowledge of the circumstances of life of tropical climates will be disposed to deny that such dry excretal matter possesses considerable potentialities for evil. Some are of opinion that the germ of typhoid fever is essentially a micro-organism of the soil, and capable of leading an independent life, and of producing itself in the earth.

My own experiments indicate that in certain soils, rich in nitrates, this organism may retain its vitality for six or more months; if this be so, there is no difficulty in understanding why the disease often appears in the most diverse localities, where previous cases are difficult to trace.

Cholera.—The diffusion of cholera among natives depends entirely upon the numberless filthy facilities which are allowed to exist, and especially in the native villages and resorts, in hot climates, for the fouling of earth, air and water, and thus secondarily for the infection of man with whatever contagion may be contained in the miscellaneous outflowings of the populations, excrement sodden earth, excrement reeking air, and excrement tainted water; these are for us the causes of cholera.

The precise parts taken by air, milk, soil, and water in the diffusion of cholera have been fully demonstrated. The whole course, not only of the last great epidemic of cholera in Europe, in 1892, but of all others, especially in England, shows that the disease is propagated mechanically, and that the influence of soil, as a mere influence of place and season, is quite subsidiary. On the other hand, soil may, and doubtless does, serve as a medium in which the cholera virus can survive outside the human body. Confirmative of this view are the striking instances from India, in which fresh sand from the banks of the rivers used as bathing places by the infected, placed in filters, has been the means apparently of giving rise to outbreaks of cholera among those partaking of the water filtered through it.

The dangers which have to be guarded against as favouring the spread of cholera infection are particularly the water supplies; and above all there is the danger of pollution of water supplies by house refuse, or where there is leakage from drains, wells, or reservoirs from which the water supply is drawn.

It may be stated that the liability of a place to cholera is exactly its liability to enteric fever and *vice versâ*. India affords us conclusive evidence that cholera-polluted water is the cause of cholera.

As regards prevention, the lines to work on are simple. Obtain a pure supply of water, and where any suspicion exists, boil the water.

See that the bheesties' mussacks are kept scrupulously clean. Avoid saline waters, which predispose to cholera; avoid drinking water after a long fast, as an alkaline condition of the stomach is present; take solid food first, especially after a long night's fast.

Let all milk be boiled and consumed at once, and let the cows be milked under supervision, and the vessels into which milk is poured should be scrupulously clean.

No rum ration should be allowed. Cholera ever attacks the intemperate first; it has a preference for alcoholic drinkers.

Avoid all unripe fruit and all excess in eating fruits. Let the meat ration be well cooked; and, finally, arrangements should be made to keep flies off all provisions. The carriage of disease by flies has recently been insisted on, and the evidence on which it is based cannot be controverted.

I shall now offer a few remarks on camping grounds, where it has been found necessary to move troops on account of an outbreak of cholera.

First, as to the geological structure of the soil. This has no influence itself—the disease has broken out at one time or another on the rocky soil of the Punjaub, the sands of Western India, and down into the alluvial soil of the Gangetic Valley. It has taken root in regions presenting every variety of soil, and situated on the most opposite geological formations. Rocky, dry ground, even, cannot be held to afford immunity. Hence the geological structure, *per se*, is of no influence. But, nevertheless, certain soils are more prone to cholera than others; rocky dry ground is least affected, while loose porous or alluvial soils are most prone to the disease. The factor, indeed, in any locality is its suitability or otherwise for stagnation of water and decomposition of organic matter.

It is thus that alluvial or porous friable soils are favourable to cholera, whilst dry, rocky soils are most favourable to conservancy. All those soils characterized by humidity are predisposed to cholera.

Thus the first indication is to choose as dry and compact a soil as possible to encamp upon.

Next as to height. Height above the sea gives, it is true, no absolute immunity. Still, *cæteris paribus*, the amount of sickness diminishes in proportion to the height ascended above the plains, and if any district be seized, it will generally happen that the low-lying parts are the first attacked.

The explanation of this is that in low-lying ground we have copious ground saturation and an opportunity for deposition and permanent resting of organic matter. Thus, the second rule for camps is to locate them on as high ground as possible, and to avoid places at the foot of any declivity or trough-shaped depression.

Thirdly, for the same reason, avoid camping near the banks of rivers or lakes; it has been well proved that the amount of sickness from cholera diminishes in proportion to the distance from river banks. It is recorded of the army under the Marquess of Hastings, in 1817, that cholera broke out when encamped on the banks of the Indus. Out of 10,000 European troops more than half died of this disease within a very short time. The camp was broken up and removed to dry ground, and the attack ceased. Possibly this great mortality was due to the water being drunk by the men.

The fourth indication is frequently to change the ground. The accumulation of fæcal matters and organic detritus, resulting from too long an occupation of the same ground, must inevitably favour the spread of cholera when once it has invaded a camp.

Finally, all the general measures of camps, such as drainage, conservancy, etc., must be specially looked to in cholera times. We know how the organism of cholera is at once killed by drying; the indication, therefore, is to make our camp as free from soil moisture and moist organic detritus as possible, so as to deprive it of its special conditions of environment.

Although cholera may be imported into any given camp or barrack, believe me when I say that, the disease will never become epidemic in that camp or barrack unless the drinking water or milk supplies become somehow or other infected. Hence the first thing to do is to secure a good water supply. Such water should never be taken from a native village, nor even near a village, and let all water be filtered and boiled afterwards.

As regards marches generally, all evidence shows that the state of the body produced by long and fatiguing marches increases the predisposition to cholera. The Indian experiences show that the number of attacks of cholera occurring on the march increase regularly according to the number of miles and the number of days. The element of fatigue is certainly here the influence, for the officers who are mounted are only very slightly affected, while the cavalry suffer far less than the infantry.

Thus, then, as regards marching in cholera times, the marches must be so arranged that the men are not constantly fatigued, and regular halts must be arranged for.

Yellow Fever.—This is a disease which is limited in its habitat. There are only three situations at which the disease bears undoubtedly an endemic character—in the West Indies, on the Mexican Gulf, and part of the West Coast of Africa.

Recent investigations by careful observers indicate that the disease principally prevails along the banks and channels of rivers which are dry at certain periods, and in the low parts of seaports, particularly those abutting or overhanging harbours, stagnant waters, or foul foreshores. Testimony of this nature clearly defines the existence of a porous, loose, and periodically saturated soil as a constant concomitant of yellow fever prevalence.

Certain conditions of the soil undoubtedly favour the development of the active agent of the disease. Climatic conditions, especially temperature, also exert an important influence upon its propagation. But its causation is more particularly associated with the presence of putrifying fæcal and other waste organic matters, such as accumulate about human habitations.

The tendency of yellow fever to form particular foci of infection resembles the mode of diffusion of cholera.

Yellow fever is particularly a disease of ships; that is to say, its origin is not directly on shipboard, but ships that are in a condition of bad sanitation with their human contamination and septic conditions present opportunities particularly fitted for the growth, development, and spread of the germs of yellow fever.

Two important facts in the etiology of yellow fever are now fully recognized: first, its separation from, and independence of, malaria;

and secondly, its propagation by human intercourse. Its origin and spread are favoured by the congregation of persons born in the cold climates of northern latitudes, especially when newly arrived in one of the three endemic regions of yellow fever. And from the endemic region the disease can be transported by ships to localities outside the yellow fever zone, as has been the case in England, Malta, Gibraltar, etc. Hence, again, it resembles cholera, in that it is spread by human intercourse, though how this acts is still a debated point. And herein lies the one great fact on which to base its prevention, the fact of its diffusion by man to man.

At those points in the yellow fever zone, where the disease may be said to be endemic, it is the newly arrived persons especially, and those not acclimatised, that are subject to the disease, while the natives, creoles, and acclimatised immigrants enjoy an exemption from it more or less complete.

The pure-blooded negro has a congenital immunity, which immunity is all the more complete the more purely the racial characteristics have been preserved. For Europeans there is no such immunity, except that acquired by residence in the yellow fever zone.

In the yellow fever zone, as in the tropics generally, the necessity of woollen and flannel clothing is apparent. It is most essential to prevent chills. Fatigue and exposure to a tropical sun predisposes to the disease in the endemic region. Hence again the early march, the breakfast before marching, and regular halts, are indicated. If the disease appears while on the march, isolate the sick, and look to the conservancy.

As regards sites for camps and barracks, I have mentioned one element in the character of this disease, and that is, its local character.

The disease is especially associated with the sea coasts and the immediate shores of rivers. It is rarely that the disease penetrates into the interior. Again, the disease is checked by elevation, and occurs principally in the plains ; therefore, on debarkation, leave the shore as soon as possible and reach the uplands.

That shore which is washed by the refuse from ships and houses that has been discharged into the sea and exposed to a tropical sun is especially dangerous.

In camps, let there be no overcrowding. The predilection of this disease for towns, and particularly for populous places, shows the danger of this, as does also the freedom from it in the open country. Drain the camp as much as possible. Attend to ventilation, and avoid placing the camp where it is exposed to the south and west winds, as these appear to favour an epidemic. Disturb the surface of the ground as little as possible ; this is a golden rule. If barracks are occupied, let the men sleep on the upper floors, and avoid the ground floor. Keep away from all ground emanations. At night there is especial danger from the poison of yellow fever. Emanations from the localities containing the yellow fever poison are, during the night, rapidly diffused upwards, and can be carried to a considerable distance by air currents. Mosquitoes have also been shown to be able to carry the poison and communicate the disease.

As regards conservancy, yellow fever is essentially a filth disease, It haunts the low and filthy quarters of seaports, the vicinity of foul drains, and in ships the foul holds thereof.

So far, yellow fever cities and yellow fever ships have been filthy cities and filthy ships ; but whether the disease would spread in a clean, well-drained city we do not know, as there are no such cities in the yellow fever regions.

A curious fact in connection with this disease is that there is only one circumstance covering its history, geography, and remarkable changes in distribution, and that is the slave trade. The advent of yellow fever into the world coincided with the rise of the slave trade ; its habitat is, or has been, the ports of debarkation of the slave trade ; its exacerbations have coincided with the most lawless period of the negro traffic. Finally, it has been eradicated from the great cities of the Atlantic sea-board since the importation of negroes ceased. The poison has been generated in the crowded, filthy, and unventilated holds of slave ships.

Regarded in this light, yellow fever has been given to us in the dejecta of another race, which, brought in considerable quantities in the bilges of ships to ports, has then been discharged into harbour mud and soil. The scourings of these ships, fermenting and multiplying in the harbour and shore mud, has generated a poisonous virus which has only too readily been carried from harbour to harbour.

In connection with this view, it is curious to note the fact that yellow fever is most persistent at places where there has been least cleansing of harbours or foreshore, or where much stagnation of the harbour water exists, as in places like Havana, Port Royal, Bridgetown, and Port au Prince.

Inasmuch as the slave trade was the original cause of yellow fever, and has now ceased, and that signs are not wanting that outbreaks are diminishing both in frequency and degree, we may hope that the deep waters of the sea may, by their washing, slowly but surely purge the shores of those countries where a cruel slave trade prevailed.

PAPER III.

HOSPITAL CONSTRUCTION.

By Capt. Sir Douglas Galton, K.C.B., F.R.S., D.C.L., Hon. M.I.C.E., Late R.E.

I am glad to have an opportunity of explaining to the younger officers of Royal Engineers my views on the general principles which govern hospital construction. It has been a subject which has occupied my mind largely for very nearly fifty years.

It is forty-nine years since the Barrack and Hospital Improvement Committee laid down the principles upon which barracks and hospitals are now universally constructed, and it is forty-eight years since I undertook the design of the Herbert Hospital at Woolwich, which was almost the first instance of a hospital built on the pavilion principle in this country. That form of construction is now generally adopted for hospitals all over the world. The reason of its almost universal acceptance is that this design affords the best opportunity for light and air to penetrate to all parts of a ward, and unless we are prepared to adopt a system of mechanical ventilation, the pavilion system cannot fail to hold its own in hospital design. Moreover, the pavilion form, with windows on each side in one storey buildings, is the only form applicable to extemporized hospitals in connection with the operations of an army.

General Principles Governing the Design.

The principles which govern modern hospital construction were principally derived from the experiences acquired in war.

The practical results in recoveries of sick and wounded men obtained by army surgeons during campaigns showed the influence of pure air and clean surroundings in advancing the recovery of sick and wounded men. Dr. Brocklesbury in 1758, and later Sir John Pringle and others, showed that in rough hospital huts and tents, and even in an open "lean-to" against a wall—in which the patients were exposed to unfavourable conditions of cold and wet—more numerous recoveries occurred from wounds and diseases incidental to camps, such as fevers and dysentery, than in permanent buildings in which air could not so freely circulate.

But this experience of the last and early part of the present century did not bear much fruit in permanent buildings until it was more forcibly brought before us by the experiences of the Crimean War. In the first winter of the Crimean War, 1854-55, the number of men who were disabled by preventable disease amounted to more than one-third of the whole strength of the army which went out from England. When the army sat down before Sebastopol the men had not sufficient shelter; no arrangements were made for the removal of refuse or for cleanliness; they were in want of clothing suitable to the weather. They suffered from wet and damp. Zymotic diseases, such as scurvy, fever, cholera, and dysentery, threatened the destruction of the army. Early in 1855 sanitary measures were enforced. These diagrams show the comparative mortality in the winters of 1854-55 and 1855-56 (*Plate* I.). You will note in the diagram how large in the winter of 1854-55 is the proportion of zymotic disease to wounds and other causes.

The sick and wounded soldiers who were brought from the Crimea to the hospitals near Constantinople were crowded into buildings which, although spacious and magnificent in external appearance, were in reality little better than pest houses. Underneath these great structures were sewers of the worst possible construction loaded with filth, mere cesspools, in fact, through which the wind blew sewer air up the pipes of numerous open privies into the corridors and wards in which the sick lay. The wards had no means of ventilation, and the number of sick placed in the hospitals was increased not only without any sanitary precautions having been taken, but while the sanitary conditions were becoming daily worse, for the sewers were getting more dangerous, and the walls becoming more and more saturated with organic matter. The natural result was that two men were lost out of every five treated in the hospitals on the Bosphorus during the month of February, 1855, and one man out of every two at Koulali.

Improvements were begun in March, 1855, but it was not till the end of June that they were completed. The effect of the completion of the sanitary works is most striking. The mortality fell in June, 1855, to less than a sixth part of what it was when the hospitals were occupied in October, 1854, and to a nineteenth part of what it was in February, 1855.

These results afford a most instructive lesson in army hygiene. The men were the same; the conditions only had been altered. The requirements of nature had been disobeyed in every particular during the first winter, and she has left on that diagram an everlasting vindication of her broken laws. During the second winter nature had been more perfectly obeyed, and the stigma of her displeasure has almost ceased to appear.

Fig. 1, *Plate* II., shows a hospital of the type in use before the Crimean war.

Fig. 2, *Plate* II., shows a wing of Netley Hospital, which was designed immediately after the war, before the lessons which it conveyed had been fully considered, and it was still on the old type.

Fig. 3, *Plate* II., shows the Herbert Hospital, designed in 1858 on the pavilion form, which has since prevailed.

Thus the Crimean war brought about a turning point in hospital construction.

Between 1860 and 1870 a notable improvement was introduced into surgical practice owing to the investigations of Pasteur into the action of ferments, and to Lister's application of the knowledge thus acquired to the treatment of wounds. The treatment may be best summarized as the maintenance of absolute cleanliness in the conduct of operations, and the prevention of access to the injured parts by those agents of putrefaction ever present in the atmosphere which are the causes of what are termed "hospital diseases." The practical abolition of these diseases in surgical cases by means of this treatment still leaves the patient in a condition which requires pure air and clean surroundings for his cure, and this treatment has therefore not diminished the importance of air, light, and absolute cleanliness as the foundation of modern hospital construction.

In respect of the importance of cleanliness, I would impress on you the following extract from a report of Sir John Simon :—

"That which makes the healthiest house makes likewise the healthiest hospital, the same fastidious and universal cleanliness, the same never-ceasing vigilance against the thousand forms in which dirt may disguise itself in air and soil and water, in walls and floors and ceilings, in dress and bedding and furniture, in pots and pans and pails, in sinks and drains and dustbins. It is but the same principle of management, but with immeasurably greater vigilance and skill. For the establishment which has to be kept in such exquisite perfection of cleanliness is an establishment which never rests from fouling itself; nor are there any products of its foulness—not even the least odorous of such products—which ought not to be regarded as poisonous."

Selection of Site.

The health conditions which are required in selecting a site for barracks may be said to apply to hospitals, only "more so." It is unnecessary, therefore, for me to dwell on this part of the question. I would, however, sum up the requirements of a hospital site as follows:—

1. The soil on which the hospital stands should be clean, that is to say, the soil should neither emit nor should it be exposed to any injurious emanations.
2. The surrounding air should be pure.
3. The water supplied for use should be pure, and after use it should be removed with its impurities to a distance from the hospital.

In connection with the choice of site, the question of the free area on which the hospital stands, is important.

It is abundantly proved that the crowding together of individuals on a limited space is favourable to the development of the dangers which arise from the vitiation of air, whilst a large surrounding air space reduces or limits these dangers. Consequently a larger free space around a building in which sick or injured are located is necessary than would be required in the case of a collection on a given area of persons in good health.

In the case of some smallpox hospitals it has been shown that the incidence of smallpox upon houses within a mile radius of a smallpox hospital, apart from any infection due to the conveyance of patients in the hospital, was as follows:—

The total number of cases under review was 2,527. For every 100 houses in the circle of a quarter of a mile from the hospital there were 17·35 cases. In the ring between a quarter and half a mile, 9·25. In the ring between half and three-quarters of a mile, 6·16. In the ring between three-quarters and one mile there were 2·57 cases in every 100 houses. On this account it has been considered that smallpox hospitals are not properly admissible in a populous locality.

Some years ago a committee appointed by the Surgical Society of Paris recommended that the minimum area of site to be allowed for ordinary hospitals in towns should be 50 square mètres, or, say, 60 square yards, per patient. This proportion of space per patient means for a hospital of 100 beds nearly $1\frac{1}{4}$ acres; of 200 beds nearly $2\frac{1}{2}$ acres; of 500 beds rather over 6 acres. These areas, however, are only admissible in cases where the obtaining of a larger site is a matter of exceptional difficulty.

The conditions which govern the shape and distribution of hospital buildings on a given site depend upon light and air.

Light.

Daylight, and particularly sunlight, maintains the purity of the atmosphere, and exerts an important influence on vitality. We all know that light is essential for the organic development of plants and animals; and on the other hand sunlight, and especially the actinic rays of the spectrum, have been shown to kill some classes of spores and bacilli, and to check the development of certain forms of micro-organisms which are alleged to be connected with disease. The Italians have a proverb which means that fever prevails in rooms to which direct sunlight has no access; and it is an axiom of hospital construction that direct sunlight should penetrate into the rooms occupied by the sick.

But, independently of this, light is required in hospitals as an antagonist to dirt. Dark corners mean dirt, because dirt must be seen to be removed. The absolute cleanliness which is essential throughout a hospital can only be obtained where a flood of light is directed to every part of the building, as much under staircases, in closets, and in cupboards, as in the wards themselves. It is a further axiom that no part of the room can be deemed sufficiently lighted from which a certain amount of sky cannot be seen. Dr. Förster, of Breslau, laid down as a rule that the arc of sky visible from any part of a room should not be less than 5°. This seems somewhat small for a hospital ward, but if the height of the ward is made equal to half its width, if one window is allotted to every two beds, and if the windows are carried from about 2 feet 6 inches from the floor to within about a foot from the ceiling, and if the adjacent buildings are placed at a distance equal to twice their height measured from the level of the ward floor, this proportion of sky illumination would be more than obtained; indeed, with windows of adequate size placed on both sides of a ward, the light would be abundant.

Hence the conditions for light necessarily affect not only the shape of the hospital wards, but also the position with reference to the points of the compass, and the distance from surrounding buildings, as well as the position, level, and size of the windows.

The arrangements for air supply are of equal importance.

Purity of Air.

I may assume that you are all here cognizant of what is the accepted definition of pure air; that you know how and why it is rendered impure in closed spaces occupied by human beings and animals; and that you understand that medical men have accepted a standard of purity for air in a hospital ward which is somewhat less pure than that of the outer atmosphere.

The question you have to consider is how to provide for a sufficient removal of vitiated air from and inflow of pure air into a closed occupied space, to keep it at this fixed standard of purity, without inconvenience to the inmates.

Amount of cubic space (breathing space) for one man in cubic feet.	Ratio per 1,000 of carbonic acid from respiration at the end of one hour if there has been no change of air.	Cubic feet of air necessary to dilute to standard of ·2, or including the initial carbonic acid, of ·6 per 1,000 vols. during the first hour.	Cubic feet of air necessary to dilute to the given standard every hour after the first.
100	6·00	2,900	3,000
200	3·00	2,800	3,000
300	2·00	2,700	3,000
400	1·50	2,600	3,000
500	1·20	2,500	3,000
600	1·00	2,400	3,000
700	0·85	2,300	3,000
800	0·75	2,200	3,000
900	0·66	2,100	3,000
1,000	0·60	2,000	3,000

The above table refers to rooms occupied for a number of hours consecutively. The table shows the effect of cubic space on inflow of air. From this you will see that 3,000 cubic feet of fresh air per hour per occupant would keep the atmosphere at the admitted normal condition of impurity.

The necessary change of air may be effected in three principal ways.

1st. It may be effected by so adapting the form of your building, the position of its windows, and of other ventilating openings, that the ordinary action of the atmosphere will effect this change. That may be called "natural ventilation." In this case it is necessary in cold weather to adopt suitable means of warming the wards by fire-places, stoves, or hot water pipes inside the wards.

2nd. You may draw out by artificial means—such as fans or heated flues—the air which has become impure by breathing, and allow its place to be taken by pure air from the outside; and in cold weather you may either warm the ward by means of heated pipes or stoves, or a supply of warm air may be drawn in from the place where it is warmed through channels arranged to facilitate its flow.

3rd. Or, on the other hand, you may propel into the space to be ventilated the necessary volume of pure air to displace the vitiated air through conveniently arranged channels, and either allow the air which it replaces to flow out through doors and windows, or you may arrange channels for the removal of the vitiated air of the ward thus driven out. In this last case the windows must be discontinued as a means of admitting fresh air, and used only for the admission of light.

These two latter instances in which mechanical means are resorted to may be termed "artificial ventilation."

The pavilion form of hospital construction is based upon utilizing the windows for the admission of air as well as light at those seasons of the year or periods of the day when the temperature admits. There are very few days in the year in this country on which, if you have adequate warmth in the wards, and adequate covering on the beds, the windows cannot be opened.

The average movement of the atmosphere is at the rate of 10 to 12 feet per second, and the air of the atmosphere moves on a very calm day at not less than from 4 to 6 feet per second, and on most days which are considered calm it will be found to be moving at eight or even more feet per second. With a ward on the pavilion principle, where the windows are placed on opposite sides of the ward, the lowest of these velocities—through ordinary sash windows opened so as to allow a free current of air to pass through—would afford a volume of air of at least 50,000 to 60,000 cubic feet per patient per hour. This large supply of fresh air is obtained without cost.

But, on the other hand, if you determine to trust entirely for your supply of air to mechanical means, and you pump a regulated quantity of air into the wards, you ought, logically, to use your windows only to admit light, and you consequently would make them fixed and not capable of being opened; in that case you need only consider the best arrangement for affording sunshine and light to the ward, and the pavilion form is not necessarily the form you would adopt.

I should not have thought it necessary to say even this much on this subject if it had not been that in the case of its newest hospital the large town of Birmingham has advisedly adopted the system of propulsion with windows purposely made not to open. This hospital has cost about £250,000. The system of propulsion is combined with a system of filtration of the inflowing air, which is intended to wash out the soot and fog, and thus to furnish a clear atmosphere in the wards. The system may have advantages for patients, and especially for patients suffering from lung diseases, in a hospital in the centre of a smoky town on foggy days in winter, when the atmosphere is laden with soot and other impurities. But such a site is an unfit one for a hospital if it can be avoided. Moreover, the expenses which the system of propulsion may entail are necessarily large. We will assume that you afford a cubic space of 2,000 feet per patient. At the Birmingham Hospital it is said to be proposed to change the air seven times an hour—that would require 14,000 cubic feet of air per hour, day and night, to be pumped into the ward for each patient.

Thus the quantity of fresh air supplied to the patient is much less than he would obtain with the natural system, and the supply of this smaller quantity requires an expenditure of more than half a ton of coal in every 24 hours for ventilation alone for each patient; moreover, this quantity must be nearly doubled, because this system requires the supply of a similar amount for changing the air in the bath rooms, w.c.'s, corridors, etc., and, again, to this you must add, as in other methods of ventilation, the coal necessary for warming the air in cold weather.

There is, however, another purely practical reason against a system of air supply to a hospital which requires educated supervision. Intricate flues for artificial ventilation and other complicated arrangements may answer well when first put into operation under the eye of the inventor. But arrangements, even if apparently simple, which require some special knowledge for their efficient working must be more or less dependent upon the continuity of management.

The changes in *personnel* which necessarily take place, and especially in military hospitals, may introduce want of appreciation of the invention, or of care in its management. Let me instance the old Derby Infirmary. That building was designed with great care in 1810. The ventilation of the wards depended on ingeniously arranged extraction flues for the removal of impure air—whilst fresh air was supplied through carefully arranged inlet flues from a central chamber, where it was warmed during cold weather. In process of time the whole *personnel* was changed—some drain or other became stopped. Neither the builder nor the committee who called him in took into consideration the special arrangements of the air flues. One of these fresh air flues lay handy to the drain; and as the simplest solution of the difficulty, the builder forthwith connected them, and nurses and patients were poisoned.

For various reasons of this character, and because the system of propulsion is inconsistent with flooding wards with pure fresh air, the Army Sanitary Committee have not been in favour of ventilation by propulsion. They have, therefore, advocated the pavilion form of ward construction.

Ward Unit.

In the pavilion system the ward, with its appertaining offices, is the unit of hospital construction. The first principle upon which the pavilion system is based, is to limit the number of patients under one roof. The second is to afford to those patients abundance of fresh air by means of cross ventilation. The third is to ensure that sunshine shall penetrate to as large a portion of the building as possible—both inside and outside.

The accompanying table shows the number under one roof in some of the recently constructed hospitals.

Name of Hospital.	No. of Ward Floors.	No. of beds in Ward unit under one roof.				Total Patients under one roof.	Observations.
		In Large Wards.		In Separation Wards.			
		No.	Patients.	No.	Patients.		
1. Tenon, Paris (Menilmontant)	3	8	156	10	17	173	In Medical Block Double Pavilion No air separation
2. S. Thomas	4	4	112	4	4	116	
3. Norfolk and Norwich... ...	2	4	96	4	8	104	Double Pavilion No air separation
4. Royal Infirmary, Edinburgh	3	3	63	3	6	69	Medical Wards
5. Friederichs Hain, Berlin — 2 Floors	2	2	56	4	8	64	
5. Friederichs Hain, Berlin — 1 Floor	1	1	28	2	2	30	
6. Hamburg	1	1	30	3	3	33	
7. S. Eloi, Montpelier	1	1	23	2	4	32	
8. John Hopkins	1	1	24	2	4	28	

The accepted doctrine of late years has been that the number of from 100 to 120 patients under one roof should not be exceeded. But this is certainly larger than is desirable in surgical and fever cases.

Size of Ward.

The size of a ward depends upon the number of patients which it should contain, and upon the cubic space and floor space which should be allotted to each patient.

Whilst the medical man prescribes for the sick, he depends for the execution of his orders upon the nurse—and as economy of labour in administering the hospital is a main object to be sought in hospital construction, the hospital should be so laid out as to enable the largest number of patients to be nursed by a given number of nurses. The number to be placed in a ward will, therefore, depend upon the number which can be efficiently nursed, and the form of the ward must be as much calculated to facilitate nursing as to ensure free circulation and change of air.

Miss Nightingale says that:—"A head-nurse can efficiently supervise, a night-nurse can carefully watch 32 beds in one ward; whereas with 32 beds in four wards this is impossible." Miss Nightingale further shows (in her *Notes on Hospitals*, 1863) that if the annual cost of nursing be capitalized, and if a hospital for a given number of sick be divided into wards of nine patients each, the cost of nursing in perpetuity would be £428 per bed; whereas if the hospital were divided into wards of 25 beds each the cost would be £231 per bed, and with wards of 32 beds the cost would be £220 per bed.

The following are the dimensions of the wards of some of the more recently constructed hospitals in Germany, France, the United States, and this country.

Name of Hospital.	Height of Ward.	Width of Ward.	Lineal Bed Space.	Floor Space per Bed.
Halle	15·9	29·6	9·2	135·6
Hotel Dieu	*18	29·3	8·4	125
Menilmontant	*17	27·9	7	107
John Hopkins	16	28·8	7·7	104
Leeds Infirmary...	16·6	27·6	7·5	107
Montpelier	†25	26·3	7·2	108
Herbert	13·6	26	7·4	97
S. George's Union Infirmary ...	13	24	6	72
Moabit, Berlin	13·9	22·6	6·2	69
Hamburg	16·11	28·8	5·10	78

* First Floor Wards. † At centre.

It has followed from these considerations that from 20 to 32 beds have been taken as the unit for ward construction. In hospitals where cases of more than ordinary severity are likely to be received it would be necessary to diminish the size of the wards on the grounds of health, and thus to make some sacrifice of economy of nursing for the sake of the patients.

Small wards are required for occasionally isolating bad cases.

Cubic Space and Floor Space.

The comfort of the patient requires that the renewal of the air should take place without draught, hence an adequate space around the patient is necessary—that we term cubic space.

The convenience of nursing requires that there should be a sufficient distance between two adjacent beds, and an adequate distance for convenient administration between the feet of opposite beds. This determines the floor space which forms the unit of floor area for the ward.

The cubic space and floor space to be allotted to each patient have been fixed for the army according to the following table :—

Table showing Accommodation, per bed, to be provided for British Troops at—

Station.	Barracks.				Hospitals.							
	Permanent Buildings.		Wooden Huts.		Permanent Buildings.						Wooden Huts.	
					Ordinary Wards (including Prisoners, Ophthalmic, and Lunatic Wards).		Light Case Wards (including Detention and Venereal Wards).		Infection Wards.		All Wards.	
	Floor space sq. ft.	Cubic space cub. ft.	Floor space sq. ft.	Cubic space cub. ft.	Floor space sq. ft.	Cubic space cub. ft.	Floor space sq. ft.	Cubic space cub. ft.	Floor space sq. ft.	Cubic space cub. ft.	Floor space sq. ft.	Cubic space cub. ft.
(I.) HOME STATIONS	57	600	50	500	85	1200	65	900	110	1500	70	800
(II.) STATIONS ABROAD :—												
Scale A. Cyprus (Troodos Camp only) Nova Scotia	60	630	50	500	85	1200	65	900	110	1500	70	800
Scale B. Bermuda ... ... Cape of Good Hope ... ... Cyprus (except Troodos) ... Gibraltar ... ... Jamaica (Newcastle) ... ... Malta ... ... Mauritius (Curepipe) ... ... St. Helena ... ... Sierra Leone (Mount Auriole)	65	750	60	600	92	1300	72	1000	124	1700	77	900
Scale C. Barbados ... ... Egypt ... ... Hong Kong (except Victoria) Jamaica (Up Park Camp) ... Natal ... ... Sierra Leone (Tower Hill) ...	72	850	70	750	100	1430	80	1125	136	1900	84	1000
Scale D. Ceylon ... ... Hong Kong (Victoria) ... ... Jamaica (Port Royal) ... ... Mauritius (Port Louis) ... ... Sierra Leone (King Tom) ... Singapore ... ... St. Lucia	80	1000	75	850	110	1600	90	1300	150	2100	95	1150

You will observe that the cubic space in warm climates exceeds that in temperate climates.

Shape of Ward.

There are two principal forms which have been adopted for wards on the pavilion principle. One is the rectangular, the other the circular. *Fig.* 4, *Plate* II., shows a rectangular ward with its appurtenances in the new Military Hospital, Holywood, near Belfast. The rectangular form affords a maximum of wall space in proportion to the area; in this form the beds are only arranged along the side walls. This form allows of the smallest distance between opposite windows, combined with adequate room for nursing, etc. It is an axiom that the shorter the distance between opposite windows the more effective will be the cross ventilation.

Adequate space between the beds ought never to be less than 4 feet 6 inches or 5 feet, which, with a bed 3 feet wide, gives 7 feet 6 inches to 8 feet as the lineal width of the bed space, and as much more as can be afforded. It should be assumed that the bed would stand about 12 inches from the wall to allow of circulation of air behind, and there should not be less than from 10 to 12 feet between the feet of opposite beds. This affords the minimum space necessary for administration, and in the rectangular ward it would bring the length of each bed space to about 12 feet 6 inches or 13 feet 6 inches. Rectangular wards would thus be 25 to 27 feet wide, with a floor space of from 93 feet 6 inches to 108 feet. To this any necessary addition must be made either in the wall space or in the width of the ward for the extra aëration wanted in the case of wounds, lying-in women, infectious diseases and so forth, as well as for facilities for a medical school.

Fig. 5, *Plate* II., shows circular wards of the Burnley Hospital. The circular form of ward is more expensive to construct; it affords a minimum of wall space in proportion to the floor space. On the other hand, the walls are all available for wall space for the beds; but where the diameter of the circular ward exceeds what would be the width of a rectangular ward, a large proportion of the floor space is away from the patients in the middle of the ward. For instance, in the Antwerp Hospital a ward of 20 beds has a diameter of 61·6 feet. The wall space per bed is about 9·6 feet, but the actual space, between the adjacent beds is 6 feet at the head, but only 4 feet at the foot of the bed. The total floor space is 149 feet, the total cubic space is 2,525 feet, but barely 90 feet of floor space, and 1,500 feet of cubic space would be within a distance of 14 feet from the vicinity of the head of the patient. The distance between the feet of opposite beds would be 47 feet 6 inches, which is too great for efficient ventilation by means of opposite windows.

So far as the convenience of a medical school is concerned, it is said that the large proportion of floor space in the middle of the ward away from the beds is convenient, in that the bed of the patient under observation can be wheeled out into that space, and thus ample means be afforded for the students to see the patient, and hear all the remarks of the clinical professor.

The circular form of ward is very cheerful, because the windows catch the sunshine at a larger number of angles than is the case with the rectangular form. The circular form is also convenient for artificial ventilation, in that the air can be extracted at a central flue, and admitted equally all round the circumference. The larger area over which the admission of air is spread favours its coming in gradually, whilst a higher velocity may be given to the central outflow. One advantage of the circular ward lies in the absence of angles. This advantage can be obtained to some extent in the rectangular ward by rounding all angles and avoiding all cornices.

In calculations of cubic space, the height of the ward is usually reckoned as 12 feet, but the actual height to be given to a ward for purposes of daylight, and for the due circulation of air, must depend upon the width and the length of the ward. For a small single or double ward, a height of 12 feet might suffice, but in wide and long wards the due proportions for the circulation of air require that this height be increased. It is only in one storey buildings that any material difference in the section of a ward can prevail, and where the space admits, the location of sick or injured in one storey buildings adequately warmed, and provided with ridge ventilation, will always prove to be satisfactory and economical. On these grounds the one storey ward is adopted in numerous foreign hospitals.

Fig. 6, *Plate* II., shows the section of a recently designed ward on one storey for an isolation hospital, where economy of construction was sought. The requisite height is afforded by utilizing the roof; the ventilation of the upper part is provided in clerestory windows.

A French engineer, M. Tollet, constructed the wards of several French hospitals with an ogival section, on the ground that the vitiated air from the patients ought to be afforded facilities for passing rapidly upwards (*Fig.* 7, *Plate* II.), and for its immediate removal from the highest part of the ward through an opening in the roof. Curved iron ribs of the double T pattern receive plaster or concrete slabs, which form the ward walls, and are carried from the floor to the apex of the roof, where an opening is left. The structure is enclosed by light walls and a roof. The windows are carried up in M. Tollet's plan from the ground to a height of 12 feet, with divisions which permit them to be opened more or less, according to the season.

Fig. 8, *Plate* II., shows a section of a ward in the new hospital at Hamburg. These wards are warmed partly by stoves admitting fresh air, and partly by means of the floor, which is heated with steam pipes placed in chambers underneath (*Fig.* 9, *Plate* II.). The surface of the floor is formed of terrazzo. A temperature of 80° Fahrenheit in the floor affords a temperature of 60° Fahrenheit at the level of a man's head.

Window Surface.

The area for window surfaces for light varies with the climate and with the surroundings of a hospital. One square foot of window area to from 50 to 80 cubic feet in the room will afford a light and cheerful room. With verandahs, in this climate, this must be increased. The windows in rectangular wards are opposite each other on each side, and it is generally found convenient so to space the windows that one bed shall be between the wall at each end and the adjacent window, and that there shall be two beds in each wall space between the other windows.

The following table shows the proportion which the window surface bears to the cubic space in some important modern hospitals :—

In Towns.	One Square Foot of Window Space	
	to Square Feet of Floor Space.	to Cubic Feet of Cubic Space.
S. George's Union Infirmary	4·6	60
Leeds Hospital	4·9	80
Hotel Dieu*	6·7	175
Tenon (Menilmontant)	6	102
Halle	8·2	123
Herbert	5·1	69
Moabit	6·2	78
John Hopkins	4·8	78
Montpelier	4·7	112
Hamburg	5·3	84

* First Floor.

In some of the isolation hospitals recently built for infectious diseases the wall space between the windows is made to hold one bed only, and a window instead of a bed is placed next to the end walls. The form of window which is preferred for hospitals is one divided into three parts; the two lower parts are double hung sashes, the upper part is made to fall in as a hopper ventilator from the lower bar, with sides to prevent down draughts.

Ward Floor.

The ward floor should be raised from 2 feet 6 inches to 4 feet or more above the ground level. The space underneath should be kept clean and free from rubbish. In the Montpelier hospital it is lofty, and used for a covered exercising ground. In the Hamburg hospital it is formed into a heating chamber for warming the ward floor.

The main object to be obtained in a ward floor is that it should be non-absorbent, and free from cracks or other receptacles for dust or dirt. In this country wooden floors have been preferred; these should be of hard wood, that is to say, narrow oak boards or teak beeswaxed. It is desirable that the angles between the floor and the wall should be rounded off in a concave form, so that there should be no place where dirt can lodge.

Floors of terrazzo adopted in Germany, France, and Italy, and in some of the new English hospitals, *e.g.*, the new Derby Infirmary, have much merit. The authorities of the latter institution state that they consider it to be the best flooring for hospitals, in that it is not found to be cold, as it attains to the temperature of the wards (60°—65°), that it does not condense moisture, and that no fluids, except strong acids, have any effect on it.

Warming.

The next point to which I would draw your attention is that of warming the wards. Equality of temperature is an axiom if you desire comfort. That is to say, in the design of your hospital you should adopt those methods of construction in your walls, your ceilings and roofs, and especially your windows, which are best calculated to retain heat. I mention the windows, because in a hospital ward the window surface is necessarily large, and with 14-inch brick walls, and an assumed internal temperature of 60° in the room, and an outside temperature of 30°, the proportion of loss of heat from wall surface to loss of heat from window surface may be approximately taken to be about 1 : 2·5. In cold weather, therefore, either a double window, or one of thick plate glass, is desirable for retaining one equable temperature in hospital wards.

Warming and ventilation in hospital wards is usually effected by one of the following methods :—

I. The open fire-place.

II. Warmed air brought into the rooms, w.c.'s, or corridors by flues from a centrally placed calorigen or heating apparatus.

III. Close stoves placed in the room or corridor to be warmed; or else hot water pipes, or steam pipes heated by a boiler in some central position, and carried by the pipes thence to the places where the heat is wanted.

Although you probably know the heat conditions which prevail with each of these methods of warming, I will briefly mention them.

If there is a bright fire in the room, the rays from the flame and incandescent fuel convey warmth to the walls and furniture of the room, whilst its rays leave the air to be breathed cool, and there is no doubt that the perfection of ventilation would be to have cool air to breathe, but to be surrounded with warm walls, floors, and furniture, so as not to feel ourselves parting with our heat to surrounding objects. With the open fire, a proportion of the heat is used for producing a current in the chimney flue; this proportion of heat does not warm the room, and hence, in considering the fuel consumed in an open fire, we must remember that a portion of the fuel is being expended to assist ventilation. Thus, for instance, with an open fireplace, a velocity will frequently prevail in the chimney of 10 feet, and in some instances of 15 feet per second; thus causing, with a flue 14 inches by 9 inches, the removal of from 30,000 to 45,000 cubic feet of air per hour.

Unless provision be made for replacing the air thus removed, the air would find its way into the room as best it can, by crevices, round doors and windows, and create draughts. Hence in hospital wards special means of admitting air should be provided.

This may be furnished by means of the fireplace itself, as in the "Barrack or Hospital Ventilating Grate," or by fresh air through special openings from the outside, and warmed—as it enters—by hot water pipes or steam pipes in the ward itself; or again, by means of air conveyed along flues from a central furnace or heating apparatus. Or, on the other hand, you may dispense with the open fire and warm the wards by means of hot air alone, drawn from a central heating apparatus, or by means of hot water or steam pipes carried round the wards. In the first case, when hot air is conveyed into a room by flues from a stove or other central source of heat in the basement, it is necessarily warmer than the walls, consequently the walls and furniture of the room are warmed by means of the heat conveyed to them by the heated air, and are thus necessarily cooler than the air itself, and the heat of the body is radiated to the cooler walls. Moreover, the warmed air is less pleasant and invigorating to breathe than cold air. If you take two equal volumes of air, one heated and the other cold, the expanded heated air will contain less oxygen per volume than the colder air. For instance, at a temperature of 32° a cubic foot of air weighs 567 grains, which would be distributed in the proportion of 448·8 grains of nitrogen to 118·2 grains of oxygen, whilst at a temperature of 80° the cubic foot of air weighs 516 grains, which would be distributed in the proportion of 408·4 of nitrogen to 107·6 of oxygen. It is probably for that reason that the air of a frosty morning is so invigorating.

Therefore, warming by warmed air alone is not the most comfortable method for keeping a ward warm.

With hot water or steam pipes in the ward itself, you may obtain some of the advantages of radiant heat in warming the walls, because with the Perkins' high pressure system, or with steam pipes, a proportion of the heat will pass to the walls. I would here like to observe that with hot water or steam pipes you will find it comfortable always to distribute the heat as far as possible. In the Burnley Hospital, which is heated by open fires in the centre, and by steam pipes round the walls, there are three rows of steam pipes just above the floor level, and one row carried round at a height of about 12 feet from the floor level, which assists the ventilation. Each of these rows of pipes is so arranged that the heat can be passed through any one row, so as to leave the others cool, and *vice versâ*, and thus the temperature of the ward is very fully controlled. Pipes should never be sunk in the floor, with gratings over, for they only form receptacles for dirt which are almost impossible to clean. For the same reason, all ventilating openings should be easily accessible for cleaning.

Ward Offices.

The ward offices are of two kinds :—

(*a*). Those which are necessary for attendance on the sick and for facilitating the nursing and administration of the wards, as the room for the medical man, the nurses' room, and ward scullery.

(*b*). Those which are required for the direct use of the sick, so as to prevent any unnecessary processes of the patients taking place in the ward, as, for instance, the ablution room, the bath room, the water closets, urinals, and sinks for emptying foul slops.

These various offices will vary but little with the size of the ward; that is to say, a ward of twenty beds will require nearly as large ward offices as one of thirty-two beds. The number of water closets and lavatory basins depends to some extent on the severity of cases treated; twelve per cent. of the number of beds may be assumed as a rough approximation in each case. But whilst three water closets per ward may suffice for a ward of thirty-two beds, two at least will be required for wards containing eight to ten beds. The superficial area to be added to the hospital, in the case of wards of thirty-two beds, for these appliances would be about 30 square feet per bed, whereas in wards of twenty beds each it might amount to above 45 square feet per bed. Time does not permit me to enter into details under this head. I would only observe that, for convenience and economy of administration, hot and cold water should be laid on to all ward offices in which the use of either is constantly required, and that when the wards are on two or more floors lifts should be provided to carry up coals, trays, bedding and patients. It is estimated that these conveniences economize in attendance as much as one attendant to every thirty patients.

There should be provided, in connection with the scullery, a separate place for keeping the necessary provisions (such as milk), fitted with a refrigerator, but cut off from the ward air; a miniature dairy receptacle outside a window and with perforated sides, which has been tried in some military hospitals, is shown in *Fig.* 1, *Plate* III.

Foul linen should never be retained in a ward; it may be placed in an outside receptacle, out of the scullery or corridor, open to the air, but it would preferably be placed in a movable galvanized iron truck on wheels, and conveyed as soon as possible to the laundry.

Ward sweepings and refuse should similarly be placed in movable receptacles, and taken out of the building with as little delay as possible; structural provision is not advocated for the retention of these matters in or near the hospital.

Medical samples must, however, be retained. *Fig.* 2, *Plate* III., shows an arrangement for the medical sample cupboard adopted by the War Office.

There must be a closet for brooms, brushes, pails, etc., but it must be very light and airy to prevent its becoming a receptacle for rubbish. Of course, you will understand that especial care is necessary in connection with drains and foul-water pipes.

Aggregation of Ward Units.

The ward, with its ward offices, as before described, is the unit or basis of hospital construction. It is a small hospital which would only require certain administrative additions to make it complete.

Fig. 4, *Plate* II., shows a complete small hospital. The ward unit forms the basis for any hospital.

In aggregating these ward units, it is desirable to arrange that there shall be a sufficient number of wards in proportion to the probable number of patients, so as to ensure that every ward shall be closed once in each year for aëration, cleaning and repairs.

The principles upon which these units of ward construction, or, as they are generally termed, pavilions, should be arranged when aggregated are as follows :—

1. There should be free circulation of air around and between the pavilions.

2. The space between the pavilions should be exposed to sunshine, and the sunshine should fall on the windows and walls. Sunshine will fall to the largest extent on the space between pavilions, and also be distributed most evenly over the wall surface in this country, by placing the pavilions on a north and south line or axis, because the slanting rays of the sun fall in the morning on the eastern, and in the evening on the western side. With an east and west axis one side of each pavilion, and part of the area between the pavilions, is sunless for most of the year.

3. The distance between adjacent pavilions should not be less than twice the height of the pavilion, reckoned from the level of the floors of the ground floor ward to the eaves if with a very sloping roof, or to half the height of the roof with a steep roof. Where there is not a free movement of air round the buildings, the distance should be increased.

4. In this climate it is desirable that the surface of the ground between and near the pavilions should be so covered with asphalte, or otherwise, as to be free from moisture.

As regards the question of wards on one floor, or wards superimposed in two or even more floors, it may be accepted that, so far as the sick are concerned, they would, as a rule, be better placed on one floor in a ward unit well raised off the ground without anything over them. These units could be entirely separate; they might be entered from a corridor open at the side or with glazed sides, as might be desired.

In one floor hospitals the pavilions would be placed nearer together than in the case of wards on two floors, and consequently the distance to be traversed by the medical men on visiting the wards would be from 30 to 35 feet horizontally between two pavilions in the case of the one storey hospital, as compared with ascending from 14 to 16 feet by a staircase in the case of a two storey building. Therefore, if land is cheap, and the site fairly level, the one storey wards might be more economical than two storey buildings. On the other hand, the cost of drainage may be somewhat greater; the supply of hot and cold water to the ward offices will be less in the one storey hospital.

The necessity for superimposed wards, which in some town hospitals cannot be limited to two floors only, would render a special construction of staircases advisable to prevent communication of air between wards.

In the new University College Hospital, which is erected on a very inadequate area in five stories, the staircase is central and detached, access being provided to the pavilions by light bridges on each floor (*Fig.* 3, *Plate* III.).

In the case of fever hospitals for the Metropolitan Asylums Board recently erected by Messrs. Harston for two floors of wards, the objection to the staircase forming a shaft for impure air between the lower and upper wards has been met by cutting off the staircase entirely from the entrance to the lower wards. The pavilions are connected by means of a covered way consisting of a roof on columns. From this covered way there is a direct entrance to the lower ward, whilst the staircase leading to the upper wards has its own separate entrance opening directly into the covered way (*Fig.* 5, *Plate* III.). Outside staircases are provided at the further end of the wards for escape in the case of fire.

To prevent community of air between the two floors of wards in the Colchester Military Hospital, the staircase has been placed intermediate between the pavilions (*Fig.* 4, *Plate* III.). Time does not permit me to discuss this part of the subject further. But before concluding, I desire to say a few words on the question of those temporary structures which are a necessity in case of war.

The experience acquired in the Crimean War was utilized in succeeding wars. In the American War of Secession, 1861–63, large temporary hospitals were erected, containing from 1,000 to 2,000 and more sick and wounded. They were formed of separate huts with windows on each side. The huts were arranged sometimes *en échelon*, sometimes radially round central administrative buildings so as to allow of free ventilation. Access to these hospitals was afforded for the sick and wounded, and for provisions by conveniently arranged railways. These large hospitals were designed on the principle of concentrating the sick and wounded in large establishments, apparently for facility of supply.

In the Franco-Prussian War of 1870–71 the hospital huts of the Germans at the rear of the armies were a still further advance in the application of fresh air and cleanliness (*Fig.* 6, *Plate* III.). But in contradistinction to the American plans, these latter were arranged on the principle of dispersing the sick and wounded amongst several moderate-sized hospitals in different towns and localities, each approachable by railway, thus avoiding the agglomeration of sick and wounded in large establishments which took place in America.

You will understand that the establishments to which I am referring are distinct from the movable field hospitals which follow the army to afford the accommodation necessary on the field of battle, and which, in the British Army, are provided by the Army Medical Department and the Army Service Corps.

What I am referring to are those structures possessing a character of greater permanence into which the sick and wounded are received at the base of operations, and which it may fall to the Royal Engineer to have to erect. Such hospitals must, as a rule, be erected out of the materials at hand. Iron is not desirable; it is impervious to air, and unless lined with wood it is hot in summer and cold in winter. With wood, on the other hand, the walls are permeable to air at all points.

The permeability to air proved the chief element of healthiness in the hospital huts erected in the American War of Secession, and the Franco-German War of 1870–71.

The most successful of the rapidly improvised quasi-permanent hospitals erected for the German Army in the war of 1870–71 were those in which the arrangements admitted of the removal of the sides of the huts in the day-time, so as to allow the air to blow directly through them, whilst in other cases free access of air to patients was obtained by transporting the beds of the patients into an adjoining meadow, where they could lie absolutely in the open air exposed to sunshine. In cold weather, however, double walls are necessary. But British troops have often to serve in a hot climate rather than in a climate of the character of that of Germany and France.

Surgeon-General Marston, C.B., suggested a very practical form of hut for hot climates, which was used in Egypt (*Fig.* 7, *Plate* III.). The idea of its design was to place the patient as nearly as possible in the condition of a person provided with a large thick umbrella as a protection against the sun or rain; that is to say, the roof was of such material and construction as to exclude the heat of the sun's rays. The hut was provided with verandahs, and capable of free ventilation all round, as well as shelter from wind on any side on which such protection was desired.

I have endeavoured, in the short space of time allotted to this lecture, to lay before you the principles of hospital construction which have been developed during the past half century.

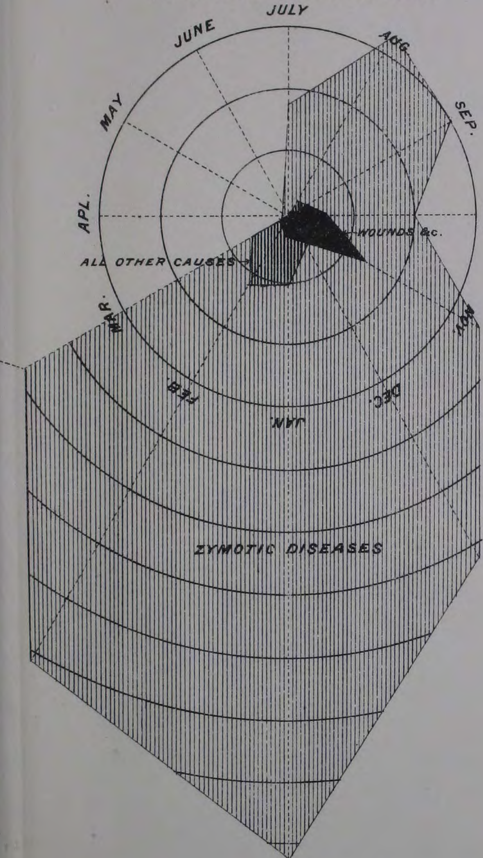
Whatever may be the discoveries of science with respect to the origin and propagation of disease, the experience of the whole civilized world in the matter of hospital construction appears to point with unerring certainty to the fact that just as pure air is the best safeguard against disease, so does a free atmosphere produce the conditions favourable to the cure of disease, and to the healing of injuries.

The Royal Engineer may not often be called upon to build a large hospital, but he may at any moment of his career be required to provide for sick and wounded in the field, or at the base of military operations. The same principles which guide the architect in constructing a permanent hospital must be his guide also in the erection of a temporary structure; his watchwords should be—light, air, speedy removal of refuse, and great facility of cleansing.

The smallest number of parts compatible with the requirements of the hospital should be arranged in the simplest form, and solely with reference to the wants of the patients, and to the way in which the service can be carried on with the smallest number of attendants. The design should be an expression of the need, and nothing more.

The hospital is the handmaid of the physician and surgeon. If they are to cure disease, the patient must be placed in conditions to enable nature to do her part, not in conditions which would thwart both nature and all the art which the physician or surgeon can bring to bear. These conditions have been laid down by medical men. My part has been to endeavour to show you how to shape the buildings so that they shall be in accordance with what the physician and surgeon have declared to be necessary, and my only regret in coming before you to-day is that you have not had a more efficient exponent of this important subject.

APRIL 1854 TO MARCH 1855.



PAPER IV.

NOTES ON RECENT RESEARCHES ON ILLUMINATION BY COAL GAS.*

BY MAJOR G. K. SCOTT-MONCRIEFF, R.E.

THESE notes are subdivided as follows :—

I. Composition of coal gas.
II. Method of improving illumination by mixture of other gases.
III. How gas should be burned for illumination.
IV. Laws of illumination.
V. Distribution and control.
VI. Calculation.
VII. Gases other than coal.

I.—COMPOSITION OF COAL GAS.

(1). *Coal, Origin and Various Qualities.*

Coal gas, as ordinarily used for illuminating purposes, is obtained by the distillation or carbonization of coal.

Coal was formed in bygone ages by the checked decomposition of vegetation which at certain geologic periods was extremely luxuriant. In the vegetable fibre there existed carbon, hydrogen and oxygen, but in the process of decomposition the oxygen and

* Compiled for the use of junior officers, R.E., from notes of lectures given by Professor Vivian Lewes, Gas Analyst to the City of London, at the S.M.E. in 1896, partly from articles in the technical press, and partly from experiments made at the S.M.E. The subjects of manufacture, testing, and details of construction are very briefly touched upon as they are fully detailed in Colonel Moore's book on the subject published by the R.E. Institute in 1893.

hydrogen was gradually more or less eliminated, leaving carbon with certain impurities, which vary in different qualities. For example, coal obtained from the North of England, burns with a rich blazing flame, and its constituents may be readily converted into gaseous matter, the oxygen and hydrogen in it having been partially eliminated. This coal has in it large quantities of bituminous matter; it is sometimes called caking coal, from the property it has of melting into a pasty mass.

Cannel coal, obtained from Lancashire and from the Scottish coal fields, is also very rich in illuminating power.

These are the two best varieties of coal for gas manufacture, yielding from eight thousand to fifteen thousand cubic feet of gas for every ton distilled. In districts where an inferior coal is found it is customary to mix a small quantity of cannel coal with the local material so as to improve the illumination. This, however, is limited by financial considerations.

Other varieties of coal have less and less bituminous matter, until we come to "steam" coal as found in the Western parts of the South Wales coal field. In this the hydrogen and oxygen have been eliminated to a further extent than in the ordinary varieties, leaving about 90 per cent. of pure carbon. This "anthracite" coal requires an enormous temperature to ignite it, and though it gives out a great heat, it is almost useless for gas manufacture, because it is the action of the heat on the hydrogen and oxygen in the coal which starts the distillation of the gaseous matter. In a gas works the financial aspect of the case demands that not only shall the coal yield a good proportion of gas, but also the residue shall be a marketable substance. This residue, known as *coke*, is best obtained from north of England bituminous coal, that from cannel being inferior in quality.

For purposes of comparison the gas obtained from a coal is called 16-candle gas or 20-candle gas, etc. This means that the light of that gas when burned at the rate of 5 cubic feet per hour will be equal to the light emitted by 16 candles or 20 candles, etc. This light is measured by a photometer, an instrument afterwards to be described.

In certain towns or districts the quality of the gas required is higher than in others. In London the standard is 16 c.p., in Manchester it is 18. In Edinburgh it is 27, in Paris it is 14 only, and yet the latter city is quite as effectively illuminated as the former—a fact which shows that the quality of the illuminant is only one out of several factors which have to be considered in the whole question of illumination.

(2). *Apparatus Required for Distillation and Changes that Occur.*

Supposing then that a certain quality of coal has been decided on, the following is the nature of the plant required for distillation :—
(i.). A retort, which is a fire-clay vessel, in section like the letter **D**, about 14 inches high and 15 feet long. This is one only out of a large number which are set in the same furnace, and are termed a "bench" of retorts. These are nearly filled (up to 4 inches or 5 inches of top) with coal, and heated by the combustion of the fuel in the surrounding furnace to about 1,000° C., when distillation begins. The hydrogen and volatile carbon form the required gas, a portion of the hydrogen and the oxygen combine to form water, and other impurities present in the coal are either deposited in the retorts or have to be removed from the distilled gas by subsequent processes.

(ii.). From each retort a pipe, called an "ascension" or "dip" rises vertically to carry off the distilled gas. It bends over at its summit and dips for $1\frac{1}{2}$ inches or 2 inches into a horizontal pipe partly full of liquid called the "hydraulic main." This pipe—in cross section, like the letter **U**—is kept half full by means of an overflow cock. It performs the double function of collecting the liquid products of distillation, and preventing a back draught into the retort. Each retort is thus kept separate from others in the bench—an important matter in practice.

What takes place inside the retort during distillation? At the sides the heat will be about 800° C., diminishing in the interior to about 400°. As the coal is heated, the bituminous matter in it is split up into solid carbon, then certain complex bituminous compounds, and such impurities as iron pyrites, sulphur, etc. As the temperature goes on increasing they become liquids, and finally gases, at first heavy vapours, but subsequently brought down to simple gases. In some cases the volatile carbon is deposited on the top of the retort (this is especially the case where the temperature is too high), giving an exceptionally dense substance very valuable for electric work, and used in such cells as the Leclanché.

Thus we see that the effect of the distillation is to break up the solid coal into (*a*) coal gas; (*b*), tar and other liquid products; (*c*), pure carbon; (*d*), and residue (coke). It is with the gas that we are concerned. As it passes into the hydraulic main the temperature is lowered, the tar begins to come out, and some of the vapours condense into liquids.

(3). *Methods of Extraction and Purification.*

In order to cause the gas to leave the retort and pass into the holders through the various stages of purification which are necessary, some artificial means of extraction have to be employed. This is done by means of an apparatus called an *exhauster*, which is practically a force pump. Were it not for this, the retorts would be under such pressure that they would leak, fire clay would not then be a suitable material (cast-iron is often used, and would have to be invariably used, but for the exhauster). The suction pipe of the exhauster is connected with the retorts, so as to draw the gas out, and the force or delivery pipe is connected with the apparatus beyond, so as to give the necessary pressure. Pressure is a term which we shall often have to use in connection with gas—it may be said to correspond to *head* in water-pipes. When we speak of 3″ pressure we mean that the gas will exert on the surface of water in a gauge such a pressure as will amount to 3 inches difference of level as compared with the atmosphere. The gas at the point of manufacture must be under considerable pressure so as to overcome the skin friction of the many pipes it may have to traverse before it reaches its point of ignition, where its pressure should be about $\frac{7}{10}$ inch. Thus we see that the exhauster is a very important part of the apparatus used in manufacture. The gas after manufacture is not passed directly from the exhausters into the pipes, but is stored in large holders, or gasometers, which correspond to service reservoirs in a waterworks scheme, and serve the double purpose of bringing to bear upon the gas a steady uniform pressure, and of storing a sufficient quantity for use in event of the retorts being stopped for any cause.

