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PREFACE.

Vol. XVI. for 1890, now presented to the Corps, contains papers on most of the branches of the Corps duty, as well as on essentially military subjects. Colonel Savile and Colonel Hutton both treat of the new question of Mobile Infantry in one form or another, while Colonel Rothwell handles the most important subject of Mobilization. Artillery subjects are dealt with in Captain Orde Browne's paper on recent experiments, and Major Savage contributes a series of Diagrams of Service Ordnance and their Mountings, which are intended as illustrations of the lists of service ordnance which have appeared from time to time in these papers.

Major A. R. F. Dorward gives us the results of his experience of what duties the Corps is actually called upon to perform in the numerous small wars in uncivilized regions, which have fallen to the lot of our army in late years.

Under the head of more technical engineering work come the papers on Sewage Disposal, Road Making, Hydrographic Survey, Electric and Petroleum Motors, and Bridges in the Bengal Presidency.

The Lydd Experiments no longer appear in these papers, but are being issued separately as one of the confidential series which has been commenced this year.

W. A. GALE, Captain, R.E.,
Secretary, R.E. Institute, and Editor.

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PAPER I.

CYCLIST INFANTRY.

BY LIEUTENANT-COLONEL A. R. SAVILE, *p.s.c.*
(26th Middlesex (Cyclist) R.V.).

I THINK I am justified in saying that one of the most startling innovations amongst the numerous military developments of the present time is the employment of cyclists for war purposes, but I hope I am also justified in assuming, from the fact that you have done me the honour to invite me to lecture to you on the subject of cyclist infantry, that at the S.M.E. this new departure is not viewed with disfavour, or that, at any rate, you believe it possesses sufficient merit to entitle it to be seriously considered.

It would, I think, have been a very strange thing if the sudden and unexpected institution of a new branch of our armed strength had not been attended by some expression of the prejudice or suspicion with which military changes are generally—and, perhaps, in many cases rightly—viewed in our service; but what I think far more strange in this connection is the undoubted fact that the opposition to the military employment of cyclist infantry has been weak from the commencement, and has apparently already been almost entirely overcome.

It is hardly two and a-half years ago, when lecturing at the R.U.S.I. upon this subject for the first time, that I ventured upon the statement that the cycle was recognised by our military conceived the bold idea of employing armed cyclists in the field as scouts and reconnoitrers.

The manœuvres of 1887 were chiefly remarkable for the employment of civilians as cyclist soldiers; there was no time available to raise and organise a military body even from the volunteer force; many failings were apparent; and it was evident that to perform efficiently the difficult duties of mounted infantry a careful course of training was necessary. This is a subject to which I shall allude again a little later. Still, owing to the zeal and energy of the men, and their keen desire to show that cyclists were really sane and rational beings, and not merely sources of terror and annoyance to peaceable citizens, the manœuvres went off well, and I think I may fairly say that we did quite as much as we were expected to do, and perhaps a little more. Many lookers-on and critics came out upon that occasion to scoff, but it is a fact that most of them returned to their homes converted, and fully imbued with a conviction that there was a future for military cycling.

The result of this experiment was almost immediate, for in the autumn of the same year the War Office sanctioned the formation of a cyclist section within the establishment of every volunteer battalion throughout the kingdom, and I was directed to draw up recommendations concerning the composition and duties of these sections. The matter was further pushed forward by the appointment, in December, 1887, of a War Office Committee, composed partly of officers of the regular forces, partly of volunteer officers, and partly of civilian cycling experts. This committee, under my presidency, commenced its sittings early in 1888, and enquired into and reported upon the following subjects which had been referred to it, viz.:—

(*a*). To draw up precise specifications of types of cycles suitable for military requirements.

(*b*). To ascertain where such cycles can best be manufactured, and at what cost.

(*c*). To consider the clothing, arms, equipment, accoutrements, and kit of a volunteer cyclist, and the means for carrying the same in the field.

(*d*). To consider the course of training of a volunteer cyclist.

(*e*). To consider the conditions of efficiency of a volunteer cyclist.

The recommendations concerning the formation of cyclist sections were also referred to the committee; they were revised in accordance with the experience gained during the investigations; the revise was approved by the War Office, and was then issued in the form of instructions as an Army Order.

In April, 1888, upon the strong recommendation of Lord Wolseley, the formation of a cyclist corps, to be known as the 26th Middlesex (Cyclist) R.V., was approved by the Secretary of State for War, and Major Percy Hewitt, late Carabiniers, was appointed to command it.

In the meantime the organisation of cyclist sections in volunteer battalions progressed steadily, and at Easter, 1888, a number of these sections, together with the cyclist corps, were assembled at Guildford, and placed, by order from the War Office, under my command. Starting on Good Friday morning for Salisbury, the cyclists reached that place the same evening, several tactical exercises were carried out, and the force then rode to Dover in time to take part in the Easter Monday review. Throughout this Easter we had detestable weather and infamous roads to deal with. By this time the experiments in military cycling had attracted the attention of, and were being closely watched by, critics at home and abroad—many of them only too ready to detect any failing and magnify it to the utmost. This, as might be expected, had the desirable effect of putting our volunteer cyclists fully on their mettle, and all worked with a will to maintain the credit of cycling. Without entering into any details, I would merely say that during these manœuvres some very hard work and some very good work was done. The defects noticeable might clearly be traced to want of military experience, and not to inherent failings in cycles or cyclists; with the one exception, that many of the men were not in a proper state of training to do the mere riding part of the work efficiently. This, however, I maintain, is not an inherent defect, but still it is a defect that must not be allowed to exist for a moment in a body of military cyclists. I fully admit that the weather during the spring of the year was bad enough to daunt all but hardy riders; still, I decline to accept this as a valid excuse. A soldier, to be an efficient soldier, must be efficient all the year round; and I cannot too strongly impress upon every cyclist soldier that he must ride during winter, and keep both himself and his machine in a fit state to take the field at any moment. In my opinion the officers should be held directly responsible for this in their respective commands.

During the summer of 1888 the movement received a distinct impulse by the experiments being extended to the regular forces.

Machines of various types were purchased by the Government and placed at the Aldershot gymnasium, where men were trained as soldier cyclists under the supervision of Colonel Onslow. This was again done in 1889, and in the present year the experiment has been repeated on a still larger scale under the direction of Colonel Fox, Inspector of Gymnasia, who was a member of the War Office Committee on military cycling. More machines have been purchased by Government, officers of the regular forces have been told off for cycle duty, a large detachment of the Royal Irish Regiment has been trained at Aldershot, and cyclists have taken part in several of the Aldershot field days and flying columns.

In August, 1888, by permission of the War Office, I undertook some cyclist manœuvres in Cheshire with the Cyclist Corps, and several of the Lancashire and Cheshire volunteer sections. We assembled at Crewe late on the evening of August 4th, and at 10 p.m. started, in drenching rain and pitch darkness, to march a distance of some 30 miles to Warrington. A night march, even under ordinary circumstances, and undertaken by trained and disciplined troops, is an operation requiring special precautions, and it is generally considered to be so difficult that most writers on tactics used to lay down as an axiom that night marches should not be undertaken if the object in view could be attained in any other manner. The operation was consequently a severe test for our young cyclist soldiers, but they came right well through the trial, and a large proportion of the force was landed in efficient order at Warrington about 3 a.m. I do not wish to imply that there were no flaws and hitches in the conduct of the march—it would, indeed, have been strange had such been the case—but I do maintain that no body of troops mounted in any other way but on cycles could have performed this march in the same time under the same circumstances, and have been fit, after only a few hours' rest, to move on again and do a long day's work.

The next day was devoted to outpost duty and despatch carrying, etc A good deal of useful and interesting work was done, and the weather being fine, the whole force marched in high spirits into Chester in the evening, and when I inspected the detachments in front of the Queen's Hotel before dismissing them I could not help thinking that now we had got quality, and that all we wanted was a little more quantity. Next day the force carried out a series of tactical operations in the country between Chester and Crewe, marching through Tarvin, Tarporley, and Nantwich, and the attack and defence of military positions by advanced and rear guards were practised. The great advance in military knowledge, in discipline, in general smartness, and in all that pertains to efficiency in a soldier which the volunteer cyclists had made during the summer, was very apparent on this day. Many little actions showing both intelligence and dash on the part of officers and men came under my notice, and it was very evident that if it had only been possible to keep the force as then constituted—the weak men and machines having by this time retired—under arms for another week or so, it would have been fit to perform any duty that could be required of mounted infantry.

On each of the occasions that I have alluded to I have had the honour to receive from the War Office an expression of the entire satisfaction of H.R.H. the Commander-in-Chief concerning the work done by the cyclists. The value of these field manœuvres can hardly be over-estimated. They teach young soldiers how to act in unison, and how to behave in sudden and unforeseen emergencies, and I earnestly hope that all commanders of cyclist volunteers will allow no opportunities for such practices to escape them.

The early part of 1889 witnessed the formation of a Royal Marine Cyclist Corps at Walmer. Here (at Chatham) you are probably aware that, owing to the zeal and energy of Major Edye, R.M.L.I., and the officers who have assisted him, the Marines have now got an exceedingly smart body of cyclists, not only at Walmer, but also at Chatham, Portsmouth, and Plymouth, and I think I may say, without fear of contradiction, that throughout the world there are no cyclist soldiers more capable of demonstrating the capabilities of the cycle as a mount for "quick-moving infantry" than the members of the Royal Marine Cyclist Corps, who, without any pecuniary assistance from either public or corps funds, have attained a very high standard of efficiency.

At Easter, 1889, I again commanded a force of combined cyclist sections during manœuvres in Hants and Berks. Profiting by past experiences, these operations were made the most useful and interesting that had yet been performed. A great deal of attention was given to outpost duty, and a very marked feature was the wide extent of frontage that could be effectively watched and patrolled by a comparatively small number of the fast, noiseless, and almost invisible cyclist scouts.

Throughout the whole of 1889 the numerous cyclist sections of volunteer battalions came a good deal under public notice. Whenever a battalion was in camp its cyclists were fully employed for orderly work, etc., and in small tactical exercises their services as scouts and reconnoitrers were found invaluable. I believe I am right in saying that in every volunteer battalion where a cyclist section has been organized the commanding officer has been able to report favourably upon it, and to state that the men, as cyclists, have been able to efficiently perform the duties required of them.

Perhaps the most important step in advance during the present year has been the official publication, by Army Order 115, of the drill of a cyclist infantry section. This much-needed work was compiled, under the direction of the War Office, by Captain Eustace Balfour, London Scottish R.V., whose zeal in the cause has never flagged from the very commencement, and to whose facile pen many able contributions to the literature of military cycling are due. This drill, combined with the diary of work which has lately been officially issued, enables all the scattered cyclist sections throughout the country to be trained on identical lines, and conduces greatly to their efficiency when combined for field duties.

Last Easter the volunteer cyclists, reinforced by a strong section of the Royal Marines, under Major Edye, turned out again under my command in greater numbers than ever before, and, for the first time since their initial employment, in 1887, took part with the main body of the volunteers in the Kent manœuvres. The sham fights which took place on the Saturday and Easter Monday hardly afforded scope for the true tactical employment of mounted infantry in any shape, for the area of available ground was small compared to the number of men engaged, and the opposing forces started on each occasion almost within touching distance of one another. It is on account of these circumstances, together with the fact that no umpire was specially told off—as had always previously been the case—to accompany the cyclists, and to note and report upon their doings, that no very new or important lessons concerning cyclist warfare were learnt; but I may mention that on the Saturday a force of over 100 cyclists, by a wide and rapid detour, passed unperceived round the enemy's right flank, and appeared directly in his rear. All good results from this manœuvre were, however, rendered abortive by a change in the plans, which brought the fight to a close at the exact hour at which the cyclists had been ordered to make their demonstration in the rear. On the same day an opportunity was afforded to the cyclists of working in conjunction with a small body of mounted infantry on horses, and the combination answered excellently. In the fight on Easter Monday, the mobility of a cyclist force was very apparent, for the men, skirmishing with their machines across country, were quite able to keep pace with such a handy corps as the London Scottish, on whose flank they were placed in the line. On one day the cyclists were allowed to act independently, and some very good distance marching was performed, showing that military cyclists, carrying rifle, ammunition, kit, etc., are fully capable of executing any march that may be necessary in war.

Another step in military cycling has been the permission granted to soldiers of the regular forces to ride bicycles in uniform, and the formation in several line battalions—notably the Royal Irish Rifles—of cycling clubs, the members of which seem greatly to enjoy and benefit by the capital exercise afforded them in the use of their machines.

I think that this summary of events gives you some idea of what has already been done as regards the employment of cyclist infantry in England, and the amount of progress that has been made during the three and a-half years of the existence of the force. I propose now to pass on to the consideration of the various kinds of machines available for use, and the qualifications possessed by cycles as a means of transport for mounted infantry.

There are several general types of cycles to choose from, viz.:—

(1). The ordinary bicycle.
(2). The rear-driving safety bicycle.
(3). The single tricycle.
(4). The tandem tricycle, carrying two riders.
(5). Multicycles, carrying more than two riders.

The ordinary bicycle, though an excellent machine from some points of view, is not at all adapted for military purposes. Compared with the safety bicycle, the height is greater, and the rider more conspicuous. A cyclist soldier must perforce carry his arms, ammunition, and kit, and these should be fastened on to the machine, and not borne on the person. As it is impossible to effect this satisfactorily on the ordinary bicycle, the machine is at once out of court as a military mount, and I need not take up time by mentioning other inherent defects.

The safety bicycle appears, from all points of view, to be the best all-round machine. It has two equal sized wheels, the rear wheel being driven by a chain. The rider sits above and between the two wheels, and his feet are raised only a few inches from the ground. The machine runs easily over considerable obstacles, and is practically safe down any hill. All that a soldier wants to carry on service can be easily packed on the machine. Its speed, acquired by gearing, is quite as great as that of the ordinary bicycle. The same machine can be ridden both by a tall and a short man. For convenience of mounting, dismounting, stowing for transport, and handling, the safety bicycle has no equal.

All tricycles possess the advantage of stable equilibrium ; the rider can halt without dismounting, and can turn about easily. The single tricycle is, therefore, in some respects, suitable for use by an officer. Being, however, a three-track machine, its progress on rough and rutty roads is much impeded, and it can only be taken off roads with much difficulty.

The tandem tricycle is a fast machine, and if one rider is dismounted for any duty, the other can ride the machine along and keep close at hand. It can carry a large amount of baggage.

Multicycles are still in their infancy. It has been suggested that this type of cycle can be adapted for the transport of machine-guns, field engineering materials, field telegraph equipment, or reserve ammunition. Machines designed for the two first of these objects have been brought into the field ; they were, however, of experimental build, and had been very hastily constructed ; both broke down at a very early stage of the operations, being unable to withstand the strain of their heavy loads on very rough and hilly roads. This, in my opinion, by no means proves that cycles cannot be applied to such uses. I think that when a manufacturer is found combining mechanical ingenuity with a thorough knowledge of what is required from the military point of view, the difficulties will be overcome ; in fact, fresh experiments have quite recently been made with cycle-mounted machine-guns and cycle ambulances, and the results have been quite sufficiently satisfactory to warrant this opinion. That cycles capable of bearing great weights can be constructed is shown by the "Carrier" machines so common in large towns. Multicycles, carrying 10 or 12 riders, with their arms, kits, and a large quantity of ammunition, have been made by Singer & Co., of Coventry. A machine of this description was thoroughly tested at Aldershot last year, and was so favourably reported on, that the Government has purchased one for further experiments. For sending forward small parties of marksmen long distances in compact bodies, such machines offer definite advantages, particularly in the case of cyclists of the regular forces ; but as in the volunteer force each cyclist has to provide a machine at his own cost for his individual use, such machines are obviously unsuitable.

At the time when the War Office Committee on military cycling held its sittings, not much attention had been given by cycle manufacturers to the wants of soldier-cyclists, and consequently the committee could not recommend any particular safety bicycle for general adoption. The chief essentials of a military machine are strength, rigidity, durability, and power to carry a rifle, ammunition, and kit. The specification of a machine combining to the utmost these qualifications was drawn up by the committee; the Government order for a sample machine was given to Messrs. Singer & Co., of Coventry, and it is now at Woolwich as the sealed pattern. Now, however suitable this particular machine may be for the use of Tommy Atkins, its great weight and its unfitness for ordinary touring and pleasure purposes will prevent its commanding a sale amongst volunteer cyclists, who choose their machines according to their individual tastes, pay for them out of their own pockets, and use them, not only for military purposes, but for their own amusement. Nor do I think that the efficiency of a volunteer cyclist now depends much upon his ownership of a machine built solely with the military aspect in view, for nearly all the leading firms of cycle manufacturers have, by this time, carefully worked out the problem, and have for sale excellently designed machines with removable fittings, and which can be equally used for parade purposes or for ordinary riding at pleasure. The only additional remark I would make in this connection is that the mount of a soldier-cyclist must be made of the very best materials, and should be purchased from one of the high-class and reliable firms, for it will have to undergo exceedingly rough usage, and carry a considerable dead weight.

Passing on now to another matter, I think I may assume that I need not include any arguments as to whether mounted infantry is or is not a useful adjunct to our armed strength; that, I take it, falls to the lot of Colonel Hutton, whose lecture to you to-morrow has a wider scope, and embraces the whole action of mounted infantry. Consequently, I shall confine myself solely to the task of showing the fitness of cyclists as one form of that mounted infantry, the usefulness of which may, for the present, be conceded.

The speed which can be obtained by cyclists is the first point that I wish to draw attention to. It did not require much experience to discover the fact that the speed of a marching body of cyclists can no more be compared to the pace of a well-trained man riding singly than can the rate of progress of a troop of cavalry scouting across country be compared to the pace of a steeple-chase; still, as one of the best recognised functions of a cyclist is his employment singly as a messenger, I think it will be both useful and interesting to lay before you some of the performances on safety bicycles on roads.

	H.	M.	S.
50 miles	2	32	35
100 "	5	27	38
178 "	12	0	0
$336\frac{1}{2}$ "	24	0	0
London to Edinburgh (399 miles)... ...	44	49	0
London to Liverpool ($201\frac{1}{2}$ miles)... ...	16	55	0
London to York (197 miles)	14	33	0
London to Bath and back (212 miles) ...	17	53	3
London to Brighton and back (103 miles) ...	6	52	10

These road records—marvellous as they appear—are established beyond a shadow of a doubt; they have all been performed under the auspices of a selected committee, they have been checked and verified by all manner of precautions, and are vouched for as accurate. Of course, the marching power of an armed and equipped body of soldier-cyclists cannot be compared with the above figures, but it has been frequently proved that a pace of from 7 to 10 miles an hour can be kept up during manœuvres for many hours without fatigue, and the men brought in in perfectly efficient condition. Naturally, the character of the road must be taken into consideration in any calculation concerning speed, and I quite admit that the nature of the road surface and the weather affect the speed of a cyclist more than they do the speed of a horseman, but, however adverse the circumstances may be, the worst speed of the cyclist can hardly be reduced to the best speed of other arms. People who know nothing about the matter often say that a cyclist can only ride on a good road. I assure you that a faster pace than can be attained by any other mode of locomotion can be kept up on a very bad road indeed; and we have the highest authority for the opinion that if on service the roads are cut up and rutty, all the movements of the army will be delayed, and that cyclists will not suffer more in this respect than other troops.

Foremost amongst the other relative advantages possessed by cycles as a means of transport for mobile infantry must be mentioned the obvious fact that the cycle requires neither forage nor water. The comparative independence of base, and the freedom of action acquired thereby, must be apparent to all who have ever had to contend with the difficulties which surround the provision of these necessaries for live animals. The bad and insufficient food, which is often all that can be obtained during field operations, does not tell upon the mounts of the cyclists, who carry in a pocket oil-can all the refreshment required by the machines during a journey of hundreds of miles. When cyclists are in action not a single man need be left behind to hold the mounts; every man can be placed in the fighting line. Colonel Hallam Parr, in his *Training and Instruction of Mounted Infantry*, says :—"Few who have commanded mounted infantry in action but have turned envious eyes to their horse-holders, and devised schemes for getting more of them into the fighting line." The machines of the dismounted men, when laid on the ground, are quite invisible at very short distances; the enemy would not know their position, and they offer no target for fire. I have noticed in the remarks of the chief umpire upon field days held at Aldershot, that the exposure to fire of the horses of the mounted infantry was the subject of comment. I think it must be admitted that cycles are less conspicuous on the road and more silent on the march than any other kind of transport. The dust raised by cycles is very slight compared to that caused by animals. The tramp of horses carrying patrols, scouts, or messengers can, especially at night, be heard at great distances, and the strength of the party can be estimated, whereas the cycle is absolutely noiseless. In an excellent paper on "The Use of the Cycle for Military Purposes," contributed by Mr. Lacy Hillier to *Longman's Magazine* of July, 1887, the distance ride performed by a small party of the 13th Hussars is noticed thus :—"The 137 miles covered by the 13th Hussars in 68½ hours would be very easily accomplished by a quartette of picked cyclists in 14 hours; whilst, if secrecy was required, the journey could be accomplished with great ease in two nights; the silent wheels would pass undetected where four mounted men could hardly hope to go unnoticed."

A cycle requires but little daily care or protection compared to the attention that must be given to any live animal in order to keep it in efficient condition. Military cycles can be made to gauge, and be interchangeable throughout; two disabled machines could be easily turned into one serviceable one; and the vital parts are few, small, and easily carried. Cycles can be very easily transported by rail; a large number of machines can be quickly packed in any kind of van, truck, or carriage, without the aid of a platform.

The cost of efficient safety bicycles for military purposes ought not to exceed about £12 each, if a number of machines are built upon one order. I do not, however, wish to lay any stress, or claim any advantage, upon the relative cost of cycles and of other means of transport for mounted infantry. Possibly a cycle may cost less than a horse, pony, camel, or even a donkey, but do not let us have a cheap article merely because it is cheap. If the cycle be found to possess certain merits, then by all means let us have some cycles, and let us apply them to such uses for which their fitness can be proved; but if any other kind of mount be superior to the cycle from all points of view, then let the cycle be discarded, however cheap it may be.

A very old argument used by opponents of mounted infantry as a permanent force is that the men when mounted on horses are apt to lose their infantry character and, by acquiring the desire to fight on horseback, to degenerate into bad cavalry. This, I think you will agree with me, is a failing which is never likely to be urged against a cyclist force, for it is absolutely impossible that such an idea as to fight mounted could ever enter into the head of a cyclist!

Finally, we all know how very difficult it is to clothe, arm, and equip a soldier suitably for riding on horseback with comfort, and equally for the efficient performance of dismounted duties; but the uniform for cyclists which was suggested by the War Office Committee, and approved by H.R.H. the Commander-in-Chief, is a perfect uniform for cycle riding and also the *beau ideal* of dress for a skirmisher.

Being anxious to bring this matter of the qualifications of cyclists before you in all its bearings, I must now touch upon the oft-discussed question as to whether cyclists possess the power to leave roads and to take their machines with them. Some people affirm that to do so is impossible, and these people, as a rule, are not cyclists; others who have frequently taken their own machines across country, and have seen the same thing done by bodies of men, are equally confident that there is no difficulty at all in the matter. My own opinion is that an active man can take a safety bicycle anywhere, but that a cyclist-soldier in the exercise of his proper functions will hardly ever be required to take his machine far from a road of some description. The whole misunderstanding seems to me to spring from non-appreciation of the fundamental principle that a cyclist-soldier does not use or require his machine for fighting purposes, and that when a fight begins he leaves his machine and acts as an infantryman and nothing else. Suppose that a small body of infantry is suddenly wanted at a place 50 miles off; a cyclist force is despatched, and rides along the most direct road to the place, which, if at all tactically or strategically important, is absolutely certain in civilised warfare to be situated on a road—in fact, in nine cases out of ten, it will be the existence of the road, coupled, perhaps, with some feature such as a bridge, ford, railway junction, etc., which gives military importance to the spot—the cyclists ride quickly up, dismount, and leave their machines under escort at the place where it becomes necessary to deploy, which certainly will not be more than a mile from the final destination; thus the men ride 49 miles, and skirmish one mile on foot. I am quite aware that it is a physical impossibility to ride a cycle for any distance over an enclosed country, but I can affirm from practical experience that a safety bicycle can be wheeled over almost any ground, and can be lifted over any obstacle that other troops can surmount, and over many which are quite impracticable for horses. This subject is excellently handled by Captain Balfour in his article upon cyclist infantry in the *United Service Magazine* of July, 1890; and Lord Wolseley's distinctly expressed opinion is that in a cultivated and enclosed country like the greater part of England, the tactical action of cavalry will be mainly confined to the roads, and he gives his opinion that the power and usefulness of cavalry would be very largely enhanced if each regiment or brigade of cavalry had with it a considerable force of cyclists. He also very pertinently adds that a cyclist who loses, or is separated from, his bicycle is in no worse a position than the cavalry soldier whose horse is shot.

Upon the various arguments which I have adduced in favour of cyclist infantry, I base my belief that such a force would be able to perform various useful and important duties in the field, and to the more prominent of these I will now direct your attention.

The speed and the staying power of cyclists seem to qualify them for employment in all the duties pertaining to messengers, orderlies, or despatch bearers both in peace and war. The establishment of relay posts of cyclists on any long line on which messages have to be sent would ensure very rapid transmission, and would liberate troopers for other duties.

Their speed and noiseless progress fit them as a means of communication between the fractions of an outpost force both by day and night, and between the outposts and the main body.

The same qualifications, and the inconspicuous character of the cycle, render cyclists eligible as scouts or reconnoitrers in any cultivated and enclosed country where the operations are mainly confined to the roads. Cyclists, being infantry, can dismount and go wherever infantry can go; and, for the same reason, a small body of cyclists has nothing to fear from an equal, or even slightly superior, party of hostile cavalry which it might encounter similarly engaged in scouting.

In many cases a cyclist escort for guns would be perfectly efficient; all the duties of an infantry escort can, of course, be performed by it, and if the ground admits of the guns being moved quickly, such ground will also admit of the cyclists keeping pace with the guns when changing position.

A statement made by me at the Royal United Service Institution, to the effect that cyclists might be used with advantage to form escorts for convoys, was ridiculed by one speaker in the discussion that followed the lecture. I do not, however, on that account see the slightest reason for changing the opinion which I originally formed. The escort of a convoy is often obliged to reconnoitre widely upon the roads to the front and flanks, and it often is compelled to adopt a purely defensive attitude. My contention is that a body of cyclists can perform either or both of these tasks efficiently, and I adhere firmly to it.

The power of carrying entrenching tools or materials for demolitions, added to speed and silence, enables a body of cyclists to make sudden raids for offensive purposes; and the men can equally be employed to reconnoitre and discover the resources of an area of country, to make surveys, or to verify and correct local maps.

The power possessed by each man of carrying a rifle, a large quantity of ammunition, and the service kit, together with the freedom derived from the fact that no additional transport need be provided, qualifies cyclists to act in co-operation with the cavalry screen in the attack and occupation of places which are locally important. It is very desirable for the proper performance of this duty that the ranks of the cyclists should include as many marksmen as possible, and every effort to attain this standard should be made.

Should infantry not be required actually with the cavalry screen, cyclists would still be very valuable to form connecting links or rallying points along the roads between the cavalry scouting parties and the heads of the advanced guards marching in rear.

In the case of a force, detached or otherwise, which is either unprovided or weakly provided with cavalry, it is evident that most of those duties which require the power of rapid movement, and which consequently fall under ordinary circumstances to the lot of the cavalry, must in such cases necessarily be performed by mounted infantry, of whatever description it may be, to the best of its ability, or else must be more or less neglected. Such employment must, however, always be considered as exceptional, and beyond the proper sphere of mounted infantry. Cavalry has its own distinguishing characteristics, and I am glad to say that I have acquired a sufficient knowledge of combined tactics to fully recognise the fact that cavalry cannot be efficiently replaced by any other description of fighting force; but I think you must allow that if no cavalry are available, cyclists could, at all events, scout and reconnoitre more widely and more rapidly than unmounted infantry. Our volunteer army is, as you know, so badly provided with cavalry, that it becomes our bounden duty to make in peace time some provision for the performance of mounted duties in that force; otherwise, should the country be suddenly plunged into war, and obliged to undertake home defence, the volunteer force would have to take the field without the military equivalent for eyes or ears.

In conclusion, sir, I hope I have said enough to convince you that there is really something good in military cycling; also I hope I have not said so much as to lead you to believe that I am a monomaniac upon this point, for I can assure you that in 27 years of army service I have seen enough of military matters to prevent me from falling into any such fatal error as that. I have endeavoured throughout, whilst pointing out what I believe cyclists to be capable of, not to decry any other arm, or even any other form of mounted infantry. All that the warmest advocates of military cycling ask for is a full and complete trial, followed by a verdict delivered without partiality, favour, and affection, and I am glad to say that the military authorities appear very willing to grant both.

PAPER II.

MOUNTED INFANTRY AND ITS ACTION IN MODERN WARFARE.

By Lieutenant-Colonel E. T. H. Hutton, D.A.A.G.
Half-pay, King's Royal Rifles,

Commanding The Mounted Infantry Regiment,

On 12th November, 1890.