Before passing into the holders, however, the gas has to undergo purification. It has to be cleansed (1) from ammonia, which is partly effected in an apparatus called a "condenser;" where the pipe passes through several vertical returns, dipping in water at the base, and partly by means of a "scrubber"—a tall iron cylinder with water trickling in at the top over some insoluble substance, such as coke or brushwood, and gas entering at the bottom. The foulest gas meets the foulest water, until at the top all ammonia is practically removed. The resulting liquid is known as "ammoniacal liquor." (2). The gas has to be cleansed from carbon dioxide (CO_2) and sulphuretted hydrogen (SH_2) from the iron pyrites in the coal, both of which impurities are most noxious, the former reducing enormously the illuminating power, and the latter being inflammable, and causing obnoxious fumes when burnt. The agent used for this purification is *lime*, which is laid in rectangular iron boxes in trays or sieves, through which the gas, which enters at the bottom, ascends. There are other purifying agents sometimes used, but quicklime is the most usual. The CO_2 has first to be removed, and then the gas is passed through a fresh supply of slaked lime to remove the SH_2.

(4). *Composition of the Resulting Gas.*

The gas thus purified is not a simple chemical compound, but a mixture of several. The following gives the composition of two London gases :--

	South Metropolitan.	Gas Light & Coal Co.
Hydrogen	50·16	53·36
Unsaturated hydrocarbons ...	3·50	3·58
Saturated hydrocarbons ...	36·25	32·69
Carbon monoxide	5·68	7·05
Carbon dioxide	0·00	0·61
Nitrogen	4·10	2·50
Oxygen	0·31	0·21

The chief ingredient in the mixture is hydrogen, a gas which burns without luminosity. It is, however, merely a diluent. It is to the hydrocarbons* that coal gas owes its luminosity, and these are classified as saturated and unsaturated. It was formerly supposed that it was the unsaturated hydrocarbons that gave the luminosity to gas, but it has now been proved that it is the saturated hydrocarbons, principally methane or marsh gas, that are the most important factors. This substance, forming some 30–38 per cent. of the whole, when raised to a high temperature, has the effect of developing in the other hydrocarbons acetylene—which is an intensely brilliant gas—and it also enlarges the area of the gas flame.

Before going on to consider the composition of gas flames, it is necessary to pay attention to—

* *i.e.*, benzene, methane, acetylene, etc.

This, however, touches upon our next subject, before entering on which it may be sufficient to summarize the advantages of a carburetted water gas installation as compared with coal gas :—

1. Reduction in the consumption of coal—a given weight producing four times as much water gas as coal gas.

2. Reduction in labour and simplicity in working. It is considered that three men only are required to produce 35,300 cubic feet per hour continuously.

3. Facility of production as required and adequacy of small storage holders.

4. Low cost of plant and independence of variations of coal market.

An Austrian professor (whose remarks I have quoted above), is of opinion that in such a town as Vienna water gas should cost about 1s. 5d. per 1,000 cubic feet.

III.—How Gas should be Burned for Illumination.

(1). *Composition of the Gas Flame.*

On this subject there is a good deal of difference of opinion among experts. Some consider that the flame is divided into two zones: (1), an outer sheath of intense combustion; and (2) an inner region of non-combustion, divided into an internal portion (*a*) in which radiant heat converts the hydrocarbons into acetylene (C_2H_2) and a luminous envelope (*b*) in which intense heat is decomposing the acetylene with emission of light, and the blue calyx at the bottom, in which the hydrocarbons are undergoing decomposition by water vapour and carbon dioxide, without previous separation of carbon.

This is known as the acetylene theory of luminosity. According to this theory (which as far as one can judge is accepted by many of the best men), the gases forming the mixture known as "gas," on issuing from the burner, under ordinary atmospheric pressure, at once tend to follow the laws of gaseous diffusion. The constituents of the gas rush to the surface of the flame with a velocity varying with the square root of their densities. Thus the larger proportion of the hydrogen finds its way to the exterior and burns first, a certain proportion of the methane follows, and so on with carbon monoxide, and the lighter hydrocarbons. Thus further up the flame the lighter constituents are weeded out, and you have the heavier hydrocarbons passing up with little loss, but heated between walls of burning hydrogen and methane. At the top of the non-luminous zone the only hydrocarbon left is acetylene.

This gas (C_2H_2) is decomposed at an intense heat into its constituents C and H. The latter combines with the O of the atmosphere to form H_2O or aqueous vapours, and the former is liberated in a bright state of incandescence. In the chemical decomposition of the C_2H_2 heat is evolved, which is one out of several sources of heat, tending to bring the carbon to the glowing state.

Several objections have been made to this theory, based principally upon the fact that it is extremely difficult to estimate the rapid changes of temperature which must evidently take place in the minute distances dividing one part of the flame from another. No contrary theory has been established, however, and there is a pretty general consensus of opinion that one at least of the causes of luminosity (if not the only cause) is the presence of minute particles of solid carbon heated to incandescence in the flame. How these solid particles are evolved from the gas is not explained by any other theory than that above described. The problem is evidently exceedingly complex, and for a layman to follow the arguments on both sides seems hopeless. But what we can apparently note as of practical importance is that the luminosity of the particles of carbon depends in some greater or less degree on temperature, and on the way in which the issuing jet of gas is exposed to the atmosphere.

(2). *Method of Giving Practical Effect to the Above Theory.*

Long before the theory on the subject was formed, practical improvements in the construction of the apparatus for burning gas had arisen by a process of evolution.

Gas if ignited as it issues from a hole in a pipe, say $\frac{1}{4}''$ in diameter, burns with a smoky flame emitting little light. Here the decomposition of the carbon is not sufficiently carried out to bring the particles to incandescence, and the diffusion of the hydrogen is not so complete as to give the necessary increase in temperature. But if we reduce the size of the aperture, and the pressure of the issuing gas, we have much better results.

This may be still further improved by allowing the gas to issue through a fine slit.

A further improvement is the "fishtail" burner, where two tiny jets of gas are allowed to impinge upon each other, the heat produced in one tending to accelerate in the other the necessary chemical decomposition. An improvement on this is the "union jet" burner, commonly used throughout the country.

So far, however, the flame is exposed to the cooling influence of the surrounding air. To increase the temperature of the atmosphere, and of the gas before it emerges from the burner, is the next step. If we can do this we increase the luminosity, because the decomposed particles of carbon are sooner brought to that high temperature which results in incandescence.

The first step in this direction is the Argand burner, which originally consisted of two concentric tubes, between which the gas flowed. The London Argand is formed of two short cylinders united at the top by a soapstone covering, pierced with tiny holes, and surrounded by a chimney of glass. Without the latter the luminosity is much reduced, both because the glass protects the flame from draught, and because the glass gets soon heated, and surrounds the flame with an envelope of hot air.

Next we have the "regenerative" burners of the Wenham and Siemens class, introduced about 1879. In these the points of ignition are at the bottom of two concentric cylinders. Here the products of combustion pass up the interior of the inner cylinder, and heat the gas, which is supplied between the inner and outer cylinder, to the point of ignition at the bottom. This is enclosed in a glass globe, and the flame curls inwards and upwards.

In the Deimel* this is further assisted by having an unglazed porcelain cone against which the flame impinges, and which rapidly becoming white hot assists the decomposition of the carbon in the flame.

We now come to the last development of the gas burner, viz., what is usually known as the "incandescent" burner. The luminosity in this case depends on a process which is entirely distinct from that previously considered, though based on the same ultimate principle, viz., the incandescence produced by the heating of solids.

It was found in 1835 that when ordinary blotting paper was soaked in a solution of calcic chloride and burnt in the flame of a spirit lamp, it left a white network of ashes, which when heated in the feeblest flame gave forth a brilliant light.

Leaving the many intermediate steps which led to the present

* This burner was introduced into barracks at Aldershot in 1891, with much success. Unfortunately, it is not obtainable now in the market.

adaptation of this principle, it may be sufficient to point out that Dr. von Welsbach, about 1885, conceived the idea of making a mantle of cotton fabric steeped in a solution of nitrates of certain metals, which, after being dried, was burnt so as to remove the organic matter, leaving the metallic nitrates in the fibres, converted by the heat into oxides, which still retained the form of the fabric.

The burner in this apparatus is such as to produce a non-luminous flame, as otherwise deposition of carbon on the mantle would rapidly bring the incandescence to an end. A non-luminous flame is produced by using atmospheric burners (the Bunsen burner), in which there is an admixture of gas and air before combustion takes place. The admixture of oxygen from the air assists the consumption of the hydrogen and hydrocarbons of the gas. The completed products are carbon dioxide and water vapour.

The mantle ordinarily in use is formed from the ash of a cylinder of cotton, fastened at the top with asbestos thread, with a loop of the same material to attach it to the supporting rod. This fabric has been steeped in a solution of the nitrates of certain metals—thoria 98 per cent. and 2 per cent. ceria being the mixture used in the ordinary Welsbach mantle—and as each fibre in the cotton is a small tube, which by capillary action sucks in the solution, we have in the finished product a network of a delicate nature containing the oxides of these metals.

The cause of the wonderful emission of light thus produced is still very imperfectly understood. It is a remarkable fact that mantles steeped in thoria by itself emit hardly any light, but the addition of 1 to 2 per cent. ceria give the brilliant light which is now so well known. Evidently some molecular changes take place in the materials, though why these should take place with the above proportions is not clear.

The light emitted is strong in actinic rays, and is therefore considered to be somewhat injurious to the eyes.

Another objection to the use of these lights in barracks is that vibration rapidly destroys the fabric of the mantles and necessitates renewal.

On the other hand the cost per unit of candle-power emitted is far less than any other form of illumination by gas or by electricity.

The latest development of this is to have an atmospheric burner of a peculiar long shape, where the mixture of the gas and air is more complete and intimate than in the Bunsen. The result is a flame very hot, and of a form corresponding to the shape of the mantle.

This gives results in c.p. per cubic foot far in excess of anything hitherto attained.

We thus see that the burners ordinarily in use may be subdivided into three groups, viz.:—I. Open flame burners. II. Regenerative. III. Incandescent.

We see also that the pressure at which the gas issues is of much importance. If it is very low there may not be sufficient fuel to support combustion in an efficient manner, if it is too great the diffusion of the gases may not have time to take place, and the liberated carbon may pass off in smoke, or in CO_2.

It is further necessary that the flame be protected from draughts, so as to burn steadily. In the case of open flame burners this is usually done by means of globes, but as usually constructed with a narrow opening at the bottom, and thick galleries or brackets, these generally are most objectionable. The glass of *any* globe obstructs the light in itself (although it may be designed to increase the illumination at certain angles, as will be shown presently), but if made with a narrow opening at the base there will be an upward current of air which will affect the shape and nature of the flame, reducing its luminous area to a considerable extent. Thus the source of light will be diminished, and the ultimate effect far less than if there were no globe. Modern globes are therefore made with a wide opening at the base.

For incandescent burners, for electric incandescent lights, and for some oil lamps, the "Holophane" globe is by far the most ingenious and useful. This globe is made of clear glass, so moulded that the interior consists of vertical furrows or prisms, which have the effect of concentrating the light in a series of rays, and the exterior has a series of horizontal prisms at varying angles, so that the concentrated rays are deflected downwards. Thus the illuminating power at angles below the horizontal (or "working angles" as they are called) is materially increased, and the whole globe is covered with a surface of light which makes it pleasant to the eye. These globes may be of rose tint, which obviates the objection to the actinic character of the light emitted by the "incandescent" burners.

To regulate the pressure various expedients have been adopted in the burners themselves. In the common Bray union jet burner this is mainly effected by a disc of gauze in the interior of the burner, which checks the velocity of the issuing gas. Another and most efficient expedient is to have a cap fitting over the top of the burner. The burner can be used without the cap, but the effect is most marked both in respect of quantity consumed and efficiency of illumination. These burners are probably the best *for their price* that can be used for barracks.

In regenerative lamps there is always a little regulating arm which can be easily adjusted so as to have the illumination at its best under variations of pressure.

The greatest efficiency in the use of gas would be attained if there were a governor of pressure connected with each burner, each cooking apparatus, heating stove, or gas engine. This is a principle which should be borne in mind in connection with the gas supply to messes and similar large establishments.

The details of these governors will be briefly described later.

IV.—Illumination of Interiors.

On comparing the relative value of the various burners which have just been described, our attention would at first be directed to the brilliancy of the light produced by the burner in question, and to the consumption of gas. If we can ascertain, by reference to any standard, the comparative luminosity of various burners, and at the same time ascertain the consumption, we can tabulate the results in terms of candle-power per unit of gas consumed. This, however, will only give us a small part of the information which we require to obtain in order to use in the most efficient manner possible the light obtained, for there is a great difference between illuminating power and illuminating effect.

For instance, we may have a London Argand burning 5 feet an hour, and emitting a light equal to 16 standard candles, but if that Argand is burning in a room, say $16' \times 30'$, it does not follow that the effect produced would be the same as 16 standard candles distributed at various points about the room. In both cases the *power* is the same, the *effect* is different.

Before going on to consider the laws on which illumination is based, it will be as well briefly to indicate how the illuminating value of the gas is measured. The usual apparatus for measuring equality of illumination is a piece of paper with a grease spot in the centre, more translucent to light than the surrounding paper, so that when light is placed on one side of it, and it is viewed from the other, the grease spot stands out as a bright spot on a dark ground, and *vice versâ.* If there be two lights, one on either side of the paper, the grease spot will appear bright on the side opposite to that on which the strongest light is placed. If the two lights are so arranged that each side of the paper is equally illuminated the grease spot will disappear. If, then, the distances from the grease spot to the two lights be measured we know that the illuminating values will be directly as the square of the distances. If one of these lights be a standard the illuminating value of the other can then be obtained at once.

This principle is given effect in the Letheby photometer, which consists of a horizontal graduated bar, on which there slides a box containing the grease spot. At one end of the bar is the standard light, at the other is the light which is to be tested, the gas being under regulation by means of a governor, and being checked by passing through a small meter. The grease spot is moved backwards and forwards on the horizontal bar until equal illumination is observed, and the reading on the graduated bar is then noted.

The legal standard used ordinarily in this country is a candle burning between 114 and 126 grains of sperm per hour. This, however, is unsatisfactory on account of minor irregularities, and frequent attempts have been made to introduce something better. That which is now considered the best is called the *pentane standard* from the gas which is burned in it, made by mixing in a holder one cubic foot of air and three cubic inches of liquid pentane, a substance produced by the distillation of petroleum. This gas is burnt, at the rate of $\frac{1}{2}$ a cubic foot an hour, in a special burner of brass, 4 inches long, 1 inch diameter, the end being closed by a brass plug $\frac{1}{2}$ inch thick, in the centre of which is a round hole $\frac{1}{4}$ inch diameter, the whole being surrounded by a glass cylinder 6″ long × 2″ diameter, the top of which is on a level with the top of the burner. Above the burner, at a height of 62·5 m.m. (2·46 inches), is stretched a piece of platinum wire, 2 inches to 3 inches long, and about 0·6 m.m. thick. The height of the flame is so adjusted that it appears to touch the platinum wire, but not to pass it.

It is clear that, although suitable for purposes of comparison, the method of light measured on a horizontal line through the centres of the sources is an insufficient guide to us in estimating the illumination of a room, both because it takes no account of the reflected light from surrounding objects, and also because it tells us nothing of the illuminating value of the rays at angles above or below the horizontal. Inasmuch as the working surface on which illumination is required will be at some angle below the horizontal, some other means of ascertaining the value of the light at those angles is necessary. It is the light given by the burner at angles between 40 degrees and 90 degrees from the horizontal that is the important practical factor in interior illumination.

To measure this, a radial photometer is necessary. Such a one has been devised and made in the R.E. workshops. It consists of an arm, pivoted at one end, of given length, and fitted at the free end with a socket for a burner, in which any given burner may be fastened, and to which gas may be brought by a flexible tube. This radial arm may be clamped at any angle. In the central pivot is a grease spot, which can also be turned to any angle, and should in an observation bisect the angle between the arm and the horizontal. A standard candle is adjusted to be on the same horizontal level with the grease spot, and can be moved backwards or forwards till equal illumination is obtained. From observations made at the S.M.E., Chatham, with this photometer, the following results were obtained :—

Table showing Illuminating Value of various Burners at Angles below the Horizontal in Terms of Candles per cubic foot of Gas consumed; pressure, $\frac{9}{10}$ths 12-candle Gas.

Angles.	As issued by Barrack Department, A.S.C.			Bray's Burners with Caps.							Regulator Burners.		Regenerative.			Incandescent.		Remarks.
	Bray's No. 5.	Bray's No. 3.	Bray's No. 2.	No. 0, 3-cap.	No. 1, 4-cap.	No. 2, 5-cap.	No. 3, 6-cap.	No. 4, 7-cap.	No. 5, 8-cap.	No. 6, 8-cap.	Peebles' No. 5.	Suggs' Workshop.	Argand.	Wenham.	Siemens'.	Without Reflector.	With Holophane Globe.	
Horizontal .	1·34	0·9	0·79	1·51	1·42	1·84	2·1	2·12	1·94	2·82	1·7	2·02	3·12	—	4·7	15·2	13·5	
20°	1·33	0·83	0·65	1·45	1·35	1·73	1·66	1·87	1·86	2·26	1·8	1·8	2·50	3·4	5·1	11·5	11·15	
40°	1·21	0·83	0·61	1·138	1·28	1·51	1·46	1·64	1·61	2·20	1·9	1·9	2·22	4·0	5·4	11·5	11·5	The efficiency of the incandescent varies much with the condition of the mantle.
60°	1·0	0·76	0·59	1·06	1·06	1·46	1·46	1·35	1·45	1·80	1·7	1·7	1·00	3·6	6·3	7·2	8·5	
80°	1·08	0·62	0·55	—	—	1·11	1·0	1·35	1·13	1·71	1·1	1·1	—	3·5	6·5	4·7	8·2	
Vertical ...	Uno	bserv	able			Uno	bserv	able			—	—	—	3·5	6·8	—	5·2	

The candle power of a given burner at a given angle under given pressure is the most important of the factors governing the proper illumination of an interior. There are others of less importance:—(1). The size of the source of light, *i.e.*, the larger the surface the less will be the dazzling and irritating effect on the eyes. (2). The distribution of the light sources, so as to get the best general illumination over the whole area in question. (3). The reflecting power of the surrounding objects. This last is a very variable factor. Whitewashed walls reflect a very large proportion of the light thrown on them, while wood panelling reflects very little.

The unit of measurement for illumination has never been authoritatively fixed. A standard candle at a distance of a foot from a page of print, held at right angles to the direction of its rays, gives an illumination which is sometimes called a *lux* or a *candle foot.* The same candle at 2 feet distance would give 0·25-candle feet, while four candles at 2 feet give $\frac{4}{2^2} = 1$ candle foot.

When the illuminated surface is inclined at an angle to the direction of the rays, the intensity of the illumination is proportional to the cosine of the angle which the luminous rays make with the normal to the plane.

Thus, if we fix upon any given illumination in a room, say 0·25-candle feet, and if we know from observation the photometric value at various angles of the lights we propose to use, it is possible by calculation to dispose those lights so that they shall everywhere produce, on a certain plane, not less illumination than that fixed upon. The formulæ upon which such calculations are based are given in *The Principles of Structural Design*, Part I., pp. 345–6. Usually the illumination at any point on a horizontal plane at a given vertical distance below the light source is what is required. If x' be the horizontal distance, h the vertical distance, and I the luminous intensity in candles at the angle a, then the illumination (in candle feet)

$$= \frac{\mathrm{I}h}{(h^2 + x'^2)^3}, \text{ or} = \frac{\mathrm{I}\, cos^3\, a}{h^2}.$$

When there are two or more sources of light, the net illumination is the sum of the illumination produced by each or all, plus the unknown amount given by reflection.

In barracks 0·16-candle foot illumination on a plane 2 feet from the floor may be taken, or 0·25 at 3 feet from the floor. With the former it is possible for a man with good eyesight to look up the trains in a Bradshaw or read small print.*

It will be observed that this branch of the subject is a matter not for the gas engineer, but for the architect or engineer of the building. Generally, one may say that the source of light should be so placed as to be well above the plane of vision, and yet sufficiently intense to flood the room with soft light. Regenerative burners, fixed near the ceiling, with ventilating arrangements carrying off the impurities in the air, are the most healthful form of using gas, but have the disadvantage of considerable initial cost.

V.—Distribution and Control.

Passing from the use of gas in interiors to the means whereby it is conveyed from the gasworks to the consumer, our direction is first directed to—

(*a*). *Pipes.*—For mains these are almost invariably of cast iron, with spigot and socket leaded joints. They should be carefully protected by the Angus Smith process in the first instance, and the joints should be very carefully made. The depth at which the main should be laid should never be less than 1½ feet (no main under 3 inches should be used), and there should always be a slope on the pipe of at least 1 in 300, so as to carry off to "syphons" or small wells at the lowest points the water which condenses in the pipes.

The mains should be laid so that the branch or service pipes taken from them should be as short as possible. In a very wide road, with houses on both sides, it may be economical to lay a main on both sides, as close to the houses as possible.

The effect of severe frost may be (1) to cause the accumulated

* The following table shows c.p. per 1,000 square feet of area usually provided :—

Country Roads	½ c.p.
Small Towns	4 ,,
Large Towns	10 ,,
Hospitals, Barracks	50—100 ,,
Cottage Parlours	150 ,,
Dining Rooms	250 ,,
Churches, etc.	300 ,,

condensed moisture to freeze; (2), to cause a deposit of albo-carbon in the pipes. Either of these causes may lead to a total stoppage of the gas.

Connections with service pipes should, if possible, be arranged by means of T pieces, but if that is not practicable, a quadrant bend is screwed into a hole drilled in the top of the pipe, and the service pipe attached to the other end of the bend. Service pipes are made of wrought iron, jointed in the same way as water pipes of the same material, but the pipes required for gas need not be so heavy as those for water. On the other hand, these pipes are particularly liable to corrosion, and very special means should be taken for their protection. The pipe should, if possible, be inserted in a triangular boxing of elm wood, the space between being filled with sawdust or similar material, mixed with tar and pitch.

Syphons are simply C.I. cylinders placed beneath the main, communicating with it by one pipe, and having another ascending to the surface, by which the water can be pumped out. A combined syphon and test box is sometimes used, in which there is a mid-feather or partition coming down from the top, so that when it is desired to test the consumption of the gas, the box may be partially filled with water; a test meter with pipes is then screwed on to the top, so that the gas must pass through the meter, the dial on which will register the consumption.

Valves and stopcocks, on principles similar to those used for water supply, are also used for the control of the gas in mains and service pipes.

Governors, to which allusion has been made above, are either for regulating pressure, or for admitting only a given volume in a given time.

The former are all pretty much on the same principle. The gas passes through one or two horizontal apertures inside the governor, in which apertures there is a vertical spindle with cones fitted on its axis, which, by rising or falling, close or open the aperture. At the upper end of the spindle is a flexible diaphragm, and above the diaphragm weights, which bring a constant pressure to bear on the diaphragm and spindle. When the pressure of the gas rises above the required amount, the diaphragm rises, and in so doing partially closes the apertures, thus preventing gas from getting in. When the pressure falls the apertures open wider and admit more gas.

Regulators of volume differ from those of pressure in that the former act wholly surrounded by gas, whereas the latter have gas on one side of the diaphragm and air on the other. In the regulators of volume there is a bell which rises or falls over the mouth of the inlet pipe. In the dome of this bell is one or more holes, and at the top is a cone which opens or closes the outlet to the burner. As the pressure rises, the cone rises.

Meters are subdivided into wet and dry meters. The former used to be universally used, but the disadvantage attending their use in frost has caused the dry meter to be much more used for domestic supply, though the wet meter is still used for large quantities, such as those which pass from gasworks. The wet meter is generally considered the more reliable. In it there is a drum revolving in water up to a certain level, and divided into four compartments, each of which in turn becomes filled with gas, and is exhausted. The contents of each compartment being known, there is no difficulty in registering the consumption. In the dry meter the gas passes into four compartments, between two of which on each side there is a disc working with flexible leather attachment like a bellows, and the two pairs are divided by a vertical partition. By an ingenious mechanism above, the gas passes from one of these chambers to the other, filling one and pressing that adjacent to it so as to keep up a pressure in the pipes beyond, and the action of the two sides is kept up alternately.

Meters are called 5-light, 10-light, 20-light, etc., each "light" being assumed to burn 6 cubic feet per hour, and the meter calculated to pass 5×6 or 10×6 cubic feet accordingly.

Control is especially necessary in the case of gas pipes supplying cooking apparatus, stoves, etc. Usually the burners thus used are on the Bunsen principle (it might be said that these are invariably used, though there are a few exceptions), where air mixed with the gas prior to its reaching the point of ignition prevents that decomposing action of the hydrocarbons which, we have seen, results in a bright incandescence. The flame is therefore produced by the combustion of the hydrocarbons while still in a complex gaseous condition; it is non-luminous and very hot. Now an excess of gas causes the burner to emit a white smoky flame, as the oxygen cannot sufficiently mix with the other gases to cause perfect combustion of the hydrocarbons. On the other hand, too much air will cause the gas to "blow down" or burn at the wrong place. Exact regulation is therefore essential for good results. In fires a good form of burner is a cylinder of fire brick perforated with holes. The whole is surrounded after ignition by numerous jets of heated flame, causing the fire brick to become soon white hot. Asbestos blocks are usually piled round, and these throw out much heat. Stoves require more pressure than jets for lighting purposes, $\frac{7}{10}$ths is good enough for the latter, but the former require $\frac{10}{10}$ths.

VI.—Calculation of Sizes of Gas Pipes.

The following considerations affect the diameter of a pipe required to deliver a given quantity of gas :—

(*a*). Specific gravity of the gas ; heavy gas travels more slowly than light gas and requires a larger pipe—other things being the same.

(*b*). Pressure. The higher the pressure the greater the delivery.

(*c*). Length of the pipe. The greater the length the more the shin friction and the less the delivery.

(*d*). Level of the ends. As a gas pipe ascends the pressure rises ; hence, a pipe which rises has a greater delivery than one of the same length, etc., which falls.

Hurst's formula is $Q = M\sqrt{\frac{D^5 \times P}{G \times L}}$, where Q = quantity in cubic feet per hour, M = a constant varying from 1350 to 1000, D = diameter of pipe in inches, P = initial pressure in inches, and L = length of pipe in yards. Thus we see that, according to this, the carrying power of a pipe varies as $\sqrt{D^5}$, or as $\frac{1}{\sqrt{L}}$ or $\sqrt{P}$. The first of these has not been found to be in accordance with practice, and it has been proposed to calculate it on the basis of $\sqrt[4]{D^9}$, which is slightly less than the above.

Another formula, which is based on the assumption that the pressure is $\frac{7}{10}$, and the specific gravity constant is

$$N = \frac{200D^2 \times \sqrt[4]{D}}{\sqrt{2 \times L}},$$

when N = number of lights each consuming 6 feet.

The following table has been calculated on this basis. Number of lights burning 6 feet an hour, the pressure being $\frac{7}{10}$ inch :—

Diam. of Pipe.	Length of Pipe in Yards.								
	20	30	40	50	60	70	80	90	100
$\frac{1}{2}$	7	6	5	4	4	4	3	3	3
$\frac{3}{4}$	17	14	12	10	10	9	8	8	7
1	32	26	22	20	18	17	16	15	14
$1\frac{1}{4}$	52	43	37	33	30	28	26	25	23
$1\frac{1}{2}$	79	64	56	50	45	42	39	37	35
2	150	123	106	95	87	80	75	71	67
$2\frac{1}{2}$	248	203	176	157	143	133	124	117	111
3	375	306	265	237	216	200	187	177	168

Easy rules to remember are as follows:—

(*a*). With four times the pressure the delivery is doubled.

(*b*). ,, ,, length ,, ,, halved.

(*c*). With twice the diameter the delivery is multiplied by 4·75.

(*d*). Up to 20 yards of length, square diameter in eighths of an inch and divide by two. This gives number of lights burning 6 feet an hour that can be supplied. Up to 50 yards the divisor should be 3 feet.

Outside buildings, such as a barrack block, etc., the pressure should be not less than 1 inch. At the entrance to the groups of buildings forming the barracks the pressure will be about $2\frac{1}{2}$ inches. The difference should be absorbed in the friction of the pipes, and in overcoming such obstacles as meters, fall of ground, etc. Pressure in pipes is analogous to that in water, and a diagram of pressures can be drawn in the same way as a diagram of hydraulic gradients. The amount of pressure absorbed in any given case can be ascertained by the use of Hurst's tables (see p. 343, Part I., *Structural Design*).

VII.—Gaseous Illuminants Other Than Those Considered Above.

There are many circumstances where the application of gaseous illuminants is desirable, but where the installation of even the smallest plant for coal gas would be prohibitive or impracticable. Under such circumstances gas made from substances other than coal is frequently employed.

We have seen that in the case of coal gas and carburetted water gas the effect of heat is to break up the complex hydrocarbons into their constituent elements. This is also the case in the great class of hydrocarbons found in the solid form of fat, wax, etc., and in the liquid form of oils. On heating, these complex bodies break up under much the same circumstances as we have seen obtain in the case of gases.

The apparatus therefore required for the conversion or distillation of such a substance as mineral oil into the gaseous form is based on the same principles as that required for the distillation of coal. It may be said, without going into details, that the best oil gas is obtained from the distillation of the residue of Russian Baku oils after the lighter kerosenes have been driven off, and that this, distilled at a temperature of 900° C, gives 98 cubic feet of 50-candle gas = 980 candles per gallon of oil, and would leave some 20 per cent. solid residue.

It will be noticed that this gas—50-candle—is far superior in illuminating power to any coal gas. The reason is that the oil gas contains a smaller proportion of hydrogen (av. 18 per cent. as against 50 per cent.), and a much larger proportion of hydrocarbons (80 per cent. as against 40 per cent.) than coal gas. This richer quality of gas makes oil gas especially useful for the lighting of railway carriages—most of which are at present lighted by it. Many of the principal railway companies have their own installations of oil gas. It cannot, however, be used with the same burners as coal gas, or rather it would be more correct to say that for the same circumstances of illumination a relatively smaller burner should be used for the oil gas, in order to give opportunity for the relatively small quantity of hydrogen to diffuse and carry out in the flame the heating action, which, as we have seen, results in the decomposition of the hydrocarbons with brilliant incandescence.

By far the most important of all the recent changes in illumination in small quantities has been effected by the introduction of acetylene gas—at once the most easily made and the most brilliant of all gases. This gas is composed of equal parts of carbon and of hydrogen. Of recent years a very simple method of making it by pouring water on calcic carbide has been discovered, and has thus made it possible to manufacture it anywhere at a very cheap rate.

G 2

Calcic carbide is a compound of calcium and carbon (CaC_2), which, when mixed with two parts of water, gives the following reaction—

$$CaC_2 + 2H_2O = C_2H_2 + Ca2(HO).$$

1 lb. of calcium carbide yields 5 cubic feet of acetylene, and it costs at present 2d. a lb. With improvements in manufacture this ought to be reduced to 1d. a lb., and there is little doubt that in future this illuminant will be very largely used. The dangers of explosion which may attend its use may be reduced to a minimum by the use of pure carbide and proper apparatus. In general, it may be said that when at the normal pressure of the atmosphere there is no danger of explosion. The gas itself in its pure state is less poisonous than coal gas, and far less so than carburetted water gas. It can be condensed to a liquid under a pressure of 323 lbs. at a temperature of 0° C, and at ordinary temperatures the pressure necessary to keep it in the liquid state is from 500–600 lbs., so that the liquified gas can be stored and transported in steel cylinders.

Acetylene gas is by far the most brilliant of all gaseous illuminants—owing to its richness it can only be burnt in small burners. Its illuminating value is 240 c.p. The air of a room in which it burnt is very little contaminated with the products of combustion.

It will be thus seen that for lighting villages, small towns, country houses, and other places of an isolated nature, the field for the use of this gas is enormous.

Illuminating gas has been also made from *resin*, from *wood*, and from *peat*, but only in small quantities or under specially favourable local conditions. They do not merit detailed description, as they are not likely to supersede any of the other gases described above.

The relative cost of various illuminants has been estimated as follows :—

Coal Gas (16 *c.p.*) *at* 2*s*. 6*d*. *per* 1,000 *c. ft.*

	Pence.
Flat flame burners giving 3 candles per c.f. ...	9·99
Argand ,, ,, 3·2 ,, ,, ...	9·36
Welsbach ,, ,, 10 ,, ,, ...	3·00
Acetylene at 2d. a lb. or £18 a ton	11·02
Electricity at 6d. per unit 16 c.p. lamp	22·50

PAPER V.

TACTICAL EMPLOYMENT OF FIELD DEFENCES.

By Colonel M. H. G. Goldie.

Few modern military writers have handled the subject of field defences, except with the object of giving technical details as a guide in construction. Those writers who have dealt with the question more broadly have arrived at two somewhat inconsistent conclusions. The immensely increased power and accuracy of modern artillery and infantry fire—especially as shown in the Russo-Turkish War of 1877—have, it is urged, made it clear that the soldier requires protection against the hail of projectiles sweeping the ground he holds. Such protection can be afforded only by field defences. By a different route the second conclusion has been reached, that after all field defences are only a sort of half-friend, since their use injures the *morale* of the soldier, and makes it difficult to induce him to leave them and fight in the open.

To meet these contradictory conditions, some writers have proposed a compromise. Field defences are to be used wherever they appear absolutely necessary, but they are not to be of a kind which shall make them very desirable resting-places. Other writers have altogether condemned the use of field defences, except in one particular emergency, that is to say, when a small force has to meet a very superior force, and hold out against it for a definite time.

Both these propositions have one all-important defect. They overlook the strong probability that the use and avoidance of field defences depend on a great fundamental principle. It is tacitly assumed in such propositions that there is no such principle. Yet that principle has been recognized as valid by more than one well-known military writer; it has been to some extent explained, as regards the defensive only; it has been acted on by commanders in the field, both in attack and defence, and when rightly applied has served them well.

The object now in view is to ascertain, by a few short studies from military history, to what extent commanders in the field have used defensive works on a definite fundamental principle, and then to enquire how that principle may be applied on a modern battle-field, so as to meet modern conditions of warfare.

It may be assumed that no army striving for victory will ever again act entirely on the defensive. If that be so, it follows that every force actually fighting will be at some points on the defensive, at other points attacking or ready to attack. But to attack means a real or fancied superiority of the assailant. Such a superiority must usually in fact, and always in argument, be numerical. That superiority can as a rule only be assured at certain points by depletion elsewhere. Whether, then, the general *rôle* of a commander in a great battle be aggressive or not, we come to this condition, that at some parts of the front the troops are numerically strong and assailing, while at other parts they are numerically weak and reduced to the defensive. No other condition can be conceived, because a force unequal to this degree of effort is unable to gain a victory; and on such terms no commander will stand and fight, unless he fails, for want of information, to recognize the terms.

Military writers who have concluded that field defences should be used only on a fixed principle have arrived at that principle by some such argument as the above. These writers have, however, confined their attention to the defence of a position. The limit is unnecessary. The principle to be now examined by the light of military history applies to the action of any force approaching or approached by another, on terms which admit of a battle.

The principle, briefly stated, is this. Where the line of battle is thinly manned, so as to supply the means of aggressive action elsewhere, there and only there the best possible use is to be made of field defences. The commander who has the initiative will, on this principle, require field defences at certain parts of his line of battle, just as much as the commander who, for the time being, has lost the initiative. In some actual instances the part of the front admitting of aggressive action has been very clearly defined. This cannot always happen; the purely defensive zones may be numerous, and the purely aggressive zones may be numerous, on a front of a few miles.

We shall begin our studies from military history with von Werder's battle on the Lisaine, and then compare with it Bazaine's defeat at Gravelotte. In both these cases a commander awaited in a chosen position the advance of his adversary; and presently will be enumerated some points in which these contests closely resembled each other. One of the commanders succeeded and the other failed. It will, therefore, be interesting to enquire on what principle each of these commanders made use of his field defences, and how far that principle contributed to the result.

It is hardly possible that the problem of one battle should reproduce the problem of another. The quality of the troops engaged, the state of their *morale*, the numbers present, the proportions of the three arms, the configuration of the ground, the abilities of the commanders, the knowledge possessed by each force of the position and condition of the enemy, the power of united action residing in each force in virtue of the situation—these are only some of the points contributing to make each problem different from every other problem; hence there is need of great care in drawing conclusions as to the effective causes of actual results.

The battle on the Lisaine was fought in January, 1871, towards the end of the Franco-German War. The third German covering army was then retiring eastward before superior French forces under Bourbaki. At the moment von Werder's most pressing duty was to cover the siege of Belfort. With this object he resolved to offer battle in a position on the Lisaine.

Belfort is approached from the west by two lines of railway, of which the northern line had then been torn up in several places, while the southern line was in working order. Three main roads also converge on Belfort from the west. Of these the southern road was commanded by the strong castle of Montbeliard; that by Hericourt led under the hill called Mont Mougnot, a natural bridge-head west of the Lisaine; while the northern road lay wholly open. Hence von Werder deemed it necessary to occupy a front extending from Montbeliard to Frahier, a distance of $11\frac{1}{2}$ miles, to do which he had only 45,000 men and 146 guns.

In deciding how to post this inadequate force, certain points had to be borne in mind.

(1). The French force, though numerically twice as strong as the German, had little transport, and was therefore tied for supplies to the southern railway.

(2). Above Chenebier, the Lisaine being insignificant, the right of the position was rather *en l'air*. Below Chenebier the river is from 20 to 25 feet broad, and from 20 to 40 inches deep ; while in places dams had been thrown across. Hence to the German left and centre the Lisaine was a frontal obstacle.

(3). The railway embankment from Montbeliard to Hericourt also admitted of defence.

(4). The country is much wooded. At that time this was the more important, as, owing to snow and ice, the paths through the woods were so slippery that rapid marching was almost impossible.

(5). The valley of the Lisaine is well commanded from some of the eastern heights, as la Grange Dame and Mont Vaudois ; higher up the slopes are gentle, except at Chagey, where the banks are steep, and closely approach each other.

(6). Defending so wide a front, the Germans had great need of good lateral communications. Hardly any existed.

Influenced chiefly by the first and fourth of these considerations, von Werder expected to be attacked on his left and centre. He therefore watched his extreme left by outposts, and massed strong bodies of troops at Montbeliard and Hericourt, with detachments at Bethoncourt and Bussurel. On the right, to Frahier, he posted detachments, with outposts as far as Ronchamp. Great artillery positions were formed at la Grange Dame, Mont Mougnot, and Mont Vaudois. On the left and centre were placed more than 30 siege guns.

Field defences, including obstacles, were used as follows :—

The ice on the river, which was then very thick, was broken up as far as possible, the dams were repaired, and the bridges blown up. The railway embankment was prepared for defence. Shelter trenches, some of which had wire entanglements, were thrown up at Bethoncourt, Hericourt, Luze, Chagey, and Mont Mougnot ; those at Mont Mougnot were in two tiers. The field guns generally were provided with emplacements. At Hericourt the woods were cut down and abattis formed, the road was barricaded, and the town prepared for defence.

On the front thus prepared troops were so posted as to leave at the disposal of the general-in-chief very strong reserves. The reserve posted at Brevilliers was composed of $8\frac{1}{4}$ battalions, 6 squadrons, and 5 batteries. The second, posted at Grand Charmont, consisted of 6 battalions, a squadron, and 2 batteries. From these reserves it was intended to reinforce seriously threatened points, but it was ordered that the moment such stress was over the reinforcement, or its equivalent, was immediately to rejoin the reserve, which thus stood always ready for any offensive movement.

In spite of his dependence on the southern railway, it was the intention of Bourbaki to engage the Germans along their front and turn their right. On January 14th he had concentrated three corps on a front of $4\frac{1}{2}$ miles, on the line Dung-Aibre-le Vernois. The 18th Corps stood to the left rear, with Cremer's division beyond it. A partial change of front to the right on the right wing was therefore ordered, so as to bring the 15th Corps opposite Montbeliard, the 24th Corps opposite Bethoncourt, and the 20th Corps opposite Hericourt. The 18th Corps was to cross the river at Chagey, and march on a point between Mandrevillars and Hericourt. Cremer's division was to cross a little higher up, and march on Mandrevillars. Time was to be allowed for this turning movement; the guns of the 15th Corps were then to be the signal for attack.

It is very important to note that the French turning movement early got into difficulties. On the 15th January Cremer's division got but little beyond Etobon, owing to the slippery state of the roads. The 18th Corps was unexpectedly stopped by the German resistance at Chagey. It thus became evident that Bourbaki had mistakenly supposed the German right to be at Mont Vaudois. Next day, therefore, having received another division from the 18th Corps, Cremer was given a new direction—on Chenebier. He then, in his turn, had to fight, and though he succeeded in forcing the Germans beyond Frahier, he was still on the right bank of the Lisaine at dark.

The French attacks were, moreover, disconnected, for the 15th and 24th Corps began the action without allowing sufficient time for the turning movement. This was due partly to the fact that the men, ill-fed and suffering from cold, were impatient; partly to ignorance of the slow rate of Cremer's march. The 20th Corps, which must have been as ill off physically, confined itself to a cannonade, while awaiting news of Cremer.

The manner in which von Werder actually handled the reserves may be gathered from the following table:—

January 15th.

Movements from the Reserves.

4 p.m.—2 battalions, 2 batteries—main reserve to Bussurel.

5 p.m.—Fusilier Battalion and 7th Co. (6th Baden Regiment), with 8 guns—main reserve to Chagey.

Movements to the Reserves.

9.30 p.m.—Bussurel reinforcement rejoins.

" —2nd Battalion, 25th Regiment, and a battery from Hericourt to main reserve (in lieu of reinforcement compelled to remain at Chagey).

January 16th.

In the morning the strength of the main reserve stood at 5 battalions, 5 squadrons, 3 batteries.

Movements from the Reserves.

10 a.m.—2 battalions, 1 battery—main reserve to Bussurel.

1 p.m.—2 battalions, 4 guns—Charmont to Bethoncourt.

4 p.m.—7th Grenadier Co.—Charmont to Bethoncourt.

" —A battalion—main reserve to Genechier.

2 battalions, a squadron, a battery—to Frahier.

Movements to the Reserves.

During the day, 2 battalions from Sochaux, 2 battalions from Bussurel, and (later) all troops that could be spared from the left to the main reserve.

In the evening of the 16th, it being no longer necessary to reinforce the front, the reserves were utilized aggressively to meet the French turning movement. Taking two more battalions from the main reserve, and joined by a battalion from Belfort, General Keller proceeded to Frahier, where he had under his command, including the above, a force of 8 battalions, 2 squadrons, and 24 guns.

At 4.30 a.m. on the 17th Keller attacked Cremer, but was driven back; at 9 a.m. a second attack, in which a German battalion from Chagey vainly tried to take part, likewise failed. The French turning movement was, however, stopped, and the whole French force began a retreat.

As von Werder had less than 4,000 men to a mile of front, it may be said he made his left defence depend on a rather thin line intrenched, his right defence on a force held in readiness for active measures. Where, then, was the critical point of the field? The French general plan of attack was embarrassed by the slippery roads, by the sufferings of the troops, and by ignorance of the German position. Probably also at that period of the war the German troops were by far the more experienced. On the other hand, the French were numerically strong. Under these circumstances Keller's attack barely stopped Cremer's flanking movement. Had that movement been continued until Cremer stood at Mandervillars, with the 18th Corps close behind, the German position would have been precarious.

This, then, appears to have been the critical point of the field; and here we find the defence aggressive, and to all intents and purposes successful. On the German left and centre both forces were practically endeavouring merely to hold each other. This appears more certain when it is remembered that the French drew off the moment it was perceived their flank attack had virtually failed. It was on the German left and centre that field defences were found of great utility. They admitted of the formation of those reserves, the action of which gave the Germans the victory.

Even more apparent is this relation of cause and effect when Gravelotte is compared with the Lisaine. The two defensive positions have points of strong resemblance. At Gravelotte the Moselle takes the place of the Doubs, the Mance takes the place of the Lisaine; and in both cases was the right of the position *en l'air.* It is curious, though not important, that both defending commanders expected attack on the left, and not a turning movement against the right.

As far as concerns the construction of field defences, Bazaine, like von Werder, paid most attention to his left. The 2nd and 3rd French Corps, forming the left and left centre at Gravelotte, had each a triple row of connected rifle pits, tier above tier, with numerous gunpits and covered communications. In front of these many advanced posts, such as Leipzig, Moscou, St. Hubert, and Point du Jour farms, were well fortified and strongly held. Still further in advance the woods, by nature difficult to traverse, were partly held.

Here, too, the right of the attacking force was the flank most nearly in contact with the enemy, and the plan of attack, practically the same as Bourbaki's, involved a partial change of front to the right on the right wing, carried out almost under the eyes of the enemy.

The difficulties which beset the French attack at the Lisaine have been enumerated. Those which beset the German attack at Gravelotte were almost identical. Bourbaki imagined the German right to be at Mont Vaudois, whereas it extended to Frahier. So the German Headquarters Staff conceived the French right to be at Amanvillers, while it was really beyond Roncourt. At Gravelotte, therefore, the Saxon turning force was, like Cremer's, continually receiving fresh orders, and was similarly delayed in its movements.

Nor does the resemblance between the two battles end here, for the German attacks at Gravelotte were as disconnected as those of the French at the Lisaine. The VII. and VIII. Corps, on the right, were involved far more seriously than was intended. Beguiled by fallacious appearances, von Steinmetz even launched his cavalry against the strength of the French defences. General Sheridan, who was present as a spectator, has described how severely those horsemen were handled in their hazardous undertaking. In the centre the prospect of surprising the French 4th Corps betrayed von Manstein, of the German IX. Corps, into independent action, in which he suffered heavy losses, and in consequence of which he was compelled to ask help from the Guard Corps. To the north, at a later hour, the Guard Corps itself made an unsupported and premature attack on St. Privat, in which they were brought to a standstill, with a heavy loss of both officers and men.

These points of resemblance between the two battles are striking. Equally striking is the one great difference between the conduct of the defence in one case and the conduct of the defence in the other. The 2nd and 3rd French Corps must have had, at Gravelotte, from 40,000 to 50,000 men for a front of 4 miles, and they were strongly intrenched. Yet not a man of that strong force was withdrawn to form a reserve which should have been under the orders of the general-in-chief. There was, however, a reserve in rear of the left, composed of the Imperial Guard, with 96 guns. This reserve was posted about 2 miles in rear, at Plappeville. In rear of the French right there was no reserve whatsoever. If the left reserve had been formed, as it might have been, from the 2nd or 3rd Corps, the Imperial Guard, with its 96 guns, would then have been available to form the missing reserve to the right.

For want of this right reserve no real aggressive action was possible on the French right wing; the flank attack could not be met as it was met at the Lisaine.

In addition to this last great chance of ending the battle successfully by means of an aggressive reserve, the French commander had at least two great opportunities of attacking, with a strong probability of success, had a right reserve been available.

(1). Between 2 p.m. and 3 p.m. the German IX. Corps had lost very heavily in guns; and the condition of the infantry was such that von Manstein, as already stated, sent urgently to the Guard Corps to ask for a brigade. It was impossible for the Imperial Guard, far away at Plappeville, to interfere; but a strong and probably effective counter-attack might have been made at that time by means of a reserve stationed on the right wing of the French army.

(2). Towards 6 p.m. the attack of the Guard Corps against St. Privat failed. The counter-attacks actually made by the French, though pushed with great courage, were mostly stopped by the German artillery fire. In this case the Guard Corps was supported by the artillery of nearly two army corps, their own and that of the XII. Corps. That artillery was opposed only by the artillery of the 6th Corps, which was very short of ammunition, since Bazaine had disregarded all messages informing him of the fact. If the 96 guns of the reserve had been brought to the aid of those of the 6th Corps, and the required ammunition had been supplied, the artillery of the two German Corps would have been engaged in a heavy artillery combat. It seems reasonable to suppose that a counter-attack by the French right reserve might in that case have been pushed home, compelling the Guards to retire on the X. Corps, which was then at Batilly. In that case the Saxon XII. Corps, having become isolated, would probably have been compelled to suspend its turning movement.

Nor can it be urged that it was impossible Bazaine should have known in sufficient time of a probable movement against his right.

At 9 a.m. a company of the 64th Regiment, posted in observation at Montigny, reported the enemy at Verneville, where some men barely escaped capture. At the same hour Marshal Le Bœuf, of the 3rd Corps, warned General de Ladmirault, of the 4th, that masses of troops were observed in the direction of St. Ail. General de Waldner, then Colonel of the 55th, saw Prussian columns on that morning continuously filing from south to north. At noon the artillery of the IX. Corps opened fire north of Verneville; and at 1 p.m. that of the Guard Corps at St. Ail—very audible warnings be so nearly equal, Johnston might hope for an opportunity of inflicting a decisive blow.

On the 4th May the Federals advanced in three columns, called the armies of the Tennessee, Ohio, and Cumberland, and commanded by McPherson, Schofield, and Thomas respectively. Schofield and Thomas marched on Tunnel Hill, where they found Johnston intrenched. At once they constructed parallel intrenchments, while McPherson marched on Snake Creek Gap, about 12 miles to the Federal right, the nearest available pass through the range of hills running south from Tunnel Hill. This defile was reached May 9th, and then, deceived by a cavalry demonstration, McPherson halted and intrenched. Sherman supported him, and also attacked Johnston, who now, alarmed for his communications, retreated, followed by Howard. On the 13th the Confederates took up an intrenched line at Resaca, running from the Oostenula to the Connasauga, with one or two small advanced works in which guns were mounted. On the 14th, at 3 p.m., Hood assailed the Federal left, but was repulsed. Meantime Federal intrenchments sprang up, fronting the Confederates; and, while these were held, McPherson, on the 15th, turned the Confederate left, whereupon the latter retreated.

Johnston abandoned his intrenchments at Adairsville without a struggle, deeming McPherson on his left, Schofield on his right, and Thomas in his front, too dangerous.

The Confederates had three miles of intrenchments at Cassville, which were also abandoned, owing to some disagreement the purport of which has been disputed.

On the 25th May the Federals arrived in front of the Confederate position at New Hope Church, and began long lines of intrenchment. On the 26th McPherson made an attempt to turn the Confederate left, but lost his way in the thick scrub covering the hills from Dallas to Marietta. Blundering against the enemy's works, he was repulsed with severe loss. Abandoning this method as here unsuitable, the Federals extended their trenches towards Acworth, so as to envelope the Confederate right. Johnston, noticing this, laboured strenuously to keep pace with their works, but vainly, his numbers being inferior and intrenching tools deficient. To cope with the evil, he ordered Hood, on the afternoon of the 28th, to move round the Federal left, form obliquely and attack at dawn. Hood, however, found himself confronting the Federal division of R. W. Johnson, which was intrenching at right angles to the general line. He was therefore recalled. As the Federals continued their extension, Johnston retired, on the 4th June, to the Brushy Mountain—Lost Mountain position.

Moving McPherson across to his left, Sherman directed him to work round the Confederate right, while a line of works was thrown up to the front. The Confederates thereupon drew back their right to Mount Renneshaw. Sherman now ordered McPherson back to his right, and pushed forward a second line of intrenchments closer up to the enemy. McPherson and Schofield, on the right, compelled the abandonment of Pine and Lost Mountains by the 16th June, and the Confederates fell back to a line of intrenchments, extending from Mount Kenneshaw for several miles by the west of Marietta, and again the Federals set to work on a series of intrenchments.

On the 22nd Hood, with two divisions, broke through a line of Federal breastworks; he then endeavoured to change front so as to sweep the line of intrenchments, but failed to do so under an overwhelming artillery fire brought to bear on him, and was compelled to retire.

Johnston, having been reinforced, had now 60,000 men and 168 guns. At this point Sherman, for once, abandoned the great principle on which he had been working, and in consequence suffered very severely. On June 27th he ordered a grand frontal attack, stating that at the time he could spare no men to work round the Confederate left; yet Johnston declares Sherman subsequently did so, though the Federal frontal attack had then failed, with losses of 2,500 to 6,000 men, according to different writers. The Confederate loss in the same period amounted only to 630 men.

By July 3rd Johnston considered the Federal right was nearer to Atlanta than his own left, whereupon he retired to a position 9 or 10 miles south of Marietta. Outflanked here by the march of Schofield and McPherson, he took up a position north of the Chattahoochee, where his intrenchments extended over a front of five miles, and were strengthened by redoubts.

Sherman at once opened trenches, and despatched Thomas and McPherson to his left, not, however, beyond supporting distance. As he thought the Federals were interposing between himself and Atlanta, Johnston then took up a new position south of Peach Tree Creek.

The critical moment of Johnston's campaign was now arrived. He saw McPherson at Decatur, Schofield at a point between Decatur and Atlanta, both beyond supporting distance of Thomas, who was still entangled among the creeks near the Chattahoochee. He prepared to fall upon Thomas; but that unfortunate moment was chosen to change the commander of the Confederate forces, Johnston being succeeded by Hood.

Hood carried out the intended attack, but it miscarried, and he was obliged to retire behind long lines of intrenchments surrounding Atlanta, which the Federals virtually besieged. He made several sallies, but they always failed; and this Hood sought to explain by referring to the disheartened state into which his men had fallen during their continued unbroken, or scarce broken retreat.

The resistance lasted till the 1st September, when Hood slipped away north, leaving Atlanta in Sherman's hands.

Thus from May 4th to July 28th, a period of 86 days, was occupied by Sherman in making good a distance of 120 miles. In that period of time he forced Johnston from one position to another, captured Atlanta, and placed *hors de combat* about 40,000 of the enemy, his own losses being about the same.

If we fix our attention on the details of Sherman's campaign, we shall probably be astonished chiefly to see such endless intrenching, and possibly have no room for any other reflection. The details, however, do not contain the real lesson; to see that, we must forget the details. Sherman, who always retained the initiative, arranged his battle-front in two zones, one defensive and one offensive, separated with the sharpest clearness. Nearly the whole of his defensive zone was intrenched. Except in certain instances, he avoided intrenchments in his offensive zone. There is something very important to be noticed about the exceptional cases. There never were in the offensive zone half measures; either the ground was left perfectly clear of intrenchments, or it was all intrenched. For this there must have been some particular reason; the fact is, a large portion of the country fought over was a mass of scrub, and not adapted to delicate time-movements.

In the defensive zone Sherman was continually beating off Confederate counter-attacks, but his main object there was to make a series of attacks, false but sufficently determined to hold the enemy down and prevent resistance being made to the flank movement.

Johnston recognized no zones of action; he had simply one long intrenched line, and he met circumstances as they arose. He does not appear in any instance to have created the means of baffling the flanking movement of his antagonist.

It is most important to notice Sherman's action on the 27th June. This was his one great frontal attack, carried out in the defensive zone; and it failed lamentably. It has often been remarked that a commander has no more difficult task than to hold back over-eager troops. Possibly Sherman was in this case.

This attack of Sherman's leads us at once to the Wilderness campaign. What Sherman did exceptionally Grant did without exception against the army of Lee. Grant's problem differed from Sherman's problem in that his objective was of a different kind. The objective of Sherman being Atlanta, he was continually pressing forward; the objective of Grant was Lee's army, in which the whole remaining strength of the Western Confederacy resided. To destroy Lee's army Grant was resolved, and he was ready to make any sacrifice to gain his end. It will shortly appear, when the losses of the respective armies come to be compared, which method is more effective in destroying the forces of the enemy, the method of Sherman, or the method of Grant.

The plan of Grant was to prepare his whole line of battle for defensive action, and then to use it for offensive action. That this may be more clearly seen, the course of events in the Wilderness campaign will be traced with the aid of Maps 4 and 5, in the latter of which is given a skeleton outline of the Federal corps movements.

Lee began the campaign with about 49,000 infantry, 8,400 cavalry, 5,000 gunners, and 224 guns. The infantry were in three corps under Ewell, Hill, and Longstreet, the cavalry under Stewart, who kept Lee informed on every point. These corps were watching the Rapidan, Longstreet being some distance in rear. To oppose them Grant had 122,000 infantry and artillery, 12,000 cavalry, and 354 guns. The army of the Potomac, forming the greater part of this force, was commanded by Meade, and was composed of the II., V., and VI. Corps, under Hancock, Warren, and Sedgewick respectively. Burnside commanded the IX. Corps, Sherman the cavalry.

On the 3rd May, 1864, Grant was in motion, and on the evening of the 4th the II. Corps reached Chancellorsville, the VI. Corps a point 3 miles south of Germanna Ford, the V. Corps the Wilderness Tavern. As the dense scrub in the Wilderness made cavalry and artillery almost useless, Grant had no wish to fight there; he consequently ordered for the 5th the II. Corps to Shady Grove Church, the V. Corps to Parker's Store, the VI. Corps to Wilderness Tavern.

Believing the nature of the ground helped to balance his numerical weakness, Lee determined, as soon as Longstreet should have come up, to attack Grant's columns on the march.

The leaders of the V. and VI. Corps, menaced by Ewell, themselves took the initiative, as did Hancock against Hill; and then ensued some desultory fighting of no special interest. That night both sides intrenched, and thus sprang up those lines roughly depicted on Map 4. On the following day the Federal commanders dashed out from their defences. Against Ewell they were quite unsuccessful, and had even to meet a flank attack, which, however, failed owing to the lateness of the hour. Hancock was at first more successful; but Longstreet had now come up, and led a great flank attack against Hancock's left. The fate of the II. Corps trembled in the balance, when Longstreet was accidentally hit by his own men. This threw the Confederates into confusion, and the battle remained drawn.

On the 7th Grant reconnoitred the Confederate position, drew off and continued his march, hoping to compel Lee to fight in the open. He had lost 15,387 men, the Confederates 11,400.

The II. Corps was now moved to Todd's Tavern, the V. in the direction of Spotsylvania Court House. The VI. Corps sent one division to Piney Branch Church, a second to the intersection of the roads, Piney Branch Church-Spotsylvania Court House, Alsop's-Old Court House, and a third to a midway point. The IX. Corps, which had taken no part in the previous battle, was ordered to Piney Branch Church. The cavalry covered these movements, which were continued on the 8th. Meantime Lee pushed on his cavalry to Spotsylvania, following with his infantry, and was securely entrenched north of the river Po before the enemy came up.

On the 9th Grant executed his intrenchments roughly parallel to those of Lee. Lee's intrenchments formed a deep curve, with a marked and dangerous-looking salient at the northern angle; this salient, known as the "Bloody Angle," was stated to have been necessary, so as to take in a knoll whence the Confederate lines would have been under destructive enfilade fire. Lee's chief apprehension, however, seemed to be for his left.

The Federal Corps stood in the following order, counting from their own right:—The II. next the V., then the VI. opposite the western face of the salient, with the IX. on the left, opposite the eastern face of the salient.

On the evening of the 9th Hancock began the attack dreaded by

Lee, but it was unsupported, and begun at too late an hour. Renewing the movement next morning, he was violently attacked by Heth, of Hill's Corps, and obliged to withdraw with heavy loss. That evening the V., VI. and II. Corps made an attack from their intrenchments against the western face of the salient and the Confederate left. A division of the VI. Corps made a lodgment under Upton's leading, but lost it, and the whole attack was finally repulsed.

On the 12th May a great attack was made by all four Federal Corps. The II. Corps, which had been brought, on the 11th, on the prolongation of the capital of the salient, attacked at the salient angle; the VI. Corps against the west, the IX. against the east face, the V. from its own intrenchments. Lee, still anxious about his left, had removed thither some guns from the salient, and with the aid of these repelled Warren's attack. Hancock and his confréres carried the salient in spite of enormous losses, but as the Confederates had meantime closed the gorge of the work, no further advance was possible.

During the 13th and 14th May the V. Corps formed on the left of the IX., and the VI. prolonged to the left. An attack was then made on the 18th, but early abandoned as useless. The II. Corps was now brought to the rear of the VI. Corps, the IX. prolonging to the left, but there was no further serious fighting. To what extent the Confederates suffered at Spotsylvania is unknown; the Federals lost 17,723 men, in what may be considered a drawn battle.

Grant now resolved to detach the II. Corps to Guinea Station, on the Richmond-Fredericksburg railway, hoping thus to tempt Lee into a pursuit, but Lee was not to be drawn. Seeing this, Grant, on the 21st May, ordered the V. Corps and then the IX. to follow the II., the VI. Corps remaining in its intrenchments to cover the movement. On the 22nd May the II. Corps reached Milford, the V. Harris' Store, the VI. Madison's Ordinary, and the IX. New Bethel Church. The same day Lee, cutting across, reached Hanover Junction, where he received a reinforcement of 20,000 men, and rapidly took up an intrenched position.

On the 23rd the situation was as follows:—The V. Corps, moving to Jericho Mills, crossed the North Anna; the VI. Corps was at Mount Carmel Church; the II. and IX. took post about a mile north of the North Anna. All the corps intrenched.