Before commencing my lecture, I am anxious that the definition of what is meant by the term "Mounted Infantry" may be made clear, and that it may not be confused with what I prefer to call "Mounted Riflemen." Mounted Infantry are infantry soldiers *pur et simple*, who, in addition to their duties as infantry, are so organised and trained as to render them capable of receiving means of increased locomotion, whereby they may act in their capacity as infantry soldiers when great mobility and rapidity of movement is necessary. A force so organised acts relatively to cavalry as infantry, in like manner as horse artillery act relatively to cavalry as artillery. Mounted Infantry may thus, for purposes of locomotion, be provided with horses, ponies, mules, camels, elephants, cars, or any mechanical contrivance which the climate and physical conditions of the country may render desirable.

Mounted Rifles, on the other hand, are horsemen who are trained to fight on foot. They are men who are mounted and intended to perform all the duties of cavalry, except that which may best be described as "the shock." It is expected of them that they should perform all the outpost, reconnoitring, and patrolling of an army in a manner similar to cavalry; the only difference being that they must rely solely upon their fire powers for defensive and offensive action. Our South African and Australian Colonies have raised, and are now raising, several corps of this description. The American cavalry are now, and during the Great War of 1862–65 were, for the most part of the same type. I am very anxious to have the distinction made very clear between Mounted Infantry and Mounted Rifles, because the two have been confused in such a hopeless manner lately by the Press, and even by military writers, that a great deal of uncalled-for controversy has resulted. There should be no confusion as regards the functions of Mounted Infantry and Mounted Rifles, inasmuch as Mounted Infantry are infantry soldiers—the pick of infantry, certainly—while Mounted Rifles are mounted troops who are armed with a long rifle. The training of Mounted Infantry as horsemen is such as renders them incapable of being worked as individual units. For example, it is impossible for our existing Mounted Infantry to be used for scouting and patrol duty in the face of an enemy's cavalry upon ground favourable to the action of that arm.

As regards equipment, the Mounted Infantryman is armed only with rifle and bayonet, the former of which he carries continually in his hand when in the presence of the enemy. A Mounted Rifleman, on the other hand, must be armed with a sword or a pistol in addition to his rifle. Were it not so the latter would, when mounted and performing outpost or patrol duty, be at the mercy of the first naked savage who closed with him from behind a bush or clump of long grass, or, in a campaign with a more civilised foe, he would fall an easy prey to any mounted foe armed with lance or sabre.

I conceive it to be quite possible that after experience and a prolonged mobilization, Mounted Infantry, such as we now have, might be converted into Mounted Rifles.

It must surely be obvious to any man who studies professional questions that with their present armament, and with the short training in riding and horse management given them, Mounted Infantry can never usurp the functions of an efficient, well trained, and ably led cavalry. It is, in a large measure, owing to the fact of the Mounted Infantry at Aldershot being trained—for financial reasons—upon horses lent by the cavalry, that so much misunderstanding and controversy on the subject has ensued, and I feel confident that if from the beginning it had been possible for them to have been properly mounted upon 14 to 15-hand cobs, this supposition would never have arisen. The fact also that a large share of the outpost and desultory skirmishing work fell to the lot of the Mounted Infantry in the Egyptian War of 1882 has, no doubt, contributed to the controversial feeling. I will explain the circumstances that brought this about. In the campaign of 1882, the Mounted Infantry were mounted on small Arab horses accustomed to the food and climate of Egypt, and at the outset of the campaign they did extraordinarily good work at Alexandria. Later on, when the troops went to Ismailia, the Mounted Infantry did the outpost work in front of the army, with the object of saving the English horses which had recently arrived in the country, and which were unused to the climate and had not recovered from their sea voyage. Lord Wolseley and those responsible for conducting the campaign had constantly in view the necessity of keeping the cavalry division intact, efficient, and ready for the decisive advance upon the Egyptian army, which eventually culminated in the decisive forced march upon Cairo. This same argument, to a great extent, holds good of the campaign at Suakim, in 1884, when the Mounted Infantry were similarly used to save the cavalry for the subsequent and decisive portion of the campaign, but which in this instance did not arrive.

I now propose to put the question of the necessity for a mobile infantry in the present day before you for your consideration. I desire to suggest for your reflection and consideration some points which may not have all occurred to you, and to submit to you the deductions which may, I think, be reasonably made from them.

The question of the value of mounted or mobile infantry is a very ancient one. We read of Darius, at the battle of Issus, sending forward five thousand heavily armed infantry, mounted upon the horses of his light cavalry, in order to seize a certain point of the river, and the seizing of that point led to his subsequent victory. It is easy to multiply similar instances, and I cannot do better than recommend you to read *The History of Cavalry*, by Denison.

If in the past the co-operation of the foot soldier was considered so essential to solid success, how much more so must it be in these days, when in face of a steady infantry fire nothing can live up to 800 yards, and when by mass firing extraordinary results can be obtained at 1,400 and 1,500 yards. The whole tendency of the war experiences since 1859 is to increase the value of fire power, and to show that decisive results can only be expected from its invariable employment. Our own cavalry regulations do not contemplate that the cavalry can supply this fire power. We find under the head of dismounted duties as follows:—"Cavalry to fight dismounted must be regarded as a help in need, to be resorted to only when the mounted combat is unsuitable." Again:—"Cavalry has not the power, nor is it in accordance with the spirit of the arm to carry on a long continued fight with fire-arms."

The meaning of the above extracts from, and the spirit of the whole of the cavalry regulations, is simply this, that cavalry are not intended to undertake an engagement on foot in which an enemy's better armed infantry is opposed to them when, in fact, a long continued musketry fight may be anticipated. The result, therefore, of the teaching of our cavalry instructions, no less than those of the Germans, is that directly dismounted cavalry are opposed to infantry fire of corresponding or even inferior numerical strength, their further action must be paralyzed from their sheer inability to compete with it on equal terms.

How then can cavalry trained upon such principles have any strategical independence? How then can they act, even tactically, with necessary self-reliance on their own powers?

Could, for instance—I submit this for your consideration—a force of British, German, or French cavalry attempt to follow the strategy pursued with such success by Sheridan and others in the American War, with the knowledge that, at any moment. their further progress may be blocked by the superior fire power of an enemy's infantry?

It is, therefore, to supply this want that mounted infantry have been introduced into our service. It is to give our cavalry this necessary infantry fire power in warfare between ourselves and any civilised nation that our present force of mounted or mobile infantry exists. It has been the intention to create for this country a combined force of the three arms, viz., cavalry, horse artillery, and mounted infantry, which shall be able under any physical condition of ground, and under all circumstances, to act freely and efficiently without any support from a slow-moving infantry. If this argument is true against a civilised foe, it is doubly so against a savage enemy, where rapidity of movement is to reap the moral as well as the real harvest of victory. No successful engagement with an Asiatic or savage foe can be decisive without the power to overtake him in retreat, and to thus complete your victory. It requires no demonstration upon my part to remind you that it is fire power which alone is really effectual against savages or even Asiatics; that lance and sabre is of small real value in comparison.

The Revival of Cavalry. The Controversy "l'Arme Blanche" v. Repeating Rifle.

I now propose to touch upon the revival of cavalry, a subject upon which so much has been written on the Continent lately. What do we now see on the Continent? On the one hand the Germans and the French perfecting the attack of cavalry by *arme blanche*, and relying less and less every year upon the fire power of their cavalry. Both nations are arming their cavalry for the most part with the lance, and thus rendering dismounted action more and more difficult. In the recent manœuvres of the Prussian Guard Cavalry Division in Silesia, a British cavalry officer who was present has stated that he never once saw the cavalry dismount for dismounted duty, though the prevailing idea among the German officers appeared to be that the dismounted action of cavalry will be very useful in future wars. He adds that he could not discover that anybody had thought much about the employment of mounted infantry. On the other hand we have the vast masses of Russian cavalry armed with a long rifle, and trained to fight on foot.

Let us consider the arguments upon which are based these two opposing theories.

The latest war experience of the Germans is the war of 1866, and the Franco-German War of 1870. Were their experiences of the value of cavalry then such as to cause them to ignore fire power for the development of "shock?" If so, they are doubtless justified in neglecting the fire action of their cavalry, and in not adopting any system of rendering their infantry sufficiently mobile to act with their cavalry. I propose to consider this point later.

The latest war experience of the Russians is the Turkish War of 1877–8, and that with the Tekke-Turcomans. The latter was in some respects similar to our campaigns in the Soudan and elsewhere with uncivilised and warlike peoples. What deductions have the Russians drawn from their experiences? What deduction may we suppose that General Gourko has drawn from his raid to and south of the Balkans? The changes that have followed in the Russian army are the best answers to these questions. The Russians seem to have decided that if cavalry are to act independently and effectively, they must develop their fire power to accomplish their *rôle*, and nearly the whole of their cavalry carry a long rifle. It was one of Skobeleff's ambitious schemes that he should invade India with 100,000 mounted men. How many of these, think you, would have been, or could have been, cavalry in the German sense of the term?

Tactical Value of Masses of Cavalry.

I now propose to consider the action of cavalry in masses tactically since the modern improvement in fire-arms.

In the days of Frederick the Great, and throughout the campaigns of Napoleon, and, indeed, later, till about 1854, when rifled arms began to be introduced, a ready forward boldness and dash were the safest as well as the most effective course for a mounted soldier opposed to infantry. Under the conditions of the infantry fire-arms of those days, the mounted men had but, at the worst, to risk the effect of two ill-directed shots: the first delivered by the rear rank at 150 yards, the second by the front rank at or under 30 yards. In other words, the danger to the cavalryman from musketry fire began at 200 yards, and ended when the front rank had expended their shot at 30 yards. After that the muzzle-loading musket or rifle could only be reloaded slowly, and the infantry soldier must stand defenceless while working his ramrod. Weather and defective ammunition frequently made the infantry fire still more uncertain and ineffective. Yet, even under these unsatisfactory conditions, good and unshaken infantry could always hold their own against the best and most devoted cavalry.

I am tempted to quote to you an extract from the *Journal of Major Macready, 30th Foot*, edited by Colonel Beamish, who describes what took place at Waterloo in very graphic terms, and thus speaks of the attack upon the infantry square in which he stood:—

"In a few minutes after, the enemy's cavalry galloped up and crowned the crest of our position. Our guns were abandoned, and then they (the cuirassiers) formed between the two brigades, about 200 paces to our front. Their first charge was magnificent. As soon as they quickened their trot into a gallop, the cuirassiers bent their heads, so that the peaks of their helmets looked like vizors, and they seemed cased in armour from the plume to the saddle. Not a shot was fired till they were within 30 yards, when the word was given, and our men fired away at them. The effect was magical. Through the smoke we could see helmets falling, cavaliers starting from their seats with convulsive springs as they received our balls, horses plunging and roaring in the agonies of pain and fright, crowds of soldiery dismounted, part of the squadron in retreat, but the more daring backing their horses to force them on the bayonets. Our fire soon disposed of these gentlemen.

"The main body re-formed in our front, and rapidly and gallantly repeated their attacks; in fact, from this time (about 4 p.m.) till near six we had a constant repetition of these brave but unavailing charges, but our ammunition decreased alarmingly.

"The best cavalry is contemptible to a steady and well supplied infantry regiment. Even our men saw this, and began to pity the useless perseverance of their assailants, and as they advanced would growl out:—'Here come these fools again.' Their devotion was invincible."

So much for Brown Bess! What the result of such an attack would be upon unshaken infantry now, armed with a low trajectory magazine rifle, I leave my audience to imagine.

In Italy, in 1859, we do not read that the fine force of French cavalry accomplished anything decisive upon the Austrians in their retreat to and across the Mincio after Solferino; in fact, their retreat was unmolested, though three splendid regiments of Chasseurs d'Afrique and five regiments of hussars of the cavalry divisions Partonneaux and Desvaux had carried out some spirited charges against the Austrian squares. Their losses appear to have been such as to have paralyzed their further efforts.

In Bohemia, in 1866, we search in vain for any great result from the tactical use of masses of cavalry, though both Prussians and Austrians possessed a magnificent force of highly trained and carefully equipped horsemen. On the contrary, in the *Times* of the 30th August, 1866, the special correspondent (himself a cavalry officer) writes as follows after the battle of Koniggrätz:—

"But Pardubitz will be a standing disgrace to the Prussians in a military sense. It is an easy hour's march for cavalry from the field of Koniggrätz. It was 4.30 p.m. when the Austrians retreated. Their pontoons were principally at Opatovic, three miles below Koniggrätz, and not covered by the guns of the fort. The Crown Prince had 13,000 or 14,000 sabres, which had not been used at all. The cavalry, under Prince Frederick Charles, mustered at least 10,000. But these horsemen, who had been maintaining their superiority on all occasions to the Austrian horse, not only never ventured to press them as they covered the retreat, not only refrained from moving towards Pardubitz, but never appeared even near Opatovic. They had four hours clear daylight * * * and did not approach Pardubitz till noon on July 4th. Had they swept round the Austrian flank, and made their appearance on the road between Holic and Hohenmauth on the morning of July 4th, they might have swept up half an army for their pains."

In France, in 1870. As regards the action of the Prussian cavalry in 1870—please to understand I am referring to decisive results of the tactical action of *masses* of cavalry—I will quote an extract from the German official account relative to the action of the Fourth Cavalry Division at the outset of the campaign. After the action at Weissenburg, on the 4th August, the Fourth Cavalry Division were instructed to carry out a reconnaissance towards Hagenau-Sufflenheim and Rappenheim, for the express purpose of seeking out the enemy. The force to which this duty was entrusted consisted of the Bernhardi Lancer Brigade and the Second Body-Guard Hussars. This was the result, in the words of the official account:—

"No indications of the enemy were found this side of the Hagenau Forest. General Bernhardi pressed forward with the main body of his brigade along the high road as far as the southern issue from the forest; but on reaching this point, close to Hagenau, a bridge was found broken up and occupied by hostile infantry, upon whom the fire from the hussars' carbines made no impression. As it was impossible for the lancers to deploy in the forest, the brigade withdrew, the enemy's skirmishers following and keeping up a continuous fire upon it from both sides of the road."

This instance, small in itself, is one of many which it would not be difficult to collect from the pages of the official account itself. Yet, surely, the demoralization of the French troops after the destruction of the army of the Rhine, and the singular absence of opposing cavalry, must have furnished ample opportunities to the German cavalry for achieving such decisive results as would have eclipsed all the gallant deeds of the American cavalry leaders in 1862–65. If what I say is true of the failure of the German cavalry in arriving at great results, still more is it true of the French cavalry in the subsequent phases of the war. The long line of communication between Paris and the Rhine—between 400 and 500 miles—was the weak point in the German advance, and if a large body of mounted men had been thrown with vigour upon any portion of the line, the results might have been such as would have completely changed the aspect of the campaign. Nothing of the kind was ever attempted. Imagine, for instance, what would have been the result if a great leader of mounted men like Morgan, Forrest, Grierson, or Wilson had attempted a raid upon this long line of communication such as they effected in the great American War.

In Turkey, in 1877–8, the Russian cavalry seem to have effected little, with the exception of Gourko's celebrated advance across the Balkans to Kazanlyk and Eski Sagra, in July, 1877. General Gourko had with him a force of the three arms, viz., 5,000 infantry, 4,000 cavalry, and 32 guns, in order to ensure his success, as he knew that he must be opposed by the Turkish infantry. With this combined force he achieved the success which made for him a world-wide reputation as a great leader. The presence of infantry, in fact, armed with a rifle which could compete with the Martini-Peabody of the Turks, enabled his cavalry to achieve a success which, acting alone, would have been improbable, if not impossible. It may be as well to remark that the Russian cavalry were armed with a short Berdan rifle and bayonet, which were but little inferior to the infantry weapons of the Turks.

Instances of a decisive success of masses of cavalry alone against infantry since the introduction of the rifle are, as far as I can make out, wanting, and we search in vain to find a repetition of the old world successes of cavalry over infantry since its introduction. Henceforth, as heretofore, wherever cavalry meet cavalry, victory will be to that side whose horsemen are the best mounted, most skilled in the use of their arms, and most ably handled and led. When cavalry are opposed to infantry, a field of conjecture opens to us. Who can tell what will be the effect in the next war of the onward and impetuous rush of the serried masses of German or French cavalry upon infantry armed with a magazine rifle? Will a cavalry leader arise who shall dare to hurl his masses of cavalry upon an enemy's infantry? A leader who, seizing a favourable moment of attack, and having suitable ground over which to manœuvre, shall re-establish the old supremacy of the horseman over the footman!

Our experiences in Zululand with the faultlessly brave Zulu warriors, in Afghanistan with the wild fanaticism of the Ghazis, in the Soudan with the Hadendowas heedless of death, tell us what can be done by the onward rush of determined men on foot. Many of us can recall the anxious moments when, in spite of the steady infantry breech-loading fire, unshaken by artillery or distant musketry, our foe has charged up to the very muzzles of our rifles. Some of us may have been present when the Hadendowas threatened and broke our squares in the Soudan desert. Some of us, perhaps, may have heard the shout of poor Sir Herbert Stewart when the head of the Arab mass was rushing upon the mounted infantry angle of the square at Abu-Klea :—"Can no one shoot these fellows ?" It was not until the wild surging mass of Arabs arrived within 40 yards of the infantrymen's rifles that their fire began to tell, and the onward rush was diverted upon the exposed rear face of the square. As everyone knows, by a tactical blunder, the rear face of the square had been wheeled outwards, and consequently a gap was left which let the Soudanese in at the rear, and nearly accomplished the destruction of the desert column. Surely Isandlwhana, Gingihlovo, Ulundi, Tamai, and Abu-Klea are proofs of what can be done by determined men in the face of breech-loading fire-arms.

There is a saying of an American general, an authority on cavalry :—"Sir, if you take the bits out of the horses' mouths, and ride home in serried mass, there are no infantry in the world that would stand before you." I venture no opinion upon this point, and I prefer to commend to your reflection and study the relative value of masses of cavalry upon infantry in formation.

The Strategical or Independent Action of Masses of Cavalry.

With reference to the independent strategical action of masses of cavalry or mounted troops, I can recall no instance of any decisive result having been achieved by the independent strategical action of a large force of cavalry or mounted troops in any recent campaign in Europe, or by European troops, except by Gourko in 1877, and by Sir D. Drury-Lowe in 1882, since the American War of 1862–65. The account of Gourko's dash for the passes over the Balkans, his destruction of the railways within 70 miles of Adrianople, and the panic caused throughout the length and breadth of Turkey, is too recent and too well known to require further comment.

Sir Drury-Lowe's dash with his cavalry division, horse artillery, and mounted infantry, upon Cairo, after Lord Wolseley's victory at Tel-el-Kebir on Sept. 13, 1882, is also well known to us all. After a forced march of 58 miles, the cavalry division reached the environs of Cairo by 9 p.m. on the 14th, or 38 hours after the battle of Tel-el-

Kebir. The mounted infantry, and a squadron of the 4th Dragoon Guards, were the same night pushed ahead into Cairo, and by midnight actually occupied the citadel, though at that very moment it was garrisoned by several thousand Egyptian troops. On the morning of the 15th, so great was the moral effect of this lightning stroke of Lord Wolseley's, that Cairo—a city of 350,000 inhabitants, garrisoned by 10,000 troops—surrendered at discretion, and the campaign was ended.

We must go back and study the history of the American War ere we find similar instances of the independent use of bodies of mounted troops. It has been the custom among students of military events to ignore the lessons and the practical experience to be learnt from the most protracted and bloody war of this century. It is curious how little the American War has been studied either by ourselves, the Germans, or French. I cannot commend to your notice any more valuable study, or more interesting reading, than this war, especially with reference to the action of their mounted troops.

The Americans, having no military traditions to hamper them, evolved a mode of warlike procedure which was eminently practical and suited to the time and country. The most conspicuous departure which they made from the old world rules of war was in their use of their mounted troops. It is impossible for me to enter into details of the early development of the value of their cavalry, made in the outset by the Confederates under Morgan, Forrest, and Stewart, and followed later by the Federals under Grierson, Wilson, Stoneman and, finally, Sheridan.

The value of the independent action of cavalry columns, under the leaders I have mentioned, which were called by the Americans "raids," proved to be enormous. The system initiated by the South was subsequently developed to its utmost by the North, with the intention, as expressed by General Grant: "To eat out the vitals of the State they moved through, and to leave nothing for the rebellion to stand upon." I would commend to your careful study Morgan's great raid into Tennessee, and also Grierson's, as being perhaps most noteworthy.

The following are *resumés* of these two raids :—

Morgan's Confederate Raid in Kentucky.—Left Knoxville July 4, 1862; strength, 1,200 mounted troops; distance covered, 1,000 miles; period, 24 days; loss, 90 killed and wounded; reached Livingstone 28th July (see *Plate* III.).

Results.—Capture of 17 towns; destruction of supplies and arms; capture or dispersal of 2,700 Federal troops; panic on the Money Market in New York; subsequent retreat of General Buell's army.

Grierson's Federal Raid through Mississippi.—Left La Grange, Tennessee, April 17, 1863; strength, 2,000; distance covered, 300 miles; period, 15 days; loss, *nil;* reached Baton Rouge 2nd May (see *Plate* II.).

Results.—The whole of the railways and lines of communication between the Mississippi Valley and the Eastern Confederate States severed; great destruction of stores; paved the way to the siege and fall of Vicksburg, and conquest of the Mississippi by the Federals.

Time does not admit of my entering into the details of the great Shenandoah raid by General Sheridan, which destroyed the James River canal, one of the great lines of supply by which the Confederate army at Richmond was fed. This feat occurred early in March, 1865, and was the commencement of the end which Grant had aimed at by his policy of "hammering continuously, until by attrition, if in no other way," he should crush his enemy. The "throttling process," by which Sheridan first of all turned Lee's flank at Five Forks, and the manner in which he subsequently threw himself across Lee's only line of retreat, and so compelled the surrender of the Confederate army at Appomattox Court House, on the 8th April, 1865, are instances which I must ask you to study carefully for yourselves, and you will find that they particularly prove what I have endeavoured to bring to your notice, viz., the importance of the independent strategical action of mounted troops, for which fire power is the main factor.

Sheridan's "Throttling Process" in the operations before Richmond, March and April, 1865:—

Resumé of Events.—Advance of the Federals, under General Veglers, from Reams, on March 29th, upon the South Side Railway, so as to envelop the Confederate army, under General Lee, still occupying Richmond and Petersburg; Sheridan, with three divisions of cavalry, about 10,000 strong, moves as vanguard; Battle of Five Forks, March 31st and April 1st, fought principally by Sheridan's cavalry; South Side Railway occupied; retreat of the Confederates, under General Lee, by the Richmond Danville Rail upon Danville begins April 1st; Sheridan, with his cavalry, heads the retreat at Amelia Court House and Jettersville; Lee moves on Lynchburg; Sheridan heads him at Sailor's Creek April 6th, and finally arrests his further retreat at Appomattox on 9th April; surrender of the Confederate army follows upon the same day (see *Plate* I.).

I have alluded in my *resumé* to the destruction of Holkar's army, November 16th, 1804, by Lake's mounted troops. Time does not admit of my narrating the facts as I should have wished, and I can only commend to your careful study the Mahratta War. I will, however, briefly state the facts for those of you who may not recall them.

In November, 1804, Lord Lake, finding it impossible to overtake Holkar with his infantry and cavalry combined, determined to leave his infantry, and at the head of his cavalry and guns to push forward and annihilate Holkar's vast horde of irregular horse before he could make good his retreat across the Jumna.

With a force of nearly 4,000 men, Lake started in pursuit, and after a march of 312 miles, got within 38 miles of Holkar's army on the night of the 16th and 17th November. Lake, hearing that Holkar was in front of him, guessed that as he was so close to the Jumna he would be in fancied security. Marching at seven o'clock in the evening of the 16th, he cleared the 38 miles, and at daylight fell upon Holkar's army asleep, without any outposts or any other precautions being taken to prevent a surprise. The guns opened a deadly fire at short range upon the slumbering camp, and like a whirlwind Lake's dragoons swept through the enemy's lines. Three thousand of Holkar's horsemen were slain, and his army completely broken up. The conclusion of this splendid achievement of Lake's cavalry is thus summed up by Major Thorn, the historian of the war, and himself an actor in the scene :—

"The pursuit continued upwards of ten miles, and as our march during the preceding day and night was 58 miles, the distance to which the enemy was pursued and the space passed over before we took up our encampment ground considerably exceeded 70 miles in 24 hours—an effort probably unparalleled in the annals of military history, especially when it is considered that it was made after a long and harassing march of 350 miles in the space of 14 days."

Here, indeed, we have a magnificent and decisive feat carried out by cavalry and artillery alone.

During the Indian Mutiny of 1857, the action of our cavalry was not as successful or as decisive as might have been expected from its achievements earlier in the century, and especially in the Mahratta Wars. It was not decisive because—firstly, the traditions of our cavalry were confined to *arme blanche;* and, secondly, they were opposed to Sepoy infantry, armed with an infantry soldier's weapon. At the Raptee the circumstances are worth referring to as an illustration of this point. Our cavalry, in pursuit of the Nana, had arrived on the Raptee in plenty of time to attack, crush, and capture him and his army, encumbered as they were by their loot. They were, however, prevented from doing so on account of a large belt of wood, some half-a-mile broad, which was held by the rebel Sepoys. Our cavalry were unable to force their way mounted through this belt of forest, and they were equally unable by dismounted action to attack the rebel infantry, and so they had no alternative but to wait, looking at the rebels, until our infantry came up. The infantry were then five miles behind, and it took them rather more than an hour to reach the wood, and that hour gave the Nana and his troops time to withdraw in safety across the river and elude the retribution which awaited them.

Deductions.

In the numerous instances which I have recalled to your memory, it has been my endeavour to demonstrate the following lessons:—

(1). That the independent action of one arm without the other two can never achieve any real or solid results.

(2). That a certain degree of tactical effect may still be looked for from the judicious use of masses of cavalry against infantry.

(3). That the independent action of cavalry alone, trained to rely mainly, if not exclusively, upon *arme blanche* is liable to be paralyzed at any moment, and that its tactical effect can at best be temporary, while any lasting strategical result is impossible.

(4). That if used in conjunction with such fire power as infantry-men carefully trained to fight on foot can alone supply, the independent strategical power of cavalry has been increased a hundredfold.

With regard to (1) and (3), I have recalled to your memory the campaigns of 1859–66–70, and the Mutiny of 1857–58, which, so far as the independent action of cavalry is concerned, are barren of decisive and lasting results.

With regard to (2), I have reminded you what our savage foes have achieved in the face of our own breech-loading rifle in 1879, and in 1884–5. I might further quote instances where cavalry have achieved results by acting a daring but judicious *rôle* upon the field of battle, and remind you of the Italian cavalry at Custozza, the French cavalry at Worth, and Von Bredow's famous charge at Vionville.

I can find in the history of the wars of the Continent, however, no record or any lasting and decisive result so obtained. The effect has been momentary, and the sacrifice to the cavalry employed great. The "speed to overcome" has been present, but the "fire to destroy" has been wanting.

With regard to (4), I have shown that the Americans, in 1862–65, by the development of the fire power of their mounted troops, achieved results not only glorious, but decisive in their effect; that the Russians, under Gourko, in 1677–78, with their rifle-armed dragoons, obtained similar results; and that our cavalry division, with a small advanced column of dragoons and mounted infantry, occupied the citadel of Cairo in 1882, and so completed the destruction of Arabi's power, which the battle of Tel-el-Kebir had shattered. You may, perhaps, ask why I have quoted to you the Mahratta War, and the action of Lord Lake's cavalry in 1803–4. It was that I might invite you to compare the splendid and decisive results gained then by independent cavalry action, with the indecisive action of our cavalry in 1857–8. The reasons appear to be that Lord Lake's cavalry were dragoons, nearly all armed with a fire-arm, and accustomed to its use. Each cavalry regiment had in addition two light galloper guns, so that for that period the cavalry had as effective fire power as could be given to them. Their opponents were irregular and partially disciplined Mahratta horse, armed at best with only an imperfect fire-arm, which was rarely of any real service. On the other hand, our cavalry, in the Mutiny, found themselves opposed to an infantry armed with an infantryman's fire-arm, and holding to their traditions that a good cavalryman is to fight only with sabre and with lance, their independent action was invariably paralyzed.

I will recall to your mind an incident connected with the Mutiny which is very pertinent to my argument. The greatest difficulty was experienced in quelling the rebellion in the Shahabad district, towards the end of the Mutiny, because our infantry, moving so slowly, found it impossible to overtake the rebels. This became so serious a question that the present Sir Henry Havelock-Allan (then Captain Havelock) obtained leave to organize and mount a company of infantry marksmen. A company of sixty infantry soldiers of the 10th Foot, under Captain Bartholomew, was accordingly trained and mounted on native ponies. Assisted by a dozen troopers and a few mounted volunteers, this diminutive infantry column was despatched to follow up a large force of the rebels in October, 1858. Malleson, in his *History of the Sepoy War*, gives the following account of their achievements:—

"This success (*i.e.*, the pursuit and destruction of the large force of rebels in the Shahabad district) is to be attributed solely to the new use of the mounted infantrymen, without whose presence the enemy would, as on every former occasion, have escaped unscathed through their 'superior speed.'"

Havelock's loss in this singular pursuit, which covered 200 miles in five days and nights, was only three killed and 18 wounded, while the rebels lost 500 killed in the actions of the 19th, 20th, and 21st October.

"Thus," continues Malleson, "60 infantry soldiers, organized on a novel plan, and aided by a handful of cavalry, had effected with nominal loss in five days what 3,000 regular troops had for six months failed to accomplish, viz., the complete expulsion of 4,500 rebels from the province, and the infliction on them of a punishment the impression of which has not to this day been effaced."

Combination of the Three Arms.