Lee had his left on the Little river, his centre and right on a deep bend of the North Anna. Grant could not attack; supports moving to either wing had two passages of the river to make, while Lee could move his troops at pleasure. Nor would Lee attack. "Leaving 7,000 men to hold the left face of his intrenchments and the apex on the river," says Humphreys, "Lee might have attacked Hancock with 36,000 men; but intrenchments make up for greater differences than that in numbers." Hancock had then about 24,000 men.

Such purposeless fighting as there was on the North Anna cost the Federals 2,000 men. On the evening of the 26th they were again in motion.

By the 28th Lee had taken up and intrenched a strong position on the south of the Topopotomoy. Meantime, the V. and IX. Corps had moved to Hanover Town, and the II. and VI. had crossed the river Pamunkey in the neighbourhood of Crump's Creek. On the 29th the VI. Corps made a reconnaissance towards Hanover Court House, and the II. towards Hawes' shop; while the V. and IX. moved along Shady Grove Road. This disclosed Lee's position, which Grant judged too hard a nut for his straight-from-the-trench method. He resolved to make a dash to the left, hoping to give Lee no time to intrench.

Therefore he moved the II. Corps to Cold Harbour, placing on its right the XVIII. Corps, which now arrived from Butler's force. When these two corps advanced in the evening, they found that Lee had anticipated them, his right having been extended, and, as usual, intrenched. They therefore intrenched as close as possible to the Confederate line.

On the 2nd June the VI. Corps took post between the II. and XVIII.; the V. extended so as to connect with the right of the XVIII.; and the IX. formed in the right rear of the V. In this order a direct assault was made on June 3rd, and completely failed, with a loss of 13,000 men. The Confederate loss for the week ending June 3rd is estimated at 1,500 to 4,500 men.

No further attempt was made against the Confederate lines, and Grant crossed the James river, and directed his further efforts against Lee's lines of supply.

General Humphreys states that in July, 1864, Lee had, including 7,000 men received from Beauregard, 38,000 infantry. As he had then detached Early with about 8,000 men, he must have had 39,000 at Cold Harbour. He began the campaign with 49,000 men, and was reinforced by 20,000. Hence his total loss during the campaign must be computed at 30,000. Grant is known to have lost in the same period 53,000 men, that is to say, his losses were to those of Lee almost as 2 to 1; the losses of Sherman were about equal to those of the Confederates opposed to him. Lee's army was far from being destroyed; Atlanta was taken.

In this campaign the Federals made but one small attempt at a flank attack, and that attempt may be omitted from the reckoning as an isolated, unsupported, and therefore useless effort. Their plan comprised in reality only direct attack; and these attacks were made from positions carefully prepared for defensive, and not for offensive action. Not once did they succeed in obtaining anything better than a drawn battle, and their losses were enormous.

The Confederates made at the battle in the Wilderness a flank attack which, by a mischance no one could foresee, just missed being a complete success. Thereafter they, like the Federals, formed only defensive positions, and lost many thousands of men in a series of drawn battles. Cold Harbour was a draw in their favour; but only since their losses were trifling compared with those of Grant. The Federals were still, at the conclusion of the battle, in a position to continue it; they were not molested in crossing the James river; and when they moved, as they then did, against Lee's lines of supply, his ultimate fate was sealed.

For these reasons it is unnecessary to take into consideration the difference between Lee's abilities and those of Johnston as a commander. Both of them in these last campaigns fought in one manner.

The difference between the two campaigns now compared consists in this, that in the one the commander who held the initiative attacked only and always from positions prepared for defence, while in the other the real attack was made in an offensive zone, the defensive zone sufficing to occupy the whole attention of the enemy.

The one exception to this line of action in Sherman's campaign has been mentioned. It is a very notable exception. It was his solitary failure; it was the only occasion on which he resorted to the method of Grant in the Wilderness campaign.

Here then we find, in a series of actions, complete success attending that commander who made it his general rule to deliver his decisive attack from a distinctly offensive zone, and who used a defensive zone which was carefully intrenched, for what may be termed paralyzing action; while in another series of actions we find failure, or, at best, want of success, attending that commander who delivered all his attacks from a line of battle thoroughly intrenched and prepared as though for defence.

One further instance will now be given which strikingly illustrates in itself the whole broad theory of offensive and defensive action. The Austrians, at the Battle of Magenta, began by dividing their field into offensive and defensive zones, but when it came to blows they at once abandoned the principle. The French adhered to the principle from beginning to end. A short description of the battle will show how, for these reasons, a great military obstacle, which was intended to aid the defence, and might have aided the defence, became of the greatest utility to the force making the attack.

In this battle, fought June 4th, 1859, the Austrian position, just to west of Magenta, was behind the Grand Canal. There was a *tête-du-pont* at Boffalora, and intrenchments on the railway, with a redoubt protected by abattis; but the true defensive line was formed by the canal, which could be crossed only at the bridges, and had steep banks covered with bushes. The bridges at Boffalora, Ponte Nuovo, and Ponte Vecchio were prepared for demolition. On the canal front of 2 miles, their defensive zone, the Austrians had 20,000 men, namely, 2 brigades of the I. Corps at Boffalora, and of the II. Corps 2 brigades at Ponte Nuovo, and one at Ponte Vecchio. To hold these the French had, in what circumstances made also their defensive zone, only 5,000 men, namely, the 2nd Grenadiers of the Guard at Boffalora, the 1st Grenadiers and Zouaves at Ponte Nuovo, and the 3rd Grenadiers at Ponte Vecchio. McMahon, with the II. Corps, and Voltigears of the Guard had crossed the canal at Turbigo, about 6 miles from Ponte Nuovo, and bore down against the Austrian right with 22,000 men. And here the Austrians had only 2 brigades of the I. Corps, or about 8,000 men.

The nearest French troops consisted of a brigade about 3,500 strong; and these troops necessarily went to the canal, as it was impossible to reinforce McMahon. The Austrians had 12,000 men distant 3½ miles, namely, the 4th Brigade, II. Corps, at Robecco, and 2 brigades, VII. Corps, at Corbetta; they had also 24,000 men distant 6 miles, namely, the III. Corps at Abbiate Grasso, and the remainder of the VII. Corps at Castelletto. No other Austrian troops were within call, and the remaining French corps were still at some distance from the field.

The Austrians early crossed the canal and blew up the bridge at Ponte Vecchio. Most unfortunately for them, the other bridges remained intact, and the French succeeded in permanently saving for their own subsequent use that at Boffalora; they also captured the Ponte Nuovo, and one or two houses on the Austrian bank.

Nevertheless, the Austrians had still their obstacle, and though they transferred 4,000 men to their right flank, they had still along that obstacle, for a considerable time, 16,000 men opposing at most 8,500 Frenchmen, while on the open flank they had but 12,000 to stop the advance of 22,000.

Meantime McMahon, who had got as far as Casale, was compelled to halt to correct erroneous dispositions, and was unable to resume his advance until 3.30 p.m. As long as the French could hold out they were receiving the full benefit of the canal, while McMahon was pouring down on inferior numbers. But the Austrian reinforcements began to reach the field; all turned on the direction they might take.

The 4th Brigade, II. Corps, followed by the III. Corps, less one brigade, took the French bank of the canal. Wetzlar's brigade of the III. Corps moved still further to the Austrian left. Only the VII. Corps moved along the Austrian bank of the canal, directed on Ponte Nuovo and Boffalora. A division of the II. Corps, quitting the overcrowded neighbourhood of Ponte Nuovo, then reinforced the right. But it was too late; time had been lost, and 20,000 Austrians could no longer stop the advance of McMahon's superior forces. For the Sardinians were now supporting McMahon, and the French corps, as they arrived, easily disposed of the Austrian forces between the canal and the Ticino. The Austrian right wing was compelled to retire, uncovering the bridge at Boffalora, over which the French now advanced. As the Austrians on the canal were forced back, the Ponte Nuovo was uncovered, and the Ponte Vecchio taken in rear. Nothing remained for the Austrians but a retreat on Magenta. The battle was practically over.

By placing the bulk of their forces along the canal in their defensive zone, the Austrians voluntarily abandoned to the French the whole utility of that zone; and by this method they left bare that part of the field where it was essential to be in overwhelming strength. The direction given to the reinforcements rendered the probability of defeat a certainty. What would have been McMahon's position, with only a single bridge behind him over which to conduct a retreat, if superior Austrian forces had been thrust between the wings of his corps at that hour when he called a halt because he found he was without a centre?

In this action, then, both forces, that force with which lay the initiative and that force which had lost the initiative, had a zone of defensive action, in which the Grand Canal practically replaced field defences of the hasty type. They had also the same offensive zone, the front from the Canal to Casale. In this case it cannot be disputed that the Austrians lost the battle by placing the bulk of their men in the defensive zone, and thus abandoning the whole advantage of the position. The French won the battle, though no doubt they took an immense risk, owing to their lack of bridging material, by adhering to principle, and placing the bulk of their forces in the offensive zone.

It has been stated in one or two recent military works that in the great battles of the future each commander will fight at some points offensively, and at other points defensively. These examples show that there is really nothing novel in the idea. Already in actual warfare commanders defending positions and commanders attacking positions have gained great successes, either because they adopted this very system, or in association with this system. And these successful commanders economized men in the defensive zone by a careful use of field defences.

Certainly these examples do not prove that no other method of attack and defence is possible, but they do show that when to good illustrations of the principle "be in overwhelming strength at certain points" has been opposed the principle "be strong at all points," the latter has signally failed. Now to be in overwhelming strength at certain points implies the use of defensive zones in which men are economized, and the best method of economizing men is to place them behind field defences, where their bodies are protected, and they have a rest for their rifles.

General Brialmont has stated the case pretty fairly when he says, "A skilful general will always select positions . . . so as to strengthen part of his front, that he may occupy it with fewer troops, and concentrate the bulk of his forces on the part which is disposed for offensive operations." This was written in connection with defence by a commander who has lost the initiative; but the following words might be equally applied to offence by a commander who still holds the initiative:—"The object of fortification on the defensive front is to keep the enemy in check as long as possible without employing many of one's own troops."

In the illustrations thus far given, the conduct of an offensive or defensive action has been considered generally without reference to the particular point against which the strongest efforts may chance to be directed. It is proposed now to pursue the subject a little further, and enquire, by means of a further series of illustrations from military history, into the consequences of adhering to or disregarding, at some particular part of the battle-field, the principle just described in the words of General Brialmont. The part of the battle-field to be considered is a flank; and the illustrations will be so chosen as to include flank attacks of greater and less intensity. It is hoped that as these illustrations are unfolded, their study will throw much additional light on the question under consideration.

A defensive position has almost always a flank exposed to attack. A force is easily locked up, and the amount of force it represents wholly lost, probably, by the blockading power of a much inferior force, if both its flanks rest on very difficult obstacles. Such, for a considerable time, was the position of General Butler, watched by Beauregard, on the James river, in the American Civil War. An exposed flank being especially liable to attack, preparations for its defence, sometimes of a most elaborate character, have always been made in anticipation. If we run over in our minds the history of actions in which flank attack has formed a prominent feature, we shall ultimately be able to place these preparations for flank defence in one or other of two categories. The first of these two categories will comprise all those instances in which flank defences of some kind have been solidly constructed beforehand, to be held at all hazards as a matter of course. Where defences have been thus constructed beforehand, we shall invariably find the flank thrown back, so as to form a crochet with the front of the position. Sometimes these flank defences have taken the form of continuous lines, covered by abaptis and other obstacles, every means that ingenuity could devise being pressed into service to render the flank impregnable. Sometimes this crochet forming the flank has consisted of detached works, intended to be held by strong garrisons, and most probably guarded by abattis and mounting guns. Between these detached works small counter-attacks could be made. Sometimes commanders have not been content to rely on a single line of works.

The second category illustrates an idea of a totally different kind, for here no defensive works are either constructed or contemplated. The commander, in the first place, awaits the development of the enemy's plans. These he learns either from observation, or by means of the usual sources of information. It has sometimes happened that, owing to the dispositions of the enemy, the general has been able to see for himself that an attack is about to be made against his flank. This happened to Frederick the Great at Rossbach. By a partial change of front that general then upset the enemy's plan, and inflicted on him a decisive defeat.

Where the defending force has been too strong for movements of this nature, or the commander has acted on information, we shall find the defence of the flank has, in the cases included in this category, been made to depend on bold and vigorous counter-attack, for which purpose troops have been so posted as to be in readiness for rapid action at the required point.

These two methods of flank defence might be called respectively the purely defensive method and the offensive method. The purely defensive method carries with it a consequence which the offensive method does not. In the defensive method there must inevitably be a line or a series of works forming with the front of the position a crochet, and the apex of that crochet is a salient.

Modern military writers, those who agree as to the validity of the offensive-defensive principle, seem, when they come to flank defence, to fall back with approval on the crochet.

General Brialmont has given in one of his works the plan of a position prepared for defence. In this plan the exposed flank is provided with redoubts so placed as to form a salient with the front, and so covered by obstacles that counter-attack would appear to be very difficult.

Colonel Brackenbury, in his work on Field Defences, points out most clearly the necessity of attack in defending a flank. But, on the other hand, he says, "Here we have one of those instances in which defence pure and simple becomes not only right, but necessary." The following sentences seem to indicate the necessity of the crochet, however much their author might deplore that necessity as an evil:—

(1). "On the flanks redoubts should be used."

(2). "Unless the flanks are so placed that they cannot be turned, they should be partially thrown back, and here more than in the front are obstacles necessary."

(3). "As the flanks are liable to enfilade fire, something in the nature of traverses should be provided."

Nor are these the only writers who cling steadfastly to the crochet. Let us take half-a-dozen illustrations and note the lesson they teach.

It will be understood that so long as these illustrations are taken from modern battles, and are also appropriate to the subject, it is quite immaterial in what particular campaign they were fought. Accordingly, the first battle used as an example will be the Battle of Breslau, since here we find a good instance of careful preparation for flank defence by continuous lines with detached redoubts in advance.

Breslau was fought November 22nd, 1757, during the Seven Years' War. The Duc de Bevern, having taken up a position to be defended by 40,000 Prussian troops, was attacked on that day by 60,000 Austrians, commanded by Prince Charles of Lorraine. As the Prussians were good fighting troops under an experienced general, and were not very seriously outnumbered, they might certainly be expected to make a good defence.

The right of the Prussian position rested on the Oder, and was therefore not liable to be turned. In front of the position flowed the Lohe, a stream easily crossed; hence the left of the position was liable to be attacked. Bevern fortified both his front and his left flank. From the Oder to the Lohe ran an enormous abattis 1,500 paces long. The front then extended to the village of Klein Mochber, and was covered by two lines of redoubts, most of which were protected by obstacles. The exposed flank was fortified by continuous lines of intrenchments, and these formed with the front a salient near Klein Mochber. At some distance in advance of these continuous lines were three redoubts. One of these was called the Gräbischen redoubt; it formed the true external salient point of the great crochet, and played a very important part in the battle. There is no evidence in these dispositions of any desire to make offensive returns.

Prince Charles of Lorraine's plan of battle was elaborate. It included four separate attacks, all made as though with the intention of being pushed home, and wholly independent of each other. On the extreme Austrian left, at Pilsnitz, General Keuhl attacked with a strong force. At Schmidefeld, on the left centre, an attack was made by a force composed of a line of cavalry, two lines of infantry, and General Wied's reserve. A third attack was made at the Gräbischen redoubt by a force composed of 35 companies of grenadiers, 12 squadrons, 2 lines of infantry, and Esterhazy's reserve. Finally, on the right, Nadasti crossed the Lohe at Hartlieb, and attacked the Prussian left flank with his whole corps.

It will be readily granted that this mode of attack was very defective. It was impossible on so wide a front so to time four attacks, all having to cross a river under fire, that they should be simultaneous; and, with such dispositions, it was impossible to support an attack which failed, and to prevent the Duc de Bevern using elsewhere, as he actually did, the troops thus set free. Everything, therefore, seemed arranged to favour the defence.

The attacks at Pilsnitz and Schmidefeld met with no success. For some little time they occupied the attention of certain of the Prussian troops; but the number of the enemy so occupied was presently reduced. And thus two of the four attacks might almost as well have been omitted. Nadasti's advance reached Kleinberg, which he took; it was his sole success. Particular attention should be given to the action of the Prussians here. They were under the command of Ziethen. Abandoning altogether the field defences, Zeithen ordered a great charge of hussars, by which Nadasti was driven from Kleinberg. This charge was followed up by a further succession of great and desperate cavalry charges and infantry attacks. By this means Nadasti was driven back almost to the Lohe, whence he did not again advance. So far, then, as the attack against their left flank was concerned, the Prussians had no need of their intrenchments; they did not, in fact, use them, but turned that part of the field into a zone of offensive operations, and were successful there.

But the fourth Austrian attack had advanced against the Gräbischen redoubt, and this redoubt the Prussians speedily abandoned, it is said, owing to some mistaken order, or an order misunderstood. The Austrians at once occupied it, brought up guns so as to enfilade the Prussian lines, and got into the village of Gräbischen.

At this point the Prussians had posted only 4 battalions and 10 squadrons, under General Schultz; and these had been early used by Schultz against the cavalry leading the Austrian attack—a counter-move which was completely shattered by a concentrated artillery fire from the opposite bank of the Lohe.

A second counter-attack, very late in the day, was ordered by the Duc de Bevern at the same part of the field. In this movement were employed 10 battalions and some regiments of cuirassiers. It is evident, therefore, that he was able to withdraw troops from his right, where he had, at Pilsnitz, 10 battalions and 18 squadrons, besides 10 battalions and 10 squadrons, under Lestewitz, between Hoefschen and Schmidefeld. At first this counter-attack appeared to be successful, and the Austrians lost ground. But the Duc de

Bevern galloped away to the left, darkness set in, the counter-attack was not pushed home, and the Austrians no longer retired. Then the Prussians gave way, and fell back, carrying with them the whole of the right wing.

During the night the Duc de Bevern felt compelled to abandon the field; he had lost 6,000 men, the Austrians about 4,000.

In this battle Ziethen, who had only 11 battalions and 60 squadrons, paralyzed by his forward action the whole of Nadasti's corps. That forward action showed that here, at all events, the time and labour spent on the flank defences were wasted. Yet the Austrians won the day, simply by the capture of the Prussian salient. For what followed on the capture of the salient? The Prussian lines were speedily and effectively enfiladed. Thus the intrenchments they had made contributed to the Prussian ruin. For the Prussian counter-attacks at the salient both failed; the first because it was numerically weak, and was overpowered by artillery fire; the second, most probably, because it was made by troops who had then long suffered from the enfilading fire of the Gräbischen redoubt.

It is certain that in this battle the salient proved fatal to the troops who had constructed it.

Another instructive illustration of flank defence is furnished by the Battle of Jemmappe, fought during the French Revolutionary wars. In this case the flank was defended by intrenchments without advanced works. The troops manning the entrenchments were veterans, and they were attacked by raw troops, under a commander of no very great experience.

The date of the battle was the 6th September, 1792. The Austrians, 20,000 strong, were commanded by Duke Albert of Saxe-Teschin. Their line, on the heights before Mons, consisted of strong entrenchments, connecting several redoubts, protected by abattis. Their right rested on the village of Jemmappe, the position running thence along the brow of the hill. The right flank and part of the front formed, consequently, the faces of a great salient; and the two parts of the front formed the unequal limbs of a re-entering angle.

Dumouriez, the French commander, formed a plan in which his forces were divided into four parts; one of these was to menace the Austrian line of retreat; a second was to act against the Austrian left, which was quite open to attack; the third and fourth, moving from different points, were intended to envelope the great salient.

But Dumouriez had not nearly sufficient troops for all these purposes, and, looking at their quality, it was scarcely reasonable even to expect they could co-ordinate such diverse movements, aiming at points widely separated, and at such varying distances from the base. Critics of the campaign have pointed out that a decisive movement against the Austrian left, combined with feints elsewhere, should have produced greater results.

Both, then, by reason of the quality of the troops engaged, and the defects of the plan of attack, a stubborn defence might be expected.

Early on the 6th Dumouriez attacked. He ordered General Harville to move by the right against the Austrian rear. General Buernonville was ordered to assail the Austrian left opposite Cuesmes, and Ferrand to turn the right. The Duke of Chartres was to attack the inner face of the salient. It was directed, however, that the latter should postpone his advance until he had heard of the success of the wings, an order which appears to insure that the attacks should not be simultaneous, though the troops held out of action could only by attacking support the troops engaged.

It so chanced that both faces of the salient were nevertheless attacked simultaneously. In the early morning Dumouriez was present with his left, which he considered the decisive part of the field. As long as he remained there orders were obeyed. Ferrand carried Quaregnon, and advanced on Jemmappe, sending Rozières forward to execute the turning movement. Seeing all thus apparently going well, the general-in-chief proceeded to the centre, and there awaited news of Ferrand's success. None coming, he sent Thouvenot, his aide, to ascertain the cause. That officer found the left attack absolutely suspended and reduced to a simple cannonade. He succeeded, however, in inducing Ferrand to resume his advance, himself leading the way. As Thouvenot pushed on, Dumouriez, out of all patience, led forward the centre. The redoubts were escaladed, and the Austrians on both faces of the salient, finding themselves fired on from the rear, retired in disorder.

Meantime little had been doing on the right, whither the general-in-chief now hurried. Placing himself at the head of the troops, he led them forward, and, in spite of strong resistance, carried redoubt after redoubt by the gorge. The Austrian retreat now became general. Unfortunately for the French, the incapacity or ignorance of their subordinate generals had no exception; Harville was not at the appointed place, and so the Austrians, who might have been routed, contrived to escape.

Each side lost about 4,000 men.

In this instance also the salient proved the vulnerable point. But it is also to be remarked that the Austrians do not appear to have made the slightest attempt at counter-attack. The whole position, including the flank, was laid out for defence pure and simple, and defence pure and simple did not avail even where veteran troops had to meet raw levies. The great feature of the action is, however, the failure of the salient.

The Battle of Toulouse is of great interest as an example of flank defence. Soult, who commanded the French at this battle, is said by Napier to have planned his defences so carefully he knew precisely where and how he would be attacked; but if the position be carefully examined, it will seem sanguine to hope that a force advancing from the north would file in front of Mont Rave, to attack the French right. Whatever he may actually have thought, Soult fortified his left or northern flank, and not his right, or southern flank; and the latter was the flank attacked, while the former flank was threatened; and this is the first point of great interest.

In the second place, Soult missed success by a very narrow margin; and consequently it is possible to reduce the cause of his failure to a certainty.

Including 3,000 cavalry, Soult's force consisted of 38,000 men and 80 to 90 guns. Of these, a reserve, including the recruits, manned the walls of Toulouse. Reille was intrenched before the Suburb St. Cyprien to beat off Hill. It will be noticed there were here two lines of defences, the inner line being a solid brick wall three feet thick.

Daricau held the left, which was covered by the canal of Languedoc. Three redoubts had been constructed on this flank. Harispe defended the front, on Mont Rave. This ridge had two summits. The northern summit, forming the north-east salient, was defended by four redoubts, two at the northern and two at the southern edge; the latter redoubts were known as the Calvinet and Colombette. These redoubts were connected by intrenchments and protected by abattis.

The southern, or St. Sypiere summit, was defended by two redoubts. It did not form a salient in the same manner as the northern summit, because the right flank, westward of St. Sypiere, was bare of defences, except at a considerable distance. The fortified suburb of St. Michel, and a small work at the Pont Demoiselles, were in fact the only defences on that side, so that, as stated, the right flank was practically open.

The depression between the Mont Rave summits admitted of the rapid movement of all arms; it was guarded by works on the Saccarin and Cambon Knolls.

Advancing from the north, Wellington had in his hands the Croix d'Orade, but all the bridges south thereof over the Ers, an unfordable river, had been prepared by Soult for demolition, and were still in possession of his cavalry, which patrolled both banks of the stream.

Wellington, in his despatches, stated his plan of attack. He intended to turn Soult's right, attacking at the same moment the apex at the Calvinet, and demonstrating against the French left. To carry out this plan, there was, under the circumstances described, but one way. The force destined to turn the French right was compelled to make a flank march between Mont Rave and the river Ers, along the front of Soult's position, at a distance of from half a mile to a mile, over ground which was very marshy near the river.

The strength of the British force, exclusive of 13,000 men and 18 guns under Hill, amounted to 39,000 men, of whom 12,000 were Spaniards, and 46 guns. In the figures given are included 7,000 cavalry.

Hill had orders to menace St. Cyprien, so as to hold there as many of the enemy as possible. Picton, with the 3rd, supported by the Light Division, was ordered to demonstrate against the French left. In front of the Calvinet is a low hill, called Pugade, which was slightly occupied by the French. This the Spaniards were to carry. Beresford, with the remainder of the force, was to make the flank march between Mont Rave and the river Ers, and attack the French left. Simultaneously with Beresford's flank attack the Spaniards were to assault the apex at the Calvinet.

Compelled by the state of the ground to leave his artillery behind, Beresford pursued his march with the 4th and 6th Divisions, covered by Ponsonby's cavalry on the left bank of the Ers, and by Vivian's on the right bank.

Picton's attack was sharp, and he suffered a severe repulse, with a loss of 400 men. The Spaniards, having taken Pugade, disobeyed orders; for, instead of allowing time for Beresford's flank march, they dashed without pause on the Calvinet, and suffered defeat with a loss of 1,500 men.

All now depended on Beresford. Suffering during his march from the French artillery fire, and leaving many stragglers in the heavy ground, that commander arrived in front of St. Sypiere with the remains of a force which had at first numbered only 13,000 men.

Soult had posted, as a reserve in rear of Mont Rave, two divisions. To these he added such men as could be spared from the defence of St. Cyprien, and a considerable force brought over from the left flank after Picton's severe repulse. Hence he had in hand 15,000 fresh troops available for a great counter-attack against the much weaker force of Beresford, while that commander was still struggling painfully forward.

The attack was made, but it was entirely mismanaged. Taupin advanced with only one division, and wasted so much time in forming up that, before he was ready, Beresford was already attacking. Taupin was killed, his men fled, and St. Sypiere was carried.

Meantime Vivian's hussars, having crossed the Ers at Montaudran, now menaced the Pont Demoiselles in conjunction with the skirmishers of the 4th Division. A brigade on St. Sypiere changing front to its right menaced the Calvinet in flank, while the 6th Division attacked in front. After hard fighting this summit also was taken.

This ended the action. The French had lost 3,000 men, the British 4,500, including 2,000 Spaniards. On the next day but one, April 12th, 1814, Soult evacuated Toulouse.

The intrenchments on Soult's left flank were of great value to him. They enabled him to check Picton's demonstration with economy; and to move the troops thus, as it were, rendered surplus to his right, to meet the decisive attack. Napier and Brialmont have both pointed out that if the 15,000 men collected under Taupin had made their counter-attack in a thoroughly determined manner without loss of time, Beresford must have been swept away.

Brialmont has likewise pointed out that Wellington's plan of attack at Toulouse closely resembled that of Marmont at Salamanca. In each case a wide movement against the flank of the enemy left the attacking force without a centre. Wellington's successful counter-stroke at Salamanca was not repeated at Toulouse, though Soult appears to have prepared for it, and fully intended it. It may be deduced that, whether the cause were the condition of the French troops, always retiring and very often worsted, or the incapacity of the subordinate commanders, the Battle of Toulouse was lost to Soult owing to failure to execute with sufficient rapidity and energy a well-planned counter-attack.

The three preceding illustrations include no instance of a successful defence. Three cases will now be cited, in all of which the defence succeeded.

The first of these is the battle of Kunersdorf, fought on the 12th August, 1759, during the Seven Years' War. The Prussians were veteran troops, commanded by Frederick the Great, to whom a victory was then of immense importance; and these troops were fighting in their own land against an enemy who had laid much of it waste. The defending force was composed of Russians and Austrians, under separate leaders, far from being equal to Frederick in influence and renown. Hence, except in numbers, every possible advantage seemed to rest with the great tactician who held the initiative.

The Russian right rested on the Judenberg, the left on the Muhlberg, two scarped heights commanding the plateau between them. The front and flanks were continuously intrenched. In rear of the right stood the reserve, composed of the Austrian forces under Laudon, with the Russian cavalry on their left.

An important feature of this position is the Kuhgrund, a ravine 400 paces long, 60 broad, and 15 to 20 feet deep. Except for a narrow space it divides the Muhlberg from the plateau, and thus nearly isolated the Russian left flank.

Having resolved to attack this flank, the King marched through the Kunersdorf wood, leaving Finck on the Trettin heights to make a strong demonstration against the Russian rear. The Huner Flies, flowing through the wood, forms a string of ponds, of whose existence the King seems to have been ignorant. These ponds so interfered with his march that from 3 a.m. to 10 a.m. was occupied in forming line and advancing through the wood to the Kleistberg.

It will be observed that the whole of the Russian frontal intrenchments had by Frederick's movement been rendered useless, and that the field of operations was now confined to a comparatively restricted front, where the advantage of numbers was much diminished.

On the Kleistberg and the Seidlitzberg were placed strong batteries, which opened fire at 11.30 a.m. The range being too great, little effect was produced; in fact, the Russian fire from heavier pieces was superior.

Deceived by Finck's demonstration, the Russians sent only a few Cossacks against Frederick, as he appeared advancing from the forest. The assault of the Muhlberg was made by 8 battalions in two lines, under Generals Schenkendorf and Lindstett. The Russian guns being badly served, there was at first little loss, but at a distance of 150 paces from the intrenchments the fire of their artillery and musketry became destructive. After one volley the Prussians took to the bayonet, the Russians fled, and in ten minutes the intrenchments were captured, with 70 pieces of artillery.

The Prussian artillery and cavalry, owing to the difficulties of the ground, having been left far in rear, the Russian left wing, though badly broken up, was allowed time to re-form on fresh battalions brought up from the right, whence also artillery was hurrying. Once again their line was broken, and once more re-formed with the right resting on the Spitzberg.

At this time Finck reached the Muhlberg, having crossed the Huner Flies at the Great Mill and Becker's Mill. With this assistance Frederick forced back the Russian line, and reached the edge of the Kuhgrund. The King now hastening to the left, carried the village of Kunersdorf, and, before he returned to the centre, despatched his troops against the Spitzberg. Upon his departure the cavalry under Seidlitz, much troubled by the difficulties of the ground, was overturned, and the assault on the Spitzberg repulsed.

Meantime the whole Austrian reserve under Laudon appeared on the plateau. Against these fresh troops the exhausted Prussians, though urged on by the King, could achieve nothing further. Finck was repulsed at the Elsbuch, and to support him Frederick, in desperation, ordered the cavalry round from the left to the right. It was led by the Duke of Wurtemburg, who fell wounded, and then his men were driven back. The Austrian cavalry now charged in support of their infantry, and the Prussians hurriedly retreated, having lost 16,000 men and 165 guns.

Many different opinions have been given as to the cause of this upset. No doubt the attack was seriously hampered by Frederick's ignorance of the ground. This caused his men to be under arms many hours during very hot weather, without advancing the state of affairs. It also led to difficulties in bringing up the artillery and cavalry to confirm the first success. It has been much debated if, by resting his men after breaking the Russian left, Frederick might not have ultimately gained the victory. These misfortunes and speculations do not alter the fact that Frederick's advance was rendered impossible, and converted into a disastrous retreat, by the action of the great Austrian reserve.

This case is an exceptional one, for here a whole army attacked a flank. That flank was saved, and a decisive victory won, not by field defences, but by the forward action of the reserve.

In the Battle of Rivoli is to be found a very noteworthy example of successful flank defence. It was fought January 14th, 1797.

An Austrian force, 30,000 strong, under Alvinzi, was advancing south, along the eastern bank of Lake Garda. A French force, 9,865 strong, under Joubert, after certain manœuvres it is unnecessary to detail, was intrenched between Zoane and San Marco. The latter force was composed of the 4th, 17th, 22nd, and 29th Light, of the 14th, 33rd, 39th, and 85th of the Line, and of the 22nd Chasseurs.

On reaching the field early on the morning of the 14th General Bonaparte found the following situation :—

The Austrians were advancing in 6 columns. On their right Lusignan, with 8 battalions, was moving west of Monte Baldo against the French left and rear. Divided from this column by the mass of Monte Baldo was the Austrian centre, composed of three columns. Of these 3 columns that to the right, under Liptay, consisted of 6 battalions, that in the centre, under Koblos, consisted of 5 battalions ; and that on the left, under Ockskay, consisted of 5 battalions and 8 squadrons. Of these 5 columns only the last mentioned had artillery, the badness of the roads being the cause.

Separated by the Monte Magnone from Ockskay's column, Quasdanowich, with 9 battalions and 13 squadrons, moved along the road west of the Adige against the French right. Vukasowich, with 5 battalions and a squadron, moved along the road east of the Adige against the French right and rear. Most of the artillery was with the last two columns.

Massena was near at hand with a force of 8,506 men, composed of the 18th Light, the 18th, 25th, 32nd, and 75th of the Line, a regiment of dragoons, and one of cavalry. Rey, with 4,156 men, was still at some distance, coming up from the south.

The Austrian 5th Column, under Quasdanowich, could strike the French right only by the defile of Incanale and Osteria Dugana. In like manner the column of Vukasowich had to pass the defile of La Chiusa. A small force well posted at each defile might therefore cause these columns considerable delay. Time being essential to enable the defending force to deal with the Austrian centre, half of the 39th Regiment was strongly intrenched at Incanale, and the other half at La Chiusa and Monte Rocca. By this means the two columns directed against the French right were for some time held out of action by a single regiment, and the men thus economized were available for use against the Austrian centre.

The column of Lusignan, moving against the French left, was not compelled to traverse any defile; on the contrary, it had considerable choice of roads. An intrenched position to the flank being judged in such case quite useless, Massena was ordered to direct the 18th Regiment along the Rivoli-Garda road, and to post the 75th in support at Tiffaro. Rey was ordered to move up as a reserve at all speed. It appears to have been concluded that Lusignan would be deterred from attack by these strong demonstrations against his right, and, if so, the conclusion was correct.

As Alvinzi still held the initiative, Bonaparte was here strictly on the defensive. Nevertheless, he decided to quit his frontal intrenchments, and move forward against the Austrian centre. He thus attacked Koblos and Ockskay; Liptay, however, was able to retain the offensive, and to throw himself on the French left centre. At first the French battle was not successful. Liptay slowly gained ground until the 32nd Regiment came up and was thrown into the fight. He was then pushed back towards Trombalora. The struggle on the right was doubtfully maintained, the 14th Regiment making strenuous efforts, until the 33rd Regiment, till then in support, was brought into the fighting line. Matters then improved.

The situation about 9 a.m. was as follows:—In the centre the Austrians, though not defeated, were unable to make headway; the 39th Regiment, which had made a long resistance at Incanale, had at last been driven from its intrenchments; Vukasowich was merely cannonading from the opposite side of the river; nothing had been heard of Lusignan.

Taking Joubert's light infantry, Leclerc's cavalry, and some of Massena's troops, Bonaparte now made a most violent attack on Quasdanowich, and drove him completely beaten from the field. That done, Joubert was once more ordered against Koblos and Ockskay, who had now resumed their advance. Observing that the Austrians moved in loose order, Bonaparte ordered Lasalle to charge with 200 horsemen. Well supported by Joubert, this charge had a great effect; the Austrians gave way and retreated, carrying with them the column of Liptay.

Meantime, Lusignan reached Pezzena about 9 a.m. Continually menaced by Massena's detachment, he ultimately reached Mont Pipolo. Here, Rey having come up, he was surrounded and destroyed.

In this battle a force on the defensive, threatened on its left by an isolated force in open country, detached to that side a superior force free to manœuvre, not only thus saving its left flank, but destroying the enemy. Attacked on the right by two columns advancing through defiles, it stopped them for a considerable time by opposing to them one regiment intrenched. The time and men thus gained enabled the defending force to strike a heavy blow on the enemy's centre. By a violent counter-attack the movement against the right was now completely overwhelmed. That accomplished, the victorious troops were led again to the centre in sufficient time to check the resumed advance of the enemy, thus rendering the victory complete.

As at Toulouse, intrenchments on a flank were here found useful, though for a different reason. The ultimate upset of the flank attack was due to energetic counter-attack.

The Battle of Chancellorsville was fought at a period of the American Civil War when the Federal troops, according to their own account, had hardly as yet learned the true meaning of discipline. Hence a few words will suffice to connect this battle with the question of flank defence.

A frontal attack under Burnside on Lee in his intrenchments at Fredericksburg had failed to make any impression. On taking over the command, Hooker, later on, conceived the idea of crossing the Rappabannock some miles above Fredericksburg, and turning Lee's left. Lee had then 53,303 men and 170 guns, Hooker 133,708 men and 400 guns.

On the 27th April, 1863, Stoneman was sent with 10,000 cavalry against Lee's communications, and was lost to sight. Two divisions of the 2nd Corps crossed the Rappabannock at the United States Ford; the 5th, 11th, and 12th Corps crossed the Rapidan at Eley's Ford and Germanua Ford; on the 30th all were about Chancellorsville.

Sedgewick, with 37,673 men of the 1st, 3rd, and 6th Corps, on the 29th, crossed the Rappabannock below Fredericksburg, so as to hold Lee to his intrenchments. Further to deceive Lee, Gibbon's 3rd Division of the 2nd Corps remained encamped at Falmouth, but on the following day joined Hooker. On May 1st Hooker moved with 73,124 men against Lee's left flank.

Hearing what was designed, Lee resolved to meet this attack by a counter-stroke. Early's division and a brigade of McLaws' division, in all 9,000 men and 50 guns, remained to watch Sedgewick. At 8 a.m. Jackson and McLaws moved direct against Hooker. By 11 a.m. they neared Chancellorsville. Hearing this, Hooker lost heart, retired his force, and intrenched himself round Chancellorsville, so as to cover his line of retreat over United States Ford.

Lee now ordered Jackson to make a flank march and attack the Federal right. He himself, intrenching 14,000 men opposite Hooker, held that commander to his front. It is said that when Lee manned his trenches, the men were in some places six feet apart.

On the 2nd May, at 8 a.m., the 3rd Corps reported the Confederates retreating, but it was noon before the pursuit began. Though supported by the 11th Corps, this movement of the 3rd Corps seems to have been easily checked by Jackson's rear-guard. At 11 a.m. Lee furiously cannonaded the Federal left, while a sharp fire was directed against the centre. At 2.30 p.m. he assaulted the Federal centre and left, At 3 p.m. Jackson was on the Plank Road, 3 miles west of Chancellorsville, masked by his cavalry, which had exactly located the Federal right. At 6 p.m. he assaulted; the 11th Corps fled. The attack was much embarrassed by the fire of 22 Federal guns posted by Pleasanton on the Plank Road. Jackson was by accident hit, and A. P. Hill wounded. A Federal counter-attack completed the confusion, and the assault was suspended for the night.

Next morning Stuart pressed the attack. He captured Hazel Grove, where he posted 30 guns. Their fire, enfilading the 3rd Corps, produced a great effect. He then connected with Lee, and Hooker retired to a position nearer the river.

Meantime Sedgewick, brushing aside Early from the heights of St. Marye, had reached Salem in an attempt to join Hooker. But on the 4th May Lee turned against him, having left Stuart to watch Hooker. Sedgewick was thus driven across the river. Lee then rejoined Stuart, but only to find that Hooker had retired over United States Ford.

The Federals lost between 17,000 and 20,000 men, many colours, guns, and small arms; the Confederates from 9,000 to 12,000 men.

Here Lee first saved his own flank by a bold forward movement. He then attacked Hooker's flank. As long as the Federals trusted to breastworks Jackson gained ground; but the attack was impeded and stopped, first by a forward movement of the Federal artillery, and second by a counter-attack. On the following day the Federals were compelled to retire, but they attempted no counter-attack.

These illustrations seem to show that flank defence has always failed where reliance has been placed on field-works exclusively, often because the salient necessarily formed has proved a point of such decided weakness. The alternative has been counter-attack, but those counter-attacks which succeeded were strong, vigorous, and well-timed. Yet in certain cases field defences on the flank have proved advantageous. At Toulouse Soult derived much benefit from the redoubts on his left; in a similar way Meade, at Gettysburg, derived advantage from breastworks on his right; but in both these cases defensive works were used against demonstrations, where an economy of men, if it can be practised, is of necessity desirable. At Rivoli one regiment intrenched on the right did much towards gaining the victory; but it was opposed to isolated columns advancing through defiles.

Flank defence has likewise been conducted, with varying success, by means other than counter-attack on the flank attacked. Thus, at Prague, the Austrians, who were formed on a great crochet, sought to avoid being outflanked by continued extension to the right. By this means the salient was laid open, and into the gap thus made the Prussians poured, cutting the Austrian army in two. At Waterloo Napoleon sought to render nugatory the Prussian attack on his right by continued hammering efforts against the British in his front; but he lacked the means and energy to conduct two simultaneous battles, and was simply overpowered. At Koniggratz the Austrians had flanking redoubts, which they did not use; it made no difference; they intended, apparently, to save their flank by counter-attack, but could not do so because their reserve only moved at a snail's pace.

At Austerlitz the Russians attacked Napoleon's right flank, but in doing so laid bare the centre. Pushing into the gap, Napoleon separated and beat the wings in detail, thus defending his flank by a great central movement. Similarly, at Salamanca, Marmont laid open his centre to attack Wellington's right. Wellington saved that flank by interposing between the separate wings. Lee, at Gettysburg, acted as though he desired to draw Meade's forces to the flanks and then crush the Federal centre. But though he strongly attacked the Federal left, the attack against their right was no more than a demonstration. Meade was therefore able to support his left by troops drawn from his right, where he had breastworks. The want of concert in the Confederate attacks against superior numbers exhausted them, and retreat became a necessity.

All these examples of flank defence can be explained on one principle. A strong flank attack has often been stopped and caused to fail by an energetic counter-attack, and sometimes by aggressive action, to which the commander making the flank attack laid himself very palpably open at a neighbouring part of the field; but in either case by an adequate assumption of the offensive. Reliance on field defences has proved fatal against strong attack. So that the examples illustrating flank defence show just what the examples illustrating defence in general seemed to show, namely, that true defence implies powerful attack, and therefore, at some parts of the field, defensive zones. Hence defensive works are useful on a flank against demonstrations; not only useless, but dangerous, against serious attack.

Most probably, therefore, the rule for defence in general is sound—the rule that only certain parts of the field must be intrenched, leaving ample space for the offensive zones. If no part of the field be intrenched, on ground of ordinary contour, the offensive cannot be so effective as it would be if men were economized defensively.

In the attack the same principle must hold good generally. Sherman, perhaps, carried his intrenching to an extreme; but his men were very expert at it, and probably he could not prevent them doing it. Still, his principle was sound, for on this principle the attention of the defenders is fully occupied along a considerable part of their line of battle, as Hooker's attention was occupied by Lee at Chancellorsville, while forces can be massed elsewhere to break through the defender's line.

Let the general principle be granted; it is still necessary to enquire how far it is now possible to hold intrenchments in the face of modern artillery fire. In order to reach any reasonable conclusion on this point it is necessary to know what modern artillery fire can do, to ascertain in what its greater efficiency consists, and then to determine if by any means that greater efficiency can be baffled.

The projectile of modern artillery is the shrapnel shell. This projectile is very effective against troops in the open, but is not so, as has been shown in various ways, against intrenchments at right angles to the line of fire. But it is not necessary that guns should attack a line of intrenchments at right angles; they may do so obliquely, and then they might produce a very considerable effect. This is easily understood. If a shrapnel shell burst as it passes over a parapet, the bullets of necessity fly forward, though not in the same line as the unburst shell would have taken. These bullets open at a certain angle; this angle is so small that when the line of flight of the shell is at right angles to the parapet there is a certain space behind the parapet within which no bullet falls, a space which, though small, is comparatively safe. If a line of intrenchment be enfiladed, there is no such safe space. If the guns fire obliquely at the intrenchment, and the degree of obliquity bear a certain relation to the opening angle of the shrapnel bullets, there is still no safe space behind the parapet. As the line of fire becomes less oblique, a safe space begins to appear, until, when fire is direct, that space is a maximum. The range of rifled guns is so great that oblique fire may almost certainly be counted on if it be anyway possible for the artillery to get the range; and this, therefore, is one of the conditions to be met if intrenchments are to be used.

Another very important consideration is that in firing directly at intrenchments the target is very broad and very shallow. Hence the range must be obtained to a yard or so. This is not the case when intrenchments are enfiladed. Here, so long as the firing is straight, an error of 100 yards in the range is of little consequence; the only difference is that the shot is effective at one part of the intrenchment instead of at another. When artillery is firing obliquely, absolute accuracy of range is not so strictly necessary as when the firing is direct, though considerable accuracy is undoubtedly required.

In the excitement of battle the accuracy of the trial ground is very materially reduced. The total losses of the French in killed and wounded at the Battle of Gravelotte are given at 15,810. It has been estimated that in the war of 1870–71 about 25 per cent. of the French losses were due to artillery fire. Taking this proportion for the Battle of Gravelotte, the French losses due to artillery fire amount to 3,952; and of this number the French infantry loss would be about 3,162, allowing a due proportion for each arm A great many men fell in counter-attacks in the farms and villages, as St. Hubert, St. Marie aux Chênes, etc., at St. Privat, in the flight of the 6th Corps, and in the 4th Corps, which was not intrenched. If allowance be made for all the losses just enumerated, no great number remains for the loss of the intrenched infantry of the 2nd and 3rd Corps. General Sheridan expressly states that he rode along the French lines, but was unable to perceive any evidence of great effect due to artillery fire. Prince Kraft, in his letters on artillery and infantry, gives numerous instances of the overwhelming effect of artillery fire on troops in the open, in villages, and in woods; also, and more particularly, on guns and gun detachments; but he says nothing about the effect of that fire on infantry in intrenchments.

But just as the guns of 1870 were a vast improvement on the guns of 1840, so the guns of to-day are a vast improvement on the guns of 1870; and therefore it must be assumed that if artillery can find a suitable position and can get the range, good work will be done even against intrenchments.

But there is a further consideration. Every foreign army is now provided with a certain number of field howitzer batteries. The day of the field howitzer is perhaps not yet fully come; but the age is one of rapid and vast improvements, and it seems probable that ere long the field howitzer will have its day. The shell from a howitzer drops at a steep angle, and, if it be filled with a high explosive, the fragments, on bursting, fly in every direction. A succession of well-placed, properly burst high-explosive shells from howitzer batteries ought, therefore, to render any intrenchment untenable. But it is obvious that to produce this result the range must be very accurately known.

This is not the place for an argument on the comparative utility of the gun and the howitzer; it will suffice to observe (1) that though the howitzer has not the mobility of the gun, partly on account of the cumbrous nature of its shell, still it may have sufficient mobility for use against infantry intrenched. It takes no part in the artillery duel, and if it keeps pace with the infantry, it will be in readiness to open a way for them as soon as they are ready to act. And (2) on account of the high curve traced by their shells, howitzers can continue to fire after the infantry has advanced to the attack. In this respect they have a distinct advantage over guns.

For these reasons it is necessary tc suppose that in future a heavy and effective fire, both from guns and howitzers, will be directed on the defender's intrenchments. But that this may be done it is absolutely necessary the attacking artillery should be able to obtain the exact range.

As this question of ranging contains the gist of the whole matter, it is necessary to devote a little space to it.

An inaccurate weapon badly laid may hit the target; a perfectly accurate weapon badly laid cannot possibly hit. Prince Kraft, in his letters on artillery, shows how out of recognition of this fact grew the modern art of ranging. In his 8th letter he says: "Owing to the inaccuracy of the old smooth-bore guns there was seldom any question of correcting the elevation. As a matter of fact, this inaccuracy could not be corrected unless several rounds in succession from the same gun had gone over or short of the target, while no one gun fired a sufficient number to give grounds for correction. It sometimes happened that a gun, though laid correctly, would, out of four rounds at 1,200 paces, throw two short and two over, and never hit the huge target at all; and in this there was nothing to be astonished at. It was quite natural that no particular value should be attributed to exact and careful laying, and that hardly any effort was made to correct it by observing the effect. . . . The accurate rifled gun, which, with its shell bursting on impact, shows in a moment what error has been made, first caused each shot to have its use for every man in the battery for training in judging distance, and induced every officer to accustom himself to judge distances, since if he judged them wrong he did not hit the target. . . . . After the officers, as well as the men, had been instructed in the elements of gunnery, the true 'instructional practice' followed. This was always practice with shell under service conditions. The targets were moved daily, and the ranges were daily varied, and a battery was often stopped during its practice and ordered to fire at another target. Not only did the batteries fire one by one, but the divisions also came into action one by one, so that even the youngest subaltern had plenty of opportunity of showing whether he could judge distance, and whether he could pick up the range correctly."

Such is the accuracy of modern rifled artillery that, if the range be accurately known and the gun or howitzer be correctly laid, a hit is a matter of certainty. There is no difficulty in training men to lay correctly; that can always be insured; but there is great difficulty in ascertaining the range, for it implies that the earliest shots must be very accurately observed, in order to ascertain if they fall short of the target or over it. It is of no great consequence who observes this, provided he is in direct and speedy communication with the battery; but someone must observe it, and his observation must be a matter of certainty. If this can be done, since the rifled gun does what the smooth-bore did not do, since it responds exactly to the care bestowed in laying, the effect is equally a matter of certainty.

But in order to observe accurately if a shot fall short or over, the observer must see the target, and he must see a great deal more. There are, indeed, great difficulties in the way of observing truly. Prince Kraft mentions some instances of difficulties which have actually occurred. In his 13th letter on artillery he describes how impossible it was found to notice the burst of a shell fired from a particular gun when heavy firing was going on. He gives in the same chapter a case from the Battle of Sedan, where, after the loss of an hour expended partly in endeavouring to discover the range, partly firing at wrong ranges, he was obliged to order a complete cessation of firing, and begin all over again by ranging with battery salvoes. Immediately after this instance follows another, in which, at the same battle, having himself wrongly attributed the burst of a particular shell to a certain battery, he accused the battery commander of firing at far too long a range.

Later on he quotes from General von Dresky an instance of erroneous observation of fire which occurred in the Battle of Gravelotte. Here four French batteries appeared to be firing through embrasures cut in a garden wall. On this wall, therefore, the German batteries ranged. But the French batteries actually stood in front of the wall, in which there were no embrasures; some branches hanging over the wall had deceived the Germans.

It is a matter of common knowledge that a deep depression in front of a target is extremely deceptive, especially if there be a deep depression likewise behind the target.

It is not very difficult, then, to see in what way the commander defending a position must act so that his intrenchments may fulfil their object. He must throw every possible difficulty in the way of that accurate observation by which alone the enemy can ascertain the ranges for his artillery. With this object in view the commander may have recourse to four methods.

In the first place he may greatly interfere with the enemy's observing parties, possibly capture them or drive them away, or in various ways hinder them from doing their work.

In the second place he may be able so to lay out the intrenchments, or parts of them, that they are not visible to the enemy.

In the third place he may adopt forms of intrenchment very difficult to discover, and, when their situation is suspected, still very puzzling to the observers.

Lastly, he may be able to mask his intrenchments.

As this is not a treatise on field defences, it would be absurd to attempt giving here an account of what can be done under each of these heads, though these are the heads under which, it is believed, this part of a treatise on field defences should be arranged. It must suffice to give a few general remarks, merely to show that these methods are reasonable.

There has probably never been a battle, except, perhaps, those in the Wilderness and in similar localities, where the attacking force has experienced any difficulty in finding suitable situations for its artillery. Many instances occur to the mind where it was found possible to employ oblique fire. As the range of artillery has increased, and the front of battle has become gradually more extended, facilities in this respect have become proportionately greater. A very slight fold of the ground, a wood of insignificant depth, an embankment, might serve to conceal a few howitzer batteries from a defensive position of any ordinary command; and it is not essential to accurate shooting that the howitzers should stand at a high level. Although the action of howitzers might give the defender an approximate idea of their position, yet there remains an advantage in concealing these batteries, so that in most cases it would probably be necessary to throw out observing parties to the front. As the gun requires to be laid on an object the layer must distinctly see—though there are a few exceptions to this rule—the battery commander is able to observe for himself. Against guns, therefore, raiding parties would not be able to effect anything, but they might against the observing parties of howitzer batteries.

In fortress warfare it is so clearly recognized that observing parties are liable to attack that means for their protection are always included in defensive schemes. If opportunities of this nature are expected to occur in fortress warfare, there is no reason why they should not be equally expected to occur in battle. As the observing parties would necessarily, for the sake of communication, be in the neighbourhood of their batteries, the first observed indication of howitzer action would furnish a clue to the position of these parties. That is all the raiders require to know. Prompt action might then be equivalent to placing out of action for a time a number of the enemy's pieces. To produce this result would be worth a sacrifice.

Let it be supposed that at some particular part of the field the commander desires to place the intrenchment for his firing line out of sight of the enemy. As the commander cannot possibly know beforehand at what parts of the front the enemy will attempt to mass his troops and break through, the spot now under consideration may be one such part. Against such a part the fiercest cannonade will be directed. The part not being designated, all the intrenched line must be prepared for this possible cannonade. Moreover, once the battle has begun the commander will most probably be unable to change anything, even if he came to know such a change were desirable. Therefore he is bound at the outset so to place the men defending an intrenchment that they may make, as a whole, the utmost use of their weapons. Before the concealed intrenchment, therefore, the field of fire must be clear and ample.

A front of battle may occupy country of the most varied kinds, and in consequence the proposed intrenchment may be formed by utilizing and adapting what exists, or by creating something anew. Let it be supposed, by way of example, that the required intrenchment is to be made on a low hill, the slopes of which are entirely bare of cover. If the intrenchment is to be invisible to the enemy, it must be placed either just behind the crest line or at a considerable distance therefrom on the reverse slope, that is, the slope turned away from the enemy. A trench excavated close to the crest line, the earth being spread on the reverse slope where the enemy cannot see it, will answer the purpose. The trench and the men in it will be concealed, and the men have a clear field of fire far away in front.

In a pamphlet written not long ago on the subject fortress defence, Captain Meyer, of the German Engineers, proposed placing the infantry redoubts not on the frontal slopes, ncr on the hill crests, where they would be in view of the enemy, but on the reverse slopes of the hill, where their situation would conceal them. It is obvious that to obtain frontal fire, without which it is infinitely worse than useless, such a redoubt must be placed at a considerable distance, at least 500 yards, from the crest line of the hill. If a redoubt were so placed, what is there to prevent the enemy advancing to the crest line of the hill, and thence firing at the redoubt? Only fire will stop the enemy; the fire of the redoubt itself is out of the question, because from it the frontal slope of the hill up which the enemy proposes to advance is invisible. Unless, then, the frontal slope be swept by fire from elsewhere there is really nothing to stop the enemy advancing and crowning the crest of the hill. It must be supposed, therefore, that the frontal slope is swept by fire from elsewhere. But in that case of what use is the redoubt? None at all as a firing line, because it has no target. It can be used only for the supports.

The same argument would apply to an intrenchment in a similar position. Hence for a concealed intrenchment under such circumstances there is but one allowable situation, namely, close behind the crest line of the hill, and it must be executed as a trench, or in some similar inconspicuous way.

If what has been stated be understood, it is unnecessary to add anything more on the subject of concealed intrenchments, for though the circumstances under which such intrenchments may be required or desirable are infinitely varied, yet the possibility of still making them is shown as well by means of one example as by means of a hundred. We pass on, then, to consider next the feasibility of baffling correct observation by giving an intrenchment a particular form.

Only two forms come up for comparison, the ordinary form with a high parapet, and a modified form having a lower parapet with a long flat frontal slope, the slope turned towards the enemy. There are three ways in which an intrenchment may reveal its own presence to an observer carefully searching for it with field glasses. First of all, there is a suspicious appearance of disturbance, caused by an unexpected slope taking such a direction as to make what is called a curve of contrary flexure, an unusual, though not impossible, formation of ground. The steeper the slope of the parapet the more obvious the appearance of disturbance. Next, unless the slope of the parapet be very carefully sodded over, or covered up in some way precisely suited to the situation, the presence of an intrenchment is revealed by the impression it gives of a difference in texture between one strip of ground and the ground that lies in front of it. The eye may not take in exactly what is there, but it takes in the impression of difference, and the consequent inference can be drawn. Finally, in certain lights, and in certain states of the atmosphere, the parapet reveals itself very clearly by its colour.

The first of these three points calls for no remark, as any advantage there may be is necessarily on the side of the parapet with the flat slope.

The least thickness given to a parapet of common soil, so as to afford protection against the penetration of bullets, is 3 feet at the top. If a parapet 4 feet high have 5 feet of base to its frontal slope, the observer from the enemy's side sees before him a breadth of about $9\frac{1}{2}$ feet of newly-disturbed ground. If alongside this be made another intrenchment, with a parapet 2 feet high, and a frontal slope of 1 in 12, the observer sees before him a breadth of about 24 feet of newly-disturbed ground. To take off this appearance of newness, both breadths must be sodded over, or in some way covered up; and clearly the work to be done in one case is to the work to be done in the other as $9\frac{1}{2}$ to 24. The advantage here would be very clearly in favour of the high parapet, were it not that the low parapet admits of a mode of construction by which it becomes to all intents and purposes concealed. This mode of construction has been already adopted in the case of the Twydale redoubt, and is said to give results most puzzling to would-be observers. Towards the highest part of such a rounded hog's-back as is here in contemplation the frontal slope gradually flattens in such a way that if the steeper slope were in imagination prolonged backwards it would pass at some distance above the highest part of the hog's-back. Leaving the steeper slope to serve as a natural glacis, an excavation is begun just where that slope begins to flatten; the earth thus obtained is thrown backwards, to form a flat but very rough surface about 24 feet broad; the top of this slope is the crest of the parapet, and it is kept at a certain height below the backward prolongation of the glacis, according to the elevation of the ground available for the observing parties of the enemy. Any additional height required for the parapet is obtained by excavating in rear of it, the earth thus obtained being either used to complete the parapet or carried away so that it is certainly concealed from the enemy. It might be necessary to sod a part, but at most only a small part, of such a slope near the crest of the parapet. If the cubic contents of a high parapet be compared with the cubic contents of the flat parapet, it will be found that the actual amount of work to be done is less in the case of the flat than in the case of the high parapet.

Undoubtedly many other comparisons might be made; it is not essential that the high parapet should stand 4 feet, nor that the other should stand 2 feet above the natural ground level. These figures are accidental. It suffices for the purpose here in view if it be inferrable that an intrenchment can be executed which by its very form renders the task of the observer difficult. This, it has been found by experience, a parapet such as that of the Twydale redoubt actually does.

It is not necessary to take into consideration the third point—the difference of colour between the parapet and its surroundings due to the newly-turned earth. This is not necessary because the parapet with a long flat slope is concealed by the glacis.

When a hog's-back has a rounded form its slope is often steepest near the foot. From the crest line of the hill the foot of the frontal slope is then often quite invisible. To bring the space at the foot of the slope well under direct fire, it becomes necessary to place the intrenchment well down on the frontal slope of the hill. But an intrenchment in such a position is particularly easy to observe; artillerists say themselves they desire nothing better. It is often asserted that in such a case obstacles should be freely used, all the space at the foot of the hill being so covered with wire entanglement that advance over it would be very difficult. That is quite true; but such an entanglement would be useless, or worse than useless, if it were not under heavy fire. Such a cross fire may be obtained from the neighbouring hillocks; but if not, there is no alternative; the intrenchment must be placed on the frontal slope, and to save it from destructive artillery fire it must be masked. The two conditions which it is necessary to observe are these:—(1), the enemy's attention must be drawn to something which appears to be an intrenchment or an infantry firing line, but is not; and (2) there must be nothing to conceal the ground to be swept by fire, or which can impede the full exercise of the defender's rifles. Hence the value of a mask boldly placed in rear of the actual firing line, the firing line itself being placed behind the lowest possible parapet, left very rough, and covered, as far as can be done, with sods.

At some parts of the field one method of forming intrenchments, at other parts a second method, will be found most suitable. But always, if possible, the officers who have to lay them out should move out well to the front, to see how the ground looks from the side of the enemy.

It is not proposed to touch here the question of constructing redoubts on the front of a position. The question is a vexed one. The object here is not to establish what field defences should be used, but merely to prove that field defences can be used and ought to be used on some selected parts of the line of battle. Nor can any attempt be made to show how a commander would probably proceed to make his selection of such parts.

A word, however, on the employment of field defences on a flank in view of a possible demonstration against them. The range of modern rifled artillery is so great, and its accuracy so much increased, that here the choice of sites for defensive works is confined within narrow limits. A line of intrenchments on a flank, if visible, is liable to deadly enfilade. A redoubt must be perfectly concealed, or it would be impossible to place troops in it, so fierce a shell fire would it draw from the enemy's howitzer batteries. Hence flank intrenchments and redoubts are now only possible on slopes turned away from the enemy. And this fact fairly well indicates where it is possible to use them.