The Russians have endeavoured to combine the old *rôle* of infantry and cavalry into their modern cavalry soldiers, and have partially followed in the wake of the American cavalry of the Great War. It is strongly held by a multitude of writers and experienced leaders of men that you cannot have the same man believing himself to be invincible when mounted, and equally unconquerable when dismounted, and to justify this assertion, I would only point to our own cavalry regulations and that of the Germans, and ask you to read them carefully, and say whether as a result of their teaching it is possible to have cavalrymen so skilled as infantry that they could stand for one moment against good infantry, trained as such, and armed with a long range, low trajectory, repeating rifle. Have any of my audience ever seen any body of German, French, or British cavalry manœuvred as infantry, or worked tactically as a fighting body on foot? The principle of one arm being dependent upon the other two is, I submit, as applicable to cavalry as it is to infantry or artillery. If cavalry are to develop their maximum effect acting in masses, either tactically or strategically, it must be by acting in combination with artillery and infantry.

It has been urged by a recent military writer, in his work, *The Elements of Modern Tactics*, "that infantry is the only arm which can act independently under all circumstances, whether in attack or defence, in motion or at rest."

This is a principle which is entirely at variance with practical experience. No one arm can be said, under all circumstances, to be independent of the other two, and I challenge the writer to show proof of his statement. Two very notable instances during the Boer War of 1881 will occur to some of us, showing the utter helplessness of infantry alone, whether in motion or halted on the defensive. One was the destruction of the 94th Regiment at Brunker's Spruit, and the other the defeat of Sir George Colley and his column on the banks of the Ingogo. At Brunker's Spruit a single infantry battalion was engaged, and the Boers shot down the helpless infantry soldiers as they pleased. The engagement on the banks of the Ingogo was of a similar kind. Our small column consisted of 350 infantry with two R.A. guns, to which was added a handful—ten or a dozen—mounted infantrymen miserably mounted and indifferently trained. The superior Boer force having compelled our column to halt and take up a position, then proceeded to gallop round them out of range, and speedily encircled the luckless infantry and guns with a zone of rifle fire. The result of these tactics, so happily conceived and executed by the Boers, was that, after a gallant struggle of eight hours, our small force lost half its number in killed and wounded, and would have been annihilated but for darkness and a storm of wind and rain, which enabled Sir George Colley and the remnant of his force to drag away their guns by hand, and so withdraw from the helpless position in which they had been placed.

The teaching of the great American War, of the great wars of 1859–66–70–77–78, and our small wars points to this fact, that if the maximum of result is to be achieved by mounted troops acting tactically on the field of battle, or strategically—*i.e.*, by independent action—it must be by the employment of a combination of the three arms, viz., cavalry possessing the highest skill and training in the use of *arme blanche;* a rapidly moving and highly trained infantry armed with the best available fire weapon; and artillery armed with the most effective guns, and possessing similar powers of mobility to the cavalry and infantry. In this manner only will you have "speed to overcome," and "fire to destroy."

I think it is a fair assumption to make that the power which can first satisfactorily solve this problem and achieve this result will, in the next great war, effect such a revolution in the tactics of the past, as will eclipse the feats of Stewart and Sheridan, and astonish the world with successes such as may rival those of Napoleon and Alexander.

Training and Organization of Mounted Infantry.

I had intended to allude to the training, organization, cost, and power of development of the existing system of regular mounted infantry, but I cannot do more than briefly touch upon it. With reference to the training and organization of mounted infantry, there are many ways in which this might be effected. First, a single battalion might be taken intact and trained as mounted infantry; or, second, a single complete company be selected from a number of battalions; or, third, a smaller detachment be carefully chosen from a larger number of infantry regiments. As regards the first plan, it would be impossible to find in the whole British army a battalion which could be trained complete as mounted infantry. The second plan, viz., to take a company of 5 officers and 126 men, would be to really emasculate a battalion. The last plan, our present system, is to take 1 officer and 32 men from certain regiments, and to combine these detachments into companies, and then to combine the companies into battalions. This system has its advantages as well as its disadvantages. Certainly it has this disadvantage—you have a great number of units working together who have never, perhaps, seen each other before. It has this advantage, however, that if you wish to still further increase the force of mounted infantry you can do so by merely increasing the size of the quota to be furnished from each infantry battalion to 66, or half a company, in place of the before-mentioned 33, or one-fourth of a company. There are the gravest objections to having permanent mounted infantry. If a permanent corps of mounted infantry were organized, they would, in the opinion of those of us who have had most experience, speedily become dragoons, and bad dragoons too.

Lessons of the Cavalry Manœuvres of 1890.

I come now to the lessons which have been learnt from the cavalry manœuvres in Berkshire in 1890. The presence of a force of three companies, or 400 mounted infantry, has proved the following points, viz. :—

(1). The value to cavalry of a force of mounted or mobile infantry.

(2). That by two months' training, and by a well thought-out system of organization, infantry soldiers can work mounted with cavalry in the field, and can at the same time maintain their efficiency.

Those were the two questions that we of the Mounted Infantry Regiment felt that we were upon our trial to prove. For the result I will quote from the *Times*. The *Times* military correspondent, a well-known and not too favourably disposed critic of the value of mounted infantry, observes in his first letter that the presence of the mounted infantry marks "a distinct innovation on accepted and orthodox tactical ideas," and continuing, he says:—"Continental soldiers, and nearly all our own cavalry officers, declare there is no need for the formation of a body of infantry to be told off specially to help them * * * that their troopers can dismount and do the work quite as well as infantry." In his last letter we read the following deduction of his personal study of the manœuvres:—"One of the results of the manœuvres has been to prove the great value of mobile infantry in regular warfare." If this is the result of an experiment in peace manœuvres with blank ammunition, what may be looked for from the same force on service with ball ammunition, 44 per cent. of whom were marksmen and all of picked physique?

Concluding Remarks.

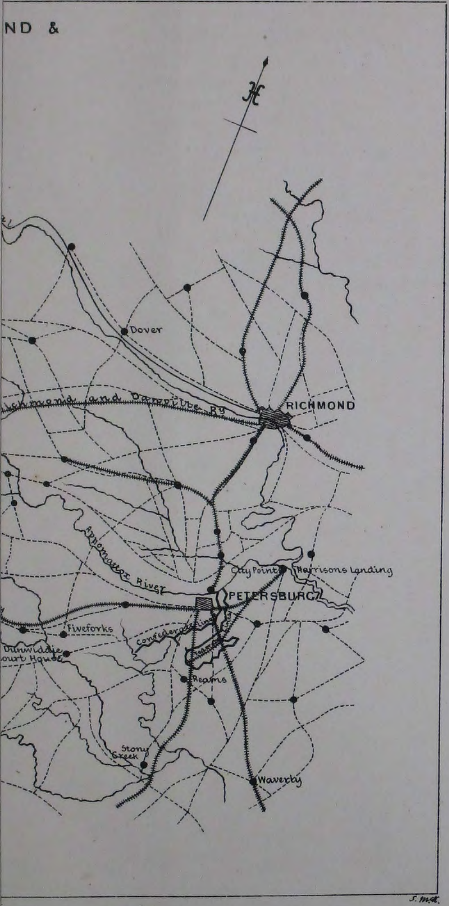
It seems to be an accepted fact that we Britons are, in all things military, to follow the lead of others. Some of us may well recollect when, after the Crimean and Italian campaigns, we worshipped at the shrine of the French. We wore trousers that were baggy and caps that had peaks. Since the collapse of the French military power we have slavishly bent the knee to everything German. We prefer to ask what the opinion of Berlin may be upon all military problems rather than to trust to our own judgment, or to believe our own experience and follow the dictates of our own common sense.

In every line of life—whether it be commercial, mercantile, naval, or the fine arts—we take our position in the very front rank, if indeed we are not unrivalled. In things military we are ready to bury our heads, and take an insignificant position. We wilfully forget that we have lived, and live, by the sword, and that we have created, and are at this moment creating, this vast Empire of ours by campaigns in every part of the globe. The experience of our armies is not confined to the Continent of

Europe, with its accepted rules of war, but it embraces campaigns in the snows of North America; the rivers and forests of Canada; the fever-stricken swamps of the West Coast of Africa; the vast plains of South Africa, with their thousand miles of communications; the sultry heat of India; the sands and deserts of Egypt, and of Equatorial Africa; and the jungles and fastnesses of Burmah. What nation in the world possesses such a record as this? What experience have the Germans had of the tropical sun of India or of Equatorial Africa, the West Coast of Africa, or of campaigns in the Soudan desert? The Italians, indeed, have had a recent and somewhat bitter experience on the shores of the Red Sea, while the experience of the French in Tonquin and Dahomey cannot be deemed particularly happy.

Gentlemen, it has been wisely said that "to follow is to remain behind." Let us take this to heart and let our motto be "Progress," in all things military as it is in all things commercial. Let us accept the facts as facts, which I have submitted to you this afternoon. Let us make from them the deductions which our experience in 20 campaigns, and in every description of country and climate, alike dictate to us. Let us venture to declare boldly, in the face of Berlin:—"Yes, as we have the finest infantry in the world, so also do we intend to make it the most mobile, to so train it that we can work a portion of it, if need be, with the rapidity of its sister arm."

Y PLATE I


ND &
Dover
RICHMOND
Appomattox River
City Point
Harrisons Landing
PETERSBURG
Fiveforks
Reams
Stony Creek
Waverly
S. McK.

PAPER III.

THE TREATMENT OF SEWAGE.

By W. Santo Crimp, M. Inst. C.E., F.R.M.S., F.G.S., Etc.

It is not necessary or desirable in a short paper to discuss the historical aspect of the question of "Sewage Disposal." Blue Books and Reports innumerable exist and are constantly being added to, in most of which some light is thrown upon a most troublesome problem, and the operations of past investigators are brought under review. We shall, therefore, consider the question as it now stands; firstly, as regards the sewage itself; secondly, the necessity for purifying or otherwise dealing with it; and thirdly, the means to be employed in effecting the last-named object.

With regard to the first question; what is sewage? We may say that it is the fouled water supply of a community. Now that the importance of providing absolutely pure water for consumption by human beings is fully appreciated, we find the community protecting its water supply by every available means. It is, if possible, collected on drainage areas free from centres of pollution; it is carefully conserved for use as required; it is conveyed into our habitations in strong iron and lead pipes, and in every way protected from contamination. Having served its high purpose, it is, however, immediately on being used, degraded and rendered filthy and offensive. The sewer, indeed, is the very antithesis of the water-main.

Sewage is a very complex liquid ; a large proportion of its most offensive matters is, of course, human excrement, discharged from water-closets and privies, and also urine thrown down sinks and gully-holes ; but, mixed with this, there is the dirty water from the kitchens, containing vegetable, animal, and other refuse, and that from wash-houses, containing soap and the animal matters from soiled linen. There is also the drainage from stables and cow-houses, and that from slaughter-houses, containing animal and vegetable offal. In cases where privies and cesspools are used instead of water-closets, and these do not discharge into the sewers, there is still in sewage a large proportion of human refuse in the form of chamber-slops and urine. In fact, sewage cannot be looked upon as composed solely of human excrement diluted with water, but as water polluted with a great variety of matters, some held in suspension, some in solution, but both present in such a condition as to render it impossible, in the present state of our knowledge, practically to cleanse and purify sewage so thoroughly as to make it safe for drinking, even when largely diluted with unpolluted water.

Another class of sewage includes all kinds of "manufacturing refuse." In the towns of manufacturing districts, a considerable proportion of this waste is passed into the sewers,* as being the readiest way of getting rid of it, and then it merely adds other ingredients to the dirty mixture flowing down these channels ; but where the works are situated on or near a stream, and the water made use of in the process of manufacture is afterwards transferred directly to the river, polluted by admixture with the special matters made use of in the different industrial processes, such refuse-matters can be treated separately as manufacturing pollution. They may be classified generally under the following heads :—

Pollution by dye-works, print-works, and bleach-works.
,, chemical works.
,, tanneries.
,, paper-making.
,, woollen works.
,, silk works.

Then another class of pollution is the drainage from street surfaces, which in towns with considerable vehicular traffic may be

* Clauses 16 and 17 of the Public Health Acts Amendment Act, 1890, prohibit persons from turning chemical refuse or hot liquids (over 110° Fahrenheit) into sewers.

as impure as sewage (*Way*). Then there is the liquid remaining after rain in the street gullies, which in dry weather rapidly putrifies and becomes most offensive. This foul liquid is displaced on the advent of the first shower of rain, and may materially assist in polluting small water courses.

The Rivers Pollution Commissioners made a large number of analyses of sewage, the results being given in the subjoined table :—

TABLE I.—AVERAGE COMPOSITION OF SEWAGE.

In Parts Per 100,000.

Description.	Total Solid Matters in Solution.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Total Combined Nitrogen.	Chlorine.	Suspended Matters.		
							Mineral.	Organic	Total.
Midden Towns	82·4	4·181	1·975	5·435	6·451	11·54	17·81	21·30	39·11
Water-closet Towns	72·2	4·696	2·205	6·703	7·728	10·66	24·18	20·51	44·69

In Grains Per Gallon.

Midden Towns	57·68	2·926	1·382	3·804	4·515	8·078	12·467	14·910	27·377
Water-closet Towns	50·54	3·287	1·543	4·692	5·410	7·462	16·926	14·357	31·283

During the past few years filter presses have been much employed in dealing with the solid matters separated from sewage, and it has been possible to ascertain, within close limits, the quantity of solid matters present in sewage ; as a general result, it may be said that when sewage is clarified by means of chemicals, the dry solids will amount to four tons per million gallons, or to 62 grains per gallon, a certain proportion of which will be due to the precipitant used. Of course, normal sewage is indicated, not sewage diluted with large volumes of subsoil or other water, nor on the other hand abnormally concentrated sewage, due to a limited water supply. We may say that the sewage referred to is that due to a water supply of about 35 gallons per head per diem. There is one other point in connection with sewage to which we may briefly refer, and that is its manurial value. According to a well-known authority—Dr. Tidy—London sewage contains in each million gallons $\frac{2}{5}$ton of nitrogen, $\frac{1}{7}$ton of phosphoric acid, and $\frac{1}{13}$ton of potash. We know from a study of the sewage question, that these numbers possess an extraordinary fascination, not only for the scientist interested in agricultural problems, but also for a great number of company promoters, some of whom find more wealth in a too confiding public than in the dirty water called sewage. As in the case of a poor auriferous quartz, it may cost more to extract the metal than can be got for it, so with sewage, and it is a fact that in this country the cases are few and far between where there can be any hope of profitably reclaiming its manurial constituents when burdened with a mass of water, as is nearly always the case.