But the teaching of history shows that, if the flank attack be serious, the troops of the defenders should not be in redoubts nor behind intrenchments. The power of modern guns emphasize this teaching. Map 13 gives the plan of an actual field of battle. The forces fronting east and west are on opposite banks of the stream C. The eastern force, apprehensive of an attack on his left flank, before reinforcements arrive, forms two lines of shelter trench, one running along the contour 540, the other running along the contour 600, and roughly parallel to the line AB. The western force brings up his artillery south of the hill A, and as far in advance as the ground allows. He is less than 2,000 paces from the village (shown in the section), and proceeds to shell the intrenchments, which are clearly visible to him. Correctness of range is of no consequence, as the target is immensely long; a shell must necessarily burst somewhere on such a target, and the shrapnel cannot but be effective. The eastern troops, suffering heavily, must quit the intrenchments, carrying confusion among their comrades facing west. There is nothing now to stop the western infantry. The fact that this actual defensive disposition was not long ago proposed as feasible proves that the old crochet has still its advocates.

There is no occasion to prove that field defences can be used in attack. It is difficult to imagine how, against modern fire-arms, the attack could be carried out without them. Sherman used them successfully, on the principle that they belong to the defensive zone, but he made his defensive zone co-extensive with the enemy's front. If a divisional leader received an order to demonstrate against the enemy the extent of front allotted to him would be considerable. He could not play his part without using intrenchments. His business is to occupy the attention of the greatest possible number of the enemy. If he fail in this, if he be forced back, if his troops be so maltreated as to be for the time useless, two very serious consequences follow. The troops opposed to him, no longer occupied, are able to fling their whole strength against the main attack; and, the ground in their front being clear, they are enabled to make their weight tell in the most convincing manner, by moving unimpeded, and without fear against the flank of that attack. At all hazards, therefore, the divisional commander must retain his footing as near to the enemy as he can get. To fix the enemy's attention he must attack, and as his attacks must have all the appearance of reality, he must make them a considerable force. For this purpose his already rather thin line must be still further thinned. The firing line thus left to cover these movements could only sustain itself in intrenchments. Moreover, the defenders will attack. Johnson sent sally after sally from his beleaguered lines. On what points the attack will fall no one can foresee, hence a further need of intrenchments, to afford time for organizing resistance.

It is obvious no thought can be given to concealing such defences. They must be constructed under fire in the positions recognized as most suitable. The officers whose business it is to choose the positions have little time for thinking, but on one point they should certainly be on their guard—the danger of enfilade; for at these short ranges the enfilading fire of infantry would be destructive. It is laid down that in taking up a position pronounced salients are to be avoided; and undoubtedly the most important defensive point is to secure a good frontal fire. But positions are never ideal; ground is necessarily irregular; prominences jut out and must be occupied, to avoid leaving the enemy forming spaces sheltered from fire. A cross fire from these, deliberately held back until a badly placed trench were completed and occupied, might clear it of men in a moment.

It is impossible to reflect on the use of field defences without including in one's ideas the chances of observation of fire by means of balloons. In his history of the American Civil War, the Comte de Paris ventured, in his third volume, chapter "Fairoaks," on the following remark:—"Le vent n'avait pas permit au ballon, amené à grands frais jusque là, de s'enlever pour reconnaître les mouvements de l'ennemi; il avait eu le sort de tous les engins trop compliqués, sur lesquels, quoiqu'ils puissent parfois être utiles, il ne faut jamais compter à la guerre."

Since those days progress has undoubtedly been made; but in many minds the question still arises if that progress be sufficient to make the balloon a terror to the defence. If it were possible by means of captive balloons to obtain perfectly correct plans of defensive positions, or, without obtaining such plans, to signal, so as to be immediately understood, the precise result of each trial shot, then probably the present mode of conducting a defence would have to be reconsidered. But to obtain such a degree of correct observation many things are necessary. The attacking force must have many balloons; those balloons must obtain a considerable elevation; there must be comparatively little wind; the day must be clear; the observers in the balloons must be exceptionally endowed; their signals must admit of no wrong interpretation; the interpretation of each signal must be prompt and correct. Very few men possess the endowments necessary for correct balloon observation; it is as often windy as calm; the atmosphere of the battle-field is seldom clear. On the other hand, it is by no means so easy as many people suppose to destroy a balloon by fire; the hole made by a shrapnel bullet is very small, and the consequent loss of gas very gradual. Judgment in such a matter must necessarily be for the present suspended.

There is one more point of view from which field defences must be regarded for a brief moment: what moral effect do they produce on the men who use them?

It is often remarked of troops not thought sufficiently well disciplined to fight in the open that they are good enough to fight behind intrenchments. If this were meant so, it would be the highest praise; but it is not meant so at all. The phrase really means that the troops to whom it is applied, not being thoroughly disciplined, would, if made to fight in the open, get out of hand, lose heart, and eventually run. It would probably be fatal to allow any but the best disciplined troops to make use of intrenchments; and, if the future at all resemble the past, there seems no reason to suppose that, to such troops, the use of intrenchments would be injurious. It is easy to believe that if troops were accustomed to manœuvre only in the open, and, when engaged in their first campaign, found they now really had to make intrenchments, they might say to each other, "There are no bullets at manœuvres." A wrong idea of the true object of intrenchments impressed ineradicably on their minds might certainly produce evil consequences.

The intrenchment is to the soldier what the shield is to the savage. With the aid of the firing trench the soldier can inflict as much damage as a dozen men without it; and the damage he inflicts enables his own comrades, at another part of the field, to advance to the attack. That is what must be impressed on his mind during his peace-training. Ill-disciplined troops have no such impressions.

No troops of any age used intrenchments more constantly than the Romans under the great Cæsar. But they made use of their intrenchments with a particular definite object, which was plain to every man in the army. Now and again a legion took refuge in and defended them to the last extremity against a vast host of barbarous foes; but these were exceptional cases. The intrenchment was a camp; its defences corresponded to our outposts; they insured to the army that rest and repose at night of which it stood in need after the daily march; for the Roman marches were very long, and often interrupted by hard fighting. Once only, at Lerida, in Spain, during the Civil War, did Cæsar, for a particular reason, omit the parapet which surrounded the Roman camp, making instead a great ditch, which formed a difficult obstacle. He says, "To hinder his troops from being alarmed or interrupted in their works by sudden excursions from the enemy, Cæsar ordered them not to throw up a rampart, which must have appeared and betrayed them at a distance, but to cut a ditch in front 15 feet broad. The 1st and 2nd lines continued in order of battle, as had been resolved on from the beginning, and the 3rd carried on the work behind them unperceived."

The Roman battles were always fought in the open; but if attacked at night they defended their camp. At his siege of Alesia, famous for its lines of circumvallation and contravallation, aided by every type of obstacle to be found in modern textbooks, Cæsar gave an early illustration of the art of dividing his battle-field into offensive and defensive zones. Including his German allies, he had between 40,000 and 50,000 men. Eighty thousand Gauls were locked up in Alesia, and another vast horde, 248,000 strong, was kept off by the lines of contravallation. The matter was settled on a part of the outer lines devoid of fortification, where the greater number of the Roman troops were led against the bravest Gauls. The latter were put to flight and Alesia captured, with Vercingetorix and his 80,000.

The Battle of Borodino does not owe its importance to the numbers of troops engaged, though those numbers were very great. Here the Russians used intrenchments. They retreated, but after losing half their men; and were immediately ready and eager to attack the enemy. This they did more than once, against the earnest wish of their veteran leader, Kutusof, who was unable to restrain them.

In the American Civil War, which lasted about four years, may be traced almost an evolution of field defences. Both Federals and

Confederates began this war as militia and volunteers, and ended it as veteran troops. It was the veterans who most persistently used intrenchments, both in attack and defence; and no one will suggest that these troops were sparing of their lives, or that any difficulty was experienced in inducing them to quit cover and attack.

No doubt at the beginning of the war intrenchments were used, but casually, on no fixed principle. There was a stronger tendency then than at a later period to fight in the open. The Battle of Shiloh, fought in April, 1862, is an example. The Federals, who fought on the defensive, were not intrenched; only at one point, called the Hornet's Nest, they were "protected by logs and other rude and hastily prepared defences." Both Sherman and Grant have recorded their opinion that at this period of the war it would have been wrong to intrench, because it would have made the men timid. What they wanted then, says Grant, was "drill and discipline, which were worth more to them than fortifications."

Later on in the war it became the rule for the force on the defensive to intrench itself where the accidents of the ground did not serve as well as intrenchments. This was the case at Fredericksburg, Chancellorsville, Gettysburg, Chattanooga, and elsewhere.

And then came the final stage, where intrenchments became as well understood a means of raising the percentage of damage inflicted as the armour which protects the batteries of every modern battleship. The attacks made by the Federals from their intrenchments in the Wilderness campaign, though barren of result, were numberless and sufficiently costly. The Confederates showed just as little hesitation when called on to dash forward against the defences of the enemy.

Towards the end of the Atlanta campaign General Hood complained that from constant retreat the Confederate soldiers were out of spirits; but he did not lay any loss of *morale* at the door of their persistent intrenching. The same men a few months later attacked Schofield, who was in an intrenched position, and only discontinued the attack when they had lost 6,252 men, against a Federal loss of 2,356. The total number of Confederates here engaged was not great. Later still Hood was attacked in an intrenched position and completely destroyed by the Federals, who had been so accustomed to use intrenchments.

The teaching of the American Civil War in this respect seems very clear. It is that intrenchments are excellent for troops thoroughly trained to their use. The explanation is that such troops perfectly understand intrenchments to be a means to an end: they have no desire to use their intrenchments merely as screens, because they know they can never thus attain an end they are determined to attain. It might not fare so well with troops who, trained on a different system, make their own discovery that earthworks stop missiles.

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PAPER VI.

ON THE EFFECT AND TENDENCY OF RECENT SANITARY LEGISLATION.

By John R. Clark Hall, M.A., Barrister-at-Law.

(*Paper read at the R.E. Institute, 10th February,* 1898).

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1. What is Recent Sanitary Legislation?

When I began to plan out this lecture the first question which arose in my mind was, how many years back should be embraced by the elastic word "recent"? Because one may almost say that all sanitary legislation is recent, recent in comparison, for instance, with the highway law, the land laws, or even the poor law, which dates back to the thirty-first year of Queen Elizabeth. With the solitary and unimportant exception of the Quarantine Act of 1825, there is not at this moment a single Public Health Statute which is fifty years old. "Public Health" as a science, or even as a phrase, was in fact absolutely unknown a few years before that time. Every man lived, not exactly under his own vine and his own fig tree, but over his own well and his own cesspool, and could pollute his own and his neighbour's water supply just how he liked. No arterial drainage, no isolation hospitals, no sanitary inspectors, but, on the other hand, no sanitary rates.

Sanitary legislation practically begins with the Public Health Act, 1848, a statute which had as its chief proximate cause the fearful epidemics of cholera which attacked England in the years which preceded its passing. From that date, 1848, the development of legislation on Public Health has been steady and continuous, and has followed the same broad lines. There was, however, a big consolidation Act in 1875 (the *Public Health Act*, 1875), which gathered up all that was good in the previous legislation, and amended or discarded all that experience had shewn to be bad; this Act still forms the main corpus of sanitary legislation—nearly all the later Acts being appendages to it or amendments of it, and I think, therefore, that it will be well for me to take the legislation of the last twenty years (roughly) as recent for the purposes of this lecture, and to preface it with such an account of the Public Health Act, 1875, as will form a basis for my explanations of the later Acts.

2. The Public Health Act, 1875. The best way will be for us to consider what was the state of affairs generally as regards public health immediately after the Public Health Act came into force, and in consequence of that enactment.

In the first place, England and Wales (I may say that Scotland and Ireland have Sanitary Acts of their own with which I shall not have time to deal, and that London has also its special sanitary laws) —England and Wales, excluding London, were parcelled out into districts called Urban and Rural Sanitary Districts—the former comprising the towns, and the latter, which were generally of larger extent, consisting of all the rural parishes contained in each poor law union. Every Municipal Borough was *ipso facto* an Urban Sanitary District, and the Town Council was the Urban Sanitary Authority controlling it. The other Urban Sanitary Districts were governed by specially elected Urban Sanitary Authorities, and until recently these were called Local Boards, except in a few abnormal cases. Each Rural District was placed under a body called the Rural Sanitary Authority, which consisted of the Guardians of the Poor Law Union, except those who sat for Urban Parishes.

Besides these Authorities, the Local Government Board had power to set up others, called Port Sanitary Authorities, with functions relating to the sanitation of Ports and Shipping. To these we shall return later on.

The chief powers and duties of Urban and Rural Sanitary Authorities related to water supply, sewerage, scavenging, the provision of hospitals, disinfecting apparatus, and mortuaries, the suppression of nuisances injurious to health, smoke nuisances, and overcrowding, and the closure of houses unfit for human inhabitation, and of polluted wells. In addition to these, Urban Sanitary

Authorities had some powers and duties not possessed by Rural Sanitary Authorities, such as those relating to markets, slaughter-houses, and pleasure grounds, the construction, improvement, and maintenance of streets and roads, and some matters of police.

Urban, and in some cases Rural, Sanitary Authorities have also the power of making and enforcing bye-laws as to keeping of animals, the removal of refuse, common lodging houses, slaughter-houses, the drainage and building of new houses, the construction of new streets, etc.

Bye-laws are really local laws, or rather regulations ("bye" here does not mean subsidiary—as in "by-road"; but town or township, as in "Grimsby," "Whitby,") which, although they have the force of law, are not like Acts of Parliament in that they are strictly limited in scope, and must not run counter to the statute or common law, or else they can be upset as invalid or *ultra vires* in a court of law. This of course can never happen to an Act of Parliament, about which the saying goes that it can do anything—except turn a man into a woman.

Provision is made in the Act of 1875 for meeting the expenses incurred by Sanitary Authorities in the exercise of the powers I have mentioned, out of the rates, or of money borrowed on the security of the rates.

The Central Authority which has the supervision and control over all these Authorities is the Local Government Board, and the way in which the control is exercised deserves a passing notice on account of its simplicity and effectiveness. It forms a striking contrast to the method of control exercised over the Poor Law Authorities by the same Department of State. A Board of Guardians can hardly move hand or foot without the permission of the Local Government Board; at every point they are met by the necessity of getting the sanction of the Central Department.

On the other hand, Sanitary Authorities are rarely required to get State consent as regards matters of detail. How, then, are they kept in hand? Almost entirely by applying the screw at one point, that point being, it need hardly be said, a most vital one.

Well, now, to come to the point in question.

I think it will be agreed that one of the most important and persistent and interesting attributes of humankind is its propensity for borrowing money. This propensity is found not only in the individual, but in aggregates of individuals, such as Companies, Societies, and other Public bodies. It has already been mentioned that Sanitary

Authorities have the power of borrowing money ; I must now add that they have the inclination to do so, and that the body which prevents them from giving way to that inclination when they ought not to give way to it is the Local Government Board. The power of borrowing on the security of the rates is, in short, only exercisable with the sanction of that Department, and to the extent of twice the rateable value of the district. What the Local Government Board have chiefly to see to is that the money is to be expended on permanent works, that is, on works which will at any rate last for some years, and that the works are generally suitable and proper. They have also to fix a term within which the loan is to be repaid, and this must in no case exceed 60 years. This is very important, because public bodies exhibit the same reluctance to repay borrowed money which one occasionally finds in private individuals. The Board are constantly being appealed to to allow a longer term for the discharge of a loan than that which they are prepared to give, and which is roughly proportioned to the estimated life of the works. These powers of the Board—the power of refusing sanction to loans, and that of fixing a term for the repayment of loans—obviously enable the Board to protect very completely the interests of future ratepayers—interests which local bodies have no very strong temptation to look after, but a very strong temptation to disregard. At the same time if the Board refuse to sanction a loan, the District Council are not absolutely debarred from carrying out the works, but they must pay for them out of the current rates—*i.e.*, the whole cost falls on the ratepayers of the year in which the works are carried out.

Let us illustrate the effect of this by example. Suppose, for instance, that the Town Council of Chatham propose to lay a silver drain pipe along Chatham High Street. They would send plans and estimates to the Local Government Board, together with an application for sanction to borrow the amount of the estimate. After considering the proposal, the Board would no doubt refuse sanction on the ground that an iron or an earthenware sewer would do just as well, and that the ratepayers of the future might probably not wish to pay for the distinction of having a silver drain pipe. It is then for the Town Council to consider whether they will drop their scheme, or carry it out by means of current rates. If they took the latter course, it would certainly mean such a marked increase in the rates that the ratepayers would turn all the members of the Council out as soon as they sought re-election, and so it need hardly be said that the Council never do take the latter course.

Thus it is that the ratepayers of to-day as well as those of the future are fairly safe from wild extravagance on the part of Local Sanitary Bodies. It may be added that the accounts of all such bodies, with the exception of the Town Councils, are subject to audit by an Auditor of the Local Government Board, this audit not being merely a scrutiny of each item as regards its correctness, but also as regards its legality.

The Board also have under the Act the approval of bye-laws made by Sanitary Authorities, the power to create, alter, or abolish Urban Districts (not being Municipal Boroughs),* to make regulations for speedy burial, house-to-house visitation, and the provision of medical aid, etc., during epidemics, to give Rural Sanitary Authorities some of the special powers of Urban Authorities, and when either Urban or Rural Authorities neglect to provide their districts with sewerage or a supply of water, to compel them to do their duty in the matter. Lastly, the Board could combine Sanitary Districts for particular purposes of the Act, such as the provision of hospitals, a supply of water, or means of sewerage disposal, and could place them for such purposes under joint Boards made up of members of the constituent Authorities ; but the combination could only be made by means of a Provisional Order—that is, by an order of the Board, which has no force or validity unless and until it has been confirmed by Parliament.

3. The Rivers Pollution Prevention Act, 1876.

In the year after the Public Health Act came *The Rivers Pollution Prevention Act*, which at first sight looks a very formidable enactment. No solid or liquid refuse of any kind is allowed to be put into a stream. A man must not tip a barrow load of slag from a furnace into the Tyne ; Mary Jane must not empty the slop-water out of a house-boat into the crystal Thames. But on a closer inspection it will be found that this statute has a great deal more bark than bite about it. It is true that you are told that you mustn't do this, that and the other, but, on the other hand, if you *do* do it you will find some ingenious clauses in the Act which may very materially hinder the law from getting at you.

For instance, proceedings as regards manufacturing and mining pollutions can only be taken with the consent of the Local

* This power is now practically superseded by one contained in the Local Government Act, 1888, which provides that orders for the creation, alteration and abolition of Urban Districts (not being Boroughs) shall be made in the first instance by County Councils.

Government Board and by a Sanitary Authority, the members of such authority being often associated with or interested in the local industry. Moreover, if the offending works are in a place which is "the seat of a manufacturing industry" (whatever that may mean), the Local Government Board can only consent if the proceedings are not likely to inflict material injury on the industry, and if means for rendering harmless the polluting liquids are reasonably practicable and available. It is true that if a Sanitary Authority refuse to take proceedings in any case, an appeal lies to the Local Government Board, who can direct them to do so. But this is a mere shadow of a power, for it can easily be understood that the Sanitary Authority who are directed to take proceedings against their will would be unlikely to conduct these proceedings in such a way as to ensure success.

Then as to sewage pollutions. At the date of the passing of the Act nearly all Sanitary Authorities turned their sewage into streams, generally with no attempt at purification. It was the cheapest way of getting rid of it. All these Authorities were practically shielded by a provision which enabled Sanitary Authorities to continue the use of any channels existing at the passing of the Act, through which they discharged sewage into a stream. Tidal rivers were also exempted, unless specially brought under the Act. Generally speaking, it may be said that for the first ten years at any rate the direct effect of the Act was very small. Indirectly it did help towards the purification of rivers, because the Local Government Board have ever since its passing refused sanction to a loan for any works of internal sewerage which would discharge sewage into a stream by a new outfall. Here we see again how very important the Board's function of sanitary loans is.

A Local Authority want to borrow £5,000 for the internal sewerage of a new estate in their district. The Board refuse sanction because the sewage will go into a stream. Then the Local Authority have to consider whether they will pay the £5,000 in one year out of the rates, or spend, say, £45,000 in buying a sewage farm, and get sanction to borrow that sum for 50 years, as well as the £5,000 for 30 years. Under the circumstances the Local Authority might grind their teeth, but they would probably buy the sewage farm.

4. The Canal Boats Act, 1877.

Next year (1877) was passed the first Act for the registration and regulation of *Canal Boats*, and for the sanitary betterment of the bargee, and the following year was signalized by the passing of a somewhat important Act as to water supply—*The Public Health (Water) Act*, 1878, which is chiefly directed to the improvement of the water supply of isolated houses, or small groups of houses, in rural districts, which are not capable of being supplied at a reasonable cost from the works of a Water Company or Rural Sanitary Authority. The Authority can prevent new houses being inhabited until a proper water supply has been provided, and if existing houses are without a proper water supply, the Act enables them to compel the owner to provide it, if it can be furnished within a certain very modest limit of cost.

5. The Public Health (Water) Act, 1878.

The Act also empowers Rural Sanitary Authorities, who have provided a supply of water by erecting stand pipes in a village, to charge owners or occupiers of houses within 200 feet of a stand pipe as if the supply were laid on to the premises themselves.

I may say here that the Local Government Board's Engineering Advisers are generally adverse to this method of supplying a village, to which Rural Sanitary Authorities are sometimes inclined to resort because of the apparent saving in first cost. The additional expense of laying the water on to the houses is however so small in relation to the extra comfort to occupiers that the policy is a shortsighted one. The better class of these will gladly pay a slightly higher rate for having the great convenience of water in their houses, and the Sanitary Authority can recoup themselves in this way for the larger outlay if they have the courage to make the house connections at the outset, when the street mains are being laid. On the other hand, when once a stand pipe supply is provided, the trouble and expense of making house connections at a later date are such that the community generally has to settle down finally to the inconvenience of fetching water, which they seek to minimize by using as little of it as possible. Thus it is that the arrangement is not one to be encouraged from the higher sanitary view-point.

In 1879 was passed *The Public Health (Interments) Act*—the embodiment in statutory form of Lord Beaconsfield's dictum that the burial question was a sanitary question. This Act enabled Urban and Rural Authorities to provide their districts, or parts of their districts, with burial accommodation. The form of this Act furnishes a very good example of our later Parliamentary methods here in England. The Act contained only three sections, and fills up about half a page of letterpress. What it does could have been done much more neatly and satisfactorily by an Act of 20 or 30 pages, but an Act of that length, in the heated state in which

6. The Public Health (Interments) Act, 1879.

religious parties were at that time in reference to the burial question, would have been fought section by section and line by line, and very likely have been finally thrown out, after occupying Parliament for the greater part of a session. To avoid all this, the Act is made as short as possible, and, one may almost say, as indirect as possible—in this way:—First it is provided that references to a mortuary in certain sections of the Public Health Act, 1875, shall be taken to be also references to a cemetery; so that whatever a Sanitary Authority can do as regards a mortuary under the Act of 1875—construct and maintain one, for instance—they may now do as regards a cemetery. To put it in other words, the expression "mortuary" in the earlier Act is to be read as including a "cemetery," or, more shortly still, a "cemetery" is to mean a "mortuary." The draughtsman of this sub-section of the Act, with the instincts of a poet, draws attention to the subtle harmony of this arrangement by inserting a few words to explain that a mortuary is a place for the reception of the dead before interment, and a cemetery is a place for the interment of the dead.

The next sub-section goes on to say, for one thing, that for the purpose of certain provisions of the Public Health Act, 1875, a cemetery is to mean a sewage works. This is too much for our poet. He gives it up. One of the most important effects of this sub-section is to impose certain restrictions on the construction by Sanitary Authorities of cemeteries outside their districts.

Then there is a section of two lines by which an Act of 16 pages —the Cemeteries Clauses Act, 1847—is incorporated bodily with the later Act. The Cemeteries Clauses Act is one of a series of very useful Acts passed in 1845–1847, which contain model clauses intended for insertion in Local or Companies Acts. Before 1847 the Statute book of each year was unnecessarily swollen out by long strings of sections in identical, or nearly identical, terms, appearing over and over again in Local Acts relating to different towns and districts. After that year these sections could be supplanted by one which simply incorporated a Clauses Act or such sections of it as were needed. The Cemeteries Clauses Act was originally intended for the Regulations of Cemeteries provided by private Companies, and contains several provisions which are not very appropriate to the case of a Local Authority. But a contentious member of the House could hardly attack in 1879 with any hope of success an Act passed in 1847 and constantly re-enacted (by incorporation with other Acts) in subsequent years. And so the Public Health (Interments) Bill got safely through.

The next sanitary enactment of any importance was one passed in 1892, enabling local authorities to make bye-laws for securing the decent lodging and accommodation of persons engaged in picking fruit and vegetables, similar to those which they were already empowered to make under the Public Health Act, 1875, for hop pickers. 7. The Public Health (Fruit Pickers Lodgings) Act, 1882.

We have already seen how in the event of epidemic, or infectious disease occurring or threatening, the Local Government Board may make regulations for certain purposes. An Act called the *Epidemic and other Diseases Prevention Act*, which was passed in 1883, enabled local authorities to borrow money with the Board's sanction for the purpose of carrying such purposes into practical effect. 8. The Epidemic and other Diseases Prevention Act 1883.

We now come to a short statute which got through in 1885—*the Public Health (Ships, etc.) Act*, 1885. This Act enabled the Local Government Board to set up Public Sanitary Authorities permanently by Order. Hitherto they could only do this by Provisional Order—that is, by an Order which was of no force until confirmed by an Act of Parliament; and although, since 1872, they could, and did, set up temporary Public Sanitary Authorities from year to year by Order, it was found that such authorities would not spend money on permanent works, such as Port Hospitals, and that they made their temporary character an excuse for inaction. So when this Act was passed the Local Government Board set to work to establish a cordon of permanent Public Sanitary Authorities all round the coast of England and Wales, with the result that no ship-borne infectious disease has now a decent chance of getting a foothold on these shores. Each Customs Port has one or more Port Sanitary Authorities whose first duty is to watch for and isolate any case of infectious disease coming to the port. We have, as it were, a complete chain of sanitary forts round England and Wales, and whenever the enemy appears we are ready to meet him. As a practical example of the value and efficiency of the arrangements, I may point to the cholera epidemic which raged in Hamburg in 1892. Not in a single instance was a Hamburg ship prevented from coming to our ports, and yet with all the enormous traffic between Hamburg and the east coast, and the fact that about 30 cases of undoubted cholera were actually imported into England from Hamburg during the year, the traffic was so watched, and the cases so followed up and isolated, that they did not give rise to the slightest outbreak of cholera in any part of England. I do not know of any other country which can make a similar boast. Many of them still 9. The Public Health (Ships, etc.) Act, 1885.

adhere to the antiquated, ignorant, clumsy, costly, and barbarous system of quarantine. I say "ignorant," because quarantine is, in effect, an admission by the government which imposes it that they are incapable of fighting with an infectious disease in the proper scientific way. Often has the voice of the representatives of Great Britain been raised at International Health Congresses against this feeble custom—and in vain. Foreign delegates have reminded us that we have quarantine ourselves at Malta for instance, forgetting that the liberty-loving Briton allows his dependencies to make pretty much what laws they please—almost as if they were foreign countries—and they also point to our own Quarantine Act of 1825, which has been practically a dead letter for many a long year, but which for one reason and another remained on our statute book until 1896, when the last shred of it was repealed by the short Public Health Act of that year.

The Local Government Act, 1888.

In 1888 a new set of authorities was created by the *Local Government Act* of that year. This is a very important enactment and is an example of the decentralizing tendency which has shewn itself in Parliament in recent years as regards Local Government. What it does is, first of all, to take away from the County Justices the non-judicial functions—such as those relating to Lunatic Asylums and main roads—exercised by them in quarter sessions, to add to these certain other functions, some of which were taken from the Local Government Board, and to hand them over to a new body called the County Council, elected on a democratic basis. But first, all boroughs which had a population of more than 50,000 were cut out of the geographical counties in which they were situated, and made counties of themselves, with the title of County Boroughs. Some counties, such as Lancashire, are perfectly riddled with County Boroughs. The rest of the geographical county, that is, that for which a County Council is elected, is called an Administrative County, and these are now much more important than geographical counties. London was carved out of Middlesex, Surrey, and Kent, and made a separate Administrative County, and the three Ridings of Yorkshire, the three parts of Lincoln (Holland, Kesteven, and Lindsey), East and West Suffolk, and some other exceptional districts had been made separate Administrative Counties, and the Local Government Board have power under the Act to create others, and to set up further County Boroughs. It is not always an advantage to a borough, in the matter of rates, to get made independent of its county. If it were, I am afraid we should have Town Councils of Boroughs whose population was not reaching 50,000 fast enough, offering premiums for large families to reside, or to be born, within their boundaries.

Well, these new County Councils and County Borough Councils have not many powers of a purely sanitary nature at present, but they have a few important ones, and the Local Government Board may, with the sanction of Parliament, give them more. The creation, alteration, and abolition of Urban Districts is now in their hands, subject to an appeal to the Local Government Board in certain circumstances; they may appoint a Medical Officer of Health for the County, and they are an authority for the purposes of the Rivers Pollution Prevention Act, 1876. In this last capacity some of them have already done some good work, notably in Yorkshire and Lancashire, which, unlike a good many other counties, have rivers entirely within their boundaries, which they can thus control as regards pollution from source to mouth.

The power to alter the boundaries of sanitary areas is one of great importance. Sometimes, for instance, the boundaries of a district which is not all in the same watershed can be readjusted in such a way as greatly to facilitate the carrying out of drainage works; or some wretched little Urban District created in the old times, before 1875, when the central department had practically no voice in the matter, and obstinately opposed to carrying out any of these new-fangled sanitary ideas, can be quietly absorbed in the district of some adjoining authority with more enlightened views.

I may here call attention to another tendency of recent legislation which, though not relating exclusively to sanitary matters, has an important bearing on sanitation, viz., the tendency to simplify areas. The Local Government Act, 1888, lays it down as a rule to be generally observed that areas for various purposes of local government should not overlap each other or intersect one another if it can be avoided, and it began by practically applying the rule to the case of Urban Districts, of which there were a good number extending into more than one county. As to these, the Act provided that the County boundary should be altered so as to bring the Urban District entirely within the County in which it had the largest population. We shall see more of this tendency when we come to the Local Government Act of 1894.

As regards the germ of further decentralization which is contained in the Act of 1888, the provision which enables the Local Government Board by Provisional Order, to be confirmed by Parliament, to delegate to County Councils some of its own powers, it may be stated that soon after the passing of the Act the Board did make a Provisional Order, divesting themselves of some of their less important powers, in favour of County Councils. But the Provisional Order, singularly enough, aroused a storm of opposition from the boroughs which were not County Boroughs (*i.e.*, those with less than 50,000 population), who protested against being governed, even in comparatively small matters, by their own County instead of by a Government Department. "What," said Alderman Smith of Kidderminster and Councillor Jones of Droitwich, "are we to be governed and judged by Brown of Malvern and the County Councillors for all the other little rural places, instead of by a Cabinet Minister? No!" So the Provisional Order fell through. The fact is that the County was not ripe for it; the Plain objected to be ruled by the Mountain—it preferred Philip, at Whitehall.

Still, we must not forget that the Act of 1888 makes a very great step forward in local self-government; it gives the sovereign people new opportunities of rating itself, and furnishes a framework which is being more completely filled in almost every Session.

I may add that the Act confers on the Local Government Board the very important power of extending municipal boroughs (which, as we have seen, are always separate sanitary districts) and of altering county boundaries, by Provisional Order. This could previously only be done by Local Act.

The Infectious Diseases (Notification) Act, 1889.

In 1889 the Infectious Diseases (Notification) Act was passed. This provided for immediate notice of cases of infectious disease being given to the Medical Officers of Health of Local Authorities, and is a most valuable enactment. Just as early notice is all important in the case of a fire, so it is in the case of an outbreak of infectious disease—the chances of stamping it out are vastly greater in both cases when there is timely notice, and in the case of disease, investigation of its cause is much simplified. The Act is, however, only adoptive as regards the provinces; that is, Urban and Rural and Port Authorities are free to adopt its provisions or not, as they choose. If they don't choose, the Act does not apply to their districts. This is a peculiarity which is found in some subsequent Acts, *e.g.*, in the Public Health (Amendments) Act, 1890, and in the Infectious Diseases Prevention Act, 1890. The former is a heterogeneous collection of smaller amendments and additions to the Public Health Act, 1875. It forbids solid matters, chemical refuse, and hot water to be turned into sewers under

The Public Health (Amendments) Act, 1890.

certain circumstances, enables Local Authorities to lay house connections to sewers, to make bye-laws as to the use of public conveniences, paving of yards, and some points connected with filth removal; it prohibits the use of a living room or bedroom or any room, built wholly or partly over a privy or cesspool, and the erection of buildings on ground filled up with offensive matter. The latter provides for the inspection of dairies and enables Local Authorities to prohibit the supply of milk from suspected sources; it also contains important provisions as to disinfection, and empowers the Local Authorities to give temporary shelter and lodging to persons turned out of their houses while the rooms are being disinfected.

The Infectious Diseases Prevention Act, 1890.

As the adoptive principle is rather a marked feature of recent sanitary legislation, I must now say a few words about it generally.

The adoptive principle.

Everybody here will probably be aware that an Act of Parliament must be either public or private, the latter being further classed as Local (such, for instance, as Acts promoted by Railway Companies, Canal Companies, Harbour Boards, Municipal Corporations), or Personal (for example, Acts relating to the succession to the estate of some large landowner, or for the naturalization of a distinguished foreigner). Public Acts may be local too—that is, they need not of necessity relate to the whole of the British Islands, or even to England and Wales—but they must relate to matters of national importance. As regards their passage through Parliament, there is a very marked difference between Public and Private Acts. A Public Bill passes through all its stages in the Houses themselves. When it goes into Committee it is a Committee of the whole House. At every stage every member can speak, or any body of members can obstruct or delay the passing of the bill. A Private Bill, on the other hand, only goes through its formal stages in the House—that is, it is read a first, second, and third time without any discussion. It is always referred to a Committee, but this is not a Committee of the whole House, sitting in the House, but a small Committee of, perhaps, five or six members of the House, who sit almost like a judicial body—hear witnesses, and counsel for and against the Bill. However excellent the Public Bill may be, its chances of getting through are always precarious; it may be made the subject of protracted party fights, or it may simply be squeezed out—especially if it is a Bill introduced by a private member and not a Government measure—from sheer want of time. One hears of such a slaughter of the innocents regularly towards the end of every session. A Private Bill has only to comply with certain rules called Standing Orders, and if the Committee, to whom it is referred, are satisfied on its merits, it is practically certain to get through.

Now the adoptive principle may be said to be an attempt to combine the advantages of public and private legislation.

Adoptive Acts are usually made up in a great measure of clauses, which have already been inserted in Local Acts and found useful. Many of these clauses have appeared again and again in various Local Acts year after year, and thus swell the statute book unnecessarily. Every year the bulk of local legislation far exceeds that of the Public General Acts, and contains a large amount of repetition. The facility with which it can be got through Parliament tempts Local Authorities to resort to it on comparatively trivial occasions, and some of the larger boroughs, instead of conducting their local government under the general laws, have quite a separate code of their own. For instance, Liverpool, and its next-door neighbours, Bootle and Birkenhead, all have Local Acts differing from each other and from the general law. It is clear that there must be considerable inconvenience in having such a lot of separate and conflicting laws in districts adjoining each other and of very much the same character, and anything which tends to reduce the extent of local legislation, such as the adoptive principle, is to that extent valuable. Another thing about this principle is that it disarms Parliamentary opposition, and helps very materially to get a Public Bill through the House. Here is a provision, say the promoters, which has been inserted in many Local Acts, and which experience has shown to be useful; but no district need have it unless it likes; we are merely giving it to the districts which want it, without putting them to the trouble of going for a Local Act.

Thus, much is to be urged in favour of the adoptive method, but to my mind the objections to that method are very considerable. It perpetrates the evil of special legislation for particular districts, and in a worse form than that of the Local Act. A man can always, with some trouble, find out what Local Acts there are relating to a place, and refer to, or buy copies, as they are always printed by the Queen's Printers. But he can only discover whether a particular section of the Public Health (Amendment) Act, 1890, is in force in (say) a certain rural district by the courtesy of the officials of the Local Government Board or the District Council, or by searching for the notices which the Rural District Council are required to insert in the local paper when they adopt. Probably the Local Government Board are the only body who keep a complete record, showing in what districts the Act or part of it is in force. What seems to me the most serious objection to this kind of legislation is, however, that there is no logical ground on which the putting in force of many of the provisions in one district, and not in the adjoining district, can be defended. For instance, if it is wrong that a man in Rochester should sleep in a room built over a cesspool, it cannot be right that he should do so in Chatham. And yet this is what would be lawful, assuming that Rochester adopted the Act and Chatham did not. If the point is important it ought to be worth fighting in Parliament for all England, and if it is not, it might be left alone.

The favour which has of late been accorded to permissive legislation is a sign of a strong inclination of Parliament towards local self-government, and this is one of the chief tendencies to which I have to call attention. Such legislation is, doubtless, in accordance with the spirit of the age, and we must bow to it.

The Housing of the Working Classes Act, 1890.

The year 1890 was signalized by an important Act relating to Artizans' and Labourers' Dwellings—The Housing of the Working Classes Act, 1890. There had been previous legislation, but the proceedings had been costly, and the new Act cheapened it, and consolidated three separate sets of Acts, under none of which very much work had been done.

Time will not allow me to say much on this subject, but it is a sanitary one of the highest importance. The first part of the Act, which applies only to Urban Districts, enables Urban District Councils to clear large areas of insanitary ground, and in place of crooked narrow streets, and courts redolent of stale epidemics, to cause healthy buildings to be erected, with plenty of air space about them. Part II. relates to smaller areas and to single houses, and applies to Rural as well as Urban Districts. Part III. (which is adoptive) enables Urban and (with the consent of the County Council) Rural Authorities to provide dwellings for the working classes. A great deal of useful work has been done under this Act since its passing.

In connection with this question of dwellings for the labouring classes, I may mention that for the last ten years or more it has been the practice of Parliament to insist on the insertion in all Local Acts, which authorize the purchase, for the purposes of an undertaking such as a railway or docks, of more than ten houses inhabited by the labouring classes, of a clause requiring the undertakers to submit to the Local Government Board, and carry out, a scheme for re-housing the displaced persons. This provision is very important in the case of large schemes, such as that for the extension of the Great Central Railway to London. In places like Leicester and Nottingham the Company take power to acquire street after street of workmen's houses, and if they were not required to build similar houses within a reasonable distance, the over-crowding and the inconvenience caused to many of the men in consequence of being driven further away from their work would be very serious. The same rule is enforced when a Local Authority obtains Parliamentary powers by Local Act or Provisional Order to take workmen's dwellings, say for the purpose of a street improvement.

The Isolation Hospitals Act, 1893.

We may now jump to the year 1893, in which the Isolation Hospitals Act was passed. It has already been said that the Local Government Board could combine districts for hospital purposes by Provisional Order, but this power was never, I believe, exercised in practice when any of the districts were unwilling; and in the comparatively few cases in which such orders were issued and confirmed the combination was not always successful—the members representing one of the Constituent's Districts on the joint Board might for some reason or other disagree with those of the other district or districts, and carry on a policy of obstruction. Very often the rock on which the combination split was the question in whose district the hospital should be placed. Generally the representatives of each district had the strongest conviction that the *adjoining* district was the proper place for it. The new Act gives County Councils large powers in relation to the provision of the hospitals for infectious diseases for any district or districts in the county. They may provide or cause to be provided hospitals for infectious diseases for any district or combination of sanitary areas in the county, and may set up Hospital Committees for the management and control of the hospitals, consisting of members of the District Councils whose districts are concerned, and of members of the County Councils in cases where the latter body themselves contribute towards defraying the expenses of the hospital (which the Act empowers them to do if they like). An appeal may be made to the Local Government Board against the inclusion of any particular district in the proposed Joint Hospital District, and an appeal is also allowed against the composition of the Hospital Committee. The County Council have power to borrow the money required for the provision of the hospital with the sanction of the Local Government Board, and to recover it from the Councils of the Constituent Districts. They can also decide, subject to revision of their judgment by the Local Government Board, where the hospital shall be erected.

The effect is certainly to smooth the way for the provision of hospitals for infectious diseases for districts and combinations of districts. If the Council of one district does not provide it with proper infectious hospital accommodation, the County Council can step in over its head and build a hospital, and set up a Hospital Committee. The mere fact of this power existing has a tonic effect on District Councils, for the presence of a Hospital Committee in and for their own district alone would be a perpetual reproach. Then as regards combinations, the County Council have somewhat of the power exercised with effect by Queen Elizabeth of knocking people's heads together till they did agree—a power only possessed in a very small and ineffective degree by the Local Government Board. The Act is also noteworthy on account of the important addition which it makes to the sanitary functions of the County Council.

The Local Government Act, 1894.

In 1894 a new Local Government Act, often known as the Parish Councils Act, was added to the statute book. This measure set up in each parish in a rural district having more than 300 inhabitants, a popular elected body called a Parish Council, and provided that, in certain cases, even smaller parishes should have such Councils. Parishes which had not Parish Councils were to have Parish Meetings, and these succeeded, as regards civil business, to the old Vestry Meetings. The Parish Councils took over, broadly speaking, all the non-ecclesiastical functions of the Vestry and Churchwardens, and the control of parish property, village greens and allotments, and had certain powers in relation to footpaths, rights-of-way, and so forth. The following small powers as regards sanitary matters were also given to them :—They could utilize wells, springs, or streams, for purposes of water supply, but not so as to interfere with the rights of private persons; could drain or clear out ponds, pools, ditches, and drains likely to be prejudicial to health ; but they must not touch upon the powers, rights, and duties of the Rural District Council in such matters. Then they have power to make formal complaints as regards two very important matters—first, they may complain to the County Councils that the Rural District Council have made default in providing their parish with sewerage or a proper water supply (just as a private individual can complain to the Local Government Board under the Public Health Act, 1875, as regards the default of an Urban District Council or a Rural District Council) ; and the County Council have thereupon similar powers of compelling the Rural District Council to do their duty to those possessed by the Local Government Board, under the Public Health Act, 1875, and, besides that, the power to do the work themselves if they choose. Here we have an important addition to the sanitary business of the County Councils, and a striking example of the tendency to hand down to a Local Authority powers previously exercised by a Central Authority alone.

The second complaint which a Parish Council may make is to be addressed to the Medical Officer of Health of a Rural District Council, and is to the effect that a house is unfit for human habitation or if not unhealthy in itself, is deleterious to the health of the immediate neighbourhood—say, by depriving adjoining houses of light and air. The object aimed at is the closing or demolition of the house by the Rural District Council, or, on their default, by the County Councils. A similar complaint could have been made under the Housing of the Working Classes Act, 1890, by four householders, but rarely was made, because people shrank from the social boycott which such a complaint would probably have brought down upon them.

It has already been mentioned that the Local Government Act, 1888, laid down the general rule that overlapping of boundaries was to be avoided in future, and provided in particular that no Urban District Boundary should cross a County Boundary, that is that no Urban District should be in more than one County. The Act of 1894 followed this up by ordaining that no Rural District Boundary should cross a County Boundary, and that no Parish Boundary should cross a District Boundary.

The labour and trouble involved in making the necessary arrangements for this purpose can only be appreciated by those who had a part in it. At last the arrangements are practically complete, and a man can take a good walk in most parts of England now without constantly treading on a boundary.

Lastly, the mode of electing Urban and Rural Districts Councillors was placed on a more popular (democratic) basis.

The Cleansing of Persons Act, 1897.

From that time to the present there is but one "purple patch" to which I can call attention. It is the Cleansing of Persons Act of last year, which provides that a Local Authority may grant free of charge to any person who announces to them that he is infested with vermin the use of any apparatus they may have for cleansing the person and his clothing. When one thinks what moral courage a man must have to be able to make that announcement, and how lonesome he must feel afterwards in his depopulated clothes, one cannot but admire the thoughtfulness of Parliament in reminding him, as it does later on in the Act, that he is still a man and a brother, by formally preserving to him intact all his rights and privileges as a true-born Briton.

It is hardly possible to state the effect of sanitary legislation of the last twenty years, even in the outline, as I have done, without giving some indication of its tendencies, but it may be useful to group these tendencies in a few short sentences before I close. Tendencies.

First of all there is a strong tendency to give the people local self-government in sanitary matters. The County Councils Act of 1888 and the Parish Councils Act of 1894 furnish the most marked indication of this.

Secondly, there is the popularization of the electorate, as evidenced by the same Acts.

Thirdly, simplification of areas. The beginning of this was a Poor Law Act of 1876, but, as we have seen, the Acts of 1888 and 1894 marked very great progress in this direction.

Fourthly, simplification of methods. Procedure by Local Acts has been supplanted by procedure by Provisional Order, which requires confirmation by Parliament (witness the Act of 1888 again), and procedure by Provisional Order has had procedure by final Order of the Local Government Board substituted for it. The Public Health (Ships) Act, 1885, the Housing of Working Classes Act, 1890, and other Acts afford instances of this.

Lastly, there is the tendency to go further into detail. The day of big things has gone—there are but little things left to be done in the way of sanitary legislation. One may almost say that it is becoming microscopic, especially when one thinks of the Cleansing of Persons Act. Who knows? We may have a Washing of Dogs Act next!

I hardly like to close with a reference to small details. Can I sum up the effect and tendency of all our sanitary legislation in one sentence, in spite of its mistakes, its clumsiness, and complication? Yes, I think I can. We have been the pioneers in sanitary legislation, and have had it in its most important features long enough to look back on it and to recognize one broad result, and to look forward with the confidence that this result will be aimed at in the future—long enough, I think, to say that the effect of all our sanitary laws has been to make us, and that their tendency is to keep us, the healthiest, the cleanest, the freshest, the soundest, and the jolliest race on this round world.

PAPER VII.

THE BACTERIAL PURIFICATION OF WATER.

By Percy Frankland, Ph.D., B.Sc., F.R.S., Professor of Chemistry in Mason University College, Birmingham.

Just about 13 years ago the chemical examination of water, which had reached its present state of development already more than a decade previously, was supplemented by the introduction of new methods, the virtue of which consisted in their power to reveal the invisible living particles present in all ordinary waters, and to actually estimate the number and ascertain the nature of such living particles, micro-organisms, or bacteria as we commonly call them.

Like most other reforms, this new or bacteriological examination of water was, especially in this conservative country of ours, at first viewed with much suspicion and disfavour; indeed, it has required many years of hard fighting on the part of its first champions to secure for it that position and respect which it now enjoys as one of the most valuable weapons of precision at our disposal for combating the subtle dangers of water-borne disease.

But so great has been the progress in every department of bacteriology during the past 12 years that those who would at the outset have gladly crushed this new science have been obliged to lay aside their attitude of scornful derision, whilst not a few have actually been drawn as zealous converts into its irresistible vortex.

The form and appearance of these minute living particles, which it is the province of bacteriology to study and explore, can only be ascertained by means of the most powerful microscopes, for we are here concerned with objects which are frequently not more than $\frac{1}{20000}$ of an inch in diameter, and of which no less than *300 millions* could be spread in a single layer upon a postage-stamp.

Of the great diversity in the appearance of these minute living forms you will be able to obtain an idea from the slide which I will now have thrown upon the screen.

As viewed on such a diagram in their isolated condition these bacteria look harmless and insignificant enough, but they present a far more menacing appearance when we look upon the next picture, in which they are seen engaged in their nefarious work, attacking in their millions the vital tissues of their victims in which they are elaborating those poisons which cause disease and death.

A glance at the following table will convey some idea of the fabulous powers of reproduction and rapid multiplication with which some bacteria are endowed :—

Theoretical Multiplication of Bacteria.

Hours.	Number of Bacteria.
0	1
1	2
2	4
3	8
4	16
5	32
6	64
12	4,000
24	16,000,000
48	280,000,000,000,000

Of the many bacteria associated with disease we are to-day only concerned with two, viz., the spirillum of Asiatic cholera and the bacillus of typhoid fever, for these are the diseases which have been conclusively proved to be capable of being distributed by drinking-water. With typhoid we are all more or less familiar, for, like the poor, it is ever with us, whilst cholera is now, thanks to the greater sanitary enlightenment of recent years, almost as great a stranger in these islands as leprosy or the bubonic plague. It will, however, doubtless be the destiny of many of you in the natural course of the career which you have chosen for yourselves to face cholera also, which has, indeed, its home in certain parts of our Indian Empire, and where by a single engineering work sometimes more lives may be saved from this malady than by all the doctors of medicine.

It is the presence of the bacteria of these two diseases—cholera and typhoid fever—that we have to fear in drinking-water, and it is their exclusion or removal from drinking-water that is the first care in the hygiene of water-supply.

How the specific bacteria of these two diseases gain access to water is sufficiently obvious when we bear in mind that the drainage from human habitations in which these diseases happen to be prevalent may contain them, and that, therefore, all waters exposed to sewage contamination must *prima facie* be regarded as suspicious.

Practically all surface waters, excepting such as are collected above the reach of human habitations, or of cultivated land, are exposed to such contamination to a greater or less extent, and we have now to consider how the various processes of water-purification affect the possibility of danger which lurks in all water that has been so contaminated.

We may conveniently divide these purification processes into two great classes—

I. Natural processes.
II. Artificial processes.

One of the most striking and remarkable examples of water undergoing natural purification is to be found in the visible improvement which takes place in a river during its flow. Nothing is more common than to see a stream polluted at a given point by some local cause, and to find this pollution gradually disappearing as we follow the stream down its course, until the water acquires the same limpid appearance as that which it presented above the point at which the pollution occurred.

Now that we recognise in the presence of certain bacteria the great danger connected with water pollution, it is obviously of the greatest importance to ascertain how bacterial life is affected by this self-purification of river-water.

Some years ago I had an opportunity of studying this question on one of the most beautiful streams in the United Kingdom—the River Dee—with which you are all familiar as the Scottish home of British Royalty, and as the veritable paradise of the angler and the sportsman. I also visited Deeside as an angler, but the bacterial fish I was in quest of were not to be caught by fly or worm, but by means of the culture-tube and the microscope.

	Micro-organisms in 1 c.c. of water.
River Dee above Braemar	88
" below Old Mar Castle and after receiving sewage of Braemar	2,829
" above the Bridge of Ballater	1,139
" 100 yards below Ballater sewage-pond ...	3,780
" above junction with Neil Burn	938
" below entrance of Neil Burn	1,860
" at Invercannie	950

This investigation, which I conducted on the River Dee, is particularly interesting, as the amount of polluting material gaining access at these several points is so small in comparison with the great volume of the stream itself, that it was found impossible by chemical analysis to detect any material alteration in the composition of the water of the river, even immediately below each of these sources of contamination. By means of the bacteriological examination, however, each source of pollution was found to have produced an unmistakable, although transitory, effect on the water of the stream.

If we enquire into the mechanism by which this most remarkable disappearance of bacteria in running water is effected, we find that a number of factors must be taken into consideration, and that whilst these factors do not necessarily all come into play at one and the same time, or in every water-course, yet, according to our present knowledge, they must be held responsible for the bacterial improvement which such running waters undergo during their natural flow.

Insolation.—One of the factors to which, perhaps on account of its novelty, great prominence has recently been given in this connection is the remarkable destructive effect which the sun's rays have been found to exert on bacterial life.

Just about twenty years ago two English investigators, Downes and Blunt, made the striking discovery that if certain liquids, which, like meat infusion, are capable of undergoing putrefaction, be exposed to the direct rays of the sun they remain perfectly sweet, whilst exactly similar liquids preserved in darkness entered into pronounced putrefaction and exhibited innumerable bacteria under the microscope. In this way was demonstrated for the first time a perfectly novel and most important property of the sun's rays, viz., the power of destroying that bacterial life which plays such a leading part, both for good and evil, in the economy of nature.

These observations have been extended within the last few years in a variety of ways, more particularly in ascertaining the precise effect of the sun's rays on different kinds of bacteria, especially those which are capable of producing disease.

Thus it has been shown by a French investigator, Momont, that—

Anthrax bacilli exposed to sunshine in the presence of air were killed in 2—2½ hours.

Anthrax bacilli exposed to sunshine in the absence of air were killed in 50 hours.

Experiments, therefore, which clearly show that the destructive effect of the sun's rays on bacteria is greatly intensified in the presence of oxygen.

Cholera Bacilli and Sunshine (Dr. Palermo).

Exposure.	Effect on Guinea-Pigs.
0	*18 hours.
10 minutes—2 hours ...	*18 hours.
3 hours	*18 hours, another *5 days.
3½—4½ hours	†Lived.

* Indicates death of the animal.

† These guinea-pigs on being inoculated eight days later with virulent cholera bacilli were quite unaffected, showing that the exposed cultures had *acquired the character of a vaccine*, and had protected the guinea-pigs.

As you are all aware, the white light of the sun is composite, and can be resolved into its constituent coloured rays by being passed through a prism.

It becomes naturally of interest to enquire whether all of these different rays are equally potent in their destructive action on bacterial life.

This problem has been most successfully attacked by Dr. Geisler, of St. Petersburg, who exposed typhoid bacilli in the different parts of the solar spectrum.

Geisler found that the rays at the red end of the spectrum had little or no effect at all on the growth of the bacilli, whilst the most powerfully deleterious action was obtained in the ultra-violet, the effect becoming less and less marked in passing from this to the red. Those of you who are photographers know that these ultra-violet rays are also the ones which most powerfully affect the sensitive film.

Geisler has also compared the bactericidal effect of the solar rays with those obtainable from the electric light. Thus, whilst two to three hours' sunshine was sufficient to produce a most markedly deleterious effect on the typhoid bacillus, it required an exposure of no less than six hours to the beams of an electric arc lamp of 1,000 candle power at a distance of one mètre to produce a similar effect.

A particularly elegant method of experimenting on bacteria with light has been devised by Professor Buchner, of Munich. The particular bacteria to be subjected to the action of light are evenly distributed in melted jelly, which is then poured into a small circular dish, the glass cover of which is immediately replaced, and allowed to congeal. After the contents have become solidified, letters or figures of any kind are cut out of black paper, and are attached to the under surface of the dish, which is then placed in the sunshine, bottom upwards, for the desired time. After the period of exposure has elapsed, the dish is placed in a dark cupboard and kept at a temperature suitable for the growth of the bacteria present. By this means it is obvious that those parts of the dish which are covered by the bits of black paper are protected from the sunshine, and that the latter can only produce its effect on those portions of the surface which are freely exposed, or without this protection. We should expect, therefore, in due course, supposing the exposure to have been sufficient, to find no growths making their appearance in the jelly except in those parts shielded from sunshine by the strips of black paper. Now this is actually the case, and Buchner, by cutting out black letters spelling the name of the particular micro-organism with which the jelly was originally inoculated, has in this manner succeeded in enabling the bacteria to write, so to speak, their own names on the surface of the jelly, a process which perhaps may not inaptly be described as photo-bacteriography.

We are, of course, primarily concerned with the removal of bacteria from water, and the question naturally arises whether this bactericidal action of the solar rays takes place when bacteria are immersed in water exposed to sunshine. In this connection I may refer to some experiments which I made several years ago on the behaviour of anthrax spores under these conditions.

Experiments of this kind with anthrax are of particular interest, since, in this case, owing to the susceptibility of the lower animals to this malady, it is possible to ascertain not only how long this organism can maintain its vitality in water, but also whether and how long it preserves its virulence in this medium under different conditions. Thus I would call your attention to the following experiments which I made some years ago for the Royal Society Water Research Committee (*Proceedings Royal Society*, p. 53, 1893).

Vitality of Anthrax and its Spores in Thames Water.

	Natural State.	Sterilized by Steam.	Sterilized by Filtration through Porous Porcelain.	
1st day...		35	65	Number of anthrax colonies obtained from 1 cubic centimètre of water.
5th day...		81	112	
47th day			135	
68th day		28	55	
91st day		41		
104th day	Anthrax just discoverable by cultivation.		44	
7 months	—	+	+	Action on Mice.

– Signifies that the water did not kill mice by inoculation. That the anthrax was not extinct in this was proved by adding broth to the water, and then inoculating mice, which died.
+ Signifies that the water killed mice by inoculation.

The same waters, but exposed to sunshine (151 *hours*).

7 months	—	—	—	Action on Mice.

The anthrax was extinct in all these three waters which had been exposed to sunshine, for on adding broth to the waters, so as to give an opportunity for the revival and multiplication of the organism, and subsequently inoculating mice, the latter did not die.

From the above table it will be seen how the anthrax spores remained alive in practically undiminished numbers in the sterilized

Thames water, whilst in the same water unsterilized anthrax was barely discoverable by cultivation after 104 days. Again, as regards virulence, the sterilized water proved fatal to mice even after seven months, whilst the unsterilized on inoculation into mice failed to kill; on the other hand, it was found possible to revive the virulence of the anthrax by adding nutritive broth to the unsterilized water, for after doing so the water became again fatal to mice on inoculation.

Similar waters containing anthrax, which, however, had been exposed to 151 hours' sunshine during these seven months, were found not only to have lost their virulence, but the virulence could not be restored by the addition of broth. These experiments furnish a good example of the bactericidal action of sunshine on micro-organisms suspended in water.

Experiments have also been made to ascertain the precise depth in water at which any bactericidal effect is still exerted by the solar rays. Thus, whilst a photographic plate was still found to be affected by the sun at a depth of 553 feet beneath the surface of the Lake of Geneva, all bactericidal effect was found to disappear at a depth of even 10 feet below the surface of clear lake water, and with turbid water the range of the solar rays is much more limited. This fact has been brought out very clearly by an Italian investigator, Procaccini, some of whose results are contained in the following table. In these experiments glass cylinders 24 inches in height were filled with water, and the sun's rays were made to pass vertically downwards, all light being excluded from the sides of the vessels. Before and after exposure to light the number of bacteria was determined at the surface, in the middle, and at the bottom of the cylinder:—

	Number of Bacteria in 1 c.c. of Water.		
June 28th, 1893, 11 noon to 3 p.m.	Before Exposure.	After 3 hours Exposure.	Kept in the dark for 3 hours.
Surface	2,100	9	3,103
Centre	2,103	10	3,021
Bottom	2,140	2,115	3,463

These experiments sufficiently indicate what may be expected of sunshine in the destruction of noxious organisms in water, and whilst due credit must be given to insolation for what it can actually accomplish, it is obvious that its powers are restricted within comparatively narrow limits, especially in a climate like that of England, in which it frequently happens that for days and even weeks at a time no sunshine is recorded at all.

Sedimentation.—One of the most important natural processes of water-purification comes into play when water is allowed to remain at comparative rest in the large basins of lakes or in the still and deep reaches of rivers. Not only do waters under these circumstances become comparatively clear and bright by the subsidence of mechanically suspended particles, but if the storage be sufficiently prolonged a very considerable reduction in the amount of dissolved organic matter may also take place. This purification of water by sedimentation is largely taken advantage of in the practice of water-engineering; for not only are a number of large communities, like those of Glasgow, Manchester, and Liverpool, supplied with water from lakes, natural or artificial, of great size, but smaller reservoirs are frequently constructed in which more or less turbid waters are permitted to deposit the greater part of their suspended particles before being supplied to the consumer. The question naturally arises as to whether the subsidence of suspended matters is confined to those grosser particles visible to the eye, and giving rise to the appearance of turbidity, or whether the minutest living particles or bacteria share in this gravitation process also. The answer to this question is furnished by the results of some experiments which I made at the London Waterworks a number of years ago, a few of which are recorded in the following table.

Samples of water were collected of the Thames water coming directly from Hampton; secondly, of the water after having passed through one storage reservoir only; and thirdly, of the water after having passed through two storage reservoirs.

	Number of Bacteria obtained from 1 c.c. of Water.
(1). Thames water from Hampton ...	1,437
(2). Ditto after passing through one storage reservoir	318
(3). Ditto after passing through two storage reservoirs...	177

Another series of experiments on the effect of storage was carried out at the Stoke Newington works of the New River Company. At these works the water of the river Lea, mixed with a certain proportion of rock-water, is brought along an artificial cutting, and is made to pass through two large reservoirs before going on to the filter beds. Samples were taken at the cutting just above the reservoirs, at the outlet of the first reservoir, and at the outlet of the second reservoir, with the following results :—

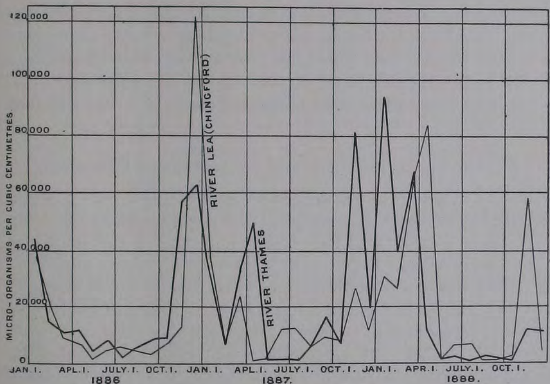
	Number of Bacteria obtained from 1 c.c. of Water.
(1). Cutting above reservoir	677
(2). Outlet of first reservoir	560
(3). Outlet of second reservoir	183

I have obtained similar results in studying the process of sedimentation in natural lakes, as is seen in the case of the Loch of Lintrathen, at the foot of the Grampians, from which the city of Dundee is supplied with water :—

	Number of Bacteria obtained from 1 c.c. of Water.
Inzion Burn, just above where it enters Lintrathen, June 10th, 1893 ...	1,700
Melgam Burn, just above where it enters Lintrathen, June 10th, 1893 ...	780
Water issuing from Lintrathen	30

The value of this purification by subsidence is being daily more appreciated, and it should, if possible, be almost invariably resorted to as a preliminary to other methods of purification. An interesting example of preliminary purification by subsidence is furnished by the city of Rotterdam, which is supplied from the extremely impure water of the River Maas, the intake being actually situated within the tidal area of the river. The plan, however, is adopted of only abstracting the water two hours after high water has been reached. During this period the river has been at comparative rest, and even in this short time becomes visibly relieved of much of its suspended impurities, this sedimentation of the coarser particles being accompanied by an important removal of bacteria, amounting to about 50 per cent. of those present. In this manner the subsequent further purification of the water by sand-filtration is greatly facilitated.

Temperature.—The season of the year is also of great moment in determining the bacterial condition of the stream. Laboratory experiments have abundantly proved that the multiplication of most micro-organisms commonly found in water is greatly stimulated by raising the temperature of the water, and it might, therefore, be expected that streams would contain considerably more bacteria in summer than in winter. But that the reverse is generally the case I showed a number of years ago in the course of regular monthly bacteriological examinations which I made of the waters of the rivers Thames and Lea, the results of which are summarized in the following diagram :—



Monthly Bacteriological Determinations of Unfiltered Water from the Rivers Thames (Hampton) and Lea (Chingford).

These relations are doubtless principally dependent on the fact that during the summer these and most other rivers are largely fed with pure spring water almost wholly destitute of bacterial life, whilst during the winter they are largely composed of water which has washed the surface of cultivated land, and which is teeming with micro-organisms. Similar results in the case of a number of other streams have more recently been obtained by various observers.

Filtration through Porous Strata.—By far the most perfect, and on the whole the most important, of the natural processes concerned in the bacterial purification of water is filtration through porous strata.

The great efficiency of this process is perhaps best illustrated by a bacteriological examination of the water obtained by pumping from deep wells sunk into porous strata like the chalk and new red sandstone formations. Such an examination generally reveals the fact that in these waters bacterial life is almost wholly absent. Thus in the chalk wells of the Kent Water Company I have on many occasions found *less than 10 microbes in 1 cubic centimètre.* To appreciate the relative scarcity of bacterial life implied by this number it is only necessary to bear in mind that in such surface waters as the Thames at Hampton and the river Lea at Chingford I have found from *1,000 to 120,000 micro-organisms* in the same volume.

Thus, great as may be the purification of surface waters effected by the united action of subsidence and insolation, their joint effect in removing bacteria does not compare with that which results from the filtration of water through great depths of porous strata, and which is attested by the general bacterial purity of spring and deep well waters.

II.—Bacterial Purification by Artificial Processes.

We will now turn to the second part of our subject, which is concerned with the bacterial purification of water by artificial processes.

We have already seen how highly important is the storage of water in reservoirs, whether natural or artificial, before submitting it to further processes of purification, so that it will not be necessary to enter into further details on this head. It may be interesting, however, to enquire as to how the bacteria may vary at different depths of one and the same water-basin, as this is of no little importance in connection with the abstraction of water for purposes of supply.

Perhaps the most instructive experiments in this direction are those of Karlinski, who examined the water of a lake in Herzegovina with the following results :—

	No. of Bacteria in 1 c.c.
Surface water of lake	4,000
Water at depth of 5 mètres...	1,000
,, ,, ,, ,, 10 ,, ...	600
,, ,, ,, ,, 12–16 mètres	200–300
Bottom on stirring up mud	6,000

These results are highly instructive, showing as they do that the water most free from bacteria must be drawn from beneath the surface on the one hand, whilst, on the other hand, any disturbance of the sediment at the bottom must be carefully avoided.

Sand-Filtration.—Whilst the subsidence of water in lakes and storage reservoirs constitutes, as we have seen, the most important preliminary process of purification, so the process of filtration through sand is the most important supplementary purification to which water can be subjected on a large scale.

This process of sand-filtration, first introduced by Simpson in 1839 at the Chelsea Waterworks in London, with a view to removing the coarse and visible suspended particles in surface water, was greatly undervalued until the introduction of the bacteriological method of water examination. Indeed, it could have hardly been anticipated that the passage of water through two or three feet of sand should be capable of removing nearly all the bacteria present, since the interstices between the particles of sand are so large, in comparison with the bacteria themselves, that it was naturally supposed that these bacteria would be able to pass between the particles of sand in much the same fashion as vehicles can thread their way through a crowded thoroughfare.

The moment, however, it was possible to make a bacteriological examination of water before and after sand-filtration it was found that this low estimate of the value of sand filters was utterly erroneous, and that the passage through such a stratum of sand was capable of working a most profound change in the bacterial quality of the water.

The following table, which I have put together from the results of my reports to the Local Government Board, will show the extraordinary efficiency of well-constructed sand-filters in removing bacteria from water :—

Average Number of Bacteria found in 1 c.c. of Thames Water supplied to London before and after Filtration.

Month.	River Thames.	Filtered.	Reduction per cent.
January	92,000	129	99·9
February	40,000	447	98·9
March	66,000	428	99·4
April	13,000	91	99·3
May	1,900	60	96·8
June	3,500	65	98·1
July	1,070	34	96·8
August	3,000	21	99·3
September	1,740	56	96·8
October	1,130	25	97·8
November	11,700	86	99·3
December	10,600	116	98·9

Suitably contrived experiments, moreover, were soon able to demonstrate the factors on which the efficiency of this sand-filtration depends.

Thus it was very soon found that a freshly-constructed sand-filter has little or no power to remove bacteria from the water passing through it, and that it is only after it has been in action for some days or even weeks that it becomes endowed with this capacity.

The acquisition of this power of retaining bacteria was found to depend upon the gradual formation of a slimy deposit on the surface of the sand, and it is this layer of slime which acts as the bacterial trap or strainer, for on injuring this film in any way it is found that the efficiency of the filter is at once most seriously impaired.

The following figures show the gradual manner in which the efficiency of a filter is developed :—

	Percentage Removal of Bacteria.
First 3 days	25
Second 3 days	70
Second week	96
Third "	98

(Lawrence Filter, Massachusetts).

Rate of Filtration.—The layer of slimy deposit being once established on the surface of the filter, its efficiency is then largely dependent on the rate at which the filtration is conducted. As might be anticipated, the greater the rate of filtration the less perfectly does it act, and the slower the rate the more complete is the removal of bacteria which takes place, or, in other words, *the efficiency of filtration is inversely as the rate.* This relationship is well brought out in the following series of experiments (Massachusetts) :—

0·5 million gallons per acre per 24 hours	·010 per cent. bacteria remain.
1·0 million gallons per acre per 24 hours	·048 " " "
1·5 million gallons per acre per 24 hours	·067 " " "
2·0 million gallons per acre per 24 hours	·088 " " "
3·0 million gallons per acre per 24 hours	·356 " " "

Whilst the following figures show the average rates of filtration employed at various waterworks:—

	Millions of Gallons (U.S.) per acre per 24 hours.	Vertical inches of Water per hour.
Berlin (Tegel.) ...	3·2	5·0
Zurich	7·5—10·7	11·5—16·4
Altona	2·6	4·0
Liverpool	2·6	4·0
London—		
Chelsea Co. ...	2·2	3·3
East London Co. ...	1·6	2·5
Grand Junction Co.	2·6	4·0
Lambeth Co. ...	2·7	4·1
New River Co. ...	2·6	4·0
Southwark Co. ...	1·9	2·7
West Middlesex Co.	1·6	2·5

In Germany, where so much of what concerns the daily life of the population is regulated by the paternal government, and almost by his Imperial Majesty the Kaiser himself, the maximum rate at which filtration may be carried out is fixed by the Imperial Board of Health at 4 inches per hour.

Depth of Fine Sand.—When it was discovered that the removal of bacteria in sand-filtration is so intimately connected with the formation of a deposit of slime on the surface, it was somewhat hastily assumed by many that the sand itself was of comparatively little moment, and that it would matter but little what depth of sand the water had to traverse, inasmuch as the real removal of bacteria was accomplished in the first two or three inches of the stratum.

I have, however, from the very first myself held the opinion, and pointed out that the results obtained in filtration are the more satisfactory the greater the depth of the sand employed, and this view is now generally accepted as correct.

Some recent experiments made at the Altona Waterworks for the express purpose of elucidating this point are very instructive in this connection.

Filtrates from Different Depths at Altona.

Number of Micro-Organisms found in 1 c.c. of Water.

Date.	Raw Water.	No. 1 Pipe 30 Millimètres below Layer of Slime.	No. 2 Pipe 60 Millimètres below Layer of Slime.	No. 3 Pipe 160 Millimètres below Layer of Slime.	No. 4 Pipe 430 Millimètres below Layer of Slime.	No. 5 Pipe 600 Millimètres below Layer of Slime.	No. 6 Pipe 790 Millimètres below Layer of Slime.	No. 7 Pipe* 920 Millimètres below Layer of Slime.	No. 8 Pipe† 1.050 Millimètres below Layer of Slime.	The water drawn from the Delivery Pipe of the whole filter.
June 16	28,881	3,596	2,976	824	446	314	306	304	1,280	2,212
,, 21	52,328	1,860	752	321	244	152	140	160	592	624
,, 25	60,310	1,994	216	163	40	48	48	62	143	164
July 2	36,320	1,876	446	176	44	46	48	44	86	98
,, 5	36,810	Liquified.	1,148	281	56	34	28	28	80	96
,, 17‡	13,824		2,946	386	102	122	108	116	208	236
,, 20	34,224		4,960	242	124	24	22	...	60	58
,, 24	11,840		3,472	102	7	11	10	13	11	12

* This pipe was placed at the boundary between the sand and gravel layers.
† This pipe was placed in the layer of stones of about the size of a walnut.
‡ The filter was cleaned on the 12th July, in which operation 30 millimètres of sand were removed from the surface, so that no further samples were obtainable from No. 1 pipe, whilst No. 2 pipe, instead of being 60 millimètres beneath the surface-slime, was now only 30 millimètres below. Even when samples were taken 5 days later (on the 17th July), although the number of micro-organisms in the raw water was considerably smaller than on the previous occasion, the disturbance is reflected in all the samples collected on that day by an increase in the number of bacteria present.

These results clearly show that it is not merely the superficial slime-layer of the filter that determines the bacterial purity of the filtrate, but that the subjacent stratum of sand is also of great importance in securing the maximum efficiency.

Influence of the Size of Sand-Grains on the Efficiency of Filtration.—Since, then, the depths of sand is of material influence in determining the efficiency of the bacterial purification, it is not surprising to find that the grain of the sand is of great importance in this respect also. Indeed, it has been shown that with very fine sands it is almost impossible to force more than a very small portion of the bacteria present in the unfiltered water through, even when there is no slime-layer on the surface of the filter at all. This will be seen from the following table, in which the size of the sand-grain employed is given, together with the volume of water passed through the filter between successive scrapings or removal of the upper layers of the sand, and the percentage of bacteria left over in the filtrate :—

Effective size of Sand-Grains.	Millions of Gallons per acre, filtered between successive Scrapings.	Percentage of Bacteria in Filtrate.
0·38	66	0·16
0·29	58	0·16
0·26	47	0·10
0·20	—	0·01
0·14	41	0·03
0·09	12	0·02

These figures clearly show that it is possible to secure greater efficiency of filtration by the use of finer sand. Like nearly all other improvements, however, this involves additional expense, entailing as it does more frequent scraping and a diminution in the yield of the filters.

The selection of the finest sand, consistent with obtaining the necessary daily volume of water by means of the available filtering area, is, however, a matter which deserves the more careful attention of waterworks engineers.

Influence of Frost on the Bacterial Efficiency of Sand-Filtration.—In concluding the subject of sand-filtration, there is a point on which I would dwell for a minute or two.

It has been repeatedly found at water works, where sand-filtration is carried on with great care and with excellent bacterial results, that during frost a very marked increase in the number of bacteria present in the filtered water occurs. Thus in the first regular monthly examinations of the London waters which I made during the years 1886, 1887, and 1888, there were two conspicuous occasions on which exceptionally large numbers of bacteria were found in some of the filtered waters, and on both occasions this disturbance coincided with a very low temperature of the river water. This will be seen by following the dotted and continuous curves respectively, the former representing the number of bacteria in filtered Thames water, whilst the latter shows the variation in the temperature of the water during the same period of time.

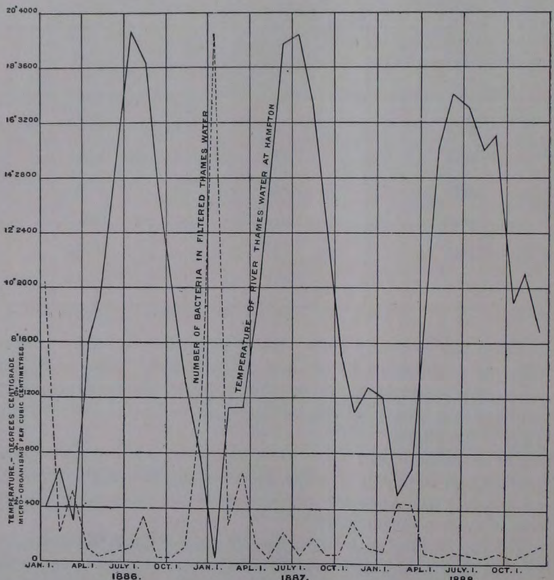


Diagram showing the Relation between Temperature and Bacterial Contents of Filtered Thames Water.

With so low a temperature of the water in the river it is highly probable that the water on individual filters was actually frozen. Now the presence of ice on the filters is well known to be one of the most serious troubles incidental to sand-filtration, the removal of the ice involving sometimes the employment of large numbers of men, and if the frost actually gains access to the sand layer it is only too obvious how its efficiency will become destroyed. In countries with very low winter temperatures open sand-filters are altogether impossible, and the expedient is resorted to of covering them in with masonry.

Now, although the usually mild winters in England would not appear to warrant such an expensive proceeding, it is imperative that this danger to the process should be reckoned with and guarded against, for it is precisely at this season of the year, as we have seen, that surface-waters are usually in their worst condition, and that the most efficient filtration is necessary.

Clark's Process of Softening.—There is yet another artificial process which is sometimes employed for the purification of water, and which consists in treating hard water with lime, thus leading to a precipitation of the carbonate of lime in solution. This, well known as Clark's process for the softening of water, is sometimes employed on a large scale for the treatment of the water supplied to a whole town, the object being to render the water more suitable for washing, boiler, and manufacturing purposes. We have, however, already seen that when solid particles are allowed to subside in water they carry with them to the bottom a large number of the bacteria in the water. It would naturally be anticipated, therefore, that a precipitate actually generated throughout the entire mass of a given volume of water would be still more efficient in entangling the bacteria and carrying them to the bottom. That in Clark's softening process a very great bacterial purification does actually take place I showed a number of years ago by means of the experiments recorded in the following table:—

Colne Valley Waterworks.

	Bacteria in 1 c.c.
Unsoftened water from well in chalk	322
Water after softening by Clark's process	4

Reduction in the number of bacteria = 99 per cent.

Artesian Well at Clyde Wharf, London.

	Bacteria in 1 c.c.
Unsoftened water	182
Water after softening by Gaillet & Huet's* process ...	4

Reduction in the number of bacteria = 98 per cent.

* A modification of Clark's Process.

It is obvious, therefore, that we have in this simple and inexpensive Clark's process not merely a method of softening hard water, but also a most efficient means of bacterial purification, which in certain cases may be of the greatest utility.

Pathogenic and Non-Pathogenic Bacteria in Water.—The account which I have given you of the bacterial purification of water would be incomplete were I not to refer to another point which must be carefully borne in mind in connection with the bacteriological aspects of water-supply.

It must always be remembered that the importance attributed to the bacterial purification of water is based on the suspicion that most natural waters *may at any time* contain bacteria capable of producing disease, and although the great majority of the bacteria which we meet with in water are doubtless perfectly harmless, we require a guarantee that any harmful forms which may be present should be prevented from reaching the consumer. This, in the present state of our knowledge, can only be secured by submitting the water to processes which effect the removal of *all* bacteria, irrespectively of their harmful or harmless nature. Hence we estimate the value of a purification process according to the efficiency which it displays in banishing all bacteria from the water submitted to it.

We have, however, some knowledge of the manner in which certain disease-producing micro-organisms behave in waters of different kinds, and this knowledge has a very important bearing on the hygiene of water supply.

Thus it has been found that the bacteria of typhoid and cholera remain alive for a much longer period of time in sterilized water, *i.e.*, water from which all bacteria have been removed, than in natural waters. It obviously becomes of great importance, therefore, to ascertain whether some natural waters are more favourable than others for maintaining the vitality of such disease-producing bacteria. It was with the object of investigating this point that I recently carried out a number of experiments in which typhoid bacilli were placed in different types of natural water, and the length of time which they survived in each was determined.

These experiments are summarized in the two following tables.

The principal points which I would emphasize in connection with these results are—

1. That in none of these three types of potable water did the typhoid bacillus exhibit multiplication, but, on the contrary, in each case there was more or less rapid numerical decline of the bacilli.

2. That in the case of the surface waters (Thames and Loch Katrine) the longevity of the typhoid bacilli was much greater in the sterilized than in the natural samples. In the case of the subterranean water (deep well), on the other hand, the duration of life was practically the same in the sterilized as in the unsterilized samples.

3. In the sterilized waters the longevity of the typhoid bacillus was greatest in the Loch Katrine, and least in the case of the deep-well water. On the other hand, in the unsterilized waters the duration of life was most protracted in the case of the deep-well water, and most curtailed in that of the Thames water.

Comparative Vitality of Typhoid Bacillus in Thames, Loch Katrine, and Deep-Well Water.

(*a*). *Waters Sterilized by Steam before Infection.*

Water.	Numerical Behaviour of Typhoid Bacillus.	Number of days after Infection on which Typhoid Bacillus was last discovered in Water.
Thames	No multiplication, but steady dimunition.	32 days.
Loch Katrine ...	Ditto.	51 days.
Deep Well ...	Ditto.	20 days ; still present. 32 days ; absent.

(*b*). *Waters in Natural Unsterilized Condition.*

Thames	—	9 days ; still present. 13 days ; absent.
Loch Katrine ...	—	19 days ; still present. 33 days ; absent.
Deep Well ...	—	33 days ; present. 39 days ; absent.

These results clearly show that typhoid bacilli gaining access to naturally pure water, especially subterranean water, will be far more likely to do mischief than if they find their way into naturally impure water exposed to surface influences. It is, moreover, a matter of experience that nearly all the well-defined outbreaks of typhoid have arisen through the contamination of well and spring waters, whilst it has more rarely been found possible to attach the blame of a widely-spread epidemic of typhoid to a contaminated river water.

Hamburg Epidemic of Cholera.—In order to show you what may be the penalty of possessing a contaminated water-supply, as well as to illustrate the practical value of attending to the bacterial purification of water, I would, in conclusion, draw your attention to the great object lesson, one of the most striking in the annals of sanitary science, which was given at Hamburg in the case of the great cholera epidemic of some seven years ago.

The water which was supplied to Hamburg in 1892 was taken from the Elbe in its tidal portion, and was thus fouled with the sewage of Hamburg itself, and this water was distributed to the city without previous filtration. In the autumn of the year in which the epidemic occurred I had occasion to analyse a sample of this water supplied to Hamburg, and I will endeavour, by means of the following diagram, to give you some idea of its excessively polluted nature.

Organic Matter (Carbon and Nitrogen) in Elbe, Thames, and Lea Water.

Elbe water supplied to Hamburg, October 2nd, 1892.
1·014 part per 100,000.

Thames water supplied to London, 1891.	Lea water supplied to London, 1891.
·242 part per 100,000.	·165 part per 100,000.

There is, as you know, the strongest evidence that this unfiltered Elbe water was highly instrumental in distributing the fatal malady amongst the inhabitants, and of the greatest interest, in connection with our inquiry, is the circumstance that the town of Altona, which is absolutely contiguous to Hamburg, also drew its water supply from the Elbe, somewhat lower down, and where the river is, therefore, even still more contaminated, but in this case the water was submitted to sand-filtration before delivery to the consumer. The following are the statistics, for which I am indebted to Dr. Fraenkel, of Hamburg, concerning the epidemic in these two places :—

Statistics of Cholera Epidemics in Hamburg and Altona (1892).

Population.	Cholera. Deaths.	Cases.
Hamburg—		
640,000	8,000	18,000
per 100,000	1,250	2,812
Altona—		
143,000	316	516
per 100,000	221	361

Average death-rate from all causes in 1891 :—

Hamburg	23·5 per 1,000.
Altona	25·3 ,, ,,

The number of cases per 100,000 inhabitants in Altona was thus about one-eighth of the number for the same population in Hamburg. Without by any means laying undue stress on these comparative figures, I think it must be admitted that they furnish most important evidence of the hygienic value of the process of sand-filtration.

This, like the recent epidemic of typhoid at Maidstone, is surely sufficient to convince even the most apathetic that the dangers attending the use of contaminated drinking water are not the mere creation of the overwrought imaginations of scientific men and hygienic enthusiasts, but that they are very real dangers indeed, of which everyone should be cognisant, and which it is criminal negligence for public authorities having the health of communities committed to their charge to overlook. No less convincingly do these bitter experiences demonstrate the practical benefits to be derived by the adoption of those methods of bacterial purification the value of which has been ascertained in the laboratory and by patient research.

PAPER VIII.

STEAM ENGINE.

By Capt. H. R. Sankey, late R.E.

The lecture I have to give you this evening is to be on a subject connected with the steam engine, and I have prepared some notes on the trials that have to be made to carry out tests for economy. The user of a steam plant pays for the coal burnt, and it would therefore suffice for his purpose if he obtained by comparatively simple measurements the weight of coal burnt in the boiler in relation to the power developed by the engine; but this information is obviously insufficient if it be desired to ascertain the economical value of each portion of the steam plant, and it is then necessary to test the boilers and engines separately, and even the steam pipes and the feed arrangements. I propose this evening to confine myself to a short description of the methods employed in carrying out the economical tests of the boiler.

Introduction.

A boiler is an arrangement by means of which the heat produced by the combustion of coal, wood, or oil, etc., can be converted into steam energy. The *losses* which in practice attend all *transformations* of energy are in this case considerable, amounting to from 50 to 20 per cent., or, in other words, boilers transmit to the steam they produce only 50 to 80 per cent. of the energy theoretically due to the heat of combustion of the coal. This figure may be called the "thermal efficiency" of a boiler, and one of the principal objects of a boiler trial is to determine it. The matter can also be exhibited by what is known as a "heat account," as follows, taking as an example the case of a boiler whose thermal efficiency is 72·5 :—

TABLE I.

Heat Evolved.	Per Cent. B.T.U.	Heat Absorbed.	Per Cent. B.T.U.
Heat from fuel	100	Heat transmitted to steam...	72·5
		Loss...	27·5
	100		100

In the above, the 100 B.T.U. (British Thermal Units) due to the combustion of the coal, and the 72·5 B.T.U. transmitted to the steam were obtained experimentally, but the losses are lumped together and set down as 27·5 B.T.U. to balance the account. These losses are due to heat carried away by the flue gases; to radiation; to leakage of steam or heated water; to incomplete combustion; to moisture in the fuel; and to several other minor causes of loss. The greater number of these losses can be measured independently, and if this is done, a more complete heat account can be drawn up as follows* :—

* This heat account is derived from a trial made by Professors Cawthorne Unwin, F.R.S., and Dr. A. B. W. Kennedy, F.R.S., in April, 1894, on a Niclausse water-tube boiler, at Messrs. Willans & Robinson's Ferry Works, Thames-Ditton. With one or two exceptions, the data for all the numerical examples in this paper have been obtained from the same trial, of which the following is a short summary :—

SUMMARY OF BOILER TRIAL.

Time—	
Duration of test	7·4 hours.
Steam—	
Average pressure above atmosphere	159·2 lbs. per square inch.
Corresponding temperature	370 degrees F.
Moisture in steam	1 per cent.
Coal—	
Total coal fired	1817 lbs.
Coal per hour	245·5 lbs.
Carbon value of coal	0·956.
Feed Water—	
Average temperature...	60 degrees F.
Total weight evaporated	15750 lbs.
,, ,, ,, per hour	2128 lbs.
Pounds of water evaporated per lb. of coal ...	8·67 lbs
Equivalent evaporation per lb. of coal from and at 212 degrees F....	10·47 lbs.
Equivalent evaporation per lb. of carbon value	10·95 lbs.

TABLE II.

Heat Evolved.	Per Cent. B.T.U.	Heat Absorbed.	Per Cent. B.T.U.
Heat from fuel	100	Heat transmitted to steam...	72·5
		,, carried away by flue gases	17·0
		,, lost by evaporating, etc., moisture in atmosphere	0·8
		,, lost by incomplete combustion ...	3·5
		,, lost by unburnt coal in ashes	2·9
		,, lost by evaporating, etc., moisture in fuel	0·1
		,, lost by radiation and leakage	1·6
		,, unaccounted for	1·6
	100		100

Such a heat account forms a valuable check on the accuracy of the measurements, inasmuch as only a small portion of the losses remain unaccounted for. The above also indicates the various measurements that have to be undertaken if it is desired to make a complete boiler trial.

It should be observed that the thermal efficiency of a boiler, and the apportionment of the losses, although depending mainly on the design of the boiler, also depends on the conditions under which the boiler has been tried, such, for instance, as the rate of evaporation, the weight of coal burnt per square foot of grate, the nature of the coal, the amount of draught, the temperature of the feed water, the pressure of the steam, the suitability or otherwise of the furnace and the grate in respect of the coal burnt at the trial, etc.

The next step is to describe the various measurements in detail.

Air and Flue Gases—

Pressure of atmosphere (30·14 inches) ... ... 14·8 lbs. per square inch.
Temperature of air ... ... 60 degrees F.
Temperature of flue gases... ... . 504 degrees F.

Ash—

Total weight of ashes, etc. ... ... 174 lbs.

Draught—

Ash-pit draught, inches of water ... ... 0·2 inch.

Measurements Required to Determine the Thermal Efficiency.

As mentioned above, we require to know, in order to obtain the thermal efficiency of a boiler, the number of B.T.U. produced by the furnace, and the number of B.T.U. transmitted to the steam per unit of time. There is, however, no instrument available by means of which these heat units can be directly measured. It is, therefore, necessary to measure other things to obtain the information required. Thus, if the rate of coal or fuel combustion in pounds is ascertained, as well as the "calorific value" per pound, that is, the number of B.T.U. produced by the combustion of one pound of the fuel, the rate at which heat is produced in the furnace can be obtained. Further, if a measurement of the rate at which steam is produced is made, say in pounds per hour, and also of the pressure at which it is produced, and the temperature at which the water is fed into the boiler, the number of heat units transmitted to the steam can be calculated by referring for certain data to tables giving the properties of steam. The actual boiler trial thus consists principally in weighing the coal burnt, and the corresponding water evaporated. The number of pounds of water evaporated per pound of coal burnt is thus obtained. Such a figure is sometimes stated as giving the thermal value of a boiler, but such a statement, without qualification, is very misleading, and causes misapprehension when comparing various boilers. In the first place, the number of heat units required to be transmitted per pound of steam increases with the pressure and varies with the temperature of the feed water. It is usual to take the B.T.U. required to evaporate one pound of water at a pressure corresponding to 212 degrees F., when the feed water is at a temperature of 212 degrees, as the basis, and hence the expression in common use "from and at 212 degrees F." By multiplying the observed evaporation by a factor* appropriate to the actual boiler pressure and feed temperature we can obtain the equivalent evaporation "from and at 212 degrees F." The number of heat units produced by the combustion of one pound of coal also varies considerably with the quality of the coal, owing principally to the proportion of hydrogen, hydro-carbons, incombustible matter, moisture, etc., it may contain. The heat of combustion of one

* A table giving these factors will be found in *The Mechanical Engineer's Pocket Book,* by D. K. Clark, M.Inst.C.E.

pound of pure carbon is often taken as the standard, and the statement is made that such and such coal has a carbon value of 0·95, for instance, meaning that one pound of this coal can produce as much heat as 0·95 lb. of pure carbon. The performance of a boiler can therefore be correctly described as :—X lbs. of water evaporated from and at 212 degrees F. per lb. of carbon value.

The physical quality of the coal also affects the result; that is to say, whether it is large or small, flaming or anthracite; the quality of the coal in this respect should therefore be noted, and also whether the firebars and arrangement of grate are adapted or otherwise to the kind of coal used in the trial.

The term "evaporated" used above implies that the steam produced and issuing from the boiler is perfectly dry steam, but not superheated. If water is present in the steam, each pound will obviously contain fewer heat units, and a correction is therefore required in the sense of reducing the statement of the number of pounds evaporated. But, apart from this, the production of wet steam is a serious practical defect in a boiler, as it materially reduces the economy of steam engines. The determination of the percentage of water in the steam as it leaves the boiler is therefore very important.

Measurement of Feed Temperature.

The temperature of the feed is measured by an ordinary mercurial thermometer, which should, however, be calibrated against a standard.

Measurement of Pressure.

The pressure in a boiler is measured by means of a "steam gauge," the readings being taken usually in pounds per square inch; but they are also taken in atmospheres, or in kilogrammes per square centimètre. The pressure thus read is, of course, the absolute pressure of the steam *less* the atmospheric (barometric) pressure: for instance, if the gauge pressure is 160 lbs. per square inch, and the barometric pressure 15 lbs. per square inch, the absolute pressure is 175 lbs. per square inch. A reading of the barometer should therefore be taken, and the gauge pressure added to the barometric pressure is the absolute pressure.

The above measurements, tabulated in the following examples, are all that are needed to obtain the thermal efficiency of a boiler, as will be seen by the following example :—

Example I.

Total coal burned during trial	... ...	1,817 lbs.
Calorific value of 1 lb. of the coal used	...	13,860 B.T.U.
Total feed evaporated during trial ...	...	15,750 lbs.
Percentage moisture in steam	... ...	1 per cent.
Temperature of feed (mean) ...	... ...	60 degs. F.
Gauge pressure of steam (mean)	.. ...	159·2 lbs. per sq. in.
Barometric pressure (30·14″) ...	... ...	14·8 ,, ,,

By referring to a table of the properties of steam it will be found that to evaporate 1 lb. of water from 60 degrees F. into dry saturated steam at $159 \cdot 2 + 14 \cdot 8$ lbs. absolute steam pressure requires 1,167 B.T.U., and to raise 1 lb. of water from 60 degrees F. to 370 degrees F. requires 310 B.T.U.

Therefore, since the moisture in the steam is 1 per cent., the heat required per pound of the steam produced by the boiler is

$$0 \cdot 99 \times 1167 + 0 \cdot 01 \times 310 = 1158 \text{ B.T.U.}$$

so that the heat transmitted to the steam during the trial is

$$1158 \times 15{,}750.$$

But the heat due to the combustion of the coal is

$$13{,}860 \times 1817.$$

Therefore, thermal efficiency is $\frac{1158 \times 15{,}750}{13{,}860 \times 1817}$, or 72·5 per cent.

Measurements Required to Determine Losses.

Heat carried away by Flue Gases.

The principal loss is the heat carried away by the flue gases, and to determine this loss it is necessary to know, first the rate at which the gases flow through the chimney, secondly, the specific heat of these gases, and lastly, the range of temperature through which they have been raised. The rate of flow is generally obtained by computation from a chemical analysis of the gases, for which purpose an arrangement for taking samples of the gases is required. From such an analysis the weight of the flue gases per pound of fuel burned can be calculated, and thus a very fair estimate of the weight of the flue gases per hour can be arrived at. The temperature through which the gases have been raised is the difference between the air temperature and the flue gas temperature; the former is readily obtained by an ordinary thermometer, the latter is more difficult to arrive at owing to the high temperature, so that an ordinary mercurial thermometer cannot be used. A "Nitrogen" thermometer or a platinum thermometer are suitable for this purpose; the latter arrangement has been lately introduced, and gives fairly satisfactory results. Various other instruments are used to measure the flue temperature and are known as pyrometers.

EXAMPLE II.

The following result was obtained from a chemical analysis of the flue gases :—

CO_2.	CO.	O.	N.
9·13 p.c.	0·55 p.c.	10·12 p.c.	80·2 p.c. by *volume.*

Temperature of flue gases ... = 504 degrees F.
" air ... ... = 60 "

To obviate the difficulty due to change of volumes of these gases with temperature, it is convenient to change into per cent. by *weight.* Moreover, the hydrogen in the coal* is present in the flue gases in the form of steam, and is not obtained in the samples for analysis, so that when this is allowed for the per cent. by weight of flue gases becomes†

CO_2.	CO.	O.	N.	H_2O.
13·21 p.c.	0·51 p.c.	10·66 p.c.	73·86 p.c.	1·76 p.c.

We can now find the percentage of the carbon in the flue gases thus :—

$$\text{Carbon in } CO_2 = \frac{13 \cdot 21 \times 12}{44} = 3 \cdot 6.$$

$$\text{,,} \quad CO = \frac{0 \cdot 51 \times 12}{28} = 0 \cdot 22.$$

* An analysis of the coal will be found on page 199.

† The calculations to convert from percentage by volume to percentage by weight, and to allow for the hydrogen, are not given because they are lengthy; they are based on the known weights per cubic foot of the gases and the atomic weights of the various chemical constituents.

Altogether, therefore, the weight of gases per lb. of carbon burnt is $\frac{100}{3 \cdot 82} = 26 \cdot 17$ lbs., which reduces to 22 lbs. per lb. of coal burnt, since the analysis of the coal gives 84·19 per cent. of carbon (see page 199).

The coal burnt per hour during the trial was 245·5 lbs. Hence the weight of flue gases per hour = 5400 lbs. (approx.).

The heat loss can, therefore, be calculated as follows :—

Loss by CO_2	=	$0 \cdot 1321 \times 5400 \times 444 \times 0 \cdot 2164 =$	68,500 B.T.U.
" CO	=	$0 \cdot 0051 \times 5400 \times 444 \times 0 \cdot 245 =$	3,000 "
" O	=	$0 \cdot 1066 \times 5400 \times 444 \times 0 \cdot 2175 =$	55,700 "
" N	=	$0 \cdot 7386 \times 5400 \times 444 \times 0 \cdot 2438 =$	432,000 "
" H_2O	=	$\cdot 0176 \times 5400 \times 444 \times 0 \cdot 48 =$	20,300 "
		*Loss per hour	579,500
		†Loss per cent. (see Table II.) ...	17·0

It should be noted that even in a perfect boiler a certain amount of heat must be carried away in the flue gas, because the temperature of these gases is necessarily higher than that of the steam. The major portion of the theoretically unnecessary loss is, however, due to the excess of air drawn through the furnace. That is to say, a definite quantity of air is required per pound of coal for complete combustion, and anything above this is to be looked upon as excess. It is, therefore, usual to calculate the quantity of air used and compare it with the theoretical quantity required. An excess of from 50—100 per cent. is usual in the best boilers and is looked upon as satisfactory. The calculations that have to be made to obtain both these quantities per pound of coal are as follows :—

To find the Weight of Air necessary for the Complete Combustion of One Pound of Coal.

Referring to the analysis of the coal, page 199, it will be seen that one pound of coal contains 0·842 lb. C and 0·0439 lb. H; therefore,

* The specific heats used in the calculations are those for gases at constant pressure. Thus calculated, the flue gas loss will include that due to the displacement of the atmosphere by the expanded volume of the heated gases.

† The percentage loss is calculated on the total heat developed per hour in the furnace, namely :—13,860 × 245·5 = 3,402,600 B.T.U.

This remark applies to the subsequent examples.

the weight of oxygen required to combine with the carbon to form CO_2 and with the H to form H_2O is :—

$$\text{To form } CO_2 - \frac{0{\cdot}842 \times 32}{12} = 2{\cdot}245 \text{ lbs.}$$

$$\text{To form } H_2O - \frac{0{\cdot}0439 \times 16}{2} = 0{\cdot}351 \text{ lbs.}$$

The oxygen required for the complete combustion of one pound of coal as used in the trial is, therefore, 2·596 lbs., and since the atmosphere contains by weight 76·8 per cent. N and 23·2 per cent. O, the weight of air will be $2{\cdot}596 + 2{\cdot}596 \times \frac{76{\cdot}8}{23{\cdot}2} = 11{\cdot}2$ lbs. per lb. of coal.

The pounds of air actually used may be estimated from the weight of oxygen present in the flue gases, as follows :—

From Example II. it is seen that in 100 lbs. of flue gas there are 13·21 lbs. CO_2, 0·51 lb. CO, 10·66 lbs. O and 1·76 lbs. H_2O ; hence

The weight of O in the CO_2 is	$\left(\frac{13{\cdot}21 \times 32}{44}\right)$	= 9·62	lbs.
,, ,, CO ,,	$\left(\frac{0{\cdot}51 \times 16}{28}\right)$	= 0·29	,,
,, ,, H_2O ,,	$\left(\frac{1{\cdot}76 \times 16}{18}\right)$	= 1·56	,,
Weight of free O		= 10·66	,,

Thus the weight of oxygen in 100 lbs. of flue gas is 22·1 lbs.

Now from Example II. it is seen that in 100 lbs. of flue gas there are 3·82 lbs. of carbon ; therefore, there are 5·82 lbs. of oxygen per pound of carbon, and the corresponding amount of air is

$$\left(5{\cdot}82 + 5{\cdot}82 \frac{76{\cdot}8}{23{\cdot}2}\right) = 25 \text{ lbs.}$$

Therefore, the weight of air supplied per pound of coal is very approximately $(25 \times 0{\cdot}842) = 21{\cdot}1$ lbs.

It will thus be seen that the excess of air is $21{\cdot}1 - 11{\cdot}2 = 9{\cdot}9$ lbs. per pound of coal or 88·5 per cent.

The following formula

$$100\left(\frac{N}{N-\frac{79}{21}O}-1\right)^*$$

is also used to calculate the percentage excess of air, where N and O are the percentage by volume of nitrogen and free oxygen in the flue gas. Referring to Example II., we see that there was 80·2 per cent. N and 10·12 per cent. O in the flue gas, hence the excess of air is

$$100\left(\frac{80\cdot2}{80\cdot2-\frac{79}{21}}\times10\cdot12-1\right)=90 \text{ per cent.}$$

Heat lost by Evaporating, etc., the Moisture in Atmosphere.

In the above calculations of the flue gas losses it has been supposed that the air is dry, but it always contains some moisture; the quantity is generally, however, insufficient to need a correction being applied. It will be observed that the moisture in the air will be evaporated by the furnace, and will form superheated steam at atmospheric pressure at the temperature of the furnace; but a portion of the heat is given out again and transmitted to the water in the boiler, and the loss is therefore reckoned in respect of the flue temperature. If it is considered desirable to ascertain this loss, the hygrometric state of the air must be measured.

Example III.

It was ascertained that the weight of moisture in 1 cubic foot of the atmosphere was 2·26 grains. But from the previous example the air used per lb. of fuel is 21·1 lbs., so that the total air per hour = 5,180 lbs., of which the volume at 60 degrees F. is 68,160 c. ft. Thus the total weight of moisture per hour = 22 lbs.

To convert 1 lb. of moisture at 60 degrees F. into steam at 212 degrees F. requires	1,118 B.T.U.
And to superheat 1 lb. of steam from 212 degrees F. to 504 degrees F. requires	140 ,,
So that the total heat per 1 lb. of moisture evaporated and superheated ... ... =	1,258 ,,
And the loss per hour ... ... =	27,700 ,,
Loss per cent. (see Table II.) ... ... =	0·8 ,,

* See page 138 of *The Heat Efficiency of Steam Boilers*, by Bryan Donkin.

Heat lost by Incomplete Combustion.

Incomplete combustion is also another important source of loss; that is to say, either an insufficient quantity of air is admitted to the furnace, or what is more likely, it is not properly distributed, the result being that a portion of the coal is incompletely burnt, forming carbonic oxide, CO, instead of CO_2, and a corresponding amount of heat is not generated. To determine this loss it is necessary to make an analysis of the flue gases to find the proportion of CO. The analysis required to determine the flue gas loss will, of course, suffice.

EXAMPLE IV.

From the flue gas analysis the percentage of CO by weight is	0·51 per cent.
Therefore the total of CO per hour is	27·2 lbs.
One lb. of CO in burning to CO_2 gives out ...	4,325 B.T.U.
Loss per hour by the formation of 27·2 lb. of CO =	117,500 B.T.U.
Loss per cent. (see Table II.)	3·5.

Heat lost by Unburnt Coal in Ashes.

A considerable amount of heat is also lost by the hot ashes dropped into the ashpit, as well as by radiation downwards of the coal through the openings between the firebars; but there does not appear to be any reliable means of measuring the loss of heat thus occasioned.

Small portions of unburnt coal collect in the tubes (if there are any), in the smokebox, and at the bottom of the flue. The proportion of heat thus lost can be obtained by cleaning the tubes and the smokebox before the trial, and again after the trial; the quantity collected is due to the whole of the coal burnt, not only during the actual trial, but also whilst getting up steam. It is obvious that considerable uncertainty must exist in determining this loss.

Another loss is due to unburnt coal, or to coal partially burnt to coke, falling through the grate with the ashes, or being blown away with the flue gases. Practically the latter effect only applies to boilers where there is a forced draught—to locomotive boilers, for instance, and there does not appear to be any very ready way of measuring this loss, which usually has to be included under "unmeasured losses." A spark catcher can be fixed to collect the unburnt coal, but this arrangement is uncertain because combustion of the sparks goes on in the flue after they are caught, and thus a portion of the unburnt coal is not collected.

Heat Lost by Radiation and Leakage.

There remains the loss by leakage, and the loss by radiation. A fair approximation of these two losses together can be obtained by what is called a "standing" test. For this purpose the stop valve of the boiler is closed, or, better still, the steam outlet from the boiler is closed by a blank flange because the stop valve may leak. Under this condition the boiler is fired so as just to maintain the pressure. The rate of coal consumption is obviously a measure of the loss of heat by radiation, and by leakage of steam or water. The leakage can be measured at the same time either by noting the fall of water in the gauge glass, if it has been previously calibrated and a scale fixed to it, supposing, of course, that no water is pumped into the boiler, or by keeping the feed pump working very slowly to maintain the water at a constant level in the boiler; the amount pumped in is then a measure of the leakage; the former is the best method if the leakage is slight, the latter if it is considerable.

The foregoing states the various measurements that have to be made to carry out a complete boiler trial, and they are embodied in the following table:—

MEASUREMENTS REQUIRED WHEN DETERMINING THE THERMAL EFFICIENCY OF A BOILER.

Relating to fuel:—

(1). Rate of fuel consumption.
(2). Determination of the calorific value of fuel and of moisture in fuel.

Relating to water evaporated:—

(3). Rate of water evaporation.
(4). Measurement of steam pressure.
(5). Determination of water present in the steam (dryness fraction).
(6). Measurement of feed temperature.

MEASUREMENTS REQUIRED TO DETERMINE LOSSES.

(7). Measurement of air temperature and of temperature of flue gases.
(8). Chemical analysis of flue gases.
(9). Sampling and weighing of ashes.
(10). Chemical analysis of ashes.
(11). Measurement of air pressure.
(12). Percentage of moisture in the air of boiler house.
(13). Radiation and leakage.

There are very many ways of making these various measurements, depending on circumstances and the degree of precision desired. Some of the methods will now be considered.

MEASUREMENT OF TIME.

A good watch is all that is necessary—in a seven hours' trial an error of one minute is an error of $\frac{1}{4}$ per cent.

MEASUREMENT OF THE RATE OF FUEL CONSUMPTION.

Coal will be taken as an example. To obtain the rate of consumption, the coal has to be weighed, and the best way is to weigh it in bags containing, say, 100 lbs. of coal each. (The number of bags to be provided depends obviously on the rate at which the coal will be burnt; three bags will usually be sufficient for tests on small boilers, and for the largest boilers ten bags may be required).

The weight of these bags should be as nearly as possible equal, and should be ascertained before starting the trial, and an allowance made each time a bag is weighed, so that each contains 100 lbs. of coal net; but sometimes the weight of the bag and coal is adjusted to 100, and a correction made at the end of the trial for the weight of the bags. A good plan is to fasten a ticket to each bag, and mark on it the number and the weight of the bag. The weighing is best done on a platform weighing machine, but if such a machine cannot be obtained, a spring balance can be used; it cannot, however, be read so accurately. In any case the balance should be checked by weighing a standard weight, so as not to depend on the graduations. A flat space $6' \times 6'$, on which to put the coals, should be provided, placed in a handy position for the stoker. This place is sufficient to hold the coal from one bag at a time, and the rule should be strictly observed that a fresh bag of coal is not to be emptied out before all the coal from the previous bag has been disposed of. The time of beginning and finishing each bag should be noted. As each bag is emptied it should be folded up and stacked with the previous ones, and before the bags are returned for refilling they should be counted and checked, with the number of bags entered on the log of the trial. In this way a continual check is kept on the trial. This checking is, of course, unnecessary if each bag is numbered. The following points should also be noted :—The number of times the boiler is fired per hour, and the number of shovelfuls placed on the fire each time of stoking; the appearance of the fire, whether it is bright, smoky, flaming; whether the grate is well covered, the thickness of the fire, or any peculiarities in the methods of firing adopted. As already mentioned, there is no difficulty in accurately weighing the coal, but a great difficulty arises in allowing for the weight of the coal on the grate at the time the trial begins and also at the moment the trial ends. These amounts can only be estimated, and an error thus introduced, which, combined with a similar error in connection with the water measurement, can only be reduced to practical limits by extending the duration of the trial to at least seven or eight hours. The best method of practically eliminating the error due to the coal on the grate will be considered after the similar question in connection with measuring the rate of feed has been described. The rate of coal consumption is, of course, the total weight of coal burnt divided by the time the trial lasted.

Determination of the Calorific Value of Coal.

It is obviously an important condition that the sample submitted to analysis should represent the average quality of the coal used during the trial. For this purpose about a quarter of a shovelful of small coal should be taken from each bag and placed in a heap apart; towards the end of the trial the coal thus collected should be thoroughly mixed together, and about 20 lbs. retained as a sample for analysis; the remainder is then thrown on to the grate.

The object is to determine the calorific value of the coal as burnt on the grate, and probably one of the most accurate methods is to use an apparatus called a calorimetric bomb. A portion of the coal sample is ground to a very fine powder in a mortar, and some of this powdered coal is carefully dried, and 30 grains are intimately mixed with 300 grains of finely powdered and dried saltpetre. The mixture is put into a metallic capsule fitted with a fuze. After lighting the fuze, the capsule is quickly placed into another metallic vessel, and the whole plunged into a vessel containing 4 lbs. of water. Combustion takes place in the capsule (the oxygen being obtained from the saltpetre). Not less than one minute is required for combustion, the water being carefully stirred during this time with a view of equalizing the temperature until it has reached a maximum. The temperature of the water is then measured, and knowing the initial temperature of the water, the rise of temperature is ascertained. The heat produced by the combustion is expended in raising the temperature of the water of the bomb and its contents, and of the vessel containing the water; and a small portion disappears by radiation and in the escaping gases. The quantity of heat required to raise the temperature of the water in the vessel is obtained by multiplying the weight of the water by the rise in temperature, since the specific heat of water is unity; this quantity of heat is, therefore, $W\ (t_1 - t_2)$. Therefore if L denotes the heat required to raise the temperature of the bomb and its contents, etc., as detailed above, and H the heat produced by the combustion of the coal, we have

$$H = W\ (t_1 - t_2) + L.$$

For any particular instrument L is, for all practical purposes, constant, and can be determined by burning some pure carbon (lamp black) in the bomb. In this case we know H, and can observe W, t_1 and t_2, and so can find L. This determination is generally made by the makers of the instruments, and the information supplied. It is, however, as well to verify the figure, as shown by the following example.

Example V.

Thirty grains of lamp black are burnt in a calorimetric bomb. The vessel contains 4 lbs. of water, and the temperatures, before and after combustion, are observed to be 56·0 degrees F. and 71·2 degrees F. respectively. The heat value of 30 grains of carbon is 62·14 B.T.U.

We have therefore

$$\begin{aligned} L &= H - W\ (t_2 - t_1) \\ &= 62{\cdot}14 - 4\ (71{\cdot}2 - 56) \\ &= 62{\cdot}14 - 60{\cdot}64 \\ &= 1{\cdot}5. \end{aligned}$$

Example VI.

The following is the result of a determination on a sample of the Powell Daffryn coal used in the trial under consideration:—A rise of 14·94 degrees F. was observed on burning 30 grains of coal. The weight of water was 4 lbs., and the value of L according to the previous example 1·5. From the equation

$$H = (4 \times 14{\cdot}94) + 1{\cdot}5 = 61{\cdot}26 \text{ B.T.U.}$$

Obviously the combustion of 30 grains of coal produced 61·26 B.T.U. Hence the B.T.U. that would be produced by the combustion of 1 lb. of coal would be

$$\frac{61{\cdot}26 \times 7000}{30} = 14{,}294 \text{ B.T.U.}$$

To this value a correction must be applied on account of the steam produced by the combustion of the hydrogen in the sample of coal having been condensed. The moisture produced can be calculated from the percentage of hydrogen in the coal, and it will be seen that the heat given out by this steam in condensing and cooling to the resulting temperature of the calorimeter cannot be utilized in practice in the furnace, and should not therefore be included in the calorific value of the coal. An estimation of the amount of this correction per lb. of coal may be made as follows:—Referring to the analysis of the coal used, it will be seen that for every 1 lb. of coal there is 0·0439 lb. of H. The weight of moisture produced by 0·0439 lb. of H is (H combining with eight times its weight of O) $0{\cdot}0439 + 8 \times 0{\cdot}0439 = 0{\cdot}395$ lb. But to evaporate 1 lb. of water from 78·5 degrees F., which was the resulting temperature of the mixture, requires 1,100 B.T.U.* Hence 0·395 lbs. of steam condensing to moisture will give out $1{,}100 \times 0{\cdot}395 = 434$ B.T.U. Thus the corrected calorific value of the coal will be $14{,}294 - 434$ or 13,860 B.T.U. per lb.

The theoretical calorific value can be determined by means of a chemical analysis, but it is not proposed to describe this analysis, as it can only be performed in a properly equipped laboratory, and by an expert chemist. The following is, however, the result of the analysis, and the manner of determining the heat value therefrom is also given:—

* Data can be obtained from any steam table.

Analysis of Powell Duffryn Coal.

Moisture	= 1· 0 per cent.
Ash	= 6· 7 ,,
Carbon	= 84·19 ,,
Hydrogen	= 4·39 ,,
Matters undetermined, including sulphur, nitrogen, oxygen, etc. ...	= 3·72 ,,

From the above values of carbon and hydrogen the heat value per lb. of fuel would theoretically be as follows :—

Heat from ·8419 lb. of carbon at 14500 per lb.	= 12,200 B.T.U.
,, ·0439 ,, hydrogen 53000 ,,	= 2,370 ,,
Total	= 14,570 ,,

It will be noticed that there is some difference between this theoretical value and the value 14260 deduced from the calorimetric bomb experiment. The reason is that the heat required to dissociate the various elements is quite indeterminate, because we have no knowledge of the manner in which the oxygen, the carbon and the hydrogen are combined in the fuel. In the face of such errors, the magnitude of which cannot be estimated, it is useless to trouble about the sulphur, nitrogen, and other constituents. It will thus be seen that such theoretically calculated values are probably far from reliable.

Determination of Moisture in the Coal.

To determine the proportion of water in the coal, 1,000 grains of the finely powdered sample of coal are weighed, and then carefully dried at a temperature of about 225 degrees F., after which the coal is weighed again; the loss of weight is due to the moisture which has evaporated, and the percentage moisture can be calculated. When the coal is burnt in the boiler furnace this moisture is evaporated from the temperature of the coal (air temperature), and at the pressure obtaining in the furnace (practically atmospheric pressure), and the steam thus formed is superheated to the furnace temperature. The heat required to thus evaporate the moisture is not all lost, because a portion of the superheat is given up to the water in the boiler as the steam cools down to the flue temperature ; that is to say, the loss is only to be reckoned on the heat required to superheat to the temperature of the flue gases, as seen in the following example.

EXAMPLE VII.

A sample of coal used in the trial referred to in Example I. is powdered, and 1,000 grains are found to lose 10 grains on drying. The air temperature at the trial was 60 degrees F., and the flue temperature was 504 degrees F.; the furnace pressure was 14·80 lbs. absolute.

The percentage of moisture in the coal is seen from the data to be 1 per cent. The total heat required to evaporate 1 lb. of water from 60 degrees F. at 14·8 lbs. absolute is found from steam tables to be 1,118 B.T.U. and taking ·48 as the specific heat of steam, the heat required to superheat from 212 degrees F. to 504 degrees F. is 140 B.T.U.; the total heat per lb. of water evaporated and superheated is therefore 1,258 B.T.U.; per lb. of coal this becomes 12·58 B.T.U., and per hour 3,100 B.T.U., or a little under 0·1 per cent. of the heat production in the furnace (see Table II.).

DETERMINATION OF PERCENTAGE OF ASH AND UNBURNT COAL.

The ashpit is raked out at the beginning and again at the end of the trial, and the ashes weighed; the percentage of ash produced per hour can then be ascertained. A portion of these ashes consists of unburnt coal, and to ascertain the heat units thus lost the ashes are well mixed together, and a sample is taken and is analysed for carbon present, or the heat value of the ash may be determined by the bomb method already described and in exactly the same way.

EXAMPLE VIII.

An analysis of a sample of ash gave 29 per cent. of carbon, and the weight of ash per hour was found to be 23·5 lbs.

Hence the weight of carbon per hour is ...	= 6·8 lbs.
The heat equivalent of 1 lb. of carbon being ...	= 14,500 B.T.U.
Loss per hour in ash (see Table II.)	= 98,600 ,,
Loss per cent.	2·9 ,,

MEASUREMENT OF WATER EVAPORATED.

Although weighing water may seem a simple operation, great care must be exercised to obtain a reliable measurement of the rate at which the feed water is evaporated. Many arrangements are adopted, some good and others bad, but the following method is at the same time simple and accurate. Two tanks are provided, one for measuring the water and the other from which the feed pump (or injector) can draw. The measuring tank should be about $2' \times 2' \times 3'$ deep for medium sized boilers, so as to easily contain 500 lbs. of water, and in the trial of large boilers two such tanks should be prepared, as it takes at least three minutes to measure water into a tank of the size given above.* The measuring tank can be either fitted with a gauge glass, or with a pointer capable of adjustment. A $1\frac{1}{2}$-inch valve is fixed in such a position as to be able to completely empty the measuring tank. To calibrate the tank it is emptied, and 500 lbs. of water are then *weighed* into the tank, using the same balance or weighing machine as that which was used for weighing the coal, and a mark is made on a slip of wood fixed close to the gauge glass, or the pointer is adjusted so as just to touch the water, and its position is marked. (This measurement should be repeated three times, and the mean taken). A $\frac{1}{2}$-inch adjusting tap should also be fitted to the measuring tank so that the level of the water can be adjusted without allowing the water to fall into the feed tank. The water supply pipe should be arranged to discharge into the measuring tank through a $1\frac{1}{2}$-inch valve. To measure a tank of water this valve is opened full bore, and closed when the water level is about $\frac{1}{4}$ inch higher than the calibration mark. The $\frac{1}{2}$-inch tap is then opened, and the water level lowered to the calibration mark. The water in the measuring tank can now be emptied into the feed tank when required. The feed tank should contain from 500 to 2,000 lbs. of water, according to the size of the boiler under trial, and should be fitted with a valve by means of which it can be completely emptied, the water running to waste. The method of working with these tanks will be described further on.

The calibration is sometimes carried out by measuring the cubic contents of the tank. It is difficult to obtain accuracy in this way.

The difficulty in measuring the total weight of coal burnt caused by the coal on the grate at the beginning and end of the trial was referred to at page 196. A similar difficulty occurs in connection with the total weight of water evaporated, owing to the undetermined quantity of water in the boiler at the beginning and at the end of the trial. In the case of the water, however, there is a boiler

* Thus if the boiler evaporates 4,000 lbs. of water per hour a single tank containing 500 lbs. of water would be emptied every $\frac{500 \times 60}{4000} = 7\frac{1}{2}$ minutes.

gauge to measure the height of the water in the boiler. At first sight this would appear to entirely remove the uncertainty, but, unfortunately, unless due precautions are taken, serious errors may result, because under a variety of circumstances the level in the gauge glass may be as much as 2 inches higher or lower than the water in the boiler. The reasons are somewhat obscure, but they no doubt depend on the expansion and contraction of the boiler shell; on the action of the steam bubbles in the water, that is, on the disturbances and waves produced by the rapid rising of the steam bubbles; on condensation of steam in the gauge glass tube producing a local reduction of pressure.

Generally on blowing out a gauge glass the water remains at a higher level than before for some little time, but if the boiler contains a saline solution the reverse will occur because the water in the gauge glass gradually becomes distilled water through condensation, and reads higher to balance the heavier water in the boiler. On blowing out the gauge glass the distilled water is replaced by the boiler water, and a lower reading is obtained, although no perceptible change has taken place in the height of water in the boiler. Under certain circumstances, when the fire door is opened, the water in the gauge glass falls, and generally, if the boiler has not been fed for some little time on first putting on the feed, the level in the gauge drops.

The gauge glass source of error has the greatest effect in Lancashire boilers, owing to their large water surface; the following example gives an idea of the amount:—It was estimated that the total error in reading the gauge at the beginning of a trial was $-\frac{3}{4}$ inch, and at the end of the trial $+\frac{1}{4}$ inch, that is, the boiler contained less water at the beginning and more at the end of the trial than was shown by the gauge, so that the error in the water measurement was equal to $\frac{1}{4}'' + \frac{3}{4}'' = 1''$ depth at the water surface of the boiler, and had the effect of apparently improving the evaporation of the boiler. The length of the boiler was 30 feet and the width at the water surface 6 feet. The volume of 1 inch depth is $30 \times 6 \times \frac{1}{12} =$ 15 cubic feet. Apparently, therefore, the boiler had evaporated $15 \times 62{\cdot}5$ lbs., say 900 lbs., more than in reality. If the boiler had been evaporating 8,000 lbs. of water per hour, and the trial lasted three hours, the error would have been $\frac{900}{8000 \times 3} \times 100 = 4$ per cent. nearly, but if the trial had been of six hours' duration the error would have been reduced to 2 per cent.

The best, and probably the only reliable, way of obviating these gauge glass errors is to arrange that the boiler shall have been for some little time in the same condition at the beginning and at the end of the trial. For this, the rate of feed, the pressure, the condition of the furnace, the height of water in the boiler, and the rate of evaporation should be the same. It was shown that similar difficulties occur in measuring the rate of coal consumption. These difficulties in measuring the coal and water rate can be practically eliminated by properly conducting the trial.

Measurement of Pressure.