We have seen what are the principal constituents of sewage from the chemist's point of view, but there is one other feature, a brief consideration of which must not be omitted. Of recent years, an increasing amount of attention has been given to the science of bacteriology, and it has been demonstrated that ordinary sewage contains something like five millions of micro-organisms and their spores in each cubic centimetre. What are the functions of this vast army of minute organisms? The question is but imperfectly understood, but it is certain that the phenomena of fermentation and putrefaction are intimately connected with it. One incident bearing upon this side of the question which came under the author's notice may be recorded. In a law suit, which was occasioned by the fouling of a stream by partly purified sewage, an eminent chemist gave evidence to the effect that the effluent which was said to pollute the river was, on account of its imperfect treatment at the sewage works, simply a weak sewage, exactly like the sewage obtained from a sewer near, in which much subsoil water was mixed with the sewage proper. So far as the analyses went, he was right, but yet there was a most important difference. A bottle of each was taken by the author and kept side by side, with the result that the weak sewage became more and more offensive, whilst the effluent water rapidly lost its faint odour, and developed a green vegetable growth. There can be no doubt that these changes were brought about by minute organisms, the presence of which chemistry failed to detect. There can be but one conclusion as regards this part of the question, and it is that we cannot hope to solve the problem of sewage treatment solely from the chemist's standpoint.

With regard to the necessity for dealing with sewage, we have seen that in order to provide himself with water, man has resorted to the rivers and streams, he has constructed suitable works, and has abstracted so much of the water as his wants demand ; but when the water is returned to the river near the town or city in which he dwells, it is degraded and filthy, and even dangerous if used for domestic purposes. When sewers were first constructed, their point of discharge was the nearest stream ; if the volume of the stream was small compared with that of the sewage poured into it, the result was the conversion of the stream into an open sewer.

In some of the large midland towns, situated near the heads of the watersheds, these conditions obtain to the present day, and many of the streams are simply rivers of sewage. London itself has suffered by the pouring into its river, right in the heart of the metropolis, the liquid, and in some degree solid, refuse of generations. No doubt the liquid impurities are not of a cumulative character, the river water constantly coming down, and the sea water mingling with it, contain the means of purifying that portion of the polluting matters which are in solution ; but during the past 100 years, millions of tons of solid matters have been discharged into the river, forming mudbanks, which will not be removed by natural agencies for generations to come.

When a river is rendered filthy and offensive by sewage discharges, the health of the community must suffer, to say nothing of the loss to manufacturers by reason of the water passing their mills and factories being rendered unfit for use in the various industrial processes in which they are engaged. In this country, where the population is large relatively to the streams and rivers, the evil effects of river pollution are, unfortunately, too well known to need further reference. We may at once, therefore, proceed to a brief discussion of the methods by the employment of which filthy sewage may be changed into a comparatively harmless liquid, not, however, such a liquid as may be used for domestic purposes. We shall first consider the question from the engineer's point of view, and endeavour to ascertain the conditions under which it is discharged at the works. From the habits of the people, we know that the flow throughout the whole 24 hours must be very variable in quantity. In the early morning, for instance, the sewage flow reaches its minimum, and consists of little besides leakage from the subsoil and from faulty fittings in connection with the domestic water supply.

The author has made a series of observations on the London and the Wimbledon sewers in order to ascertain the real fluctuation. These have been placed in a tabular form as given below :—

TABLE II.—PERIODICITY OF FLOW OF SEWAGE.

Town.	Maximum Percentages Discharged.				Excess of Maximum over Mean Discharge Per Cent.	Gallons Per Head Per Day.
	7 a.m. to 7 p.m.	During 6 Hours.	During 6 Hours.	During 1 Hour.		
Aylesbury ...	56	42·2	31·4	5·90	42	60
Leicester ...	60	42·8	31·3	5·70	37	42
London... ...	68	49·0	37·0	6·64	60	36
Providence ...	61	42·0	33·0	5·63	35	...
Wimbledon ...	66	48·2	39·5	7·40	78	29
Averages ...	62·2	44·8	34·44	6·25	50·4	..

It should be mentioned that the experiments at Wimbledon were made in an outfall sewer quite close to the town, and that as the minimum velocity allowable in a good outfall is about $1\frac{1}{2}$ miles to two miles per hour, the respective maximum and minimum periods of flow will be reached at a later time dependent on the distance of the sewage disposal works from the town. Thus, although at Wimbledon the maximum discharge is reached at about 11 a.m., in the case of the Barking (London) outfall works the maximum is not reached until some four or five hours later. This is a matter of some importance, not only as regards the tank treatment and arrangements for dealing with the sewage, but also from the chemist's point of view, since isolated samples of sewage taken for analysis may be exceptionally misleading unless these facts are taken into consideration. In the case of sewage disposal works somewhat remote from the town contributing to them, the sewage during the early part of the forenoon consists for the greater part of leakage, and samples to be of any value should be taken for 24 hours consecutively, and the amount of each sample should bear an exact ratio to the sewage flow.

As bearing upon the construction of settling tanks, it may be mentioned that taking the average of the London and Wimbledon gaugings, 40 per cent. of the sewage is discharged during six hours of maximum flow, and 50 per cent. during eight hours; the greatest hourly maximum amounting to 7·4 per cent. Further reference to these numbers will be made at a later period.

There is, however, one difficulty connected with sewage disposal which is very much greater than that of providing for these hourly fluctuations in the flow of the sewage proper, and that is the variable quantities of rain-water that have to be dealt with. Certain assumptions have been made by some writers with regard to the proportion of each fall of rain that will be yielded to the sewers. In the opinion of the author, the subject is one of extreme difficulty, and it is impossible to formulate a rule that shall be any approximation to the real facts of the case.

At Wimbledon the separate system has been carried out, so far as the water from the roads and the front part of the roofs is concerned, but notwithstanding this, the volume of rain-water yielded to the sewers under certain conditions is exceedingly large. The following instances extracted from the pumping returns of the last two years may be quoted:—

The total volume of sewage was doubled by a fall of ·15 inches of rain, whilst on another occasion ·66 inches of rain only gave a like result. On other occasions ·41 of rain increased the volume $2\frac{1}{2}$ times, whilst ·64 produced the same result. The volume was increased three times by falls of ·17 and ·71; four times by falls of ·16 and ·69; falls of ·17 and ·65 gave an increase of five volumes; ·62 and ·75, seven volumes; ·69, eight volumes; ·92, nine volumes; and 2·62 only gave the same increase. The explanation of these widely different results may be found in the condition of the surfaces draining to the sewers, and in the rate at which the rain falls. In very wet weather, when all these surfaces are saturated, we find very small falls of rain produce the same effect as large falls when the conditions are of the opposite nature. If we leave volumes for a moment, and turn to increases in the rate of flow, we find that ·19 of an inch increased the flow five times; ·21, four times; ·23, five times; ·24, five times; ·29, eight times; ·67, 10 times; and ·92, $12\frac{1}{3}$ times. In this latter case the maximum rate of flood discharge was reached in 13 minutes from its commencement.

When these figures are attentively studied, it will be conceded that when sewage is to be treated, the separation of the rain-water from the sewage, to the fullest possible extent, is of the greatest importance. Whether it should be first allowed to mingle with the sewage, and then be discharged by means of storm over-flows, taking with it, of course, a proportion of the sewage, or whether it should be intercepted from the sewers altogether, is a question which the author cannot hope to settle. The conditions in thickly populated urban districts, and in thinly populated rural districts, are widely different; but we may look, perhaps, for a solution of the difficulty in the direction of absolute separation in the case of the rural districts, and entire inclusion in the case of the urban districts, since it is well known that in these latter districts the excretions of animals upon the roadways are the cause of serious pollution of the rain-water falling upon their surfaces, more particularly in dry weather, when such surfaces are but rarely efficiently washed.

If we examine for a moment into the provision made in outfall sewers for the sewage proper, we find that as a general rule it is assumed that one-half of the sewage will be discharged in six hours. As a matter of fact, one hour or less should be the unit for the construction of such data, and taking the figures obtained by the author in London and at Wimbledon, we find that $7\frac{1}{2}$ per cent. may be discharged in one hour.* If we take the sewage discharge at five cubic feet per head per day, the maximum rate of discharge per thousand persons will be 6·2 cubic feet per minute.

From an examination of the evidence relating to the Metropolitan Main Drainage Works, we find that the provision originally made was at the rate of 13 cubic feet per minute per thousand; whilst in the case of the schemes prepared for the Lower Thames Valley Main Drainage Board the allowance was 10 cubic feet per minute per thousand, but in the latter case the separation of the rain-water was to be carried out as fully as possible. As we have seen in the brief examination of the rain-fall and its effect on the sewage flow, comparatively small falls—such as $\frac{1}{5}$ and $\frac{1}{4}$ of an inch—will, under certain conditions, cause the flow to be increased five times. It is quite clear, therefore, that the provision originally made in the Metropolitan sewers was insufficient, and that the storm overflows have been brought into operation much more frequently than was

* Recent experiments in the large London outfalls show that seven per cent. is discharged per hour during the period of maximum flow.

originally contemplated, and there has been abundant justification for the comparatively recent enormous addition to the main drainage system.

Having pointed out some of the difficulties that have to be contended with in dealing with sewage, we may now proceed to a short consideration of modern appliances in connection with sewage treatment.

The first of these appliances to be considered is the settling tank, which, in the minds of many people, seems to possess the mysterious property of purifying sewage, in addition to clarifying it; there is, however, a wide difference between these two terms, which difference cannot be too strongly insisted upon.

It is an undoubted fact that great improvements have been made in the construction of settling tanks. The earlier ones were, as a rule, constructed with flat bottoms, and the arrangements for drawing off the clarified water were of a very defective character, the outlets being frequently placed near the bottom of the tanks. Settling tanks should not only serve the purpose of clarifying the sewage, but they should be so constructed that the settled sludge may be removed with a minimum of labour. This object may be accomplished by constructing the tanks with segmental bottoms in cross section, and with a longitudinal fall towards the inlet of about 1 in 100. At the outlet end a floating-arm-valve should be provided for the purpose of drawing off the clarified water down to the level of the sludge, without disturbing the latter. The sludge should of course be swept into a reservoir near the inlet end, and dealt with in any suitable manner. If it is intended to filter-press the sludge, large gratings with a mesh of about three-quarters of an inch should be provided in the tanks, in order to intercept all large substances.

Although the lines upon which settling tanks should be designed have been indicated, the question of capacity is a most important one, and one with regard to which there is much difference of opinion. It is generally admitted that with an efficient chemical process a period of two hours should be allowed for the subsidence of the suspended matters; and in those cases where the outfall sewers discharge their contents directly into the tanks by gravitation, it is clear that the tank must be of sufficient capacity to contain two hours' sewage flow during the period of maximum discharge, and this quantity will amount to nearly 15 per cent. of the day's flow. Provision must also be made for those moderate falls of rain which occur so frequently in this country, and with regard to this provision no absolute rule can be laid down, since sewage effluents may be of varying degrees of purity according to local circumstances. If, however, we assume that it is necessary to fully treat all sewage diluted with two volumes of rain-water and under, it will be necessary to construct tanks with a capacity equal to 45 per cent. of the day's flow. The following examples of tank accommodation may be quoted:—Coventry, 42 per cent.; Birmingham, 56 per cent.; Burnley, 56 per cent.; Leicester, 40 per cent.; Wimbledon, 85 per cent. In the case of Wimbledon the works have been designed to allow for a large increase in the population.

In the paper by Dr. Percy Frankland, recently read at the Congress of the Sanitary Institute at Worcester, three towns are referred to, in the case of one of which the tank capacity is only 25 per cent. of the day's flow, and in the other two rather less than 20 per cent. In the case of the two last mentioned towns, the effluent from the tanks is first passed downwards through a small coke filter, two feet in thickness, and then upwards through a similar layer, the coke being changed at intervals of about three months. These tanks are worked on the intermittent system, with regard to which the following statement by Dr. Frankland is of interest:—

"The analyses given below show that this complicated system of intermittent precipitation yielded results very similar, but by no means superior, to those obtained by the simpler method of continuous precipitation. * * * * * Moreover, the process of filtration through coke, as carried out at these works, appears to deteriorate rather than improve the character of the effluent."

This is a conclusion in perfect accordance with what might have been anticipated where sewage effluent is passed through an exceedingly small filter which may contain a large quantity of the foulest suspended matter found in sewage. With regard to the question of intermittent treatment *versus* continuous flow, the author decidedly prefers the latter, since the constantly varying character of the sewage tends to become equalised in passing through the tanks when these are on the continuous system.

Although the foregoing remarks apply to the settling tank as usually constructed in this country, an exceedingly useful form of tank has recently been designed by Herr Kuiebühler, engineer for the sewage works of Dortmund. These tanks are certainly constructed on better lines than are the English tanks. They are circular on plan, and are of considerable depth, the bottoms being in the shape of an inverted cone. A large cylinder is fixed vertically in the middle of each tank. The sewage—after passing through roughing tanks in which the sand and other heavy matters subside—is treated with lime and sulphate of alumina, and is then discharged into the central cylinder, down which it passes nearly to the bottom of the tank, and it is then distributed in a horizontal direction by means of specially constructed arms. The heavier solids fall to the bottom, while the lighter are carried upwards for some distance, where they remain suspended in the water, forming a filtering medium. These particles then aggregate together, and by reason of their then greater specific gravity, fall to the bottom, whilst the clarified effluent overflows into a network of channels placed near the top of the tank. Perhaps the most interesting feature in connection with these tanks is the facility with which the sludge can be removed, even while the tanks are full of water. Passing down the central cylinder, and reaching nearly to the bottom of the tank, is a pipe six inches in diameter, connected with a large iron reservoir, from which the air is exhausted by means of an air pump. The sludge then rises until the reservoir is nearly full, when by a suitable arrangement of valves its contents are discharged into sludge drying beds.

At Essen tanks on a somewhat similar principle have been constructed, but the tanks, instead of being deep like those at Dortmund, are shallow, and a large iron vessel like a gasholder is placed in each of them. The air is withdrawn from the cylinder by means of an air pump, and the sewage then rises to the height of the syphon outlet, and so long as a partial vacuum is maintained, a constant flow is secured. This system is known as the Rockner-Rothe.

In the opinion of the author these two systems are worthy the attention of all having to design or superintend sewage disposal works, as by their use sewage can be chemically treated quite near towns, in consequence of the compactness of the works and the small area of ground required. In very inclement countries, and those in which extremes of temperature are experienced, the tanks may be roofed in at a very small cost.

Having designed suitable tanks, we may next examine some of the chemical processes as in actual use.

The purification of sewage by means of one or more reagents has occupied the attention of chemists since the commencement of the present century, indeed, the first patent in connection with this matter was taken out in the year 1762 by Deboissieu, since which date about 450 patents have been obtained, an enumeration of which cannot be entered upon to-night.

It will be conceded that the solution of the "sewage problem," as far as the employment of chemicals is concerned, is now placed upon a satisfactory basis, since the vast number of failures or negative results which have been obtained in the use of chemicals, have served to reduce the question to one of comparative simplicity.