The pressure is usually measured by means of a steam gauge.* Such gauges cannot be depended upon, after being in use for some time, to give sufficiently true readings for testing purposes, and for this reason the boiler gauge should be compared either before or after the trial with a standard gauge, or with a mercury column. A portable arrangement is to be obtained provided with a standard gauge, and the pressure is obtained hydraulically by means of a screw. This apparatus is shown in *Fig.* 1. A mercury column

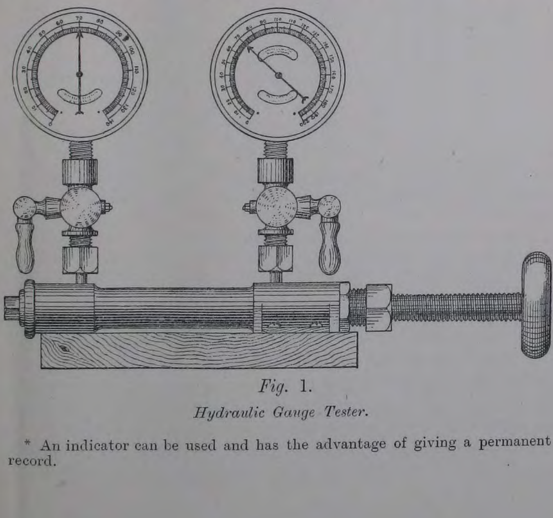


Fig. 1.

Hydraulic Gauge Tester.

* An indicator can be used and has the advantage of giving a permanent record.

gives a more certain result, but only a few such columns are available. Both these arrangements have the disadvantage of testing the gauge in a *cold* state, whereas it is used hot. The following apparatus, which is shown in *Fig.* 2, meets this latter objection :—

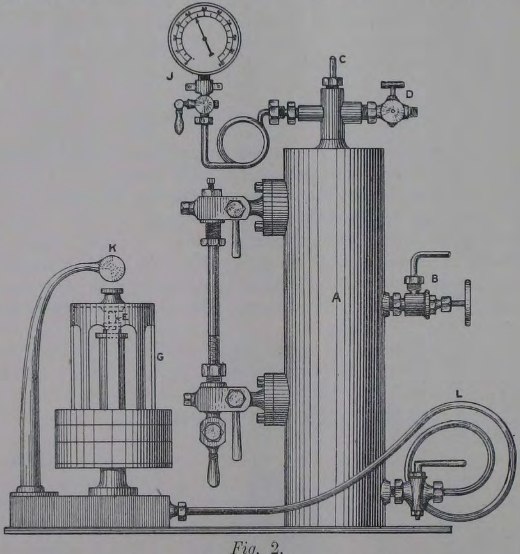


Fig. 2.
Gauge and Indicator Testing Apparatus.

A is a brass barrel connected by a pipe L to an hydraulic piston E, and filled with water to the level of this piston. Steam is admitted by a pipe C and escapes by a cock B, which enables any desired pressure to be maintained on the surface of the water. From the top of the piston E is hung by a spherical joint a carrier G, on which may be placed weights in the form of rings. The area of the piston is $\frac{1}{10}$ square inch, so that each pound that is added measures an increase of 10 lbs. per square inch in the pressure necessary to keep the carrier floating. The weight of the carrier and piston are accurately 1 lb., representing, therefore, 10 lbs. per square inch.

The pressure gauge to be tested is attached to the fitting on the top of the barrel, which also carries a cock D, for use when testing the springs of indicators. A weight, which together with the carrier and piston is equal to $\frac{1}{10}$th the pressure at which it is desired to test the gauge, is put on the carrier, and the cock B is adjusted until the piston floats under the stop K. Setting the carrier in rotation during this operation minimizes the effect of friction. The steam pressure is thus adjusted to that corresponding to the weight on the carrier, and the reading of the gauge can be compared.

The barrel is furnished with a water gauge glass, which shows if the level of the water in the barrel is the same as that of the column under the piston E. The stop K is to prevent the piston being blown out by excess steam pressure, but is on a standard which can be turned so as to allow of the weights being placed on the carrier.

Determination of the Water Present in the Steam. (Dryness Fraction).

This is a difficult operation, and it may be stated that there is at present no apparatus which meets with universal approval. Two principal difficulties occur, one in connection with the apparatus, and the other in obtaining a true sample of the steam, and it is necessary to distinguish between two sources of moisture in the steam, namely, priming and condensation. The former is due to fine particles of water which are entrained by the steam bubbles as they burst when leaving the surface of the water in the boiler, and it is to be observed that this water has not been evaporated by the boiler, and has therefore only received the water heat, and not the latent heat of evaporation. The "condensed" water, on the other hand, has been evaporated by the boiler and then condensed against the sides of the boiler or of the outlet valve. Some of this condensation falls back into the boiler to be re-evaporated, but a portion is drawn into the steam, and it is only with this latter portion that we are concerned.

This subject is fully treated in a paper read by Professor Unwin before the Institution of Mechanical Engineers in 1895,* from which the following extract has been made descriptive of

* Professor Unwin's Paper, "The Determination of the Dryness of Steam." *Proceedings of Institution of Mechanical Engineers*, January, 1895.

Carpenter's calorimeter, which aims at measuring the whole of the water present in the steam, namely, the priming water plus the condensed water.

Carpenter Calorimeter.—The calorimeter (*Fig.* 3) consists of a vessel A about 7 inches high by 3 inches diameter containing an inner chamber and a jacket.

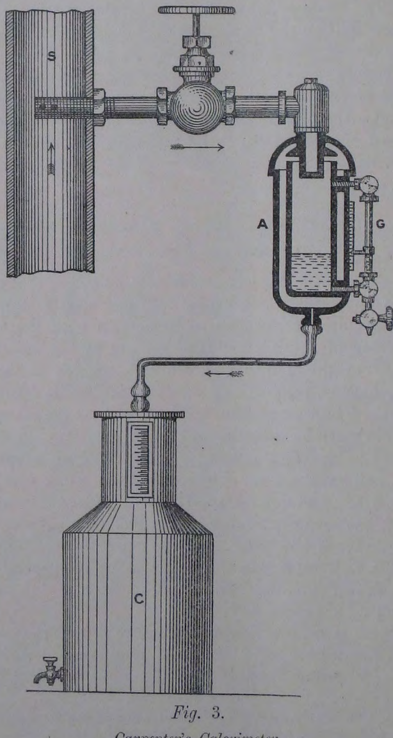


Fig. 3.

Carpenter's Calorimeter.

The steam from the steam pipe S passes first into the inner chamber. The separating chamber is therefore perfectly protected from radiation. As the water accumulates in the inner chamber its level is shown by a gauge glass G, and the amount in hundredths of a pound can be read off on a scale.

A very small orifice at the bottom of the outer chamber regulates the amount of steam discharged. The escaping steam passes through a flexible tube to a simple form of condenser C. The increase of weight in any given time in the condenser is noted, and the amount accumulated in the same time in the separator.

If x is the dryness fraction of the steam, w the weight of water caught in the separator, and W the weight of steam condensed. Then $x = W \div (W + w)$.

There is a gauge glass and scale on the condenser graduated to read pounds and tenths of a pound at a temperature of 110 degrees F. But as the variation of volume in the condenser with temperature affects the readings considerably, it is best to place the condenser on a platform weighing machine.

Salt Test.—In this method, which only measures the priming water, salt, generally common table salt, is introduced with the feed until the boiler water contains 1 or $1\frac{1}{2}$ per cent. of salt in solution. During a test in which the amount of feed is measured a sample of boiler water is drawn off at the beginning and end of the test. The level of water in the boiler should be exactly the same when the two samples are taken.

Let W be the weight of water in the boiler, and S_1 and S_2 the per cent. of salt in the two samples. The amount of salt removed from the boiler during the test is $W\ (S_1 - S_2) \div 100$. Let w be the amount of feed supplied and x the dryness fraction of the steam. Then xw lb. of pure steam are generated and $(1 - x)\ w$ lb. of priming water carried over. The mean saltness of the priming water is $(S_1 + S_2) \div 2$.

Hence $$\frac{(1-x)\ w}{100}\ \frac{S_1 + S_2}{2} = \frac{W}{100}(S_1 - S_2).$$

$$x = 1 - \frac{2W}{w}\ \frac{S_1 - S_2}{S_1 + S_2}.$$

This method deals with the whole amount of steam produced, and not mere samples.

Another method of applying the salt test, devised by Mr. C. T. Wilson, is as follows :—

To one part of the salt boiler water 100 parts of pure distilled water are added. As a colouring matter, add a small quantity of concentrated solution of yellow chromate of potash. To this a decinormal ($\frac{1}{10}$ per cent.) solution of silver nitrate is added slowly. With each drop the solution will turn locally red, but on shaking this disappears. When all the salt has been acted upon the whole fluid will change from a yellow colour to orange. The quantity of nitrate solution is noted. The whole experiment is then repeated on a sample of condensed steam *undiluted* with water. The ratio of the quantities of nitrate in each case expresses the priming per cent.

Measurement of Air Pressure.

It is important to know the draught under which the boiler is working, and this is done in a simple way by means of a glass U-tube fitted with a movable scale. A connection to one limb of the U-tube is made with the furnace by means of a piece of flexible tube, and suction is thus produced which makes the water stand at a different level in each limb. The difference between these levels (measured by the movable scale) is the chimney draught expressed in inches of water. Professor Osborne Reynolds has improved this apparatus as follows :—The gauge (*Fig.* 4) consists of a U-tube of $\frac{3}{8}$-inch glass tube expanding towards the top into bulbs $1\frac{1}{4}$ inches diameter for a length of 2 inches, then contracting back to $\frac{3}{8}$-inch. This tube is filled with water until the level stands about $\frac{1}{4}$ of the way up the bulbs. Rather more than half a bulb full of *heavy* oil is then poured into the bulb on the pressure side A. If the density of the oil is ·9, the reading is magnified about eight times that of an ordinary water gauge.

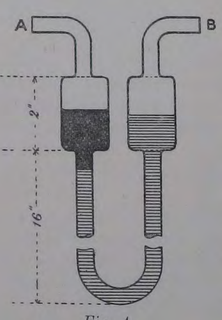


Fig. 4.
Professor Osborne Reynolds' Draught Gauge.

Measurement of Temperatures.

Measurement of Air Temperature.—There is no difficulty in obtaining this temperature with sufficient accuracy by means of an ordinary thermometer of good make. The thermometer should, however, not be placed close to the boiler, and should be screened from radiant heat.

Measurement of Feed Temperature. — There is no difficulty in measuring the feed temperature with an ordinary thermometer of good make.

Measurement of Flue Temperature.—This temperature varies from 300 degrees F. to 700 degrees F., and is beyond the range of an ordinary mercurial thermometer ; special thermometers are, therefore, required, such, for instance, as a nitrogen thermometer. The peculiarity of this thermometer consists in that the space above the mercury column is filled with compressed nitrogen in the place of mercury vapour. It is found that at comparatively high temperatures the mercury does not boil in the presence of nitrogen.

Somewhat recently an electrical thermometer has been introduced by Prof. Callender, of Cambridge (now of Montreal), which gives good results. This thermometer depends on the change of electrical resistance due to temperature. The resistance is in the form of a fine platinum wire, which, suitably protected by a tube four feet long, is inserted into the flue. The measurement is made by a Wheatstone Bridge arrangement, combined with a graduated galvanometer, the graduations being marked in temperature degrees. By means of special resistances inserted into the circuit a very great range of temperature can be measured, and this also allows of the instrument being readily calibrated. The leads from the measuring instrument to the platinum resistance would cause an error through their change of resistance by temperature. To eliminate this error, a couple of wires of the same description and length are carried along with the actual leads, their resistance being arranged to act in opposition to that of the actual leads, and as they are exposed to the same change of temperature, they will at all times balance and correct the error of the leads ; they are called "balancing" leads. A battery of six Leclanché cells is required to produce the necessary current. A detailed description of this platinum thermometer will be found in Appendix I.

It is important to select a proper place in the flue for the insertion of the thermometer. It should obviously be as close as possible to where the flue is connected to the boiler, so that the gases will not have lost any heat by radiation, but care should be taken that it is not exposed to radiant heat. The hole made in the flue to receive the thermometer should be carefully closed around the thermometer stem, with cotton waste, for instance, to prevent air being drawn in. Readings of temperature should be taken every quarter of an hour.

Method of Obtaining Samples.—It is somewhat difficult to obtain reliable samples for analysis, and great care must be exercised. The composition of the gases is variable to a certain extent from moment to moment, depending on the state of the fires, the regulation of the draught, etc. To obtain an average sample, it is therefore necessary to draw the gases into the sample bottle very slowly. Each sample, containing about 250 cubic centimètres, should take from five minutes to a quarter of an hour to obtain.* About 12 samples should be collected during a trial of 6 to 7 hours.

The following is a description of a good kind of sample bottle, which is shown in *Fig.* 5, and consists of a glass tube 4 centimètres in

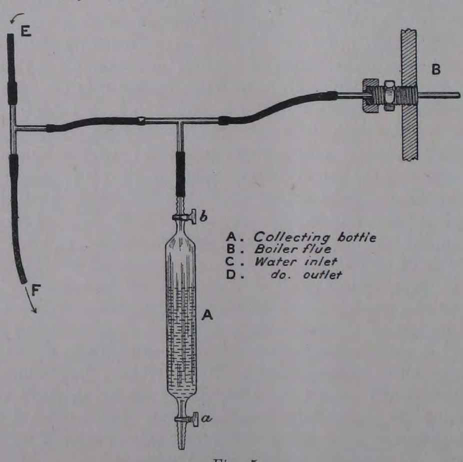


Fig. 5.
Flue Gas Collecting Apparatus.

diameter and 22 centimètres in length, drawn down at the ends. At each end there is a stop-cock, the one for admitting the gases from the flue, the other for regulating the flow. Some of the flue

* The apparatus is so constructed that samples may be taken very rapidly if desired. This is useful for some purposes, for instance, if it is desired to ascertain the effect on combustion immediately after stoking, when the composition of the gases is very variable.

gases, in particular the CO, is soluble in water, and for strict accuracy it is necessary to collect over mercury; salt water, or dilute hydrochloric acid is, however, also used. It is found that a solution of common salt only dissolves a small percentage of CO, so that the error is small, and by letting the gases bubble through the water for some time before taking a sample, so as to let the water absorb all it can of the soluble gases, even this small error can be eliminated.

To use the apparatus the bottle is previously completely filled with a solution of salt in water. A current of water is allowed to flow from E to F, which induces a flow of gas along the tube B. Any water which may have collected in B will be driven out, and when a flow has been set up, the stop-cocks *b* and *a* may be opened. By means of the cock *a* the time taken to collect each sample of the gases can be regulated. It is almost unnecessary to state that both cocks *b* and *a* must be closed just before the bottle is completely emptied of water.

Analysis of the Gases.—This analysis can be carried out by the usual methods in a chemical laboratory, and a description of these will be found in Appendix II.

There is, however, a portable instrument made by F. Jackson and Co., which gives very good results, and it has this great advantage, that the analysis can be made during the trial, and the trouble of taking gas samples to a chemical laboratory is avoided.

The apparatus is known as Orsat's, and is shown in *Fig.* 6.

L is an eudiometer, which is encased in a glass tube. This tube should be filled with water to form a jacket, and thus ensure an even temperature for all the gas measurements. F, G, and H are flasks containing solutions of alkaline pyrogallate, cuprous chloride, and caustic soda, for

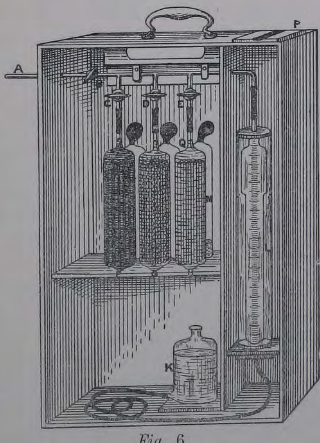


Fig. 6.
Orsat's Apparatus for Gas Analysis.

Table III.

Time.	Steam Pressure by Gauge.	Height in Glass. Inches.	Temperature. Feed. ° Fahr.	Temperature. Atmosphere. ° Fahr.	Temperature. Waste Gases. Fahr.	Draught. Ashpit. Ins. of Water.	Draught. Funnel.	Water. Time. Commence.	Water. Weight. lbs.	Water. Interval. Mins.	Coal. Time. Begin. Finish.	Coal. Weight. lbs.
10.15	159	4·9	59·3	60	494	0·24	Not taken during this trial.	10·12	500	13		
10.30	162	5 0	59·4	60	492	0·27		10·25	,,	13	10·16 – 10·40	100
10.45	157	5·1	59·6	61	492	0·28		10·38	,,	14	10.46 – 11.3	,,
11.0	157	5·0	59·8	62	490	0·28		10·52	,,	15	11.5 – 11.20	,,
11.15	157	4·8	60	62	486	0·27		11·7	,,	15	11.24 – 11.47	,,
11.30	163	4·9	60·4	62	508	0·28		11·22	,,	12	11.52 – 12.13	,,
11.45	162	5·4	60·6	62	503	0·26		11·34	,,	13	12.17 – 12.37	,,
12.0	157	5·4	61	61	499	0·27		11·47	,,	14	12.40 – 12.53	,,
12.15	158	5·5	61	61	503	0·28		12·1	,,	13	12.55 – 1·17	,,
12.30	163	5·8	61	60·5	501	0·27		12·14	,,	14	1.21 – 1·41	,,
12.45	160	5·8	61	60	503	0·28		12·28	,,	14	—	—
1.0	167	5·5	61	60	505	0·28		12·42	,,	15	—	—
1.15	163	5·7	61	60	501	0·27		12·57	,,	13	—	—
1.30	163	5·6	60·5	60·5	501	0·26		1·10	,,	14	—	—
1.45	163	5·9	60·5	60·5	510	0·26		1·24	,,	14	—	—
								1·38	,,			

At the end of the trial, the last bag of coal having been emptied on the firing plate and finally fired, great care is taken, whilst maintaining the same rate of evaporation, to adjust the water height in the gauge glass to the point at which it was at the beginning of the trial by careful regulation of the feed: the pressure is watched, and the instant it begins to fall definitely is taken as the end of the trial. At this moment the furnace ceases to be able to supply sufficient heat to maintain the pressure at the rate of evaporation, and it may therefore be assumed, with a fair degree of accuracy, that the fire and the boiler generally are in the same condition as at the beginning of the trial. The ashpan is cleaned out and the ashes weighed.

During the trial the times of commencing (and finishing) each bag of coal and each measured quantity of water should be plotted, as shown on *Fig.* 7. In this way a check is kept on the trial during its progress.

Various Inaccurate Methods of Making Boiler Trials.

Boiler evaporation trials are sometimes made at atmospheric pressure. Such trials are quite delusive and worthless, because in the first place the temperature of the water in the boiler is only 212 degrees F., and thus, owing to the increased heat gradient, the transmission of heat from the furnace will be greater, so that the flue gases will be at a much lower temperature than when the boiler is evaporating at the pressure it is intended to work at. In this way the flue gas loss is much reduced. Radiation and leakage losses are also diminished, owing to the lower temperature of the boiler. The following numerical example will give some idea of the reduction in flue gas loss due to evaporating at atmospheric pressure. Taking the boiler trial given in Example I., in which the water was evaporated at 174 lbs. absolute pressure, the water temperature was 370 degrees F., and the flue temperature 504 degrees F.; if this boiler were evaporating water at atmospheric pressure, the water temperature would be reduced to 212 degrees F., and the flue temperature to about 350 degrees F. Thus the flue gases would be heated 154 degrees F. less when evaporating at atmospheric pressure, assuming the same combustion in the furnace. It was seen that 5,400 lbs. of flue gases were discharged per hour, and that the specific heat of these gases was 0·242. Hence the reduction in flue gas loss is 200,000 B.T.U.'s per hour, and for the present argument it will be accurate enough to assume that these heat units are put into the steam. In the trial referred to, Example I., 2,464,000 B.T.U.'s per hour were put into the steam. Thus, if the trial had been carried out at atmospheric pressure, 2,664,000 B.T.U.'s would have been put into the steam, and the efficiency of the boiler would have been 5·8 per cent. better, or an increase of no less than 8 per cent.

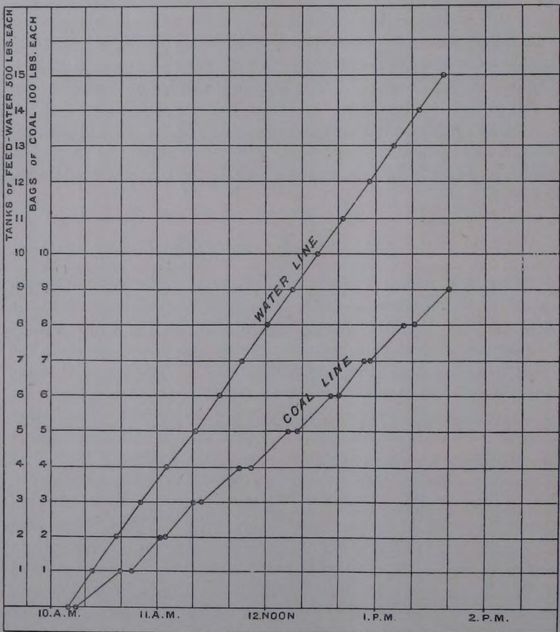


Fig. 7.

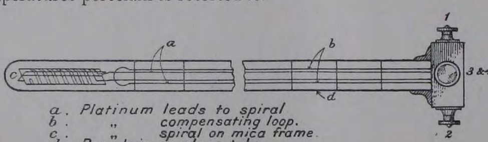
Moreover, a boiler when evaporating at the full rate under atmospheric pressure foams and primes to a very large extent, and consequently a considerable portion of the feed is not evaporated at all, and thus an apparently very high rate of evaporation is obtained.

Unless the dryness fraction of the steam is measured, and the correction made, the boiler may be made to appear from 10 to 25 per cent. better than it really is.

Another way of "jockeying" a trial is to take care to have a large fire in the grate at the beginning of the trial, and to make the trial as short as possible, and at the end of the trial to go on evaporating until the pressure drops considerably. In this way at least 10 per cent. spurious efficiency can be obtained. This dodge is especially effective in water-tube boilers containing a large amount of brick-work, which stores up the heat before the trial commences, heat which has been obtained from coal which is not weighed. A good deal can also be done by constantly raking the fire and deducting the ashes without allowing for the unburnt coal in them. Another trick is to blow out the gauge glass just before the beginning of the trial; the gauge glass then reads very high. At the end of the trial the fire door is opened as often as possible, and care taken not to blow the gauge out. The effect of both manipulations is to show more evaporation than actually took place. Lancashire boilers, owing to their large water surfaces, are the most suitable for this form of treatment, as the following example will show. It is possible to get quite 4 inches spurious gauge reading in this way. Referring to page 202, it will be seen that in the case there discussed the efficiency was affected to the extent of 4 per cent. by 1 inch error in the gauge glass reading if the trial only lasted three hours. With 4 inches error the efficiency of the boiler would apparently be increased 16 per cent. The causes which produce high-gauge glass readings, and those which produce low readings were previously mentioned at page 202; the former are put into operation at the beginning of the trial, and the latter at the end to fully take advantage of this form of trick.

APPENDIX I.

* The figure (*Fig.* 8) represents a Callender platinum thermometer. The platinum wire is of very fine gauge, 5—8 mils. wound non-inductively on a very light framework of mica of a Maltese cross section. The ends are welded to platinum wires of larger gauge, threaded through holes in mica washers. These washers not only provide insulation, but also prevent convection currents within the tube. The mica discs also carry a loop of platinum wire, of similar gauge to, and of the same length as, the leads above mentioned. These are called balancing leads, and are so arranged in connecting up the instrument as to compensate for any error that would otherwise occur through alteration in resistance of the connecting leads to the spiral. The containing tube may be made of hard glass for temperatures up to 500° C., but for higher temperatures porcelain is resorted to.



a. Platinum leads to spiral
b. " compensating loop.
c. " spiral on mica frame.
d. Porcelain or glass tube.
1&2. Platinum spiral terminals.
3&4. Compensator terminals.

Fig. 8.
Callender's Electrical Thermometer.

The method of connecting up and obtaining readings with this thermometer is shown in *Diagram* 1.

When the two points C and O are of equal potential value, no current will pass through the galvanometer. The resistance of circuits SR^1 and SR^2 are equal, and it is arranged that when the platinum coil is at 0° C. the resistance of the circuit AFO = resistance of circuit OGD. With increased temperature the platinum coil undergoes an alteration in resistance, increasing directly as the temperature. This results in a displacement in the point of equal potential O with C.

* The above is an abstract from *The Potentiometer and its Adjuncts*, by W. Clark Fisher.

The amount of displacement is ascertained by moving the sliding contact until no deflection is again obtained. Should the amount of displacement be greater than the range of the slide wire, an alteration in the number of resistance coils RC in the circuit is made. It will be seen that if the resistance of the slide wire is suitably proportioned to the platinum coils, and if the resistance coils RC are arranged in definite units of the slide wire, a direct indication of the amount of increased temperature is obtained.

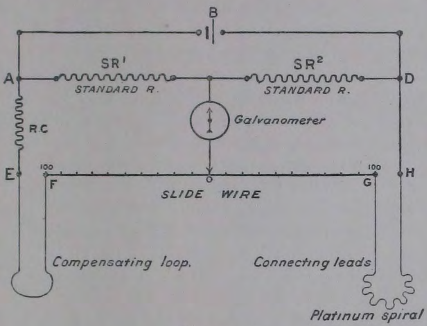


Diagram 1.

A modification of this arrangement, in which the balancing leads are dispensed with, is shown in *Diagram* 2. Here the battery

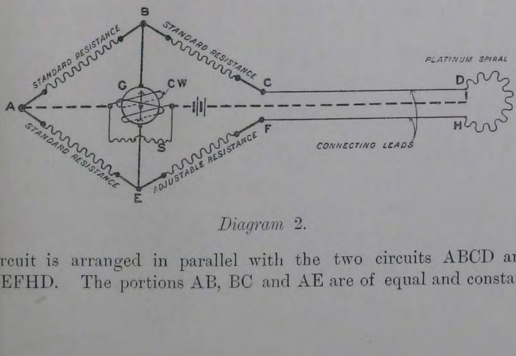


Diagram 2.

circuit is arranged in parallel with the two circuits ABCD and AEFHD. The portions AB, BC and AE are of equal and constant resistance. The remainder, consisting of the connecting wires CD, FH, the platinum coil DH and adjustable resistance EF, are variable. The points BE are connected together through a galvanometer G of open divided scale. The galvanometer takes the place of the slide wire before used, and as the constancy and sensibility of a galvanometer used under these conditions are variable, being dependent upon the impressed E.M.F. at its terminals, together with any temperature error that may exist in itself, without some compensating arrangement concordant results will not be obtained. To get over this difficulty, two coils of wire CW, known as "field coils," are so placed that their axes are at right angles to the ordinary coils of the galvanometer, and are connected in series with the battery circuit. Any irregularity in current flow would, therefore, have the result of proportionately affecting the field and deflecting force, so that, irrespective of any variations of E.M.F. at its terminals, the deflections of the galvanometer remain constant in value. The shunt coil S of low temperature coefficient compensates the error due to temperature alteration; a similarly and suitably proportioned resistance being placed in series with the galvanometer results in a neutralizing or compensating effect, as any alteration through temperature in the galvanometer has a corresponding opposite effect in the field coil.

The platinum coil being at 0° C., all circuits are made equal to one another, as indicated by the galvanometer remaining at zero. Alteration in the temperature of the coil produces a proportionate deflection of the galvanometer. The galvanometer scale is usually calibrated from 0° to 100° C., and should the temperature rise above that figure, the resistance coils in EF are so proportioned, in relation to the platinum coil, as to reduce, when plugged out, the resistance of the platinum circuit by the extent it was raised to produce a deflection of 100° C., or any multiple of the same; thus the galvanometer is again brought to zero. The resistances so plugged out may be made to bear direct the values of the temperatures causing their retirement from use. The connecting leads CD and FH, being on opposite sides of the bridge, balance each other, and any variation in the lead AD is dealt with by the "field coils."

APPENDIX II.

Fig. 9 shows a form of apparatus employed in gas analysis. The whole apparatus is filled with mercury; the gas is then introduced into the eudiometer A and its volume measured. The stop-cock *b* and the three-way cock *c* are then opened, and the gas passes over into the laboratory vessel *d*, followed by some mercury to drive all the gas out of the capillary tube. The reagent is then poured into cup *e* and admitted to the laboratory vessel by the three-way cock. When the absorption is complete, the mercury bottle is placed on the upper shelf, and the cocks being opened, the gas passes back into the eudiometer. When the reagent rises to *c*, the three-way cock is turned to communicate with the cup so that the reagent passes into it. Some mercury is then driven over into the eudiometer so as to clear the gas from the capillary tube, and the volume is again read.

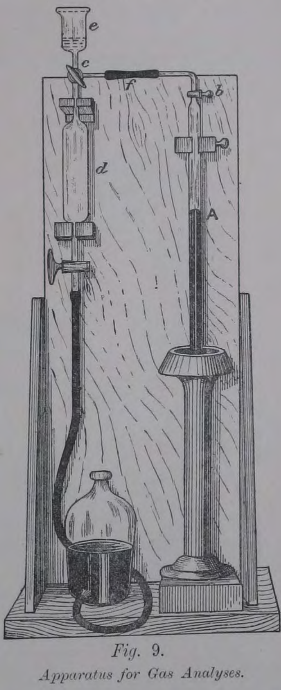


Fig. 9.
Apparatus for Gas Analyses.

The two ends of the capillary tube at *f* are made funnel shaped, and connected by a thick indiarubber tube. By lowering the eudiometer a little when the gas is passed from *a* to *d*, and raising it for the passage in the opposite direction, the whole of the gas is driven out.

Another method of analysis consists in the use of Hempel's gas burettes and pipettes. The gas is introduced into the burette A, and its volume measured by levelling the liquid in each tube (see *Fig.* 10). The burette A is attached to a pipette C containing a reagent for absorption of one of the gases, and by raising and lowering B the gas is driven into and out of C. When the absorption is complete, the level of the reagent C at D being adjusted the same as at the commencement, the volume of the gas is again measured as before and percentage decrease obtained.

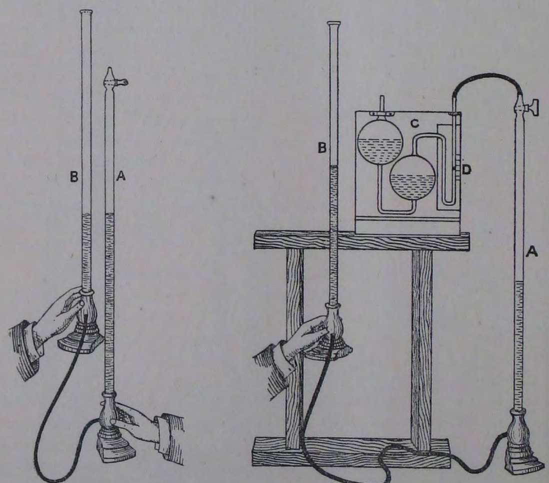


Fig. 10.
Gas Analyses.

APPENDIX III.

De Ridder's Flue-Gas Sampling Apparatus.

* A very simple and efficient apparatus for sampling and testing the waste gases from the flues of steam boilers has recently been introduced into this country in the form invented by De Ridder (*Fig.* 11). It consists of a cylindrical tank A, filled with water, on

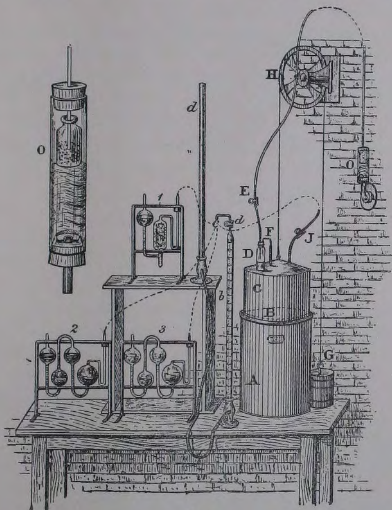


Fig. 11.

which floats a brass buoy B, completely covering the surface of the water, and so preventing the gas from coming into contact with the water; also of a receiver C, into which the gas is drawn from the flue

* Extract from the *Engineer* for June 18th, 1897.

by the action of the counterbalance weight G working over the pulley H, the gas having previously passed through the filter O, which contains spun glass to remove any soot or dust, and chloride of calcium in a small flask to absorb the moisture. From this the gas passes through a one-eighth copper tube, of any length, to a small bubbling flask D fixed on top of the receiver C; by this flask D the rate at which the gas is drawn off is made visible, and it can be regulated by the clip E; this flask also prevents the gas from returning to the flue when samples are being drawn off for testing. The gas then enters the receiver C by the tube F, and the apparatus is so arranged that a sample may be taken from the flue in a few minutes, or extended over a whole day.

The tests are made by means of Hempel's gas burettes *a* and *b*, and absorption bulb No. 1, containing a strong solution of caustic soda, which absorbs any carbonic acid gas (CO_2) contained in the gas sample, and the percentage of the same is at once seen by the reduction in volume of the gas when brought back from the absorption bulb to the graduated burette *b*. Tests for oxygen (O) and carbonic oxide (CO) are effected by means of the absorption bulbs Nos. 2 and 3 respectively.

PAPER IX.

LESSONS TO BE DERIVED FROM ENGINEERING WORKS IN GREAT BRITAIN.

BY MAJOR G. K. SCOTT-MONCRIEFF, R.E.

(*Lectures delivered at the S.M.E., on the* 30*th and* 31*st March*, 1898).

LECTURE I.

I HAVE been asked by the Commandant to give some account of the various works visited in the tours which it has been my duty and privilege to organize in connection with the Construction Course during the past four years, and especially to point out the differences which exist between modern practice and that which obtained, say, twenty years ago.

I think I shall be best fulfilling General Fraser's desire if, instead of devoting the time to a description of some few of the particular works which have been visited, I divide the whole subject into certain sections, and referring to the works visited under these sections endeavour to indicate how engineering practice has advanced in each case.

Before I do so, however, I should like to say a few words about the tours generally.

Engineering tours have formed part of the course of instruction at this school for a long time past, and I have in my office records and reports of these tours, from which, if one had the time, one might collate a very fair history of British engineering for the past fifty years or so. Of recent years, owing to changes in the organization of the Corps, the tours are more numerous, but each of shorter duration than was formerly the case. Some twenty years ago the Construction Course lasted for about seven months, one class of officers only was instructed each year, and in addition to the course a certain number of selected officers, under the guidance of the instructor and his assistant, went for a tour lasting at least a fortnight. On the conclusion of this they had a week to elaborate their report. Nowadays two classes of instruction take place annually, and for the purposes of the tour each class is divided into two parties, so that there are four tours undertaken annually instead of one, or at the most two, as formerly was the case. On the other hand the tours are now more limited in duration, ten days being about the average time spent on them. The officers have nowadays to make out their reports while they are on tour, and the result is that these reports do not compare favourably with those sent in formerly.

As the time is so limited, it is necessary to work as much as possible from some centre. These centres vary from time to time for obvious reasons. A few years ago Chester was a very good centre, as there were works going on in Wales in connection with the Liver pool Water Supply, also on the Manchester Ship Canal, etc.; but all these are now finished, so that is now of little use as a centre. At the present time Glasgow is a good centre, Cardiff is another.

The works visited are now limited, as far as possible, to those which are likely to have some reference to the probable work on which R.E. officers may be engaged in at home or abroad. They may be divided into the following heads :—

(*a*). Buildings, as Barracks, Hospitals and Workshops.
(*b*). Roads and Highway Communications.
(*c*). Production of Materials.
(*d*). Docks and Harbour Works.
(*e*). Water Supply and other Sanitary Works.
(*f*). Railways.

In this lecture I shall endeavour to touch upon the first four of these, leaving the two most important for discussion subsequently.

(*a*). Buildings.

The recent construction of barracks under the Barrack Loan Act has afforded officers, under instruction in this school, most excellent opportunities of seeing the details of this very important branch of their duty. Several of the tours have included Aldershot in their programme, and have found there the latest types authorized of every class of barrack under construction, and not only barracks, but all the necessary accompaniments of a large military station, such as rifle ranges, water-supply works, drainage works, hospitals, etc., so that the visits have been always full of varied interest and usefulness. I need not say much about the details of these works, as they are probably known to many here, nor need I dwell upon the kind attention with which we have always been received by Colonel Sir A. Mackworth and our other brother officers there, who, although very busy, have always devoted to us far more time than we had reason to expect. I think I may say, however, that the quality of the work there will bear favourable comparison with anything that we see in other places.

With regard to hospitals, two of the most important which have been visited of recent years are the Derby County Infirmary, and the Victoria Infirmary at Glasgow. The former has been built recently, almost regardless of expense, and may therefore be regarded as an ideal of what the latest experts consider a hospital ought to be. A full description of this hospital is given by Lieut.-Colonel Noel, R.E., in the Royal Engineers *Professional Papers* for 1894, but I think I may mention a few details here. We have recently had the advantage of lectures on Hospital Construction from one of our greatest English authorities, Sir Douglas Galton, and it may be interesting to see how far the construction at Derby is in accordance with the principles enunciated by him. One of the points laid down by him of importance was that the floors should be non-absorbent, and free from cracks in which dirt could lodge. At Derby the ward floors are formed of "terrazo" with no skirting. This is made up of a mixture of fine marble and cement, upon the top of which larger chips of marble are embedded. It is then worked down to a smooth surface by being rubbed backwards and forwards with sandstone. It is unquestionably smooth and non-absorbent, and no dirt can possibly lodge below it as is usually the case with wooden floors. The disadvantage of a somewhat cheerless appearance is reduced to a minimum by using the warmer colours of marble. This method of hospital floor construction is a new departure in English practice.

Another important point in connection with hospital construction is the supply of fresh air without creating draughts. At Derby there is a warming apparatus under every third window in the wards, consisting of three copper coils which can be used singly or altogether, at pleasure. Fresh air is admitted through a grating and passes over these coils, so that it is heated prior to admission to the wards. The coils are so placed that they may be cleaned easily when necessary. In addition to this method of warming the wards, there is placed in the centre of the ward a ventilating stove—two to each ward—supplied with fresh air from ducts passing under the floor from the outside. The smoke from these stoves passes down below the floor until it reaches the wall, when it is conducted up a chimney. This class of stove has been used in several military hospitals, but it has not proved satisfactory, as the smoke duct becomes full of soot; and at the recent addition to the Cambridge Hospital at Aldershot the smoke flue has been taken direct upwards and is enclosed in a tube of faïence ware, which is more ornamental in appearance than an iron pipe, and can be utilized to assist ventilation by being connected with the outlet for vitiated air.

At the Victoria Infirmary at Glasgow the subject of warming and ventilation has received entirely different treatment. The whole of the hospital is heated by warm air from a central source. At the basement of the building the air is sucked through two vertical fans, which impel $1\frac{1}{4}$ million cubic feet of air per hour. Before passing these fans the incoming air is filtered by passing through a revolving screen, $20' \times 10'$, of cocoanut fibre, over which a stream of water is slowly trickling. This screen arrests all particles of soot and dirt which may be floating in the atmosphere, and effectually prevents fog, and to a great extent dust, within the hospital. If desired, as for instance in winter, the incoming air is warmed to any degree by passing over heated coils of pipes before being forced into the building. Each patient is allowed 6,000 cubic feet of fresh air per hour, and the air in the wards is changed six times in an hour. The incoming air enters the ward through an opening 6 feet above floor level, and $2'\ 10'' \times 9''$ in area. The outlet is at the opposite end of the ward, at the floor level, and is $1'\ 0'' \times 1'\ 4''$ in area. The outlet communicates with a duct leading to a shaft at the top of the building, which terminates in a small wooden lantern, divided up into small apertures, fitted with flaps of American cloth, which act as reflux valves, preventing wind from blowing down the shaft.

Opinions as to the value of this system as compared with other methods of ventilation, are very conflicting. The nursing staff and the financial department are loud in its favour, because of the cleanliness, economy and absence of noise. Some medical authorities, however, are of opinion that patients do not recover so quickly in wards ventilated in this manner as in those ventilated by natural means.

Both in Derby and in Glasgow the lighting of the wards is by electricity, and is of course much more convenient, and more sanitary, than by any other means.

In all modern hospitals all the corners are rounded off, all the materials, in the corridors as well as in the wards, are of the hardest and smoothest nature, so as to leave in all parts no place where dust can lodge.

I now pass on to the consideration of workshop construction. Although the great shops of the various railway companies at Crewe, Swindon, Derby, etc., have been visited, and have afforded many instructive lessons, yet, I think, none has been of so much value, as an object lesson, as the recently built works at Rugby of Messrs. Willans & Robinson, designed by Captain Sankey (see *Plate* I.). These shops are situated close to the L. & N. W. R. They are worthy of study, both on account of the simplicity of arrangement as well as for the excellence of the materials used. The general arrangement will be readily seen from the plan, so that it is only necessary for me to say a few words about the details of construction. The shops are one-storied buildings, lighted by means of a weaving-shed, or serrated roof, with glass on the steep side, which is arranged to be in a northerly direction, so that an excellent soft light is obtained without glare of the sun, or glint on any metallic surfaces. The roofs are supported on light trusses of mild steel, which are supported on mild steel columns. The floors are of wood blocks. The only other wood in the buildings is the boarding for slates, but as this is separated into distinct portions by the arrangements of the trusses, it is considered that the buildings are practically fireproof. In order to deal with a fire, there is an efficient system of pipes and hydrants, the mains being 7 inches in diameter, and the branches 4 inches, and there is a tank above one of the buildings, capable of holding 80 tons of water, which is available for hydraulic purposes. The size of the fire mains and branches is most noteworthy, for as a rule fire service pipes are made so small as to be of very little use in event of a really serious conflagration.

The materials of which these workshops were built was chiefly obtained locally. The earth excavated for the foundations, etc., was burnt to ballast, some of it being used for concrete and some crushed, to be used in the mortar instead of sand. The cement was obtained at the Rugby Portland Cement Works, close at hand. This cement, I may mention, is manufactured by the dry process, and is of an excellent quality. The concrete was of five parts clean clinker, two parts sand, and one part cement. The mortar for the brickwork was made of blue lias lime and the sand from the crushed ballast, and was found to give far better results than ordinary pit sand. The bricks came from Kenilworth, and were very good. The steel in the roofs, etc., was supplied by Messrs. Dorman, Long & Co., who are well-known manufacturers. It will be thus seen that, with a few exceptions, the materials for these works were almost all locally procurable, and yet the work is of the very best.

(*b*). Roads and Highway Communications.

New roads are not now frequently to be found in Great Britain, at least of any length—of course a few chains of new road here and there are common enough. One of the most instructive examples of new roads seen in our tours is that constructed by the Glasgow Corporation along the line of their new aqueduct. This road traverses a somewhat wild mountainous region to the east of Ben Lomond, in Stirlingshire. There is nothing very remarkable in either its alignment or its construction, except that it exemplifies, as ordinary country roads seldom do, the principles of road construction in hilly regions, with which we are all familiar. It formed rather a striking contrast with the old road between Loch Katrine and Aberfoyle, from which it branches off, made, no doubt, many years ago, in which the gradients are steep and the alignment bad, and which is therefore neither good for traction nor for maintenance.

Even on this new road it is noticeable that in one place, where there is a steep descent to a valley, the road zigzags down the slope, in spite of the fact that text-books severely condemn zigzags as very indifferent engineering.

Although roads on such a scale are rarely found in Great Britain, there are many examples of highway bridges, and in some of these we find notable instances of new practice.

At the Rutherglen Bridge across the Clyde, near Glasgow, there are some interesting details of new procedure. This bridge was built to take the place of an old stone bridge which had been founded on timber piles, but which had become unsafe on account of the scour of the river having undermined these foundations. A temporary bridge had to be built to take the traffic, and that temporary work is in itself an instructive subject for military engineers, whose duties often include the construction of similar structures. A sketch of this is shown (see *Plate* II.). It will be seen that the greater number of the spans are 33 feet, with the exception of the central span, which is 59 feet, and is crossed by a light girder. The piers at either side of this span are double. As regards the permanent work (see *Plate* III.), the two most notable features are the method of constructing the foundations, and the design of the arches. The foundations were not constructed on piles, but on solid rock, 55 feet below H.W. level. Piles were first driven round the site of the pier to act as guides for a caisson or cylinder, into which compressed air was forced, on the principle of the diving bell. Inside this cylinder the workmen were able, first to excavate the soft soil overlying the rock, and, after the rock had been reached and prepared, to build up in solid masonry the lower courses of the pier. Such a method of construction is most stable, but it is expensive, and it therefore is of much importance to reduce the number of the spans. In this case the bridge was of three spans, the centre one being 100 feet, and the two side ones 90 feet each. The thickness of the arch ring was calculated to bear a traction engine and a marine boiler, in all weighing 80 tons, in the centre of the span, and a load of $12\frac{3}{4}$ cwt. per foot run all over. To find the thickness, a chain was made with weights corresponding to the uniform load, hung on the links, and the whole suspended on a vertical board from pegs whose distance apart corresponded to the span, and with a dip corresponding to the proposed rise. Other weights corresponding to the loaded engine were suspended at various points of the chain, and the new curve assumed by the chain carefully noted. The thickness of the arch ring was then drawn so as to include within the central third of its width all possible variations of the curves of the loaded chain.

This method, although practical, is, strictly speaking, only applicable to the case of an arch as free to turn about its springing as a loaded chain is free to turn about its points of suspension. It is not theoretically correct in the case of an arch built in the ordinary manner.

The centering for these arches was erected on piles, and then supported on wedges of greenheart, a wood selected not only on account of its hardness, but also because of the oily nature of the surface, which was found to lessen friction. The material for the arches was granite.

At the Broomielaw Bridge over the Clyde at Glasgow, recently reconstructed, and visited on one tour, the methods of constructing the foundations were similar to those described above.

At the new North Bridge at Edinburgh another novelty characteristic of modern engineering was met with. The old North Bridge was built in 1763 and consisted of four semi-circular arches of 75 feet span, built of sandstone. Of recent years the Waverley Railway Station, which occupies the ground below the bridge, has been largely increased, and it was found that the position of the piers of the old bridge interfered seriously with the station below, and also the gradients of the streets leading to the old bridge were inconveniently steep; so it was decided to rebuild it of steel arches with three spans each of 175 feet, 22 feet rise each. These steel arches *are free to rotate at their abutments*, as they terminate in steel circular blocks, working in a steel casting which goes across the width of the piers. The object of this construction is both to allow for expansion and contraction, and to enable the stresses due to moving loads to be calculated with more exactness, and to be met in the arrangement of the metal in the ribs. The roadway of the bridge is borne on a series of brick arches, which are carried by longitudinal plate girders, the weights on which are transmitted to the main arch ring below by T-iron verticals, suitably stiffened.

This work was carried on under peculiar difficulties, as it was necessary to keep the traffic going during the whole time of construction; so one half, longitudinally, of the work was done at a time, the half of the old bridge being kept open for traffic until the half of the new work was ready.

In addition to bridges as means of keeping communications open on both banks of a river, another means has of recent years been made use of, viz., by means of tunnels. This has certain definite advantages over bridges in the case of such important waterways as the Thames and the Clyde, as bridges tend to interfere with the river traffic, an interference which has been partially obviated in the case of one notable bridge—the Tower Bridge in London—by its peculiar construction. The difficulties attending the construction of tunnels under rivers, however, are very considerable, and the cost is great. Three of these tunnels have been visited on the tours from this school, viz., those for the Glasgow subways, the Blackwall Tunnel under the Thames, and the Waterloo and City Electric Railway now under construction.

In the Glasgow subways the tunnels are two in number, 11 feet in diameter, running parallel to each other; but in the Blackwall Tunnel the diameter is 25 feet. As this is the largest of these modern structures, a description of it will suffice to explain the principle on which all were constructed, although there were certain peculiar features in each case.

The sides of the tunnels are formed of circular segments of cast iron, encased in a grouted ring of Portland cement mortar, which performs the double function of giving additional security against the entrance of water, and of protecting the outer surface of the iron from decay. These segments of iron are secured together by being bolted together at flanges which project inside. In the case of the Blackwall Tunnel (see *Plate* IV.) these segments were 6 feet long by $2\frac{1}{2}$ feet wide and 2 inches thick. They were bolted together by four bolts at each joint. This is of course the finished lining of the tunnel; but to enable the work to be carried out it was necessary to provide some temporary security both for the work of excavation, and to enable the workmen to build up the permanent lining. This temporary security was attained by the use of a shield resembling the cap of a telescope, of a diameter somewhat larger than the finished lining, and pushed forward by means of 28 rams worked by compressed air, situated all round the circumference, and worked in pairs. The front of the shield was divided into four platforms, in which the men worked. The whole of this work was carried out by means of compressed air forced into the working, and entrance being made by an air box, which in some cases was not only sufficient to prevent the water from the river above from swamping the work, but actually to dry the sand through which the tunnel heading was being driven. In the Blackwall Tunnel the strata passed through are indicated in the section, and it was interesting to see at the head of the work the various layers of deposit which had been brought down by the river during long ages. Every precaution was taken to enable the workmen to escape in safety should any sudden inrush of water take place. At the back of the shield there was a door which could be shut and exclude the water from the whole of the working in rear, and the mere fact of the working being full of compressed air was considered a safeguard against a man being suddenly overwhelmed. As a matter of fact, no accidents were experienced.

The finished section of the work is shown in the drawing. (*Plate* IV.)

(*c*). Production of Materials.

I have named this section *production* rather than *manufacture* of materials, because there are some materials which do not require any manufacture, but which may of recent years have become better available for the purposes of the engineer, owing to increased facilities of production. Such are timber and stone. But with regard to these we have learnt little that is new in the tours. It is true that foreign timbers are beginning to be more used in this country than they were formerly, but the methods of their production are not such as we have had any opportunity of witnessing. As regards stone, the only difference that obtains of recent years is that which arises from the introduction of new explosives, and these, indeed, are but sparingly used in quarrying operations, so that under this heading we have little new to report.

In brick and tile manufacture there is also little new to report. The advance in sanitary science has caused more attention to be paid of late to the proper construction of glazed stoneware pipes, and similar articles, but in this there is little that calls for detailed mention in such a lecture as this.

In the manufacture of cement there has been notable advance of late, and some description of these improvements would have been most apposite to my present purpose; but we have recently had the advantage of a lecture from one of the best authorities on this subject—Mr. Carey—and so I think it is unnecessary for me to say more.

When we come to iron and steel, we find ourselves face to face with by far the most important innovation of modern times in connection with the materials of the engineer. The recent death of Sir Henry Bessemer has caused attention to be specially directed to his great invention, and to the subsequent modification of manufacture of steel direct from pig iron known as the *open hearth* process.

Evidence of the great changes in engineering caused by the cheap manufacture of steel have met us at every point in our engineering tours. Where wrought iron was formerly used in bridge and roof construction mild steel is now universally employed. Where cast iron was formerly used in the compression members of trusses, steel bars or angles are now substituted, and even in columns, which might be naturally supposed to be built of cast iron, as the metal is under simple compression, steel is now substituted, built up in forms suitable for resisting the peculiar stresses induced by direct thrust. The cast-iron girder, which until comparatively recent times was considered a very suitable form for floors and bridges, is now as much out of date as cast-iron artillery, and in general the use of cast iron as a material for structures is now limited to certain unimportant details, although in machinery its use is still ever increasing.

Comparing the various methods of steel manufacture, there is no doubt that the Bessemer process, whereby all the carbon is first expelled out of the pig iron, and a certain quantity is then re-introduced in a charge of ore rich in manganese, is less homogeneous, less under control, and less reliable, than the open hearth process, wherein the metal is continually subject to chemical test and supervision, so that the removal of the carbon from the pig iron can be arrested at the exact time when the proportion is best for the purposes of the steel required, thus ensuring a more exact and homogeneous metal than is possible under the other process. It has thus happened that all the accidents which have occurred in steel structures have taken place with Bessemer steel.

Bessemer steel is, however, cheaper than Siemens-Martin steel, and is almost universally used for rails, while the latter is used for roof and bridge work.

Another important modification of engineering consequent upon the introduction of steel and the improvements in rolling mills is the limiting sizes of market sections, which are now much larger than used to be formerly the case. A few years ago the limits of wrought-iron plates were 15 feet in length, and 24 square feet in area. Nowadays steel plates 50 feet in length, and with a maximum area of 250 square feet can be obtained, so that in built-up work not only is the material better than formerly, but the weakness and expense caused by a multiplicity of joints is to a very great extent avoided. Those firms who make the manufacture of steel bridges a speciality find no practical difficulty in getting plates as long and as broad as they require.

The Harvey process of hardening steel, whereby a skin of extremely hard metal is formed on the surface, is another of the features of modern metal manufacture. This process consists of subjecting the steel at a white heat to the action of a number of jets of water, thus forming a series of minute and dense crystals over the whole surface. This process is, however, little used in structural work.

(*d*). Docks and Harbour Works.

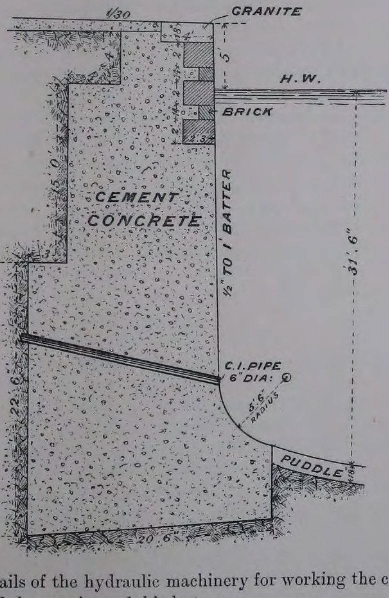
Of all the docks now under construction in the United Kingdom perhaps the most important are the Barry Docks in South Wales. Barry is a small island in the Bristol Channel, about 9 miles west of

Cardiff. It is separated from the mainland by a very narrow channel, and it occurred to some enterprising persons that if this narrow channel could be converted into basins, connected by locks with the sea, of sufficient depth for vessels to enter at all times and states of the tides, considerable advantage would be gained. The reasons for this advantage are that the site is close to the mineral fields of South Wales, and that the range of the tide in the Bristol Channel is so great that it frequently happens that vessels are kept out of Cardiff Docks, owing to want of depth in the approaches, for several hours. These natural advantages in the case of the Barry Docks have been so improved that now a flourishing seaport has sprung up, and is still rapidly increasing. In 1884 the population was 100—it is now 25,000.

As will be seen from the plan (*Plate* V.), the entrance to the docks is at the eastern end, sheltered from the westerly winds by the island. From the south and south-east little damage is expected from storms, but protection is afforded by breakwaters. The water-way between these is large enough to admit the largest vessels, and the entrance channel is being deepened, so as to improve the approaches. This deepening is an interesting operation, and a little description may be appropriate here. A barrel pier raft is floated over the spot where the rock is to be blasted, and is there moored. A 3-inch C.I. pipe is then let down and its end pushed into the soft mud. Rock drills worked by compressed air are let down the 3-inch pipe, and holes drilled in the rock to a depth of about 12 feet. The drill is then withdrawn, a pole of wood temporarily inserted to prevent the mud from filling up the hole, and then the charge, 12 lbs. of tonite (a nitro-cellulose compound, something like blasting gelatine), inserted. The charges were fired by electricity, much in the same way as we are accustomed to do in our field demolitions. When the charge was ready for firing, the raft was warped away to a little distance—there was very little commotion on the surface caused by the explosion.

There are two entrances to the basins, one of which is available at any time of the tide. This lock is 647 feet long, 65 feet wide and 60 feet deep. The acreage of the dock now in use is 70 acres, and there is another dock under construction of 45 acres. The shipment of coal is a most important matter in connection with these docks. All round the basins are constructed coal tips or shoots—26 in number, each capable of lifting 20 tons. Communicating with these are railway sidings, on which the trucks can be brought direct, with their freight of coal, on to the tips. All the tips are provided with weighbridges, one on the "full," one on the "empty" road, so that the weight of coal put on board can be measured exactly. As much as 1,900 tons of coal have been loaded in a steamer, which has entered and left the docks on the same tide, when, if it had had to go up to Cardiff, it might have been waiting outside for a favourable depth of water to get in.

SURREY COMMERCIAL DOCK.
Section of Dock Wall.



The details of the hydraulic machinery for working the coal shoots are beyond the province of this lecture.

I need not point out the importance, from a national point of view, of a place such as this, where the coaling of ships of war could, if necessary, be carried out so expeditiously. The defences of this place have been considered concurrently with the development of the works.

As regards the details of construction, the stone for the masonry has for the most part been obtained from quarries within a short distance—four miles. The foundations appear to have given little difficulty, the soil being either red sandstone or marl. In two places, owing to faults, it has been necessary to drive piles, and under the engine house for the hydraulic machinery the foundations consist of a block of concrete 25 feet thick.

Another important piece of dock work visited recently was the enlargement of the Surrey Commercial Docks in London (see *Plate* VI.). These docks are not, like the Barry Docks, a thing of yesterday. They were begun in 1694, and additions have been made from time to time during the last 200 years. In 1894–96 it was resolved to amalgamate some of these small basins into one large central basin, having an area of 21 acres. The ground has a section somewhat as follows:—Clay 6 feet, peat 2 feet, silt 4 feet, and sand and gravel below that to a very considerable depth. The dock walls were made of concrete of section shown in diagram. The material was obtained from the excavated sand and gravel, which was clean and good, mixed with Portland cement, in the proportion of from nine to one in the interior (sometimes eleven to one) and five to one in the faces. The depth at which the excavations were carried out was 38 feet. Whether mass concrete is a good material for dock walls I am not prepared to say, but it was the case that cracks had appeared in the work at the time of our visit. The locks connecting the various docks are 30 feet wide, and are of concrete faced with granite blocks.

Another dock of some importance, now under construction, is that at Methil, on the north shore of the Firth of Forth. This, like Barry, is a work that has sprung up of recent years, owing to increased coal traffic in Fife. The works consist of a basin $713' \times 405'$, and a sea wall 1,000 feet long. The tide has a rise and fall of $16\frac{1}{2}$ feet. The soil is rocky, somewhat disintegrated near the surface. The line of maximum exposure is from the south-east. The work of construction of the sea wall was most instructive. The foundations were in the rock some $4\frac{1}{2}$ feet below the natural surface. The clearing of the unsound rock was carried out by means of divers, one of whom was continually employed. The material of the wall is concrete in mass, the proportions being one cement, two sand, four stone. It was deposited at low water, and, in order to prevent the sea water from washing out the cement, the work was protected by wooden shutters placed against wooden trestles, temporarily placed for a little distance ahead of the finished work. Every precaution was taken to have the new work well keyed to the old.

Another very important piece of work now under construction is the new pier at Dover. The general idea of this harbour is to have at the inshore end an open viaduct of ironwork for a distance of 1,260 feet, and a length of 1,500 of solid masonry at the end of this. The object of the open work at the inshore end is to give a free circulation of water in the harbour, and as the tide flows from the east, it will tend to prevent deposits at the sheltered end. The piers at the open end will consist of three wrought-iron piles braced together. The foot of each pile is screwed into the bed of the sea, and tested with a weight of 100 tons. The superstructure will be carried on these piles by means of three lattice girders, above which there is trough decking filled with concrete, and the roadway is blocks of wood, the total width being 30 feet. The remaining portion is, as shown in *Plate* VII., a solid mass of concrete, 50 feet broad at bottom, with 25 feet roadway at top, the foundations going 3 feet into the chalk bottom. The concrete is built up of large blocks of varying size.

LECTURE II.

(*e*). Waterworks and other Sanitary Engineering Works.

Of all branches of civil engineering none has advanced more of recent years than those works which concern the impounding of water for the supply of large towns, the conveyance of the water to the point of supply and its control during its course.

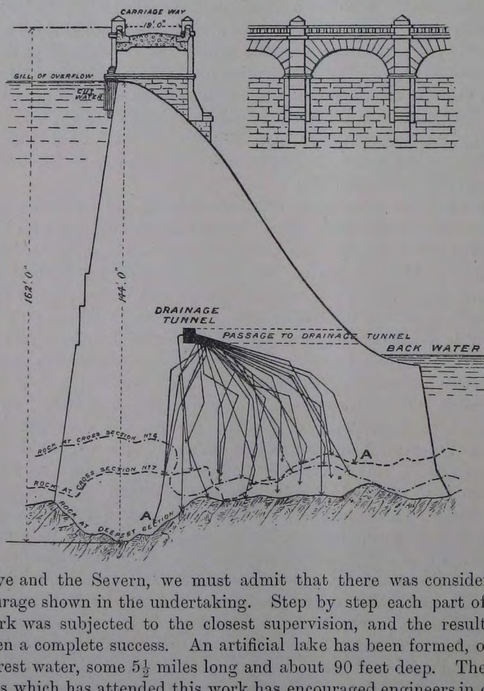
Some forty years ago the impounding reservoirs in this country, and indeed throughout the world, were constructed by means of earthen embankments. A wall of clay was constructed from the surface to some water-tight stratum below, and then on the surface an embankment was formed in which there was a core wall of puddled clay, supported on either side by earthen layers. This embankment was constructed in some valley where the length, as ascertained from the configuration of the sides, was as little as possible, and the ends of the embankment were constructed so as to be so united to the natural ground on either side that no water should turn the flank of the work. These earthen embankments are still constructed in many places, where, owing to the nature of the strata below, a masonry dam is not considered suitable. For instance, the water supply of Cardiff is obtained from reservoirs impounded by earthen embankments in the Brecon Beacons, and a large service reservoir, with such embankments, for the supply of Glasgow has recently been finished at Craigmaddie, some eight miles from that city. But inasmuch as the impounding reservoirs of this description are generally made in hilly districts, so as to secure as pure and as soft a water as possible, and as these districts are as a rule of the older geologic formations, it is usually possible in such sites to obtain good foundations for masonry dams, which are now a feature of modern waterworks engineering.