The exact position may be briefly recapitulated in the words of Dr. Dupré, F.R.S :—"As regards processes of precipitation, I will merely remark that inasmuch as no proportion of chemicals which can practically be employed will do much more than clarify the sewage, the proportion of chemicals employed should be kept as low as is consistent with the object to be attained, namely, clarification, and that more particularly the use of large quantities of lime should be avoided."

Of all the agents used in the clarification of sewage, lime is the most universal, probably because it is cheap and most certainly effective. The lime should be first thoroughly slaked, and then applied in the form of milk of lime, *i.e.*, mixed with about 10 times its weight of water, or, better still, if the circumstances will admit, in the form of lime-water, each gallon of which will contain about 80 grains, or about five tons of lime in each million gallons. The usual dose of lime, when applied as milk of lime, is one ton to each million gallons, or 15·68 grains per gallon, but the tendency is to reduce the quantity of lime to the smallest effective amount, since an alkaline effluent mixing with organic matters, such as abound in the muds of many rivers, is liable to enter into putrefaction of a most offensive nature. Indeed, an excess of lime in an effluent may cause it to act as a precipitant of the suspended organic matters present in the river water, thus producing deposits which in hot weather may become exceedingly offensive.

Lime is often used in smaller doses in conjunction with other chemicals, notably sulphate of alumina and proto-sulphate of iron.

Lime and sulphate of alumina is now used at a great number of sewage works, the doses being eight grains and six grains respectively of each, per gallon of sewage.

London sewage is treated with about four grains of lime (in solution) and 1½ grains of proto-sulphate of iron per gallon, and it is found that this dose is sufficient for clarification. In the summer the effluent is further treated with permanganate of potash, the dose being about $1\frac{1}{2}$ grains per gallon.

Lime in large quantities, about three tons to the million gallons, is used in the "Amines" process, with a small quantity of herring brine. Sterilisation of the effluent is the principal object sought to be attained, and Dr. Klein has reported favourably upon the process in that respect. Clarification is very rapid and complete, and deodorisation is effectively performed. The effluent is highly alkaline, but when applied to crops at Wimbledon did not apparently injuriously affect them. The amount of sludge produced is larger than when small doses of lime are used, but the sludge does not become putrid, and may be disposed of by exposure to the atmosphere in the first instance, when it quickly parts with a great deal of its moisture, and may then be carted or otherwise dealt with.

Among processes in which lime is not used may be mentioned the "A.B.C." and the "International." In the first of these, alum, clay, and charcoal are extensively used; clarification and deodorisation are both very complete, and a sludge of high manurial value is said to be produced.

Treatment by the "International" process involves the use of small filters of polarite after the sewage has been treated in tanks with ferrozone.

It may be said generally of these chemical processes, that all are successful in clarifying, and to more or less extent of deodorising and purifying sewage.

The cost of treating the sewage, when calculated at a rate per million gallons, varies with the chemicals used and their amounts. As an example, the lime and sulphate of alumina process may be quoted :—

	s.	d.
Lime, $\frac{1}{2}$-ton per million, at 20s.	10	0
Sulphate of alumina $\frac{1}{3}$-ton per million, at 60s. ...	20	0
Labour, say...	5	0
Total	35	0

At Kingston-on-Thames, the A.B.C. Company are paid threepence in the pound on the rateable value of the town, the company doing all the work connected with the treatment of the sewage.

Closely connected with the question of chemical processes is that of the disposal of the sludge. The author has already fully dealt with this question in a paper read before the Institution of Civil Engineers, and in his work, *Sewage Disposal Works*, and the briefest reference only will now be made to it.

Whether sludge should be filter-pressed, as is now done at a large number of sewage works, or whether it should be dug into the land as at Birmingham, or taken to the sea as in the case of the Metropolis, is a matter which must be determined by the local conditions in each case.

The following facts with regard to the quantities of sludge produced at Wimbledon may be of interest. During the year 1888, 365 million gallons of sewage were treated; one-fourth of this volume was due to rain-water and subsoil leakage, and the remaining three-fourths was sewage proper; the total flow averaged 40 gallons per head per day for the year. Three thousand and fifty tons of sludge cake were produced, or 8·2 tons of cake per million gallons; and if the process of drying were carried further, and the whole of the water were got rid of, the dried solids would amount to four tons per million gallons as nearly as possible, or 62 grains per gallon. Lime and carbon were used during the year in the treatment of the sewage, the total quantity so used for both precipitation purposes and sludge pressing amounting to 12 grains per gallon on an average; five grains of sulphate of alumina were also used per gallon. Thus we find that the dry solids originally in the sewage were increased by one-third. The author has obtained particulars from other towns where filter-presses are employed, and the average quantity of cake produced amounts to 9·28 tons per million gallons. The apparent discrepancy is no doubt due to the fact that in some cases the sludge is calculated upon the dry weather flow, and in others upon the average; at Wimbledon, for instance, the sludge cake would amount to 11 tons per million gallons if calculated on the dry weather flow.

When it is necessary to purify sewage as well as clarify it, the tank treatment must be carried a stage further, and the effluent must be passed through filters, or over and through land. Concentrated filtration on small filters has lately been adopted with much success at Acton, Friern Barnet, and elsewhere. At Acton the principle purifying material of which the filter is composed is known as polarite. The author has experimented with a small filter of this material, and he is able to speak highly of the results obtained. The company constructing these filters state that 1,000 gallons of sewage may be purified on each square yard per day. It must, however, be pointed out that where concentrated filtration is adopted, clarification must be carried to the fullest practicable extent, otherwise the suspended matters remaining in the tank effluent will very rapidly clog the surface layer, the expense of removing and renewing which is rather high, probably not less than 10s. per square yard per annum. At Friern Barnet the tank effluent is disposed of upon four small filters, each one-third of an acre in extent, composed of burnt ballast, coke breeze, and earth, and very good results are obtained. The filters are used intermittently, and on one being dried off the surface material is merely harrowed over. The sewage of 8,000 persons is dealt with at these works, lime and alum being the chemicals employed in the tank treatment.

A more usual way of effecting the purification of sewage is by applying it to land. In some cases, as at Beddington, Norwood, Bedford, and elsewhere, sewage is applied to land in its crude condition, being subjected to a rough screening only. Although this plan may not be productive of a nuisance when the works are remote from houses, the author is of opinion that upon hygienic grounds sewage should be clarified before being applied to land. An enormous quantity of filth is brought to the sewage works on the occurrence of a heavy fall of rain after a long period of drought, and in those cases where clarification is not attempted, a great mass of solids may be seen covering the surface and coating the crops for some distance from the large carriers; and it is these occurrences which have brought some sewage farms into well deserved disrepute.

At Wimbledon clarification is effected in two ways. The sewage from about 22,000 persons is clarified by means of tanks and chemicals, whilst that from the high level sewer, which conveys the sewage of about 3,000 persons, is merely filtered upwards through burnt ballast, which is placed in specially designed small filtering tanks; and so effective are these filters, that although all the strained sewage is often applied to one small field of two acres, except when it is being dried off and the crop is being removed, it would be difficult to find upon the surface of this field any of the suspended matters found in sewage, and in the hottest weather it is difficult to perceive any odour.

We occasionally hear that a nuisance exists at such-and-such a sewage farm, and straightway anti-irrigationists exclaim that sewage farming must necessarily always be attended with noxious results. In the opinion of the author, ill effects are due either to the absence of tanks, to bad management, or to the careless and improper manner in which the land has been laid out, and it may be remarked that badly managed sewage works of all descriptions are bound to be offensive. It would undoubtedly have been better for a great many sewage farms on heavy clay soils, if the experiments by Dr. Frankland on intermittent filtration had never been heard of. In numberless cases these clay soils have been deeply under-drained, as though such drainage would convert impervious clay into a porous filter; the result has always been disastrous. Undrained clay cracks badly enough in dry weather, and drained clay dries more rapidly and cracks far more, thus giving the sewage direct access to the drains, from which it emerges in an unpurified condition. The result has often been that where clay lands have been under-drained, they have been rendered absolutely useless for the purification and cleansing of the sewage in dry weather.

The proper treatment of such land is to pay the utmost attention to the surface to ensure that there shall be no hollows or low places in which the sewage can lodge and become stagnant. Each time the land is broken up it should be deeply ploughed, and, if necessary, subsoiled, so that the topmost layer for a depth of about 18 inches shall always be in a more or less porous condition. In this way we get lateral filtration and the maximum purifying power out of the soil, and also provide a suitable home for the nitrifying organisms which we now know are the great scavengers of the sewage farm. When clay soils are so treated, and the sewage is first clarified—if only by means of filters as at the Wimbledon high-level works—the author has no hesitation in saying that the sewage of 250 persons may be effectively cleansed on each acre.

In the case of gravelly and other porous soils, a different course of treatment may be adopted, and the purifying effect of these soils may be increased to a very large degree by judicious under-draining. It is generally accepted that the sewage of 1,000 persons may be treated on each acre of land of this character.

The value of the crops grown upon a sewage farm will of course depend upon the laws of supply and demand. Near large towns, small areas of land are usually employed because of the high price of the land, and as the volume of sewage applied per acre is then large, oziers, rye grass, and roots must be grown, with such other crops as may be dosed with large volumes of sewage. As an example of prices obtainable for the produce of a sewage farm, that of Wimbledon may be cited. The farm is highly cultivated, is near the finest market in the country, is supplied with sewage to any required extent, whilst the soil is of varying kinds, and well suited to the production of heavy crops. The result from the financial point of view may be thus summarised :—Total working expenses, £9 per acre ; total receipts, £13 per acre ; but as the land cost upwards of £300 per acre, the result is a loss to the ratepayers. From the sanitary point of view, the farm is eminently successful, and it would be difficult to find a sewage effluent anywhere which is as consistently good.

In concluding this brief survey of the sewage question, the author would remark that the disposal of sewage is no longer the troublesome problem of past years. The principles are now so well understood that in order to ensure success, all that is necessary is, first, to make a comprehensive survey of every situation in connection with each particular case, and then to apply the most suitable remedy, finally remembering that good management must be insisted upon as a vital element of success.

PAPER IV.

ROAD MAKING.

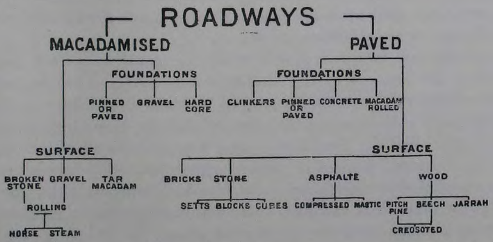
By H. Percy Boulnois, M. Inst. C.E.

The subject upon which I have the honour to address you this evening is "Road Making," a branch of civil engineering which, to some people, may appear somewhat simple, owing, no doubt, to the fact that roads come constantly under their notice, and from this familiarity contempt as to how they are made perhaps follows.

Comprised under the head of roadways have sometimes been included tram lines, railways, and even canals, but the subject of my lecture will be devoted exclusively to the particulars of making roads for ordinary wheeled traffic only, and I think you will find that the subject is not altogether simple, and that some skill and experience are necessary in order to be successful in this branch of engineering.

I have not been able to divide my lectures into two equal parts, so I propose to go on this evening until the time allotted to me has expired, and I will then finish to-morrow evening.

First, then, let me call your attention to the following diagram or genealogical tree (which I will proceed to explain), showing the various ramifications of modern road construction:—



The condition of the roads and streets of a community is the principal sign of its prosperity or otherwise. However wealthy a country may be in mineral or agricultural resources, such wealth is of little avail without proper means of intercommunication and transport.

Whenever a new country has been conquered, one of the first acts of the conquerors has been to form new roads, generally with a view to the transport of the necessary machines of war, ammunition, baggage, and provisions; and although these lines of road may not have been the best for the commerce or intercommunication of the people, yet if they were properly constructed in the first place, they have afterwards remained as a nucleus from which other roads sprang to help forward the commercial prosperity of the country.

The Roman Empire was an example of this policy, for we find in every country that they conquered traces of their roads, some of them existing at the present time in a sufficient state of preservation to show the skill and enterprise of this great nation.

The methods which the Romans adopted in making these roads is described in Dr. Smith's *Dictionary of Antiquities*, and from this description it appears that their roads were a process of evolution. First came the "Via Terrena," a mere track worn by the feet of men and beasts, and possibly by wheeled carriages; then the "Via Glareata," where the surface was hardened with gravel; and although pavements were introduced shortly afterwards, the blocks were allowed to rest merely on a bed of small stones. Eventually, the roads seem to have been constructed on the following principles.

The "Via Appia," the great south road, was the first ever laid down upon scientific principles. It cut through hills and masses of solid rock, filled up hollows, bridged over ravines and rivers, and passed over swamps, which demonstrated the vast expense and prodigious labour that must have been lavished in its construction. Its details may be described as follows.

Two shallow trenches (sulci) were dug parallel to each other, marking the breadth of the road (about 15 feet). The loose earth between the sulci was then removed down to a solid foundation or "gremium." On this was laid the "statumen," consisting of stone not smaller than the hand could just grasp. Above the "statumen" was the "rudus," a mass of broken stones cemented together with lime, rammed down hard, and about nine inches in thickness. Above the rudus came the "nucleus," composed of fragments of bricks and pottery (smaller than the pieces composing the rudus), cemented together with lime, and about six inches in thickness. On the top was the "pavimentum," composed of large polygonal blocks of the hardest procurable stone, fitted and jointed closely together in the form of a mosaic.

Such were the Roman roads, and they must have been more costly of construction than some of our best stone-paved streets of to-day.

With this short introduction, I will now turn to the more prosaic and practical portions of my lecture, viz., the design and construction of modern roads.

When it has been decided that it is necessary to form a road in any district, the selection of the route is the first consideration to which attention is directed. In order to secure the best, and, at the same time, the most economical line, it is necessary to carefully study the map of the district; or if no map exists, to at once set about making the necessary surveys.

With the map, and an aneroid barometer if the country is hilly, the engineer may then proceed to "prospect" for the new road, and having determined upon the best line, taking care to avoid physical obstructions as much as is compatible with undue length of road, he then roughly stakes out the proposed line of road, and carefully levels and plots the longitudinal section of the road, taking such cross sections along the route as he may deem desirable.

I will not enter into any detail with regard to these preliminaries, as no doubt you are all fully acquainted with the branches of surveying and levelling which are necessary for these operations; but, before proceeding to describe the actual processes of good road-making, the following hints to guide you in the selection of the best line for a new road will, I venture to think, be useful to you.

Gradients.—Although the Romans made their roads almost in straight lines from point to point, and thus showed their daring skill in the construction of bridges, cuttings, embankments, and retaining walls, it was an extravagant way of proceeding which would not be tolerated in the present day, and in some cases made their roads almost prohibitive for wheel traffic.