In an earthen embankment the safety valve of the whole is the waste weir over which the surplus water passes in time of flood. If this weir be too small for the work it has to do, or if there should be such weakness in its construction that it is undermined by the action of the overflowing flood, the safety of the embankment, and the lives of the inhabitants in the valley below, are seriously imperilled. Again, if the water should find its way into the puddle trench, and work out to the lower side of the embankment, the effect of its action will be to remove the clay little by little and to increase the breach, with possibly serious results.

So we find that even where earthen embankments are used modern practice has tended to use concrete rather than puddle for the trench, as being more reliable than clay. It is, of course, more expensive per cubic unit, but then this disadvantage is met by the diminished width of the wall when constructed of concrete.

In all modern embankments the waste weir is made of considerable length ; it is constructed of the hardest and best masonry, and it is situated at the end of the embankment so that it may be founded in natural ground. The outlet pipes used formerly to pass through the embankment, but modern practice generally takes them entirely clear of the work, and, in event of this not being possible, takes them through the natural ground at one side. Failures of earthen reservoirs have generally been caused by one or other of the points alluded to above, and when they have happened, the terrible devastation that has ensued has been such that most careful examination of all new embankments for some time after their completion has always been necessary. One of the most instructive failures of modern times was that of the embankment impounding the supply for one of the largest manufacturing cities in the north of England. The puddle trench was taken in the first instance to a depth of about 80 feet—the stratum into which it was taken was the millstone grit sandstone, which, though full of fissures near the surface, was considered sufficiently safe at a depth of 80 feet. After the reservoir was filled, it was found that a considerable leakage took place, and although this was considerably checked when the level of the water was lowered, yet it was evident that something serious was wrong. Temporary measures proved unavailing, and at last it was decided to make an examination of the foundation, and, if possible, discover the cause. It was found that the water had found its way, by means of a fissure, round the puddle trench, and was steadily washing out the clay. Ultimately it was decided to reconstruct the trench, taking it down to a depth of 160 feet, of course at enormous expense.

Although the construction of puddle has not, as far as I am aware, been altered during recent years, very considerable changes have been contemplated by some of our leading engineers in the construction of concrete. Mr. G. F. Deacon, who is the chief exponent of these new views, is now building two masonry dams, one in Wales for the supply of Merthyr and one in Cumberland, of concrete, in which Portland cement is not the binding material. He is of opinion that hydraulic lime, when properly ground and carefully mixed, produces as good, if not better, results than Portland cement, and he has arrived at this conclusion after a series of most exhaustive experiments. Mr. Deacon's opinion is the more worthy of acceptance in that he is the engineer of perhaps the greatest masonry work in the world—the Vyrnwy dam in North Wales. This was one of the first of the great masonry dams for municipal water supplies built in Great Britain. Prior to about 1850, masonry dams had been little used anywhere for the impounding of water, and the few that had been built in Spain and Italy were constructed on very unscientific principles. How French engineers first took the matter up, and built colossal dams upon careful data, how their theories were improved upon by Professor Rankine and other scientists, how the confidence of the public in earthen dams was shaken by the failure of some in England, would be a very interesting study, but would be foreign to my present purpose. It is sufficient to say here that during the last 20 years, wherever it has been possible, masonry dams have been used instead for impounding water rather than earthen ones. The feature that gives the Vyrnwy dam pre-eminence above all others is this, that it was deliberately designed with the intention of passing the surplus water over the crest of the dam. In so designing it, the engineers had to face the possibility of the falling water so scouring the foundations on the down-stream side as to imperil the safety of the whole work. When we consider that the work was situated in the uplands of Wales, and that if failure occurred it would mean disaster down the whole valley of the



Wye and the Severn, we must admit that there was considerable courage shown in the undertaking. Step by step each part of the work was subjected to the closest supervision, and the result has been a complete success. An artificial lake has been formed, of the purest water, some $5\frac{1}{2}$ miles long and about 90 feet deep. The success which has attended this work has encouraged engineers in other places to follow the same lines in the designs of masonry dams. It is true that, compared with the section of Vyrnwy, a certain amount of economy has been introduced into the designs of recent dams, but the Vyrnwy type is being followed in the case of all that, as far as I am aware, are now under construction. I think that dam may fairly claim to be an engineering feat of the very highest order, and worthy to be classed with the greatest achievements of the engineers of the Victorian era.

Reverting to the dam which Mr. Deacon is now building for the supply of Merthyr, and which, as I stated above, is being built in hydraulic lime, the maximum depth of water to be impounded is 70 feet. The dam is situated in a valley of the Brecon Beacons, some 10 miles from the town of Merthyr. The material of the dam is concrete, in which are embedded immense blocks of stone. The method of the manipulation of the concrete is worth describing. The lime—obtained from Aberthaw—is first slaked in the usual manner. It is then crushed fine in a trough with a rotary motion, the object of this treatment being to eliminate any coarse inert particles, which might afterwards be a source of weakness. After settling, the finely ground lime is mixed with sand—not sand as found in a natural state, but crushed rock. The mortar thus formed is then mixed with broken stone of size small enough to pass through a 2-inch ring, and then conveyed to the site, where it is deposited in layers not more than 3 inches thick, and after being deposited, these layers are rammed as tightly as it is possible to ram them by means of special implements. It will be noticed that this procedure is quite different from that followed usually in concrete, where the cement is mixed with a certain quantity of shingle (*i.e.*, sand and gravel of irregular proportions); water is then poured upon it when it is being mixed, and the whole is deposited without any ramming. By Mr. Deacon's method the lime is first ground with water, sand is then added, making it into mortar, then the stone is mixed with it, and finally it is rammed *in situ*. The resulting concrete is almost of the same specific gravity of the materials of which it is formed.

A series of large and important dams are now under construction for the water supply of Birmingham. These works are situated in the valley of the river Elan in Radnorshire, and at present there are four dams of the Vyrnwy type under construction. These dams are all being made of Portland cement concrete, with blocks of stone embedded. The Corporation of Birmingham have the right to construct three dams besides, in event of the city requiring an increase in its supply.

An interesting feature of these works is that none of it is being done by contract, all the workmen are employed and paid by the resident engineering staff. This system has been found to work very well.

The works include not only the construction of the dams, but the construction of a temporary railway from Rhayader, some three miles below the lowest dam, to the highest dam, several miles up the valley. At the time of our last visit to these works, no fewer than four dams were in progress. In addition to the railways, there are ordinary roads and bridges. Of these one of the most noteworthy is a suspension bridge over the Elan.

The workmen are accommodated in a model village near the lowest dam. This village is built of wooden huts, with quarters for single and for married men, hospital, school, recreation room, canteen, baths, etc., all very complete, and all under the rule of an ex-sergeant of a line regiment, who rules his little kingdom with benevolent despotism. This village has its own water supply, with a small impounding reservoir and concrete dam situated in the adjacent hill. In connection with this there is a very well organized system of fire protection, under the command of the village superintendent above mentioned.

The details of the huts are well worth studying, but time hardly permits me to mention more than one detail, viz., an expedient for the spanning of some of the larger rooms by using semi-circular trusses, built up of planks about 8 inches deep, and in lengths of about 4 feet, each truss consisting of three or four of these planks, arranged so as to break joint round the circumference of the semicircle. In this way a cheap and very effective truss is obtained.

The works for the conveyance of the water from the impounding reservoir to the town are frequently of much interest. Wherever it is possible "cut and cover" work is adopted, *i.e.*, where the water is conveyed through a channel of a depth not so great as to necessitate tunnelling, where the channel can be excavated, the sides lined with concrete or brickwork, and the roof arched over. If this class of work were feasible it would be adopted everywhere, and the only difference would be that in some places the lining would be of one material, and in other places of another. On the Birmingham water supply the lining is of Staffordshire blue bricks, some of which are specially moulded, while on the Edinburgh waterworks the sides are lined with concrete with centering formed of movable iron frames. Of course, it would nowhere be permissible to leave the channel open to the air uncovered.

The natural slope of the ground however does not permit this simple method of dealing with the aqueduct to be adopted everywhere. In some places mountains have to be tunnelled through, in other cases valleys have to be crossed. The tunnelling is necessarily a work of extreme nicety. Some of the tunnels now under construction are of great length; one on the Birmingham line is some four miles long, though in this case it is possible to attack it from several shafts. Another on the Glasgow Works goes straight through the mountain dividing Loch Katrine from Loch Ard; here it is only possible to work from both ends, and the work will not be finished for some years yet.

The crossing of valleys is still done in this country by means of cast-iron pipes, with careful arrangements for closing the supply in case of a burst. Steel pipes have not, as far as I know, been used in this country.

The works for the increasing of the water supply of Glasgow are of a very instructive character. Glasgow is fortunate enough to have at a short distance (some 22 miles) a natural reservoir—Loch Katrine—of the purest water, situated at a sufficient height above the level of the city to enable the water to be brought in by gravity. The first works for the bringing in of Loch Katrine water to the city were constructed in 1853–59, and were formally opened by the Queen in the latter year. Since then the population has largely increased, and it was found necessary to have another channel or aqueduct. Since the old aqueduct was made the science of hydraulics has become entirely revolutionized by the researches of D'Arcy, Kutter, and others; it has been found, for instance, that the condition of the sides of a channel has a very marked effect on the quantity discharged. The old aqueduct never supplied the quantity it was calculated to do, partly because the tunnels were largely left with their sides rough, and partly because the alignment was not the best that could be devised. The new and the old work taken together form a very instructive object lesson, and I may here touch upon a few of the points of difference. In the crossing of small ravines, water-courses, etc., for instance, the old aqueduct was carried in tubular girders of wrought iron resting on masonry pillars. The tubular girder, 40 years ago, was considered to be very good engineering, and we see examples of it in such works as the

Britannia Bridge over the Menai Straits. But it is never used nowadays. Modern practice always works in the direction of substituting masonry for ironwork wherever it is possible to do so. In the new Glasgow Aqueduct these crossings are effected by means of concrete bridges faced with granite. As these bridges are situated, for the most part, in wild and inaccessible glens, the periodical repairs which are absolutely necessary in the case of iron bridges, and which involve the greater expense on account of the difficulties of the site, are wholly avoided.

I now come to say something about these works in connection with water supply more in the immediate vicinity of the towns:—service reservoirs and filtering arrangements.

I have already alluded to the Craigmaddie reservoir for the supply of Glasgow. This reservoir is calculated to hold a fortnight's supply for the city, to be available for use in case of repairs to the aqueduct between it and Loch Katrine. In connection with it there are accurate arrangements for gauging the quantity of water flowing in. As the quantity flowing out of Loch Katrine is carefully noted, a comparison of the two records indicates whether any leakage is taking place in the aqueduct. The method of gauging is as follows:—The water is admitted into a series of basins connected with each other in such a way that in the last of them the water is practically quiescent, and any sensible velocity of the surface eliminated. At the end of this basin it flows over a notch of known length into a channel below and the depth of the water over the sill of the notch is accurately noted. By a simple application of hydraulics the quantity flowing over the notch is at once determined from the area and the depth.

Loch Katrine water is so pure and so soft that it requires neither filtration nor any other treatment before delivery to the city. This state of affairs rarely happens in the case of town supplies, and filtration arrangements are usually a necessary item in the works which have to be constructed. The principles of filtration have been already explained recently by Dr. Frankland, and all that is necessary for me to do is to give some examples of how such principles have been carried into effect. I take for instance the filters of the East London Waterworks, situated near Tottenham, the supply being obtained from the River Lea. The filter beds are about one acre each in extent and there are 25 of them at present in operation. The filtration takes place through $2\frac{1}{2}$ feet of sand, 9 inches of fine ballast, and 9 inches of coarse ballast. Two of the 25 beds are cleaned every three days. It takes about $1\frac{1}{2}$ days for the freshly cleaned filter to get into working order, *i.e.*, to obtain that jelly-like substance which is of so much importance in arresting the passage of organic matter. The cleaning of the filter becomes necessary when the quantity of the water flowing through in a given time is materially diminished. For instance, the normal rate of filtration is one million gallons per acre per 24 hours with a head of $3\frac{1}{2}$ feet; but after the filter has been for some time in operation, the amount that is passed is so very much less than this that it is necessary for practical reasons to increase the out-turn, and to effect this the filter is cleaned by about $1\frac{1}{2}$ inches being scraped off the top. The sand so scraped off is full of minute organisms which, but for the inconvenience caused by the slow rate of flow, might be left with advantage to continue their beneficent work of purifying the water. The sand is washed, and used over again. The bulk of the filter is never disturbed.

The East London Waterworks have recently completed new service reservoirs capable of holding 1,240,000,000 gallons. The experience of this company emphasizes the fact that in all municipal water supplies it is absolutely necessary to make provision for the probable requirements of the future, as well as for the pressing needs of the present, and that it is not only the duty of the engineer who designs the work to make expansion possible and easy, but it is also the duty of the municipal authorities constantly to consider whether the time has not arrived to commence new works to cope with future demands. It is not possible to build a large service reservoir in a few weeks or months, and hence it is not permissible to wait for the need before applying the remedy; the remedy must be applied to prevent the need.

I have little to say about other sanitary engineering works, not because the subject is unimportant, nor because it has not received its due amount of attention in the tours. On the contrary, the science of sanitary engineering is the most recent of all branches of construction, and it is one which we have, of recent years, devoted very special attention to in this school, and in the tours which are now under review. The reason why I prefer to say little about the matter is that of late we have had the views of some of the best authorities on the subject, and those views are still far from being unanimous. The subject of sewage disposal, for instance, a few years ago could broadly be divided into two divisions, irrigation treatment, and chemical treatment. Of late a third method has arisen which is by its advocates, considered better than either, viz., biological treatment. It is hardly possible for one who has not devoted much special study to the subject, to say which is best. In our tours, we have sometimes visited both the former methods of treatment, and to our unsophisticated judgment both appeared to be very satisfactory.

Visits have also been frequently paid to the sanitary museums, which are nowadays frequently to be found in various places. The best of these (as far as I know) is the Parkes Museum in Margaret Street, London. At this institution there are to be seen all the very latest appliances in connection with all branches of modern sanitation, and the curator of the museum is most obliging in expounding the principles which each illustrates.

(*f*). Railways.

Although the greater number of railways are built on the 4′ 8½″ gauge, there are a few places in Great Britain, especially in Wales, where other gauges may be met with. At Portmadoc there is the 1′ 11½″ gauge line for the traffic with the slate quarries at Blaenau Festiniog, a line which has been successful chiefly because the bulk of the traffic is all down hill, and requires very little haulage. This line is of special interest to us because this is the gauge which has been fixed by the Government of India for the light lines on the North-West Frontier. Then there is the Snowdon railway on the Abt system, common enough in Switzerland, where there is a central rack between the rails. This system is laid at the ordinary gauge, the steepest gradient is about 1 in 15, and the sharpest curve 10 chain radius.

For the most part, however, railways in this country are of the ordinary gauge, and a visit of one or two days to such a line under construction forms part of every tour.

The most important railway that has been constructed in Great Britain of late has been the Great Central Line from Yorkshire, through Nottingham, Leicester, and Rugby, to London. This line, being intended for much heavy and fast traffic, has been designed with easy gradients and wide curves. The cuttings and embankments are in many cases of great size, the viaducts and bridges of the hardest materials, and the permanent road of the soundest construction. For our purposes some of the other lines, such as the West Highland, the Vale of Glamorgan, or the East of Fife Central, are more suitable, because, although the work is very sound, it does not partake of the colossal character of the Central Railway, and is more like the railway work which we may have to do.

Comparing railway construction in this country with what was customary some years ago, we see that, in the first place, machinery plays a more conspicuous part in the work of excavation and of constructing embankments than it used to do. Wherever the soil permits the excavation is now generally carried out by means of steam navvies. These can dig out at one scoop a cubic yard of earth, which would take a navvy about an hour to excavate. Then the laying of temporary lines with light engines and tip waggons has increased the facilities with which embankment work can be carried out.

In the West Highland Railway, which, I may mention, was constructed with special reference to the tourist traffic, and, passing through some of the most beautiful scenery in Scotland, was made with the smallest possible amount of cuttings, we have a line which is a specially useful study for R.E. officers, the hasty nature of whose work will often not permit of much time and labour being spent on earthwork of a heavy description. The cuttings on this line were, for the most part, through whinstone, an igneous rock, with very irregular planes of cleavage, difficult to work, and necessitating much blasting. This rock was not of much use in masonry, except of the roughest character, as in retaining walls, drains, etc. The embankment across the Moor of Rannoch was very interesting. Drains laid parallel to the line were, for a certain length, effective, but in the softer parts of the peat-moss the site on which the embankment subsequently came was first drained across, the drains covered with flat stones, and then the embankment floated on brushwood. This is by no means a new method, but there are few places in England where such a construction is necessary. No doubt a considerable amount of extra ballast will be required for some years to come to maintain the line in proper order.

In the West Highland line it is noticeable that every little watercourse is crossed by a fair-sized culvert, which at first sight seems to be extravagant but is really a wise precaution, because in winter the melting snow causes the discharge to be in every case considerable. All minor masonry structures are built of random coursed rubble, of stone obtained from rock cuttings (*Fig.* 1, *Plate* VIII.).

Another instructive line in mountainous country, visited in one of the tours, is the branch of the Highland line between Grantown and Inverness. Among the various masonry works on this branch the most interesting is a bridge across the valley of the Findhorn, a river that is notoriously liable to sudden floods. At the point where the railway crosses it the river is very changeable in its course, and therefore difficult to deal with. The viaduct (*Figs.* 2 and 3, *Plate* VIII.) consists of 9 spans of 130 feet, or a total length of 1,336 feet, and the greatest height above the valley is 143 feet. The line here is on a curve of 2,600 feet radius, and on a gradient of 1 in 60. These conditions made construction work of peculiar difficulty, and in addition there was trouble with the foundations of the two piers lying on either side of the river. The other piers were founded on hard clay, but in the case of the two mentioned there was a bed of quicksand 25 feet deep overlying gravel. These piers were therefore built on piles 40 feet long, $12'' \times 12''$ in section, and at 3-feet centres. The machine used in driving these piles was similar to that used recently in Chatham Dockyard for a like purpose—that known as Lacour's. The piers themselves were built of Aberdeen granite in cement mortar, 3 to 1, and in the foundations 4 to 1. The spans were steel lattice girders erected in a somewhat novel and interesting manner. The roadway of the bridges was carried on the upper booms of the girders. Between these girders in the box formed by the roadway above, the wind bracing below, and the lattice work at the sides, was a movable staging made of wood and iron, sufficiently long to reach across $1\frac{1}{2}$ spans. This staging had on the outside two movable flaps or shelves, which could be lowered to occupy a horizontal position at right angles to the girders, of which the staging was composed. On these shelves the true girders were built up, and when one pair was completed, the shelves were withdrawn, the staging then boomed out till it spanned the next opening, and the operation repeated. There were special arrangements for preventing the staging in its passage forward from damaging the completed work, either below (in the initial stage of its progress) or above (when it had got so far forward that the end tended to sag down and tip up the rear part against the lower side of the upper boom). As the viaduct was on a curve, special arrangement had to be made for slewing the end of the staging when it reached the next pier, so that it might occupy the proper position of the chord of the arc in the new span. The holding-down bolts for the girders were 2 inches in diameter, and 14 feet 7 inches long, built down into the solid masonry. When it is considered that the bridge is on a curve, and that the roadway is on the upper boom, it will be seen that there is an enormous bending stress coming on these bolts, and that the size of them is not by any means too great. One end of the girders is fixed, the other rests upon steel roller bearings. The weights of the girders are 180 tons, the total load per span being 900 tons. The piers are made for a double line of line, though the girders, cuttings, and embankments are at present all for a single line. If the line should ever require to be doubled there will be no difficulty in doing so, though if the piers had all been made for a single line the widening of the masonry would be both tedious, costly, and unsatisfactory, as the new work would not bond well with the old.

Another interesting bridge on this line is at Aultnaslanach. Here the line has to cross some very treacherous ground, soft moss over very hard gravel. It was quite impossible to make an embankment, as the moss simply spread outwards in huge waves. After carefully considering various forms of construction, it was decided to use a wooden bridge, cross-braced all over—an interesting fact, for it shows that even in this country, where timber bridges are to a very large extent superseded by masonry, or else by iron or steel, timber still has its uses. This is especially instructive for R.E. officers, whose duties necessarily take them to countries where timber is much more easily available for such work than any other material. This bridge consists of 5 spans, each of 25 feet. It is of the ordinary strutted type, and, as will be seen from the diagram, the timber work is very heavy throughout (*Figs.* 1 and 2, *Plate* IX.).

With regard to tunnels, there is little that is new in modern practice. Improvements in instruments and in machinery make it nowadays possible to work long tunnels from both ends only, instead of from both ends and several shafts, as was at one time necessary. Usually a "heading," or opening, about 8 feet square, is driven from end to end of the proposed tunnel, generally in English practice at the bottom of the full opening. This is afterwards enlarged to full size and lined. In some cases—for instance, in one tunnel which we saw under construction on the Vale of Glamorgan Railway—the tunnel is taken out to full size at once. Locomotive engines have now been devised of such a size as to be able to go inside the headings and bring out the excavated material.

The masonry of the larger bridges on the W. Highland line was made of concrete. The gravel and sand for this was obtainable from the streams on the spot, and the cement was brought up from the base. This method of construction is one that can frequently be adopted with success in mountainous districts.

With regard to minor bridges and culverts, the old-fashioned type of wing wall was what is known as the "box" type. This is now very largely superseded by the type in which the wing walls are splayed. Wherever possible these bridges are made with masonry or brick arches in preference to girders, as the former require no annual outlay for maintenance; but it is not always possible to have this form of construction, because of the extra headway necessary for the arches. Where an extensive viaduct has to be carried across a valley it is always preferable to construct a series of arches. The methods for supporting the centerings of the arches in these viaducts are often most ingenious and instructive. As soon as possible after the centerings are in position a temporary line is laid to each arch so as to facilitate the bringing up of the materials (*Plate* X.).

Where iron work is necessarily used in minor bridges there are many methods of supporting the roadway. Formerly it was customary to have cross girders with jack arches between, a method which is still largely used. But there are several other methods now common, the most common of which, perhaps, is trough girders, which indeed are sometimes used without any main girders at all.

It is probable that in the near future concrete with iron or steel rods or bars embedded in it will be more largely used than even these plates.

Perhaps the most ingenious and difficult piece of engineering that it has been our lot to see during the tours was the construction of the Glasgow Central Railway. The object of this line was to afford through traffic between the large mineral fields to the east of that city and the outlet to the ocean on the west. Part of the line was constructed through the busiest part of the city, along and underneath Argyle Street. On account of the soft nature of the soil, and the vicinity of the Clyde, it was not found practicable to take the foundations to any great depth, and consequently the street is now supported on arches between cross girders, with just sufficient head room below for the railway to be made. During construction no interruption of the street traffic was permitted. The arrangements for carrying out the work under these restrictions, and for preventing the collapse of the houses on either side, were both interesting and instructive. Every house on either side had to be carefully underpinned, and as many of these houses were large buildings, such as churches, warehouses, etc., and some of them were pretty old, the work had to be done with the utmost nicety and caution. To the casual passer-by on the street there was little to show that such an important work was going on so close to the surface. A small hoarding in the street, in which a crane was working, was all that appeared to the eye, but on entering this enclosure, and descending a small shaft, one found that the surface of the street for a short distance was supported on steel girders, and that these again were carried by retaining walls, whose position corresponded approximately with the pavement at either side. At the head of the gallery the work of underpinning was going on. To effect this, first, spaces not exceeding 4 feet in length were excavated under the foundation of the existing wall, shored in some cases with timber, and then a shaft excavated to the depth of the foundation of the new work. At a distance of 16 feet another excavation of 4 feet in length was made. The shafts so made were then built up with brickwork in cement and packed up firmly with hard wedge-shaped bricks against the existing foundations. Another 4-foot length was done leaving 16 feet interval, and so on till the whole of the intervening portion was filled up, by lengths of 4 feet at a time.

Great difficulty was experienced also with the diversion of the sewers, water pipes and gas mains.

Wherever it was possible arches were used instead of cross girders to support the street. The general section of the line was 27 feet wide and 22 feet in greatest clear height. The centering for the arches was arranged by leaving the original soil until the arch was finished, excavating the side walls and building up in lengths, and using the central soil to take the arch. In one place it was found necessary to take a branch line towards the river, and this necessitated a tunnel of bell-mouth shape, 29 feet in width at one part, and 58½ feet in width a little further on. This was a very difficult piece of construction.

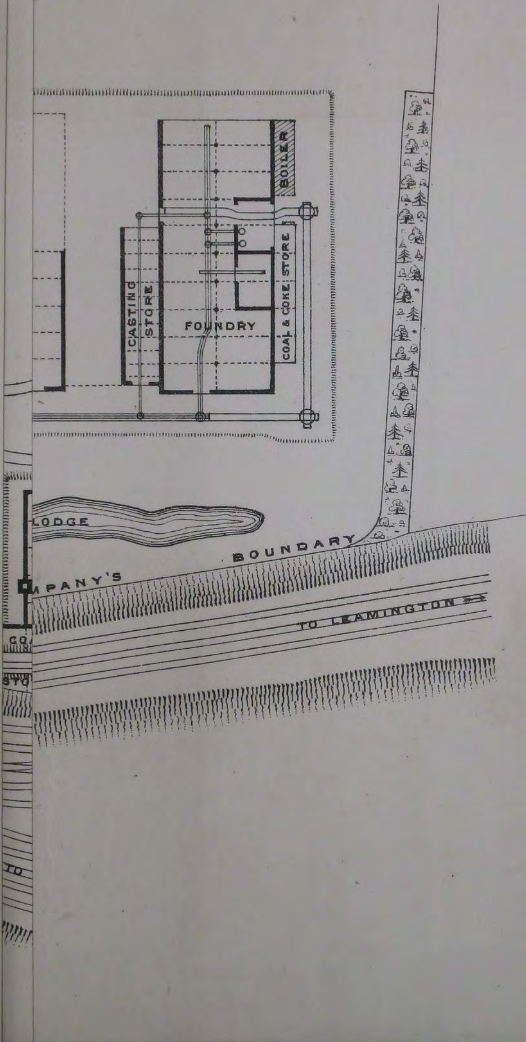
Railway stations have of course improved much of recent years. The "island platform" type seems to be that most used nowadays in small wayside stations, as it is not only easy to work from a traffic point of view, but is also economical, as it involves the construction of only one set of offices, waiting-rooms, etc.

Concluding Remarks.

In conclusion, I should like to take this opportunity of mentioning the extreme courtesy and kindness with which we have always been received on these tours. My only regret—a regret which I know is shared by many of my brother officers—is that it is so difficult to return in any way the kindness and hospitality with which we have been always greeted. I venture to express the hope that any of my audience who may have the opportunity will extend to our brothers in the civil engineering profession the same kindness that was invariably shown to us.

I may also observe that however useful these tours may be to officers under instruction, to the instructional staff they are simply invaluable. There is always a tendency in a school of this nature to become too academic, and to lose that touch with practical work which is so very essential. By these periodical tours one is enabled to see the latest developments of engineering science, and also to be brought into personal touch with the men who have designed or are engaged in carrying out the works. In this way it is possible to adjust theoretical instruction so that it shall not take a place of undue importance, and one is thereby constantly reminded that there is often much difference between what is theoretically desirable, and what is practically possible. It is in this way only that the instruction in this school can hope to remain worthy of the reputation of the past, and of the Corps to which we belong.

PLATE I.


BOILER
CASTING STORE
FOUNDRY
COAL & COKE STORE
LODGE
MPANY'S BOUNDARY
TO LEAMINGTON
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PAPER X.

SIEGE RAILWAYS.

WITH SPECIAL REFERENCE TO TRAFFIC ORGANIZATION.

BY LIEUT. E. H. M. LEGGETT, R.E., TRAFFIC MANAGER, ROYAL ARSENAL.

NOTE.

LIEUT. LEGGETT desires to express his indebtedness to the Editor of the *United Service Magazine* for his kind permission to reprint in this paper certain paragraphs on the general influence of railways upon fortress warfare, which have already appeared in an article on that subject, by the same writer, in that journal.

PART I.

General Influence of Railways.

BEFORE entering upon a detailed consideration of the question which forms the subject of this paper, it seems desirable to say a few words as to the influence of existing railway systems upon the nature and number of siege operations which may be found necessary in carrying through a modern campaign. It is somewhat remarkable that this point has not been considered more fully by military writers, who, if they deal with it at all, have merely referred to the interesting problem opened up, but have refrained from any detailed analysis. Lieut.-Colonel Sir George Clarke, R.E., in discussing the changed conditions which fortifications since Sebastopol have been called upon to face and to utilize, dismisses the question in the following words:—

On Fortification.

"Railway communications which, anticipating rifled weapons by a few years only, have developed *pari passu*, constitute a factor of a different kind, but hardly less important."*

The only reference made by Brialmont† to the subject occurs in a passage in which the author combats the proposals of Major Scheibert, of the German Artillery, for the defence of frontiers by means of specially strengthened and armed infantry positions, rather than by massive forts and stationary armaments. The argument is specially interesting, as the use of the railways is brought in as a leading feature. Briefly, Major Scheibert wishes to cover the frontiers by selected and prepared positions, defended by fieldworks of a superior type, and armed with mobile artillery, ensuring a greater flexibility in attack, and a less serious loss if the positions are successively evacuated and exchanged for others in rear, to which the railways will enable the heavy stores and armament to be withdrawn and thus preserved to the defence. General Brialmont disagrees on the ground, among others, that the railways will be so blocked in case of retirement that no such use of them for transporting artillery and heavy stores would be possible. It would seem that the General has a poor idea of the capacity of a properly organized railway. It is not to be supposed that the troops of a retiring army would retreat by rail, and as their supplies would have to be kept up in the one direction, there seems no reason why the return traffic in the reverse direction should not be as suggested by Major Scheibert. Without going further it may be said that the German policy shows signs of agreement with Scheibert rather than with Brialmont.

Strategy.

Whatever be the class of fortification, however, provisional or permanent, it is clear that the points selected must almost invariably lie on a main line of railway—in countries in which railways exist—

* *Permanent Fortification—Past, Present, and Future.* Major G. S. Clarke, R.E., 1889 (*R.A.I. Papers*).

† *Regions Fortifiés*, Brussels, 1890.

both to bar that line to an invader and because such posts will form the natural starting points for an advance into the enemy's country. The line of advance is nowadays more and more determined by considerations of transport; and the enormous and growing weight of military stores leaves a general but little option in selecting his line of advance if any railway is in existence and can be utilized. While, however, we may expect to see the first engagements fought in the vicinity of these important points, it is hardly probable that the defeated army will, after the examples of Metz and Sedan, allow itself to be shut up in one of these fortified traps. The inconvenience to the communications of the invader will of course make it worth while for the defence to leave in such places a garrison sufficient to hold them against any capture by a *coup de main*, and even to necessitate the detaching by the invader of a force sufficient to mask them against the sallies of the garrisons upon his lines of communication. But the main body will fall back to concentrate at further defensive positions in rear of the first line of frontier fortresses, and will at all hazards attempt to maintain its mobility, even when the second line of defensive positions has gone the way of the first.

On the Necessity for Fortress Operations.

It would seem a fair deduction to expect to find the large fortresses to be attacked relatively fewer than under historical conditions; while the *forts d'arrêt* at junctions and other important points on the railway lines will *per contra* be more in number. By the irony of fate the same cause which has made these places so important strategically has also rendered them more vulnerable. Their position as centres of railway communication in peace has given them a commercial importance which has accentuated the tendency towards aggregation of population in defensible towns; and has thus added in most cases a large civil element to other cares of the military commandant.

A growing humanitarianism is responsible for the desire to avoid as much loss and suffering as possible to non-combatants in time of war; and when to this is added the force of the populace themselves, anxious to save as much of their property as they can, it will be seen that the moral effect produced by a heavy bombardment at the earliest moment may not unnaturally tend to expedite the surrender. It is no doubt to meet such cases that most foreign armies, recognizing that even with railway transport the bringing up of a siege train is a matter of time, have adopted heavy field howitzers which can accompany the field army and undertake this preliminary and tentative work.* At the same time the railways can enormously expedite the bringing up of the heavy siege ordnance to reinforce the field armament should the latter be insufficient; and thus in any case the railways will tend to hasten the opening of the siege operations, and, by curtailing the time for preparation on the part of the defence, can greatly increase the chance of success without any more formal operations. As an instance of what can be done even under far less perfect arrangements than those obtaining to-day, it is recorded by Rüstow that in the war of 1864 heavy ordnance was brought from fortresses in East Prussia and placed in battery before the Duppel redoubts in less than ten days. While referring generally to the results expected of bombardment, it may be also mentioned that the improved supply of ammunition as brought up by rail will render possible a greater intensity of fire, and thus increase the effect both moral and physical.

The greater speed with which reinforcements of troops can be forwarded to the aid of investing forces is obvious and needs no remark.

Limitations to Power of Railways.

It is necessary, however, to bear in mind that even a modern railway has its limitations, and that the difficulty of working a line in an enemy's country, to say nothing of the damage purposely inflicted upon it, makes it impossible to obtain the carrying capacity which peace results and theoretical considerations would promise. It must be generally hopeless to expect to restore more than one line of a double railway; and on this it would be fair to take 1,500 tons daily as a good average weight delivered in rear of an advancing army. Since an army corps requires 500 to 600 tons of all sorts of stores daily, it follows that a single line can hardly do more than supply a modern army in the field. There will thus be very little railway capacity to spare for siege material in the earlier stages of a campaign; and it would seem that if the bombardment by heavy field artillery is without result, the only thing to do will be to watch the place and construct temporary loop lines round it, in order at all events, and as early as possible, to restore the lines of communications for the field army. The field army has to press on and keep the enemy on the run at all costs, and with rare exceptions, such as the Crimea, campaigns must be won or lost in the open, and siege operations are only incidents in the war which fit in with, but are entirely subservient to, the main plan of campaign.

* Major Hickman, R.A., *R.A.I. Papers*, 1894.

Many a war, I admit, has ended with a siege, the last despairing effort of the defence to gain time to organize a popular rising or in the hope of external intervention on the side of humanity. But this stage can only follow a bold campaign on the part of the invader, in which no time is lost for any object which is subservient to the main plan.

Main L. of C. Railway.

Hence it is to the supply of the main field army of the attack that all efforts must be put forward, and if necessary the fortress operations in rear of it must wait. Before, therefore, devoting themselves to the utilization of the railways for siege purposes, the whole attention of the military railway engineers has to be given to making good line of communications from the base to the rear of the field army. Should the frontier and intermediate fortresses across that line have fallen to the preliminary bombardment already mentioned, the constructional work will consist mainly in making good the damage done to the lines by the enemy in his retreat. But should these barrier fortresses remain invested, the most pressing work will undoubtedly be the laying of loop lines round the fortresses to bridge the gaps. These loop lines must be on the same gauge as the main lines which they connect, and should be far enough from the fortresses to avoid any danger or interference in working from their guns. This distance we may put at five miles from the place, and the length of the loop lines in favourable country will thus be about twelve to fifteen miles. As construction can go on simultaneously from both ends, it will be seen that with sufficient staff the work should be done in about ten days if not interfered with by the enemy, and under normal conditions as to ground. Nor will the whole of this time represent delay to the advance of the field army, which carries supplies for three days, in addition to what it can find in the country and obtain by road transport. The deduction is evident, though by no means novel, that fortresses are powerless to bar the advance of a superior and determined invader.

Summary.

In estimating therefore the progress in the conduct of siege operations, we must take into account the increased mobility in concentration for attack due to railway enterprise, which has been such that the history of even the latest sieges gives us but little assistance in formulating our ideas. In fact, it becomes necessary to give rein to the imagination and to steer clear of the trammels of tradition, keeping in view solely what can and what cannot be done according to theory as modified by peace experiments.

To summarize the opinions briefly expressed above it is suggested that railways will influence siege warfare in the following ways :—

(*a*). By increasing the number of points held by the enemy behind permanent or provisional fortifications on the falling back of their field armies.

(*b*). By accelerating the initiation of siege operations, and thus expediting the result aimed at, and in many cases combining with other influences to obviate the necessity for a formal attack.

Illustration. The part played by the railways in the Franco-German war affords some support to these theories. The theatre of war was on the whole not well provided with railway facilities from the German standpoint. The lines, as must generally be the case, were laid out to converge upon the capital, and were so situated that practically only two independent routes existed from the frontier to Paris. These were :—

1. (*a*). Hagenau, Saargemund, Metz, Nancy, Toul, Vitry, Chalons, Paris.

(*b*). Hagenau, Saargemund, Strassburg, Luneville, Nancy, Toul, and by 1 (*a*) to Paris.

2. Strassburg, Schlettstadt, Belfort, Chaumont, Paris.

There was also the north-west line from Metz, through Thionville, Montmédy, Mezières, Soissons, to Paris, and this line would have been of far greater importance in the campaign had the connection Thionville-Saargemund, which was actually under construction when the war broke out, been in working order. There was also a line under construction from Verdun to Metz, but during the campaign Verdun was useful only as a starting point for traffic collected in the vicinity. No through connection existed or could be improvised between the main lines sketched above, the Vosges mountains interposing such an obstacle to even road transport as to render the possession of one or other of the main lines a matter of necessity to the Germans. The northernmost of these two main lines was blocked at Metz, and the middle and south lines at Strassburg, while serious trouble was expected from the fortresses of Toul and Vitry. Immediately after the pitched battles which resulted in locking up one of the French armies in Metz, Toul was invested on 17th August, and Vitry capitulated on 25th of the same month. Since the south lines were held securely by the French at Strassburg, Schlettstadt, and Belfort, it became obvious that all efforts must be first concentrated on the north line. The idea of any regular siege of Metz was never entertained from the first, and the construction of a loop from Remilly to Pont-à-Mousson was at once proceeded with.* So early as August 9th, Captain Goltz, of the General Staff, received orders, in conjunction with field railway detachments Nos, 1 and 4, to restore the damaged main line between Saarbruck and Remilly, and next to construct a new railway passing to the south of Metz, as shown on the map. The first portion of this order was completed on August 13th, and on the following day the new junction line was commenced. This line was 23½ English miles long, was solidly built to a 12-foot formation and on the standard gauge. It included two viaducts, one of which was no less than 350 feet long and 22 feet high, besides two bridges over the Moselle and Seyle rivers. Yet this line was completed on the 23rd September, after only five weeks' work, or at the rate of ¾ mile per diem.

Meanwhile, Toul was being as heavily bombarded as the difficulties in the way of bringing up artillery would permit in the interrupted state of the railways in the rear. This place is reported in the German official history as "paralyzing the railway organization." It eventually fell on September 24th, on the exhaustion of its ammunition, and as the Metz loop was complete the day before, the German army came into possession of a complete line from base to front. Had Toul been capable of a longer defence, such as that of Belfort, it is quite possible that the interests of the German plan of campaign would have been better served by the construction of a loop line round the place, begun at the same time as the Metz railway, than in trusting to the result of siege operations on a scale which was necessarily inadequate from the presence of the Metz interruption to communications in rear. Such a line round Toul would have been completed with certainty by the date on which Toul actually fell, while it is quite likely that had Toul been better supplied with ammunition, it might have held out much longer. In such a case the Metz railway would have been required for the transport of heavy siege material instead of serving the interests of the field army.

To turn to the Southern Lines. The key to these communications is Strassburg, through which access can be gained by long detours with the entire French system. Strassburg was perfectly secure against assault, but could be approached direct by rail, and a regular siege train of 200 guns and 100 mortars was therefore brought up by

* Von Tiedmann's *Siege Operations of the Franco-German War.* Translated by Major Tyler, R.E.

the Rhine line, which was not yet of use as a part of the main line of communications. The siege began on 22nd August. We shall have occasion later to refer to the enormous traffic involved in the siege of Strassburg. At present it is sufficient to say that the place fell on September 27th, opening up an alternative line to the front as far as Nancy, whence one line was available to Paris. It does not appear that any suggestion was made to run a loop round Strassburg, though the country to the north of the town is favourable to such an undertaking. It may well be that both at Strassburg and Toul the Germans underrated the capacity for passive resistance of which even an old-fashioned fortress is capable under a good commander.

Meanwhile the investment of Paris was complete on 19th September in anticipation of the clearing of the communications, and throughout the first three weeks of October the remaining fortresses north and south were simply watched or bombarded tentatively with field artillery. Powerless to stop the advance, and off the main line of communications, the Germans could afford to let them wait. Even Verdun, situated in the very centre of the line of advance, could only stand up like a rock amidst an angry sea, around which the waves rush to re-unite for the dash on the cliffs beyond.

On the fall of Metz, on October 23rd, men and material became available, and the systematic reduction of fortresses north and south was undertaken. Though Schlettstadt fell, the long stand made by Belfort is famous, and the line of railway commanded by it was not available in time to aid in the siege of Paris. The north-west line, however, was cleared in a couple of months, Thionville, Montmédy and Mezières being taken one after the other in the order named, the line being thus gradually cleared behind them, and the artillery sent on by railway from siege to siege. Similarly Rocroy and Perowne to the north-east of Paris were not tackled till late in December; and when the latter of these was taken on January 9th, 1871, a separate line for the siege works on the north of Paris became available.

The dates on which the bombardments of Paris took place show the absolute dependence of the attackers on their railway communications. The batteries on the east front, served from the terminus of the Metz line, opened fire on December 27th, two months after that railway became available. For the south front all ordnance and stores had to be carted across country from the same terminus to Villa Coublay, 55 miles. Here bombardment began on January 5th, or nine days later than on the east. On the north front, thanks to the obstacles interposed by the north-west line of fortresses, the siege batteries were not armed till January 21st, only one week before the end of the siege and the surrender of Paris. Even after the capture of Forts Issy and Vanves the general officer in command professed himself unable to undertake the further attack on the enceinte without the services of a line of railway for siege stores alone. Yet everything that could be done by the Germans to hasten forward material was done. The guns and stores for Paris were loaded up in railway trucks in Strassburg and in German fortresses early in October, and were pushed forward as fast as the German Engineers could repair the railways won from the enemy. The time taken to repair the line, owing to the heavy demolitions inflicted upon it by the French, was so great that these guns did not arrive before Paris till early in December.

The front covered by the batteries of the attack was necessarily a long one, and the whole of the transport from the railway terminus had to be done by road. Thus three weeks were consumed in arming the batteries with 300 guns and mortars, each with a complement of 500 rounds of ammunition.

It is to minimize such delays that every nation has since set itself to organize a system of supplementary railway transport between the terminus of the main line of communications and the ultimate destination of the material in battery. This then is the function of siege railways, to afford to every battery of the attack an unbroken line of railway communication with the base of operations, perhaps hundreds of miles away.

PART II.

Siege Railways. General Scheme.

It is of importance to obtain a clear understanding as to the point at which the siege railways proper commence. It is generally taken that all lines in advance of the siege arsenal are siege railways, and *per contra* that those in rear are lines of communication. Such a distinction may be responsible for a widely held view that siege railways must be something essentially different from the main lines, and they are commonly, and I venture to say erroneously, often called "trench tramways." It is more easy to degrade a railway to the condition of a tramway, if necessary, than it is to glorify a tramway to the powers and functions of a railway. And when we remember the vast mass of material which will have to be carried on these lines, it is surely important at any rate to reserve to ourselves the powers of a railway rather than to voluntarily forego the advantages which engineering service provides.

It may be taken as a matter of course that the site selected for the siege arsenal will be on a main line of railway, or that rail communication will be as quickly as possible opened between the arsenal and the termini of existing lines, or those points on the latter which form the consigning stations for siege traffic on the general line of communications. At Metz portions of existing main lines were available, and in similar cases where loop lines round the fortress are constructed the same will apply. Thus the junction at which the siege traffic branches off from the line of field communications is the true starting point of our siege railways, whether the arsenal is situated at the junction or not. From the junction up to and including every branch into individual batteries the lines are under the jurisdiction of the G.O.C. Siege Force. The working of the junction itself must be under the organization of the main line of communications, the preference in traffic working at this point being determined by whichever operation, field or siege, is paramount at the time in the general scheme of campaign, as determined by the commander-in-chief. Thus, should the field army be operating beyond, and the siege be comparatively a secondary matter, any delay at the siege junction must be avoided for general field army transport, even at the cost of inconvenience and delay to siege stores, and *vice versâ*. At other times, such as the final closing round Paris in December, 1870, the considerations of the siege may outweigh all inconvenience to a field army operating against insignificant bodies of the enemy. I have dwelt on this point at what may perhaps seem unnecessary length, because every railway man will agree that all railway working is to some extent a matter of compromise. Everything cannot receive equally immediate attention, and it is of importance to have the relative precedence of traffic clearly defined. In any case—except the unusually favourable one of a separate line from the base being solely available for siege traffic—the siege traffic must pass over the main lines of communication in order to reach the siege junction or terminus, and all the siege railways in the world will be of no avail if the main line in rear fails to deliver the loaded railway wagons on the sidings of the siege junction. This part of the problem remains the same whether the main lines are previously existing railways or are military lines specially constructed, and, speaking generally, the traffic organization is identical in either case.

Traffic Organization of L. of C.

In the British service it is understood that the railways taken over will be worked as far as possible with their existing civil staff, if this remains at its post, a contingency hardly to be expected save in rare cases. On lines laid by the army, or for which no civil staff remains, an R.E. railway company, with a strength of five officers and 155 men, is expected to work a 25-mile section of single line. The R.E. companies not being unlimited in number must take the sections nearest to the front, handing over those in rear to men of the railway reserve under analagous organization. The general railway staff consists of a director and three subordinate heads of departments, traffic, locomotive, and permanent way. Each section is organized under the officers of the railway company working it, on the same scheme as to division of duties. The arrangements of continental armies differ mainly in distinguishing between the duty of construction and the subsequent working of the railway. The duty of construction is generally left to men of special companies or technical sections, which will absorb the greater number of men borne on the peace establishment of the railway troops; while the men for the working of the line in the three great divisions of traffic, locomotive, and permanent way maintenance are provided by special traffic companies. The men for the latter are generally railway reservists employed in peace upon the civil railways of the country. The separation of construction from traffic working has much to commend it in cases where really large bodies of men are available, but for everyday expeditionary work it may be fairly questioned whether the British system of turning out an all-round man, and consequently an all-round unit, is not of more practical utility. Germany can put 16 traffic companies into the field, each consisting of 6 officers and 206 men of the railway trades shown in the Appendix, and France draws one traffic section of 1,165 men from each of the 6 great railway companies of the country. The German company is supposed to work a section of from 30 to 40 miles of railway on the line of communications; and a French section should take over 120 to 150 miles. Adopting mean figures, we find that the proportion of men per mile is as under :—

English Company	...	155 men,	25 miles,	6 per mile.
German ,,	...	206 ,,	35 ,,	6 ,,
French Section	...	1,165 ,,	140 ,,	10 ,,

It is, however, a fact that in the German railway manœuvres of 1892 no less than 19 men per mile were employed on traffic duties, and the smaller number estimated for war purposes may be due to an expectation of utilizing part at least of the original civil staff. In addition to the men of the traffic companies the Germans provide a large staff of special goods porters, organized in workmen companies, trained in the loading and unloading of goods wagons, calculated at about six men per mile, and, probably, chiefly employed at terminal stations. The Germans believe—and every railway officer will agree—that to get the best work out of the railways the loading and unloading cannot be performed by mere fatigue parties, but is in every sense technical work. When we come to analyze the trade composition of the German railway company, we find that 12 engine-drivers are provided, pointing to the running of a maximum of eight trains daily to the front, two of these being combined for the return journey on a 35-mile division at a military speed of 12 miles per hour. Should night and day traffic be necessary, a double company for each section becomes necessary, since to shorten the divisions would seriously hamper and delay the through traffic on a long line. A through train is worked therefore from point to point, being handed over from one division to the next, the railway organization of each division as to locomotives, men, and guards being complete in itself. The shorter the divisions the more frequent these changes will be, and a compromise is thus necessary, which shall give a length of line not too great for the detailed supervision of one company commander, while avoiding unnecessary changes of control of traffic at too frequent intervals.

The Base Station.

In conjunction with the military officers of the supply staff, the director of railways arranges through his traffic manager for the forwarding of the stores loaded up at the base and in the frontier fortresses. These, coming perhaps over a number of railways converging upon the true starting point of the line of communication, are at the latter station marshalled and made up into train loads for different destinations. The starting station will almost certainly require to be enlarged in a railway sense, and a great number of sidings laid down on which the loaded wagons can stand ready for immediate forwarding when required, but on no account before that time. Once started, there must be no stopping *en route*, and no blocking of stations and sidings on the main line required for the loading and unloading of stores. This point is perhaps one in which our experience is likely to differ from that of continental nations who make war across their own frontiers. With us, landing on a hostile coast, rolling stock will be scarce and must not be kept under load longer than absolutely necessary. On the continent, however, the whole of the resources of the civil railways of its own country are available for the invader of a neighbouring state whose lines are laid on the same gauge; and though it may not appeal to the commercial railway manager to talk of trucks standing loaded for days and weeks before despatch, yet such a course is not only desirable, but even necessary to avoid the least possible delay in delivery at the front. I have already mentioned at an earlier stage that the German siege train for use before Paris in 1870 was ready loaded in trucks early in October, though not actually despatched from the base till the end of November. We have then our siege material loaded up in railway trucks, each labelled with its contents and weight, requiring only the affixing of the destination label in order to start upon its journey to the front. The details of that journey do not here concern us, and we may pass direct to a consideration of the siege junction.

Selection and Organization of Siege Junction.

The proper organization of the siege junction is a matter of the first importance, since any check here may derange the traffic of both siege and main line of army communications. It will be generally possible to select an existing station for the purpose, though this will almost always require enlargement to deal with the great bulk of traffic. The work performed at the siege junction is altogether of railway kind, sorting, marshalling, shunting, and stabling railway wagons off the main line, and does not include any transshipment which may be necessary for siege purposes. Of course, if the main line of communications is one that runs normally right up to the fortress, the siege junction ceases to exist as such, and can be, in fact, amalgamated with the siege arsenal. Even then, however, the railway duties require a system of sidings on to which trains can be run as they arrive, and from which the individual trucks can be run into the arsenal as wanted. A good type of station for such work is shown on the diagram, the arrangement being one for which it is claimed that the main line is always kept clear of trains shunting, and at the same time trains of wagons can be run from the sidings to the arsenal without any intermediate fouling of the running lines. The arrangement remains the same, whether the siege arsenal is adjacent to the station or at any distance from it. In either alternative the line from the siege junction to the arsenal must be laid on the same gauge as the main line of communications; that is to say, the gauge of the country, or of the expeditionary line laid in the absence of civil railways (*vide Plate* I.).

Site of Siege Arsenal.

There is some difference of opinion as to the distance at which the siege arsenal should be situated from the batteries. It must, at any rate, be out of range of the most distant fire from the fortress, and though laid down by the *Siege Artillery Drill Book* as at 7,000 yards from the fortress, we may look to this distance being increased rather than diminished in the future. With the adjunct of well laid out siege railways, it does not seem to matter to a mile or two where the arsenal is placed, the most important consideration being that of convenience to the main line of railway communication The siege arsenal comprises the general collecting depôts and magazines for stores of all kinds, *de guerre et de bouche*, together with the artillery park and engineer workshops. The French and Germans calculate that, having regard to the strength of siege corps, one arsenal will be necessary for each 200 pieces of ordnance in the attack, covering, as these would, some 10 miles of front. If the fortress is of such a size that a duplication of arsenals is necessary, we may be reasonably safe in anticipating the existence of more than one main line of railway leading to a place of such importance, and in leaving such a case till it arises.

Plan of Siege Arsenal.

The general plan of the siege arsenal is a matter which cannot be decided by the railway director, though no doubt he will be able to make his views heard in the proper quarter. The separation of the different classes of stores, including the establishment of the main magazines at some distance, is a matter of course, and will materially aid in the working of the railway traffic. Generally speaking, a branch on the same gauge as the main line of communication must be run to every store or group of stores, to enable material to be deposited without break of bulk. Should a different gauge be necessary for the siege railways or any part of them, branches on that gauge must also be run to these groups of storehouses in the arsenal; and, finally, there must be in the arsenal a system of parallel sidings laid down on the two gauges, on which transfer direct from the large to the small trucks can take place if necessary, to avoid the delay in passing stores into the sheds (*vide Plate* II.). It would seem that when such direct transshipment cannot take place within 48 hours of the arrival of the main line truck, the latter should be unloaded in the arsenal. Military storekeepers are very fond of unloading everything into their storehouses in order to check and re-check the quantities, but the importance of time and of labour is surely sufficient to more than compensate for any slight loss due to the informality of the direct transfers. Where the siege lines are laid on the same gauge as the main lines, those responsible for the supply of each kind of material must try to effect supply from the stocks already loaded in the wagons, simply passing these through their books as if reloaded and transferred. Such a system, combined with judicious foresight as to the ordering up of supplies from the base, will save untold labour and delay. So far as ammunition is concerned, the reserve in the siege arsenal should be kept up to 500 rounds per piece, and the less this is drawn upon to meet current wants in the batteries which can be supplied direct the better.

Advanced Depôts.

The reserve of ammunition and similar expendable stores will not, however, be too greatly centralized. The front of attack upon a modern fortress, even if only three detached forts and intermediate works are engaged at once, cannot be less than seven or eight miles, if indeed not considerably more; and the great distances involved have created the necessity for advanced depôts in rear of each section of the attack. These, it is laid down,* should be as near the batteries they serve as is compatible with concealment and security, and may thus be taken as approximately ½-mile in rear of the 1st artillery position. These depôts are to contain one day's supply for the batteries served by them, and are thus practically small editions of the siege arsenal, but without the workshops and general stores.

1st Artillery Position.

Finally, the 1st artillery position itself, on which, though here considered last, the position of the depôts depends, is taken up at distances from the enemy's works estimated by various authorities at from 2,500 to 4,000 yards. The margin allows of considerable latitude in the selection of site, and it is at any rate certain that advantage will be taken of all cover afforded by the contour of the ground, woods, etc. It is on the damage done by these batteries that success of the operations will be decided, and it is

* *Siege Artillery Drill*, 1896.

on the regular and full supply of ammunition that the efficiency of the batteries themselves depends.

Main Siege Line.

It is therefore recognized that a main line of siege railway connecting the arsenal with the depôts must be an essential feature of the siege railway organization ; and that the depôts must in turn be connected with their batteries by branch lines, both for the transport of the ordnance and for the supply of the batteries in action. The plan on which the railways will be laid out must afford the greatest simplicity in working, for upon the avoidance of all blocks hangs the regular working of the traffic. Hence a main siege line starting from the siege arsenal and running along the rear of the artillery position has been adopted as the basis of the railway system in all continental siege practice operations.* The advanced depôts are situated on this line, and may be expected to be found at intervals of about two miles, forming, as it were, the stations from which the traffic is redistributed. These depôts are the natural starting points for the lines branching off into the individual batteries, the general working being much simplified and better controlled if there is one junction for the whole of the traffic for each group of batteries, and that junction at the depôt. The system is thus much as shown on the typical diagram (*Plate* III.).

Traffic on Siege Lines.

The siege railway problem has not escaped its share in the eternal battle of the gauges. It has been argued that as these lines may be eventually pushed forward beyond the 2nd artillery position into the advanced engineer attack, the gauge must necessarily be a very narrow one. It will be dangerous to pursue this line of argument without reference to the traffic to be carried. The basis on which the daily traffic has been calculated is generally that of supplying the batteries with 100 rounds per piece per diem. This will give roughly 40 tons daily for a 4-gun heavy battery, and 25 tons for a medium battery. These weights are more likely to go up than down with the constant changes that occur, and it follows that for ammunition alone the main line of siege railway serving three British units, two heavy and one medium, must carry over 400 tons daily. But the latest experience shows that against comparatively small fortresses 100 guns and howitzers are none too many, and when to the ammunition is added the many general stores, spare parts and hundred and one incidentals, it will be seen that a capacity of 1,000 tons daily is none too much for the main siege line.

* *Vide Attaque et Défense des Forteresses*, V. de Guise, Brussels, 1898.

As bearing on the question of the weight to be carried the following figures are instructive.

The ammunition expended in certain sieges was as follows :—

Strassburg	31 days,	4,000 tons.
Paris	62 ,,	2,500 ,,
Belfort	73 ,,	1,800 ,,

Major Rocehé, of the Italian Army, writing in the *Rivista d'Artiglieria* in 1894, estimates the quantity required for the siege of a first-class fortress at 11,000 tons.

As to the number of guns, to which the quantity of ammunition is of course proportional, opinions differ considerably. General Sauer says 200 and General Brialmont 700. At the fall of Sebastopol the Allies had 800 guns in battery. The figure is at any rate likely to exceed the lower of these figures, and even for smaller operations the number must be comparatively large. The actual numbers in some specific cases were as follows :—

Strassburg	300 guns and mortars.
Thionville	158 ,, ,, ,,
Montmédy	74 ,, ,, ,,
Longwy	70 ,, ,, ,,
Mezières	73 ,, ,, ,,
Paris	300 ,, ,, ,,

The German estimate is 500 rounds per piece, which, on the average of 160 pounds per round, gives nearly 40 tons for each gun or mortar, or a total of 12,000 tons for the 300 pieces brought up to Strassburg. The figures of the *Official History* show that the total weight of stores of all kinds delivered by rail at Strassburg during the siege was 46,000 tons, which required the services of more than 2,000 carts and teams of horses daily to distribute.

Break of Gauge and Transshipment.

If the main siege line and battery branches are laid on a gauge differing from that of the line of communication, it will be necessary to transship this weight daily from the main line wagons to the siege rolling stock. The experience of large English goods stations is that one man should transship $1\frac{1}{2}$ tons of general stores per hour. For service conditions, however, implying an absence of mechanical assistance, not more than one ton per hour—if so much—can be reckoned upon. An entire break of gauge at the siege arsenal would thus keep at least 100 men continually on this work, while seriously delaying the forwarding of the stores, and blocking the sidings and approaches. From the railway point of view a not less serious consideration is the delay of one day to the rolling stock, an average number of 100 trucks being thus locked up and taken out of service. It is also to be noted that any break of gauge must necessitate the carrying of the whole of the siege rolling stock on main line wagons from the base at a time when all available railway accommodation is urgently required.

No doubt these considerations are responsible for the generally accepted view that every effort must be made to carry on the main siege line and the branch lines from the depôts into 1st artillery position batteries on the same gauge as the main line of communication; that is to say, either on the gauge of the country or on the military gauge adopted for general army communications.

As already mentioned, the great range of modern ordnance affords such latitude in selecting the sites for batteries that it must be seldom that the configuration of the ground will be such as to prevent this gauge being used. At the same time it must be remembered that such a difficulty may arise, and in the event of a narrower gauge railway being unavoidable, the break must occur in the siege arsenal. What this secondary gauge should be we will discuss later.

Lines to 2nd Artillery Position.

It has been laid down in the text-books that as the attack progresses the armament will be pushed forward to positions nearer to the enemy's works, known as the 2nd artillery position. This is generally assumed at from 1,200 to 2,000 yards from the place. The feasibility and indeed the necessity for this operation under modern conditions has been questioned by many writers on the subject. Major Hickman, R.A.,* in summarizing the ideas of artillery officers, denies the advantage on the following grounds, so far as heavy howitzers are concerned. He puts forward:

1. The difficulty of moving the heavy artillery,
2. The increased difficulty as to supply of ammunition,
3. The increased difficulty of concealment at short ranges,

together with other technical artillery objections, against which can be set only a slight gain in accuracy of fire. It is, however, agreed that the lighter natures of artillery will have to be advanced sooner or later, if the place holds out, to the ranges indicated above, and their supply of ammunition, though smaller, is probably a more difficult matter than that of the 1st artillery position. The scope of

* *R.A. Institution Papers.*

trace for the connecting railways will be certainly much reduced by the difficulty of finding cover, and the work of laying the lines must be hastily performed, conditions which point to the necessity of a light and portable type of line for this work. It will be conceded at once that if a narrow gauge has to be used for the 1st artillery position, the same gauge will be used for the more advanced works, as one transshipment will be bad enough, but two would be fatal.

Lines for Engineer Attack.

Before going into the question of what the narrow gauge should be, it is important to see if the lines are likely to be carried into the trenches of the engineer attack. As regards both 1st and 2nd artillery positions, we are troubled with no considerations of fitting the lines into a narrow trench of limited width and right-angled corners. There are indeed many who contend—especially in Germany—that no engineer attack can or will be possible. If any heavy guns remain in the defence, sapping will be an impossibility, or at any rate the curved fire of howitzers will make it so. If the guns do not exist, where is its necessity? As well say that the final attack of infantry on a position is to be made by sap. There can be no dwelling in the advanced infantry position, but the attack must be pushed home under a concentrated bombardment from every gun and howitzer in the attack. The fact, however, remains that the 1st and 2nd infantry parallels may retain their importance as points of debouchment for the infantry attack, and into these it may be desirable to run hand trollies for the conveyance of smaller stores, scaling ladders and engineer tools. It cannot be believed that anything in the nature of a regular traffic into the trenches must be provided for, and so far as the question of gauge goes, therefore, there seems nothing to choose between the 2′ 6″, the 2′ 0″ or the 1′ 6″ for hand trolley work.

Gauges. Summary and Conclusion.

We have then the following general conclusions as to gauge:—

1. The main siege lines to depôts and batteries of 1st artillery position, on the gauge of the country if possible.

2. If the nature of the country forbids the extension of the main gauge, the narrow gauge line commences at the siege arsenal.

3. The railways to 2nd artillery position are necessarily narrow gauge, and should be, therefore, identical with any narrow gauge lines laid for the 1st artillery position as a continuation of these. If no narrow gauge is used in the 1st artillery position the narrow gauge for the 2nd artillery position must start at the siege arsenal.

4. The railways for the engineer attack, if any, will be identical in gauge with the other narrow lines used in the operations.

What then should be adopted as the narrow gauge for siege railways? If what has been said as to the traffic requirements and the necessity for avoiding transshipment is agreed, the answer must unquestionably be, the gauge adopted for general use in the field, and for the following reasons :—

1. Should an expeditionary line be necessitated through the absence of existing railways as a main line of communications, no break of gauge will occur at the siege.

2. In such a case not only will the main line trains run on to the siege railways without transshipment but the whole of the special rolling stock required for the siege works can be brought up on its own wheels and carrying a load, instead of encumbering main line wagons required urgently for other work.

3. A large stock of railway plant will be available, since the material of main and siege lines will be interchangeable.

4. Should main lines exist in the country, a change of gauge may be necessary in any case, and the difficulty will be the same whatever the narrow gauge adopted for sieges be ; and in such a case the whole of the plant provided to guard against an absence of main lines will be available for the siege operations.

It is therefore natural that we should find all the continental nations adopting the same gauge for siege work as for their general communications. These are :—

Austria	75 c.m.—2′ $5\frac{1}{2}''$
Germany	60 ,, —1′ $11\frac{1}{2}''$
France	60 ,, —1′ $11\frac{1}{2}''$

It is hardly possible to define the exact reasoning which has led to these gauges, though, speaking broadly, it seems to have been put forward as a leading condition that the lines should be the lightest which can deliver 1,000 tons a day, and can support locomotive traffic without any excessive amount of engineering and maintenance work, a condition which any gauge less than 1 foot $11\frac{1}{2}$ inches does not seem to fulfil. The selection of 2 feet 6 inches by Austria is no doubt arrived at in the same way, combined with the fact that the comparative absence of permanent railways and roads on her eastern frontier will render her still more dependent upon such lines as can be laid during a campaign. Certainly the conditions under which a British army may be called upon to work will be not less difficult in this respect than the Austrian anticipation, and the adoption of 2 feet 6 inches gauge, as laid down in the *Manual of Military Railways*, favours this view. As the question of a gauge for siege purposes is understood to be under consideration, perhaps it may be permitted to express an earnest hope that no decision may be arrived at which requires the transshipment of siege stores from this to a yet narrower gauge.

Tractive Power.

Before entering upon any discussion as to types of permanent way required for narrow gauge siege railways, an obvious preliminary is the consideration of the method of traction to be adopted. There are three systems open, all of which offer special advantages under certain conditions, and which can, and no doubt will, be utilized simultaneously. These are :—(1), locomotives; (2), horses and elephants; (3), manual.

The noise and smoke of locomotives renders their whereabouts difficult of concealment, and this has been urged as a disadvantage. The smoke nuisance can, no doubt, be got rid of by mechanical smoke-consuming arrangements; but the objection as to noise is no doubt serious in dealing with the advanced works of the attack, when the arming and supply must be done by night. On the main siege line, however, and to the batteries of the 1st artillery position, concealed as these no doubt will be, the objection will hardly apply. The more important point is the stability of the lines themselves for locomotive traffic, and whether any loss of portability and speed in laying, occasioned by the heavier track, is worth the advantages secured. We have already seen that it will not be safe to count upon much less than 1,000 tons per day passing on the main siege railway along the attack.

The following table shows the relative power of traction on rails of an 8-inch cylinder narrow-gauge locomotive of average type, a horse, and a man :—

Grade level.	Loco. 200 tons.	Horse 10 tons.	Man 2 tons.
1 in 100	70	3	$\frac{2}{3}$
1 in 50	39	2	$\frac{2}{5}$
1 in 25	20	$\frac{3}{4}$	$\frac{1}{6}$

The speed of horse traction may be taken as 3 miles per hour, and of a locomotive as 6 miles per hour, showing that while in tractive power the locomotive is worth 20 horses, in ton miles it is equal to no less than 40. Now 1,000 tons of stores means, with the trucks which carry them, 1,400 tons of dead weight to be hauled in a time of, say, 12 hours. The average distance will be about 5 miles, made up of the distance from arsenal to 1st artillery position, plus half the front of attack, plus the length of the battery branch. Thus 12 locomotives will be kept at work on this traffic, each making three double journeys at a speed of 6 miles per hour; and no less than 350 horses would be required for the same duty, each making two double journeys at 3 miles per hour. But as a team of 6 horses would be required to haul one 10-ton truck, and each horse cannot exert its full individual power, the number will be still greater; and, further, a period of rest is also necessary. It would seem then that about 500 horses are necessary to do the work of 12 locomotives in arming and keeping supplied siege operations in which 1,000 tons of stores daily are consumed.

The argument has been recognized by the continental powers, who have all adopted locomotive haulage for their main siege lines in peace experiments, reserving horse traction for batteries in advanced positions and for those of the 1st artillery position, which the exigencies of the operations require to be inconveniently situated. In the great siege manœuvres before Paris, in 1894, locomotives were used for the whole of the traffic on the main siege lines, or on a total of 15 out of the 30 miles of lines laid, horse-haulage being used on individual battery branches. Thirteen trains were run daily on the main line, including a special bakery train for the supply of the investing force. Even, therefore, should special circumstances render it impossible in every case to employ locomotives, yet to voluntarily abandon their use in every case would surely be to deprive ourselves of a most powerful aid; and any discussion on the subject of siege railways, without reference to this possible adjunct, may lead to a false idea of the power of the railways themselves, and of the considerations which should rule their design and working.

For the batteries of the 2nd artillery position it is practically agreed that locomotives cannot be relied upon, since not only must the lines be laid hastily, but the curves and gradients cannot be so carefully considered. For this stage, therefore, horses must be used, and to take the engineer attack it will doubtless be impracticable to do more than manual haulage of light trolleys.

General Type of Permanent Way.

From what has now been said as to the conditions of use of narrow gauge siege railways, the following points may be summarized :—

1. The gauge should be that adopted for field service.

2. The plant should be of the lightest type compatible with the traffic to be carried.

3. The road should be capable of carrying a light locomotive on those sections which can be laid with sufficient latitude of curve and gradient.

The question of making up the line into bays of short length for speed in laying has been much discussed, and the field railway plant of the continental armies has been designed on that system. It must, however, be remembered that these lines are intended to follow an army in the field and to keep it in touch with the permanent railheads, implying a capability of construction at the rate of not less than 10 miles per diem, laid telescopically with all the difficulties which that process carries with it. To such a degree is this speed of laying valued that the continental armies are even prepared to give up, if necessary, the use of locomotives on their purely field lines, reserving them for such sections as can be packed and ballasted at leisure, and for the lines laid during siege operations, the length of which will be less, and the time available for construction longer. The Germans, therefore, have deliberately adopted two types of permanent way, which we may call the medium and light respectively. The former is designed to carry locomotives, and the latter for horse and manual traction only. The medium type can be made up into portable bays, but is not necessarily so; the light type is invariably made up. The functions of the two types in siege operations may be—

1. Medium type; for main siege lines and branches into batteries of 1st artillery position.

2. Light type; for branches into advanced batteries and possibly the engineer attack.

The gauge of both types is, of course, identical. The laying of the line will be referred to later, but the word slow, as applied to the medium type, is comparative only. The following results of large scale peace experiments are quoted by foreign technical papers.

Rate of Construction.

German medium permanent way, 625 yards per hour for 31 miles of continuous laying, Janickersdorf to Loburg, in 1895, quoted by *Allgemeine Militär Zeitung*. Light permanent way, 700 yards per hour, quoted by *L'Avenir Militaire*. If these figures are correct, the difference in speed is negligible, and the main distinction would no doubt lie in the different number of men required, the lighter material having the advantage of exposing fewer men to danger in laying lines to advanced batteries. Even were the results not so favourable, it is still doubtful whether a moderate increase in the rate of construction is worth the heavy sacrifice in carrying capacity which must follow the selection of a very light plant.

The main siege line can be certainly commenced at two, if not more, points simultaneously, and a rate of construction of only 250 yards per hour, or $1\frac{1}{2}$ miles in the 24 hours, would enable this to be laid in three to four days, to which another day only would be added for the battery branches, laid simultaneously. It is difficult to conceive that the preliminary arrangements, including the bringing up from the base of the heavy armament and a suitable supply of ammunition, could be complete in less than a week. Peace experiments and the experience of the Franco-German War point to a longer interval even than that; and so far therefore as the 1st artillery position is concerned the argument of portability may be pressed too far. Lightness of permanent way is like lightness in bicycle construction; it can be elevated into a fetish, and when everyone tries to go one better than his neighbours, sooner or later the machine falls to pieces and the rider picks himself up ruefully with many remarks which are not complimentary to the maker. Yet it is not the fault of the maker but of the man who rides over rough roads on a delicate machine made for the smooth racing track. Siege railways are not going to be laid on level parade grounds, and the usage they will receive is likely to be pretty severe.

Locomotives.

Let us now consider, one by one, the different elements which make up the siege railway plant.

The great difficulty occasioned by the narrow gauge of 1 foot $11\frac{1}{2}$ inches of France and Germany is that of designing a locomotive which shall be sufficiently powerful without great complication. So great indeed is the difficulty of design that these countries have adopted the Fairlie type of double-ended engine, with two chimneys and smoke boxes and sets of tubes and a central fire box. This is known as the Zwillings Lokomotif or locomotive jumelle (twin engine). A very long wheel base is obtained, consisting practically of two six-wheeled bogies, the wheels of each bogie being coupled, and thus making the whole weight available for traction and adhesion. The gross weight of 15 tons thus gives only $2\frac{1}{2}$ tons per axle. It seems that this is unnecessarily small, since the greatest load likely to travel over the line is 12 tons, *i.e.*, a heavy howitzer and its carriage, weighing 8 tons, on a truck weighing 4 tons; and on a bogied construction such a truck loaded would give 3 tons axle load. It is difficult, however, to say to what limits the weight of siege ordnance will run in the future, and it seems not unfair to assume the maximum load passing over the line as a main line narrow gauge wagon 4 tons tare with a 12-ton load, a total of 16 tons, or 4 tons per axle for the main siege line. It would therefore follow that a 4-wheeled locomotive weighing 8 tons will bring no excessive weight on to the line, and as an engine of this weight can be built with 8″ cylinders to give a hauling capacity of 200 tons on the level or 40 tons on 1 in 50, this locomotive would appear to meet the requirements of siege operations. At the same time the fact should not be lost sight of that should circumstances admit of strengthening the main siege lines it may be quite possible to bring the ordinary narrow gauge main line engines of the lines of communication within the area of the siege operations. This would certainly appear to have been feasible in such a case as Sebastopol, when the operations were so protracted as to have enabled the main line from Balaclava to be continued on the same scale of stability along the rear of the allies' position. As bearing on the question of locomotive design the minimum radius of curve permissible has to be considered. The German locomotive alluded to can pass a hundred foot curve, but with a 4-wheel coupled locomotive on a 2-foot 6-inch gauge line there seems no reason why a 5-foot wheel base should not be obtained which would admit of the engine passing a 66′ curve. Curves even sharper than this, however, will certainly occur in the advanced works, and this in itself constitutes a bar to the employment of locomotives beyond a certain stage.

As regards rolling stock, if the main siege line and branches to batteries of 1st artillery position are laid on the gauge of the line of communication (whether that gauge be broad or narrow), the traffic service of the first position will of course be carried out by means of the main line wagons to avoid transshipment. At the low speeds which will rule on siege railways even the 4-foot $8\frac{1}{2}$-inch standard trucks of English main lines can pass curves of 80 feet radius, and the bogied rolling stock used for main lines of communication on the 2 foot 6 inch gauge can pass a curve of 30 feet radius. So far, therefore, as the curve question is concerned, nothing special for siege work seems required. The French, Germans, and Austrians apparently contemplate using on their siege lines the same narrow gauge rolling stock as adopted for their field railways. These vehicles are all of bogied construction. The bogies are of very simple type, and are each provided with springs and a brake. They can be used singly, in which case the load is 5 tons, or two can be placed under a platform mounted on pivot shafts on which any construction of ends, sides, or covered van can be built.

Rolling Stock.

The French double-bogie truck can thus carry 9 tons, which is equivalent to the weight of the gun and carriage of the heaviest piece of siege artillery. For troops and wounded men seats and hammocks can be arranged on the platforms of these trucks. I have already mentioned that a special bakery train was run daily during the French siege manœuvres in 1894, and some special saloon carriages to carry the President of the Republic were also run.

Special Gun Trucks. The conveyance of heavy ordnance on a narrow gauge line has presented certain difficulties which have induced attempts to design special trucks for the purpose, the principle of most of these being to build a narrow truck on which the frame of the gun carriage would rest while the wheels project on either side. The obvious difficulty is that of preventing the whole arrangement from falling over if the line should sink to one side or the other. With the greatest care it will be impossible to obviate entirely this danger on a journey of some four or five miles from the arsenal to the batteries, and it would be difficult to over estimate the serious delay and inconvenience which would be caused by the upset of a heavy howitzer in the middle of the process of arming the batteries. Not only would the piece itself be delayed, but a block on the main siege line would probably upset the arrangements for the batteries beyond, and in fact might render the railway useless for an hour or two at a critical time.

The stability of the line itself, however, increases with the gauge and length of the sleepers, and the increased stability of the 2 feet 6 inches line as compared with the 1 foot 6 inches or 1 foot $11\frac{1}{2}$ inches is sufficient to much reduce and almost obviate any danger from the sinking of the track.

Ramps. The method of loading up guns is fully detailed in the *Manual of Military Railways* and need not be repeated here. A portable ramp is used in France for loading and unloading standard gauge wagons. Some such type would certainly be required should the standard gauge be continued to the 1st artillery position, and in any case will be wanted in the siege arsenal.

Permanent Way. On the authority of the foreign technical papers already quoted it appears that the Germans have adopted a 19-lb. rail for their medium (locomotive) line, and a 10-lb. rail for their very light railways, while the Austrians have taken a weight of 15 lbs., and the French about the same. In every case the length of the sleepers is approximately double the gauge, thus giving good security against overturning. The Austrian type (known as the

Dolberg pattern) has one wooden sleeper and one iron cross-bar to each bay of 4 feet 9 inches length, which certainly gives a very weak road.

As typical examples, the following description of the German lines is taken from the foreign press:—

Medium line, for locomotive traffic. The rails are 19 lbs. to the yard, flat bottomed, and 16 feet 4 inches long, designed to give a large bearing surface to the tread of the wheel. The sleepers are 4 feet long, 5½ inches wide between joints, and 7 inches under joints, which are made on a sleeper and are not suspended. The sleepers are spaced at 2 feet 2 inches centres, and are of iron or wood. The joints are opposite one another and are connected with fish plates or angle irons with four bolts. The line is issued for laying in parts, or make up into bays of the full length of the rails, 16 feet 4 inches. In this case the bays weigh 3½ cwts., but no trouble seems to be found in handling them, according to the *Militar Zeitung*, the correspondent of which said that he was struck with great amazement at the energy of the Sappers.

Light line (known as the Haarmann type) is also made up of a flat bottomed rail, only 10 lbs. per yard, and of peculiar section, being rolled with the web set at an angle to the bottom flange, and the latter being wider on the outside than the inside. These peculiarities are to reduce the danger of the rail turning over under a heavy load. The line is made up in bays of 2m. and 5m., that is to say 6 feet 7 inches and 16 feet 4 inches, weighing 70 lbs. and 160 lbs. respectively. The sleepers are of pressed steel, shaped like the letter U inverted, the rail being fastened to the sleepers by means of two clip plates secured by screws passing through the sleeper from the underside. There are 3 sleepers to the short bay and 6 to the long bay. The bays can be carried by 1 man and 2 men respectively. The bays are joined up by means of special clip fastenings which hook into one another. Special curved bays are provided, 6 feet 6 inches long, four of which take round a right angle on a radius of 16 feet. It will be seen that this type is exceedingly light, and while suitable for very advanced works, is perhaps hardly heavy enough to escape severe crippling from the passage over it of heavy guns.

Construction Works. Trace.

There can, unfortunately from the railway point of view, be but little latitude in the trace of siege railways. While every effort must be made to obtain a route for the main siege line, at any rate to the depôts, which shall be as free as possible from severe curves and gradients, these will be inevitable in the battery branches, and the most that co-operation between the artillery and engineers can do is to secure consideration of this matter when deciding on the battery sites. The Germans, with their usual attention to details, have drawn out a set of limiting conditions for the trace of lines over which their light locomotives can be worked. It is to be hoped that it may be possible to lay out the main siege line within these limits. Quoting from the *Avenir Militaire*, the German experience is as follows :—Gradients less steep than $\frac{1}{50}$ present no inconvenience, and need not interfere with the regularity of the train service. On grades of $\frac{1}{40}$ and $\frac{1}{50}$ of a greater length than 400 to 500 yards, intermediate lengths of level line should be provided of a length double that of the train. Gradients steeper than $\frac{1}{40}$ are avoided as far as possible, in the interests of the regularity of the train service, and banking engines are necessary when the grade is longer than 300 yards. Similarly for grades of $\frac{1}{30}$ and $\frac{1}{25}$ when the length exceeds 200 and 100 yards respectively. Gradients of 1 in 18 can only be passed when not exceeding the length of the train, and when the latter can get a run at the bank. All sharp changes of grade are avoided, and grades should be as straight as possible. When the line is at the same time on curve and gradient, the latter must not be more than 1 in 60, and the radius of the curve 200 yards or more, while portions of line leading to a grade of this kind should also not be on a curve of less than 200 yards radius. These conditions appear somewhat high, and are, in fact, got out for train loads of 60 to 70 tons. With train loads of 40 tons there seems no reason to limit the grade to more than 1 in 33 and the curve to 150 feet on the level, with the usual compensation if curve and grade occur simultaneously.

Formation.

It goes without saying that while a solid formation and well ballasted permanent way offer great advantage as regards passage of traffic and facility of maintenance, no time can be spent on doing more than to merely enable the trains to be run at low speed and with safety against derailment. Existing roads can be utilized as much as possible, and were so during the French manœuvres, but across country the least possible preparation would be done, and that can consist only of filling up hollows with brushwood and fascines, the line being taken round buildings and other obstructions. Should embankment work be necessary the width at top must be 2 feet more than the length of the sleepers, to give the necessary stability against side slips. Bridge work is generally of the trestle type ;

and in Germany these are put up by special bridging detachments and not by the railway construction companies, which, speaking generally, only lay the lines on the formation prepared for them by infantry labour.

Laying of Permanent Way.

We come now to the laying in of the permanent way. This matter is dealt with at some length in the *Manual of Military Railways* and need not be gone into so fully here. At the same time, so far as the laying of a continuous length of some miles is concerned, such as would be required for the main siege line from the arsenal along the rear of the 1st artillery position, certain matters of traffic enter into the systems adopted. Let us take, therefore, the German medium type of line made up in bays 16 feet 4 inches long and weighing about $3\frac{1}{2}$ cwts. The system appears to be that ordinary narrow gauge bogie platform wagons are loaded in the engineer park of the arsenal, each with 30 bays complete piled on top of one another. One truck therefore carries 164 yards of line, weighing 5 tons, and 4 trucks will carry enough for one hour's work at railhead, which experiment has proved to be at the rate of about 600 yards. It would probably be well to bring the material in sets of 4 trucks, each hauled by a train of horses, as any derailment of a locomotive at this stage would be fatal. On reaching railhead the horses of the leading truck are unhooked, and the bays laid into the line by gangs of 6 men, of which there should be 4. The linking in would be done by 4 men in rear of railhead, and the truck would be pushed forward by men specially detailed for this work, and independent of the laying men. As soon as the truck is empty it would be thrown clear of the line by levers to allow the next one to come up. If a train of 4 truck loads is thus despatched from the field arsenal every hour, a constant supply will be kept up at the front. While No. 2 train is being unloaded, the trucks of No. 1 train will be pulled on to the line by their horses, with the aid of portable shoe ramps. The time thus taken can be made up in the greater rate of speed of the empty train on the return journey. This programme will require a crossing of full and empty trains at intervals of $1\frac{1}{2}$ miles, *i.e.*, every half-hour, and crossing places will have to be provided for this purpose and for subsequent traffic.

Construction Traffic.

In the laying of any considerable length of line, the regular working of the material trains is a matter of the highest importance, since any block must throw the railhead gangs out of work, and so stop the entire progress. A carefully prepared time-table must therefore be punctually adhered to, remembering that in case of any block it is the full train passing to the front which takes precedence. The regulation of this construction traffic will be much simplified if the line of a portable telephone can be carried along simultaneously with the railway.

Following the laying-in party will come gangs for packing and straightening the line. Any brushwood or other material required by them which cannot be found near the spot must be brought up on trucks making part of, but in rear of, a material train, and these must be unloaded as soon as possible. Speaking generally, no truck should be on the line which does not form part of a material train. It is almost invariably the rule, even in the construction of civil railways, that the traffic on a line under construction should be regulated by the engineer responsible for the laying of the line, and this holds to a greater degree on any military line laid for siege operations or otherwise, in which celerity of laying is a prime consideration. While, therefore, the traffic manager of the siege railways maintains a general control, the best arrangement would no doubt be to attach a special officer to the engineer in charge at railhead, from whom, and from whom alone, he will take orders as to the regulation of traffic, constructional or otherwise, during the laying of the line.

Traffic Working.

As the siege lines are constructed they are handed over to be worked by the traffic manager, who is an officer on the staff of the director of siege railways. The traffic manager is responsible, through his director, for the efficient working of all the lines throughout the zone of attack as far as the junction with the main line of communications, and including the traffic organization of the field arsenal, which may, or may not, be situated at the siege junction. There is no reason why the administrative organization of the siege railways should differ in principle from that obtaining on the railways of the line of communication, a proper sub-division of duties being necessary to give that chain of responsibility on the maintenance of which the efficient working of the railways depends.

It is evident that the principal branch must be that of the traffic, for which the railways exist, and though the other branches deal straight with the director of railways on technical points, they may and must be given orders by the traffic branch for supply of locomotives and horses, the repair of bad places on the lines, and other details affecting the working of the railways. As I have said in another place, and here repeat, there must be no red-tape, no waiting for formal requisitions; the whole point is that traffic must go forward, and no formalities between departments can stand in the way.

It is hardly necessary here to go through a description of the whole system of traffic organization, which is detailed in other books and papers, but rather to point out the special points as affecting siege work.

During the Preliminary Stages.

On completion of the investment stage and the driving back of the enemy within the line of detached forts, it may be fairly expected that the main siege line will have been laid, and the sites for batteries selected. It will therefore be desirable, during the construction of the batteries, to push up to the advanced depôts in rear of the 1st artillery position trucks containing a 48-hours' supply for each gun and howitzer to be placed in battery. As 24 hours' supply is to be kept in the depôts, the trucks containing this quantity can be unloaded, but the remainder should be stood on sidings clear of the main line in readiness to follow the artillery into the batteries with the least delay. The transport of the artillery itself will constitute a special operation of a magnitude straining all the resources of the railways, and the more preliminary work that can be done in bringing up ammunition and other stores beforehand the better.

It is in this preliminary work of arming and equipping the batteries of the 1st artillery position that the absence of any break of gauge will show its advantage, since the avoidance of delay at this stage, when every day adds to the strength of the defence, is of supreme importance. The traffic work will be difficult to systematize at this stage, and both day and night working of the railways will probably be necessary at short notice. The most that can be done is to insist upon notice, however informal, of material to be moved to be sent in to the central traffic office at the siege arsenal. This will be placed in telephonic communication with the advance depôts, which, as we have seen, are also the junctions for the traffic of each group of batteries. A representative of the traffic staff will be posted at each of these depôts to act as a station-master for the group of batteries served through his junction. These men can keep the traffic manager informed as to the progress of unloading in their different sections, and afford the central authority that information which will enable him to foresee the release and return of rolling stock to the arsenal. By carefully ascertaining the nature of the supplies to be forwarded from the different storehouses or magazines in the arsenal, the traffic manager can thus make up train loads on his sidings for despatch to these different sections, and so economize haulage power and avoid any interference of traffic on the lines.

The arrangements when the siege is in full swing will be more simple to work, though approximately on the basis indicated above. The necessity for a careful organization, however, increases with the number of guns placed in battery, which will certainly not diminish as the operations progress. The importance of the traffic organization has been officially recognized, but no indications are given in official works as to the system to be adopted.

As Systematized

The general system will certainly consist of a central traffic office connected, as already mentioned, by telephone with the various depôts and traffic distributing points on the main siege line. Empty rolling stock is supplied to the storehouses requiring it in the siege arsenal, and the loaded trucks are removed at frequent intervals and placed on outgoing sidings laid in the vicinity of the arsenal. For this work one locomotive or a number of teams of horses will be specially required. On to the same sidings are also shunted wagons from the lines of communication, the contents of which do not need to be transshipped. A regular service of trains, either of one locomotive load, or equivalent to, say, the power of 8 teams of horses, will be arranged at fixed hours to proceed along the main siege line and drop the trucks at each junction. Some of the branches may be worked by locomotives and some by horses. In the event of a large group of branches being available for locomotive work, an engine will be stationed here to serve that group, distributing the trucks as left by the main line train at the depôt junctions. In the case of smaller branches, the main line time-table may be arranged to admit of the locomotive running its truck up to the battery. In either case the empty trucks, as unloaded in the batteries, will be brought down to the junctions, and collected by the main line train on its return journey to the arsenal. Special trucks for carrying wounded may well be stationed at each junction, and trains carrying these may, except at critical times, such as that of general bombardment, take precedence of those carrying stores. The time-table will take into account the crossing places provided, or may require additional ones to be put in in the interests of the traffic. The station-masters at each junction will regulate the crossing by telephonic communication.

This is as much as can be said on a subject which essentially consists of details dependent on local circumstances. In any case, it will be apparent that the best management will not be able to do much without a plentiful supply of engines or horses, trucks, and labour to load and unload the wagons. An engineer has been defined as the man who can do with one dollar what any fool can do with two. Similarly, the difference between good and bad traffic management lies simply in making the best use of the means available, and in knowing what to ask for to meet any given set of circumstances.

Space does not admit of my going into the question of railways in defence. The general principles, however, are analogous to their use in attack, though the application of the principle is doubtless capable of more deliberate attention. The provision of zone and other permanent defence lines taking the place of the main siege railway is obviously a matter forming an important element in the main scheme of defence.

To conclude, it may be said that this paper is largely pleading for the recognition of the locomotive, the heavier rail, and the wider gauge. I admit this at once. Records of siege work in the past, and the probable advance in armaments in the future, all point to the magnitude of the undertaking in a siege of even a second-class fortress. As war, nowadays, is a matter for big battalions, so is a siege the luxury of an army well equipped with the engineering and other technical appliances, which alone make those big battalions and heavy armaments efficient. To underrate the magnitude will be to diminish the chance of success.

APPENDIX.

Railway Traffic Company—German Establishment.

Rank.	Total. No.	Railway Duty.
Officers :—		
Captain	1	Special duty.
1st Lieutenant	1	
2nd Lieutenants	4	Station-masters.
N.C.O.'s :—		
Sergeant-Major	1	
Under Officers	40	4 assistant station-masters. 1 baggage clerk. 12 engine drivers. 7 guards. 7 brakesmen. 6 telegraph clerks. 3 telegraph line inspectors.
Lance-Corporals	20	3 guards. 1 foreman of telegraphs. 2 foremen of platelayers. 12 locomotive firemen. 2 stationary engines.
Men :—		
Privates	139	4 shunters. 18 signalmen. 14 platelayers. 7 engine fitters. 4 greasers. 2 carriage cleaners. 55 porters. 35 brakesmen.

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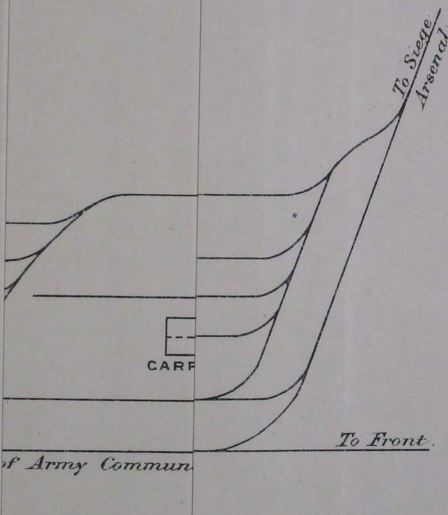
PLATE I.



PAPER XI.

GEOGRAPHICAL SURVEYING IN INDIA.

BY COLONEL SIR T. H. HOLDICH, K.C.I.E., C.B., R.E.

IN discussing the subject of "Geographical Surveying in India," it is very necessary to define at the outset what it is that we mean by India.

India is not a "country" like Britain, or France, or Germany. It is a continent as large as all Europe, and includes not only quite as many nationalities as Europe, but nationalities with far greater distinction in ethnographical characteristics and geographical surroundings than exist anywhere within the limits of Europe. There is, for instance, far more difference between the fair-skinned Pathan, or Sikh, of the north-west, and the dark-hued Dravidian people of the south, than will be found between the Welshman and Italian. The difference between the Esquimaux and the Spaniard is probably not more marked than is that between the Ghurka and the Bengali. The India of heat-ridden plains and tropical landscape, the historical India of Clive and Hastings, is rapidly changing, and our national interest in this great collection of other nationalities centres itself more and more towards the north-west—the borderland of Persia, Beluchistan, and Afghanistan—and withdraws further from the flat plains and plateaux that run to an apex at Cape Comorin. So far as geographical surveying is concerned, our interests south of the Himalayas, and east of the Indus, are at an end. Indeed one must go very far afield even on the north-west, in these days, to find any large extent of unexplored territory, although there are many points on the border still of which it may be said that we want a closer geographical acquaintance than that which we already possess. India, for the purposes of this lecture, then, will include all those border countries with which we have been making ourselves more or less familiar during the last 15 or 20 years; thus we may add Afghanistan, Beluchistan, and Persia on the north-west; Kashmir and the Pamirs on the north; and have something perhaps to say about Burmah on the north-east. And under the term "geographical" we may accept all that class of survey which does not admit of the minute exactness in topographical detail such as is not only expected, but demanded, whenever time and opportunity are available. You will understand that geographical surveying does not vary in principle in any way from exact surveying. The difference is one of degree, and method, not of principle. The more the time at our disposal, and the better (owing to military or political conditions) our chances may be, the nearer we gravitate to the recognized standard of exact topography, and revert to the one system which dominates surveys of all classes whatsoever in India.

This system in all its stages recognizes nothing short of the most minute exactness that can be obtained by the most skilful use of the best class of instruments in the best possible hands; and it is this system which has enveloped the India of the plains south of the Himalayas long ago, and which is now partially repeated from time to time in districts whose development demands surveys on large scales, and for special objects.

I need not describe it further than to impress on you that the great skeleton of geodetic triangulation which permeates India, traversing her back from the Himalayas to Cape Comorin, and extending along her ribs in lateral lines to the coasts on either side, linked up by long series of triangles which follow the coast lines, and checked by most carefully and scientifically planned measurements at regular intervals, is the basis, the foundation, of all these long feelers which extend into Burmah, to the Pamirs, the Oxus, and the Persian borderland. These feelers may be actual unbroken series of triangles themselves, or they may be the result of a consistent series of operations more or less analagous to that of a direct triangulation; but whatever they are, they have their roots in India, and are just as certainly based on the observatory at Greenwich for their zero or starting point as are your own geographical explorations in South Wales. I wish to impress this on you so that you should not suppose that geographical surveying, as pushed outwards into Southern Asia from the Indian border, is simple pioneering, that class of survey in which an explorer vanishes into space with instruments and equipment for the determination of his absolute position in latitude and longitude, as if his record were to be made on a trackless ocean. We never, if we can help it, lose sight of our landmarks. We fix them as we go, and they follow each other along like milestones on the great world's highway, stretching over mountains and through deserts to the farthest limits that we can reach; and each landmark is a compendium of geographical information in itself. We know not only its latitude and longitude relatively to Greenwich, but its altitude with reference to the sea, and the exact bearing or azimuth of all other visible landmarks from it. It is this which forms the distinctive feature of Indian geographical surveying, and the system is just as applicable to any other country as it is to India, or the countries round India. You will understand then that we are not dealing with exploration of that nature which the first pioneers across a great continent carry through with them, where so many other vital interests are in the field that the mere matter of a survey record becomes entirely subordinate, depending on good luck and occasional opportunity for its vitality. Such exploration is not surveying, and such records usually find final expression in a thin red line running across a more or less blank sheet of paper, with a few twisting sinuosities on either side to denote the hills. The opportunity for such exploration on the world's surface as this, is rapidly becoming so limited that it is difficult to say where future possible opportunities for the preliminary work of the pioneer may lie. On the other hand, the class of survey which we may call geographical—or first survey—is in greater and greater demand every day. Even if we have succeeded in pushing it as far as the limits of the Indian hinterland will at present permit, so far as to have secured our junction with the scientific surveys of Russia on the north-west and north, and to leave only intermediate areas for consideration, there is still much to be done even in those intermediate areas; whilst we have only to turn to Africa with its unbounded opportunities in military reconnaissance, boundary demarcations, and actual campaigning to realize that great as may have been our chances within the last 20 years in southern Asia, they are nothing to those which lie before you young R.E.'s of the present day.

Thus we may describe geographical surveying as "Topography, based on Triangulation," just as we should describe any other form of surveying, and if triangulation in the strict sense of the term is impossible, on something as near akin to it as we can attain. This is the whole law and the gospel of geographical surveying, and you should remember that anything less does not mean surveying at all.

In the admirable school of instruction which you are so well acquainted with here you are already taught all the first principles of the science. I need tell you very little indeed about the instruments which you will use, or the manner of using them. Nothing can be more practical or to the purpose than the pamphlets which are put into your hands, giving you all the assistance you can require in the way of formula and data for projecting your survey sheets, and reducing your preliminary observations. My best advice to you is to keep them carefully, and if ever you see the opportunity of putting your instruction to practical effect, study them carefully, get the forms and the formula at your finger ends, so that there may be no hesitation and no clumsiness in the field; for when you find yourselves face to face with your work, it may well happen that even minutes are of consequence.

But the area over which there is opportunity for the practical application of your theoretical studies is inconveniently small in England. It is, moreover, impossible to find in this well nurtured country anything that is at all analagous to the wide open plains and mountain ranges of great continents, or to give even an approximate ideà of what the real practical difficulties of your position may be; so, with but a very few general remarks on such preliminaries as are involved in the choice of instruments and preparation of equipment, I will confine myself to illustrations of such points as will confront you with an aspect of especial rockiness when you are once fairly in the field.

On whatever shores you first pitch your tent, wherever you first set your feet on the edge of a new domain for geographical enquiry, with its mystery of physical conformation still to be unravelled, you want four well ascertained facts as your data from which to effect your start. You must know, with reference to the particular point from which you take off (1) its latitude; (2), its longitude; (3), its altitude; (4), the true bearing or azimuth of some other point from it; and in addition to this you require a linear value, *i.e.*, an exact measurement which will form a base. Sometimes these obligatory data will be supplied to you. In India, or anywhere near India, they will certainly be supplied along with very much more important preliminary information. You have only to apply to the survey department to get them. But if your work lies in Africa, or elsewhere, and you are dependent on Admiralty charts and other special sources of information, then be cautious in *verifying your data*. Indeed, in any case, this is a matter which cannot be too strongly impressed on you. Find out the nature of it, how it has been evolved, whether you are likely to be able to improve on it, and never under any circumstances accept a list or *précis* involving the use of figures without most careful check. You would think that all this might be unnecessary in documents emanating from high official quarters containing your instructions in precise terms. Experience has taught me otherwise. Never, under any circumstances, trust any geographical statement, especially if it involves figures, without ascertaining its authority.

Into the questions of equipment I need hardly enter at all. It is one which you will have always with you, and it varies with every phase of work and with every development of instrumental means. I will assume that you are efficiently equipped more or less on the "mobilization" scale for Indian trans-border surveys, an equipment which fits in well with what I have seen of the principles of surveying which are set before you in this school.

Given that you already possess the obligatory data to which I have already referred, and that you are landed fairly at your starting point with the long blue stretches of seemingly endless plains before you, backed, maybe, by lines of mountains which will appear like the cardboard slips of the stage, range after range crossing your horizon and full of length without breadth, your very first difficulty will be to identify and recognize those points which form your data. If there are many of them, if they consist of well defined peaks, or prominent landmarks spread in front of you, every one of them should have been previously projected in its right position in latitude and longtitude, on a well mounted plane table—or, at least, on a cloth-mounted sheet of paper duly inscribed with its parallels and meridians at 5′ or 10′ intervals, with graduated scales of latitude and longitude drawn in it, together with a linear scale. In dealing with your plane table board, or with mounted paper, or anything else that is liable to expansion and contraction, never forget the golden rule to have all your scales on the paper so that they too may contract or expand proportionately with the board or the paper. Then make every effort to reach at least one fairly well fixed point, and from it, with the aid of your plane table, determine the position and appearance of all the others. Lastly, consider carefully where your triangulation is to take off in extension of that which has already been completed, *i.e.*, what points will form the best ends for the new base which is to project a series perchance into the heart of a continent.

But suppose (and this after all is the most practical supposition) that you have none of these things—no initial latitude or longitude, no base, or linear value; then I have a few words to say about each of these requirements. Your value for latitude can be easily ascertained, for it can be determined on any fine night, with a six-inch theodolite, by observations to north and south stars, to within a few seconds of the truth—so far as you can tell, for there may be causes of error, to which I will refer presently, that you cannot detect. Your latitude station will form one convenient end of your base, which should be levelled and measured with all possible care. There are various methods of measurement, but none of them to my mind are better than that which involves a steel chain, and a steel tape to serve as a standard for reference. I have tried many systems, and that which has proved most satisfactory is a careful system of direct measurement with the chain in the hands of a few well-trained chainmen. Accuracy, even in chaining, is not learnt in a day, and the more practice you can get at it the better. In the course of a day a base of two miles in length may be measured some three or four times over, and the extreme differences should not exceed a few links if your chainmen are practised hands. But you will have to cut your coat according to your cloth, and your length of base will be determined by many other considerations than those of your own convenience.

Pari passu with your latitude observations at night you determine the azimuth of your base, *i.e.*, the same observation will give you both. This, with an initial longitude, furnishes all that you require to compute out the co-ordinate positions of the hill peaks and prominent objects which you have observed from either end of your base, and to project these positions on the plane table prior to commencing topography.

But the longtitude ? How about that ? Well, my advice is that if you have absolutely no value to start upon, assume one; but treat your assumption with all respect. Do all you can to preserve it from day to day till time and opportunity enable you to apply a final constant correction throughout your work. My reason for this advice is that under most of the conditions which call for special surveys of a geographical nature your opportunity for determining an absolute value will be but small; and when you have got the observations you will never be certain of your results. In the case of boundary demarcations, for instance, absolute determinations of longitude are frightful pitfalls. You can never tell when the telegraph will not unwind itself across your path, and at once give the lie to your astronomical deductions, upsetting your record, and scattering a constant error along the line of survey. Much better leave it alone, and accepting any approximate value which is sufficiently near the truth to introduce no appreciable error in the corrections necessary in your astronomical deductions, admit candidly that you do not know your longitude exactly. If driven to an absolute determination (and the chance of this gets daily smaller), I think that the results attained from observing the occultations of Jupiter's satellites are the most satisfactory. But remember always that the whole map system of India is still suffering from the error of the Madras observatory determinations of the longitude of India by occultations of Jupiter's satellites. It is impossible to conceive that under ordinary field exigencies you could have the opportunity for obtaining observations so well balanced and so apparently consistent as those of Madras. They were taken with all the trained experience of one of our best astronomers, and reduced with infinite care. Yet the results are wrong by two miles and a-half, an error which is an unmixed source of inconvenience, if not of difficulty, in dealing with the mapping of our European neighbours in Asia.

With the telegraph at your disposal all difficulty vanishes except the practical one of securing a free line, and as the telegraph pushes itself into every field that you are likely to enter, you will probably have far more to do with that unrivalled method of determining your position in longitude than you will with any "occultations" or "lunar distances."

I have of course necessarily omitted all reference to the details of working your instruments for the attainment of your data or your initial triangulation, feeling sure that you will learn that here better than I can tell you. You should be able to determine your position in longitude by aid of the telegraph to within a few seconds of arc (say a few hundred feet), and as nearly as you can determine your latitude. There is, however, always a hidden source of error in latitude determinations which does not affect the longitude in an equal degree. The proximity of mountain masses or possibly of deep sea depressions, even the unceasing action of the earth's crust rising in some points relatively to the earth's centre and falling in others, produces what we call "level deflection" in various degrees, which may affect your work appreciably, and yet be indeterminate in value. For instance, the presence of the great mass of the Himalayas, north of Delna Dun, where we have one of our chief Indian observatories, pulls the level northward by force of gravitation to such an extent that no observed latitude of that place can be correct within 40 seconds of arc, or nearly a mile! This is an extreme case, but remember that the same source of error pervades all lands of hills and plains. It is this which still leaves triangulation, or some direct system of earth measurement, a paramount necessity in such countries as have hitherto remained unmapped. Were it not for this, a telegraph wire for longitude, and a theodolite for latitude, would meet all survey requirements short of actual topography.

So when you have clear weather and unlimited time you can work out your own scheme of triangulation from your own base; and, if you are lucky, can keep a whole staff of subordinates busy with the topography and the plane table. But it happens sometimes that the weather is not clear; and it happens often that time is not your own; but that you must move steadily forward by daily marches, leaving but a narrow margin of time for observations. This happened to us in our journey from Quetta to Kuhsan, near Herat, where we had to import a fixed point of departure (fixed, that is, in co-ordinate position relatively to Greenwich) as the basis of the commencement of the Russo-Afghan boundary. Our Indian triangulation carried us to the Helmund, and would have taken us yet further had not a thick haze (thick as London fog) swept down from the north, and blotted the landscape from view. We were reduced to traversing with plane table and chain for some days, till a clear view at last gave us the chance of a latitude, and an azimuth to a far distant peak lying south, which the plane table indicated to be one of the points of the Beluchistan system of triangulation. Here then we again recovered our Indian data, but not quite satisfactorily. From that point to Kuhsan we moved steadily northward, sometimes at the rate of 20 to 30 miles a day, and never lost connection again. As each day's march over those interminable Persian border flats was finished, a base was measured with the chain, and observations taken at either end, both to points already fixed behind us, and to every prominent forward peak near the presumed line of route. The positions of these were all computed out, and the distances of the forward peaks from the base determined. As soon as the stars were visible, an extemporary observatory at one end of the base was rapidly prepared, and latitude by north and south stars, and an azimuth, were observed and computed on the spot. The base had already its approximate position marked by the topographer in the plane table sketch which he carried on from day to day. This position was now checked, and his forward points projected by distance and azimuth so as to be ready for the next day's work. Thus by linking up each day's triangulation with that of the day previous, we reached Kuhsan without a break in the line of operations; and we never left the line of route to visit a single peak (*see Plate*).

Subsequent opportunity enabled us to obtain an accurate longitude by means of the telegraph at Mashad, in N.E. Persia; and from that point direct triangulation was carried down to Kuhsan, and extended from there eastward right through the Oxus valley to Kabul. We *then* found that in the course of the upward march points had been observed which subsequently became part of the general scheme of triangulation, and we were able to reverse the process and carry the value of the Mashad longitude down by a few successive steps to the point where we had lost ourselves in mist. The telegraph value determined at Mashad only differed from that which we carried up with us by the process I have described by a few seconds in arc; and when we had crossed Afghan-Turkestan we closed on the Kabul triangulation finally with a difference that was quite inappreciable on the scale of geographical survey.

Such results as these only really prove that small errors engendered in this rough class of geographical triangulation, where no definite artificial points to be observed can be set up, and where it is merely a question of reaching the highest point you can, and observing all you can—that such errors have a tendency to counteract and to neutralize each other. There was probably a great deal more error embodied in the series than showed itself at the end of it. But such results justify all endeavours towards accuracy, and they teach the lesson of perseverance.

It may indeed happen that the measurement of small daily bases is impracticable from the nature of the country. This happened more or less in the effort to carry the triangulation of India across the Hindu Kush into the Pamir country three years ago. We were fairly "bunkered" in the tight, narrow valleys which lead up to the little Pamir beyond the Hindu Kush. There was hardly a yard of favourable ground for a base, and huge cliffs and glaciers shut us in on either side with a solid wall of obstruction that it was hopeless to think of surmounting. But perseverance was again rewarded. The perseverance was that of Colonel Wahab, R.E., and his was the reward. He took the first opportunity that occurred of reaching the summit of an 18,000-foot peak, as we emerged into the little Pamir; and he subsequently took many others, with the result that twice he was rewarded by being able to identify on his plane table the whole array of magnificent snow pinnacles that are included in the Gilgit series of Indian triangulation; and with his theodolite he obtained accurate observations not only to these peaks, which he saw overtopping the broad back of the Hindu Kush, but to many a Russian and Chinese peak as well. The daily base system was at once dropped, except for purely local purposes, and we arrived at Lake Victoria with our triangulation connected with India and the proofs of it in our hands. Much pains had been expended by the Russian staff in the determination of their own position. Not again were they to be forced into accepting our data for their topography if they could help it. They had done so previously in Turkestan. Their longitude had been carried by telegraph to Osh, within measurable distance of our camp (about 80 miles north of it in a direct line), and a fine battery of chronometers was worked in circuits till it touched our position, in order to fill in the gap. In longitude they claimed that they could not be in error with reference to Osh by more than 5 seconds of arc; and no doubt they were justified in this, for the Russian chronometric work is of first-class order. They assumed the value of Osh to be definitely fixed with reference to Greenwich. We could claim something even a little better, granted that the telegraphic longitude of India could be assumed as absolutely correct. As regards latitude, it happened that much depended on the latitude of Lake Victoria. It was a factor in the international agreement; and it was necessary to be very exact about it. So there was unusual interest attached to the comparison of our respective values, both in latitude and longitude, of pillar No. 1 at the eastern end of the lake. In longitude we found to our surprise that we had nothing to discuss. To the very last second of arc our results (Russian and English) agreed; but in latitude they claimed a position some 10 seconds to the north of ours, as the result of their astronomical determinations.

But we had not only astronomical determinations of our own to depend on, we had also the very remarkable result of a direct connection by triangulation with India—and these results tallied with our "astro" determination to a second. Thus there was really no further room for argument, and we maintained our position.

Before I drop the subject of triangulation let me remind you that *altitudes* are a large feature of it, and that the relative relief or altitude of the plains and hills of the geographical area before you is a very important part of its configuration. But whilst you should never neglect to take observations for altitude to all high and prominent points, you should remember that the practical workman wants to know the heights of the plains and plateaux quite as much as the heights of the mountains, and that the latter are only really important as points for reference to your topographers in the plains. Whilst on this subject let me advise you to depend as little on barometric determinations of all sorts as you possibly can, and adopt the practice of taking altitudes with a small angle-measuring instrument (such as the clinometer) which can be usefully added to the topographical equipment. Whilst pursuing your work of triangulation with the theodolite be careful to secure reciprocal or complimentary observations for altitude as often as you can. It is only where you possess the double observation (*i.e.*, from A to B and from B to A) that you can determine a general value for refraction which will be applicable to your other observations which are not reciprocal. This is an important point, for although the tables included in your admirable Survey School notes give a co-efficient of refraction which equals 0·07, it is not at all unusual for the atmospheric conditions (especially in high altitudes) to be such as to cause a very considerable modification of this average value, and to necessitate recasting the tables. I have said nothing so far about your initial altitude, which, with the latitude and longitude of your initial point, is a necessary datum for the commencement of your survey. This, if it must be an absolute determination, is always a matter of difficulty, requiring a long series of careful observations spread over several weeks, together with a contemporary record of barometric readings, either at the sea coast or some point of which the altitude is already well ascertained. You are under these circumstances reduced to dependence on barometric results, and the instrument which I should recommend you to make use of is George's standard mercurial barometer, which packs more readily, and is less liable to damage, than most. It requires a little careful manipulation to expel the air completely from the tube, and it is sometimes a little difficult to read; but it is on the whole the most satisfactory instrument with which I am acquainted. It certainly gave us excellent results in the Pamirs, where, as I have said, we were not dependent on the value obtained from it, as we had a direct connection by triangulation with India. In Turkestan during the progress of the Russo-Afghan boundary demarcation the results were not so satisfactory, and we had to await the comparison with Russian daily records on the Caspian Sea before we could dispose of an error which, if I remember right, amounted to nearly 500 feet.

There is not much more that I need add on the subject of triangulation. Remember General Woodthorpe's golden rule "get as high as you can;" "observe all that you can;" and even if you do not quite see your way to the extension of a well-balanced series of triangles across the country which lies before you to map for the first time, do not despair, or abandon the use of your theodolite. Remember that a latitude combined with an azimuth to any far distant point (the further the better) either north or south of you gives you your longitude with reference to that point with a precision equal at least to that with which you can ascertain your latitude; and that you could, if necessary, carry your longitude down with you from Cairo to the Cape of Good Hope by this method with facility and exactness.

Now for a word or two about topography, and here I feel that I am perhaps treading on delicate ground. It is not at all unusual for young officers to count themselves as finished practical topographers when they have mastered the use of the plane table. Thank heaven! in these days every officer knows more or less of the use of that very simple instrument. It is so very simple, and the problems involved in its use are of such an elementary character, that I need not refer to them in detail. I can safely leave that to your instructors. For geographical purposes the plane table has long ago superseded all other forms of instrument, or combination of instruments, that ensure accurate topographical delineation; and the only difference that now exists between our fashion of using it on the Indian border and the practice of America or Russia is that we do not claim for it that, under any circumstances, it can supersede the theodolite. Russians and Americans do claim this. Russian artists save themselves much preliminary work in mountain climbing, and subsequent labour in computing theodolite observations, by the simple process of what they call graphic triangulation — that is to say, that by adding slow motion screws to the azimuthal movement of the plane table, and by a few extra refinements to the "alidade" or plane table ruler (such as a telescope), they turn the plane table into an alt-azimuth instrument of a very inferior class, and carry out their triangulation with it alone. I have the greatest admiration and respect for Russian surveyors. Their geodetic and strictly scientific work is of a quality which surpasses our English triangulation, and is nearly, if not quite, on a level with that of India; but their graphic triangulation with the plane table is a failure. They are occasionally hopelessly in error before they have extended 100 miles from the original base. But all general rules have their exceptions, and there are circumstances under which we are obliged to use the plane table as a triangulating instrument. What I wish to impress on you at starting is that a man who knows how to use his plane table is not necessarily a good plane tabler any more than a man who knows how to use a gun is a good shot. The one requires as much practice with trained eye and trained hand as does the other. So generally has this come to be recognized nowadays that we employ a special staff of workmen in India (and you will find them in Africa also) to work as topographers and explorers; men who have spent years in the topographical branch of the survey department, working under all sorts and conditions of climate, in every variety of country, from the wide stony plateaux of Beluchistan to the dense forest-clad tropical hills of Burmah. They are selected men to begin with, often drawn from the ranks of the native army, and many of them have passed what is called the Rurki class with distinction. Thus we get the best of good material to work upon, and words would either fail me, or appear too extravagant, were I to record my opinion of what these native surveyors have done in clearing up the waste places of Asiatic geography. Some of them have a perfect genius for rapid topographical delineation of ground. Most travellers in the Asiatic wilderness draw on our resources for assistance of this description, and there is not one of them who has written of his travels and experiences who has not been enthusiastic when he refers to the determined, patient, untiring devotion to their work evinced by these men—Welby, of the 18th Hussars, who lately crossed Tibet from end to end, and has written so well of his adventures; Bower, of the 17th B.L., who preceded Welby on a more northerly track; Frank Younghusband, who struck into the "Heart of a Continent;"

Theodore Bent, who, ere he died, cleared away the mists from the mediæval geography of southern Arabia and Abyssinia; Sykes, of the Queen's Bays, who has ransacked Persia from end to end—all these men have made use of them. Littledale alone did not rely on any assistance; but there are very few men capable of uniting patient persistence in surveying with the untiring energy of the sportsman as Littledale does. His work is most admirable, but it is not saying too much to suggest that it would have been better had he made use of trained assistance.

But whilst I wish to impress on your minds that even the excellent practical instruction which you get here cannot turn you into finished workmen without the experience of all those countless varieties of stress and difficulty which are only to be met with in larger fields, I can hardly place too high a value on the advantages of this preliminary training. It is everything to know for a certainty that an officer (inexperienced as he may be) knows what he is about when he is associated in the field with surveyors; that he will begin his work at the right end, and continue on sound methods. For illustration, I can quote the late campaigning in Tirah, which, added to the opportunities afforded by expeditions to the Tochi valley, to the Mohmand country, to Swat and to Buner, so severely taxed the resources of the survey department in trained officers, that I found myself almost single-handed with two divisions of the Tirah F.F. moving over a large extent of new ground to provide for. Geographical surveying, as you are aware, is not always carried out with the advantages of a political mission to back it, or the opportunities afforded by peaceful occupation of the country. Our frontier military expeditions have done more than political missions to open up new military surveys of the borderland, and this particular occasion was one of importance. Not only had we never seen the Afridi country, but the chances were great that we should not see it again, whilst it is not too much to say that had we been able to obtain really sound geographical information beforehand the whole plan of the campaign might have been altered. In the course of this combination of military topography with general geographical mapping it happens usually that the information obtained from day to day is required on the spot. You know enough about plane tabling to be aware that a general outline of the main features of any hill country can often be obtained from a distance; passes can be located, altitudes of them fixed, and prominent towns and villages with their connecting roads mapped in, long before they are reached. Thus the military mapping connected with these expeditions is of great practical value at the time, both as illustrative of the physical conditions of the country in front, as well as descriptive of that already passed over. It happened in this case that no triangulation was possible. The support of a full division would hardly have been sufficient to safeguard a survey party to any sufficiently commanding point to enable the theodolite to be used effectively, and no division was available for such purposes. But there were a certain number of prominent landmarks already fixed from long distances, the outriggers of previous expeditions north and south and east of Afridi land, that, combined with a few well-known frontier peaks nearer the Indian border, justified our plane tabling on the normal military scale of one inch = one mile. There was no difficulty about the native plane tablers. I had my reserve of them at the Quetta headquarters of the survey—good men and true, drawn from the ranks chiefly, and well tried in many fields—but officers? Where was I to get the indispensable leaders for the divisional parties who were to tackle the generals about escorts, watch for the opportunities afforded by foraging parties or scouts; decide what points could be reached; keep the plane tabler from interference whilst he applied himself solely to his own work; decide when he was to clear out of danger; take altitudes for him, and relieve him of all the inevitable wrangling with guides and interpreters; in fact, do everything except the actual topography, and keep a keen eye on that too? Well, now, any of you young officers who have had your training here, who might be in hard training for hill climbing (this is very necessary), good linguists, and the happy possessors of persuasive manners with your superiors, could do this thing. I found two such officers, and one of them was Lieut. Leslie, R.E., who (well supported by a native plane tabler who possessed iron nerve and the constitution of an athlete, combined with that eye for country that it seems to me only hill men possess, and excellent artistic skill) soon found himself an authority for the movement of troops, and won the special recognition of the Commander-in-Chief. He is now Major Leslie, I am glad to say, and his views on geographical surveying have doubtless expanded. He had nothing but his Chatham training to support him at starting. I give you a trace* of the work done with the Tirah force (I regret that it is such a rough copy, but

* Not reproduced.

there was no time to prepare a better one), and you may note that the greater part of it was done under fire, and that during the process Leslie's plane table was twice hit. There were of course two or three other parties in the field besides his, but they had not his opportunities.

I should like to add a few words upon field reproduction of mapping. Reproductions are almost essential nowadays to the general's report on a campaign, and special plans prepared during the actual progress of an engagement on scales somewhat larger than the normal geographical scale—*i.e.*, three or six inches per mile, are very much appreciated for the purpose of illustrating the movement of troops during an action. Our system in India has been to use a small printing frame and sensitized paper (usually ferrotype), and to reproduce the plan of action as soon as the drawing ink on the tracing cloth is dry by the process of sun printing from a tracing which acts as a negative. This reproduces in white outline on a dark blue ground, and is to my mind as clear a form of reproduction and as satisfactory an illustration as can be desired. It can be turned into blue printing on a white ground by preparing a negative from the trace with some form of photographic paper, and using this instead of the original trace to print from. Another process (called the ferro-gallic) for producing black outline on white ground is much in vogue in the Ceylon survey, and gives most excellent results; but it requires the use of a specially prepared patent paper which might not stand exposure, or retain its qualities if not fresh. All these processes require the use of a tent for the sake of darkness during manipulation. This is a disadvantage, for in these days even a small 80-lb. Kabul tent is looked on with suspicion as savouring of luxury in campaigning. It is a subject which requires your best attention here at headquarters, for I am convinced that we have not yet solved the problem of field map reproduction satisfactorily. At present we want a whole day to reproduce a dozen copies—and this is too much for modern war exigencies.

Now to sum up those points to which I desire your special attention.

(1). Verify your original data. Be sure you have all you can get, and that you are not building up an elaborate construction on a foundation of sand. I assure you there have been some serious difficulties lately raised in the field of boundary demarcation by omitting this precaution.

(2). When making your start, direct all your efforts towards initial accuracy. Remember that one observed angle is worth 50 deductions, and stick to the very simplest form of triangulation that is possible. The simplest means to attain the simplest form is to get as high as you can, and to observe all you can.

(3). Get your latitudes with the utmost care, and *frequently;* also introduce fresh azimuthal values from astronomical deductions *often;* and *occasionally* check your linear values by a fresh base.

(4). Don't involve yourself in the determination of an absolute longitude if you can help it. Endeavour rather to tie on to any existing longitude that is available, till the good time comes when you can arrive at a satisfactory determination by telegraph. Remember that the absolute longitude value matters little in comparison with the differential value. It does not matter what the longitude of Africa may be so long as we are all agreed to use the same value. Supposing, for instance, that your work ties on that of some neighbouring power in Africa, and that you meet on a meridian line accepted as the boundary by treaty. Meridians form the worst possible boundary definition, but that does not prevent their employment by high officials who do not know how longitudes are fixed; and you may find yourself facing this difficulty. In such a case your absolute determination may easily place that line two miles too far west, and your international colleague may place it as much to the east. Where, then, is your boundary? Your absolute determination is no better than his, probably, and even if you come to a mutual decision, it will finally never reconcile itself to surrounding geography as soon as that geography is based on a sound determination. If, on the other hand, you can start with a sound determination, never let it go. Carry it by triangulation to the end of your work, and carefully preserve your computations as you go. The instant that discussion arises, be able to appeal to them as the groundwork of your faith in your position. If your computations are sound, they will never be seriously discussed by a scientific adversary, who can only make his bow and adopt your conclusions.

AFGHAN BOUNDARY COMMISSION

TRIANGULATION EXECUTED ON THE MARCH.

For fixing the Longitude of Kushan.
310 miles completed in 19 days.