It is necessary in modern practice to decide what should be the steepest permissible gradient, and in connection with this it has been found by experiment that a man can walk up a slope of 1 in 1·2, a horse or mule up 1 in 1·75, but that when a load has to be pulled up the force of gravity comes into play, and consequently gradient becomes an important factor when dealing with the "duty" that can be got out of power. Hence a horse pulling its maximum load on a level can only pull four-fifths of that load on a gradient of 1 in 50, and only one-fourth of it on a gradient of 1 in 10; so that it is evident that the saving in horse-flesh is considerable when the gradient of a road can be reduced.

The following table shows some of the effects of gradients upon forces pulling loads.

TABLE SHOWING EFFECT OF GRADIENT.

On a level road a horse can draw	100.
„ rise of 1 in 100 a horse can draw	·90.
„ „ 1 in 50 „ „	·81.
„ „ 1 in 40 „ „	·72.
„ „ 1 in 30 „ „	·64.
„ „ 1 in 26 „ „	·54.
„ „ 1 in 20 „ „	·40.
„ „ 1 in 10 „ „	·25.

To some extent gradients are guided by the character of the country through which a road passes; for instance, on the Simplon Pass in Italy, there are gradients of 1 in 17 and 1 in 13, whilst in some parts of the United States of America gradients of 1 in 11 are allowed by law; but if the country is carefully contoured before setting out a new road, steep gradients may be materially reduced, remembering that a vertical rise is equivalent to an increase in the length of the road proportional to the angle of inclination.

Experiments made by Sir John McNeill showed that a stage coach weighing three tons, drawn up a slope of 1 in 30 a distance of one mile at the rate of six miles per hour, was equivalent to its being drawn along a level road a distance of 1·62 miles at the same speed.

In deciding the gradient, however, other considerations must have their due weight.

It is necessary, in designing the lines of levels of the proposed road upon the sections which have been plotted, to settle certain levels where rivers or impedimenta have to be crossed, especially if certain fixed head-room has to be provided, and also to bear in mind the question of balancing as much as possible the earthwork cuttings and embankments, so as to avoid long cartage of materials.

Steep gradients are to be avoided in addition to the question of greater draught, because a road is liable to be seriously washed and damaged during heavy rains. It is also subjected to greater wear from the horses feet both in ascending and descending, in addition to the great damage always caused by the necessity which arises to "skid" or brake the wheels of a descending vehicle, besides the extra danger to traffic during frost or snow.

No absolute rules can be laid down with regard to maximum gradients to be allowed, but the following information upon this point may be of service.

If a long gradient is unavoidable, let the lower portion be the steepest, if possible, and if a few level stretches can be inserted, so much the better.

If the proposed inclination is not steeper than 1 in 33, it will not pay to materially increase the length of the road, so as to flatten the gradient.

Technically, the rate of inclination should be guided by the angle of repose of any vehicle for the particular material of which the surface of the roadway is constructed; that is to say, if the force necessary on a level road to overcome friction is one-thirtieth of the load, then the same fraction denotes the angle of repose for that surface; but in practice there are so many disturbing elements to be considered, such as friction of the wheels of the vehicle, the power applied to retard descent, etc., that such minute investigations into ordinary roads for wheeled traffic would be almost useless.

There are no laws in this country for regulating the gradients of roads except when the level of any road has to be altered in making a railway, when by the Railway Clauses Consolidation Act, 1845, a turnpike road or any road in Ireland shall not be altered to any steeper gradient than 1 in 30 and any other public carriage road to 1 in 20, unless a report thereon shall be specially made by an officer of the Board of Trade.

The steepest gradient allowed by the Engineers of the Ponts et Chaussées in France, is 1 in 20.

In some of the States of America 1 in 11 is legally allowed.

The maximum gradients adopted for roads in Central India are as follows:—

1st class roads	1 in 25.
2nd " "	1 in 20.
3rd " "	1 in 20.
4th " "	1 in 18.

To sum up the question of gradients the following hints may be of service—

(1). Let the gradients of the road be as easy as the configuration and obstacles of the country will permit.

(2). Let the gradients balance as much as possible the embankments and cuttings of the road.

(3). Avoid steep gradients over culverts or bridges by raising the approaches, but do not lessen the waterway by lowering the crown of the arch.

(4). Where long gradients are unavoidable let the steepest part, if possible, be at the foot.

(5). Endeavour to avoid any steeper gradients than 1 in 30.

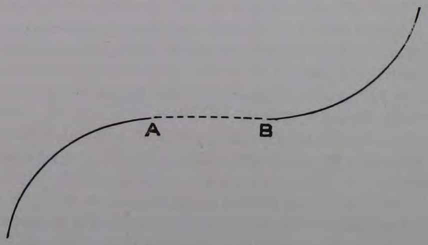
Alignment.—The next point to be considered is the "Alignment" or direction of the road.

Considerable care is necessary in the determination of the best alignment so as to combine shortness of route with avoidance of physical obstructions, such as swamps, rivers, hills, deep valleys, or the necessity for quick bends, and also, if possible, to pass near to a quarry where suitable stone may be got for the purpose of making the road; and of course other necessities will arise in every locality which will require careful consideration.

In setting out the road see that the straight parts are absolutely straight lines, and that where changes of line occur connect them by tangential curves of proper radius.

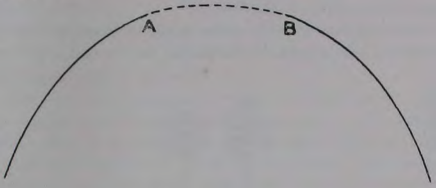
Unless on zigzag roads up the sides of hills, the radius of a road curve should not exceed a chain (66 feet) in length.

Where curves come thus:—



they should be connected between A B by a *straight line.*

When thus :—



they should be connected by a *flat curve.*

We will next consider the question as to what width shall be given to the proposed road, and whether it shall be provided with foot-walks.

Width of road is governed by three considerations—

(1). The maximum amount of traffic that has to be provided for, not only at the time of construction but also the probable increase.

(2). The land available for the construction of the road.

(3). The amount of money at the disposal of the Engineer for its construction.

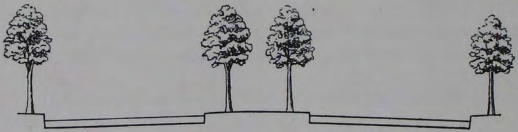
The width of the vehicles likely to use the road must be taken into account, and a margin for passing safely at speed allowed. In this country for ordinary traffic multiples of eight feet are considered a fair width to allow for a road or street.

Where sufficient land can be acquired it is well in laying out a road to provide a greater width of land than is actually necessary for the purposes of the made road bed, so as to provide for further extensions if necessary. The road, however, should not be made of greater width than can be kept in proper repair; this extra width of land will allow for ditches, banks, etc., and gives it a broad space for the sun and wind to assist the evaporation of water upon the surface of the roadway.

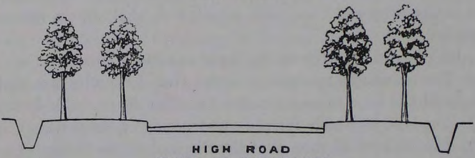
The proportion of width which the footpath should bear to the carriageway must be a question which local circumstances alone can determine.

In England the Model Bye Laws regulating new streets provide that the footpaths shall be each one-sixth of the entire width of street, including the paths; thus if the distance between the walls of the abutting properties was 36 feet, the footpaths would each be six feet in width, leaving 24 feet between the kerbs, which it will be observed is a multiple of eight, and allow three ordinary vehicles to pass each other rapidly in safety.

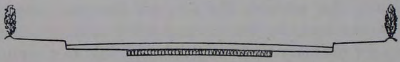
The following diagrams give some types of cross sections of roadways, showing how the roads, footpaths, etc., are arranged :—



WESTERN BOULEVARD.
NEW YORK.



HIGH ROAD
PARIS TO CHERBOURG.



HOLYHEAD ROAD

Dimensions of Roads in Central India.

	(Class of Road).			
	1st	2nd.	3rd.	4th.
Width of land in ordinary cases ...	108	80	72	54
„ where land is valuable ..	78	62	54	54
„ of roading	30	24	20	
„ of metalling (foundation) ...	18	15	14	
Depth of „	12″	12″	9″	
„ of broken stone	6″	6″	6″	

Having thus far discussed the questions of the gradients, lines, and widths of the proposed road, the next points to be considered before its construction can be commenced are those of its shape or cross section, and the materials and manner of its construction.

In designing the cross section three important points require careful consideration—

(1). Proper drainage of the surface and sub-structure.

(2). Strength to resist the weight and blows of the traffic.

(3). Ease and comfort of traction.

The modern practice, gained by experience, has shown that the curved or arched form of cross section meets the whole of the above requirements and this form is adopted, except upon the sides of hills or other local circumstances where a "cant" or hanging road may sometimes be constructed in preference to what is known as a "barrelled" road.

Care must, however, be taken that the cross section is not too high in the centre, or in other words, have too much barrel, for on a road which is made too convex there is a tendency for the traffic to avoid the sides and follow the same track along the centre of the road, as in this position alone can the vehicles remain in an upright or perpendicular position; the consequence follows that this portion of the road bears a disproportionate share of the traffic, with the result that ruts or hollows are worn, in which water (the great enemy of all roads) lodges, to the great detriment of its surface.

Telford adopted a flat elliptical curve for the cross sections of his roads.

Walker recommended a cross section composed of two straight lines joined near the centre of the road by a flat curve, and falling about 1 in 24 towards the sides.

Codrington says the fall from the centre to the sides need not be more than six inches on a road 30 feet wide, and should never exceed nine inches, and that for a road 18 to 20 feet wide, three or four inches is sufficient :—

In the City of Liverpool our practice is as follows :—

FIG. 1.

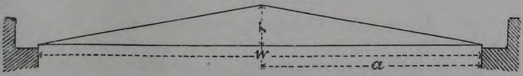
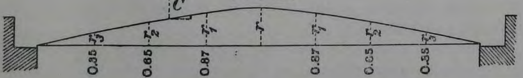


FIG. 2



Whether a flat ellipse, an arc of a circle, or two straight sides joined by a curve in the centre, is the best cross section to be adopted, it is well to remember that the height in the centre should be about one-sixtieth of the width of the road between kerbs.

Having decided the form of cross section of the proposed road, the next point to consider is the manner of its construction, and the materials of which it is to be made.

The first and most important point is the question of foundation, for unless the sub-structure, which really carries the weight of the traffic, is good and substantial, the best possible road surface will be of no avail.

The drainage of the sub-soil is also an important matter in wet localities, or otherwise it may happen that the road will sink or be blown up after heavy rains.

If the ground is soft it will be hardened by good drainage, which can be easily managed by cutting shallow trenches transversely across the road bed, at distances of from half to one chain apart, connected with the ditches at the sides of the road or with other outlets, and filling these trenches with rubble stone or other dry material.

On very soft, spongy ground or bog it is a good plan to carry the road on a raft, made with fascines or long fagots of brushwood, laid first transversely across the road and then longitudinally under the road, the top layer being laid transversely ; this is then covered with gravel or stones, and is ready for the foundation or "bottoming" of the road.

In the selection of the materials to be used for this bottoming, local circumstances must to a great extent be your guide.

If rock can be easily procured, the foundation or bottoming should be designed as follows :—

Upon the road bed—properly shaped to the contour of the road and well beaten or rolled—a course of large pieces of rock should be set by hand upon their broadest faces in the form of a close firm pavement. These stones should be from seven to ten inches deep, and be laid across the road ; they must have all projecting irregularities broken off with a hammer, and the interstices between them filled with spalls or chips, firmly wedged in or patched by hand with a light hammer, so that when all is finished there shall be a fairly even surface.

Where rock cannot be procured, large stones or gravel may be used, or such other material as the designer of the road may find procurable in the district, bearing in mind that the hand-pitched rock bottoming is the best with which modern science is acquainted, and that the duties of this bottoming are threefold :—

(1). To carry the weight of the traffic.

(2). To act as a sub-drain for the surface of the road.

(3). To prevent the earth under it from rising or "spewing up" on to the surface of the road.

For ordinary country roads of light traffic the bottoming can be formed with screened or sifted gravel, that which passes through the screen being used for the road. In some districts, the pots and pans, and other "hardcore," as it is called, from the waste refuse of houses, is used; in other districts hard clinker from foundries is used, but none of these make so good a bottoming as the hand-set stones or rock as specified by Telford, the first king of road makers.

Upon the bottoming prepared in one of the above-mentioned manners, the road material or "metal" should be laid in two layers, each about three inches in thickness, and brought up to a little above the finished contour of the road, to allow of the inevitable sinkage which takes place owing to the compression of the traffic, or the rolling which follows the construction of the road.

As to the choice of the proper material with which to metal the road, local circumstances must be again considered, and the assistance of local persons, especially masons, quarrymen, and others (if there are any), can be sought with advantage with a view to obtaining information from them about the different rocks and stones of the neighbourhood.

As, however, "the proof of the pudding is in the eating," the only true test of the value of any stone for road making purposes is by observing its behaviour when laid as a road metal. This cannot, however, always be tried, and I have consequently inserted at the end of this lecture some remarks by a Mr. Stock "On the Valuation of Road Metal and Setts for Paving," wherein he suggests certain tests with a view to obtaining some information upon the point (see Appendix A).

Failing, however, the opportunity of making the experiments he suggests, the following methods may, I think, be advantageously tried (if the means are available) in order to throw some light on this important question of the selection of the best road metal.

(1). Make a trial for *toughness.*

This can be done by setting a man to break measured quantities of different stones, and noting how much he can break in a given time, and then comparing the results.*

(2). Ascertain what power the stone has to resist *abrasion.*

To do this, weigh a certain quantity of stone, broken to the proper size for road metal, put it into an iron cylinder or box suspended on a spindle, and have it revolved a given number of times; then weigh the stone again, and note what it has lost by reason of the stone knocking against each other and against the sides of the cylinder. Compare different stones by this test.

Another plan would be to press a piece of the stone against a grindstone with a uniform pressure, and note the loss of weight caused by such contact from a given number of revolutions.

(3). Ascertain power to resist *compression.*

This can be ascertained by putting samples of stones under an hydraulic press; or, if this is not procurable, it can be managed with a long, easily made lever.

The weight or specific gravity of a stone, appears to be no test as to its fitness or otherwise as a road metal.

Clay-slate has a higher specific gravity than a tough flint, and yet the latter is incomparably superior as a road material, the former being almost worthless.

The qualities of a good road metal may be summarised as follows:—

Power to resist abrasion.
Strength to resist compression.
Toughness.
Power to resist decomposition or action of the weather.

As I have before stated, local circumstances must be taken into consideration when determining what stone to use, bearing in mind that the cheapest stone is not always the most economical.

I, however, give the following list of stones applicable for the purpose as a guide to their selection:—

Syenite.—This is a granite, in which hornblende takes the place of mica. It is an excellent road material, the darker the colour, the more durable it is found to be.

Granite.—This should have a preponderance of felspar, and have as little mica as possible. Close grained granites are the best.

Trappean Rocks.—Some of these make excellent road metal.

* Toughness is, however, not all that is required. Leather would be almost impossible to break in this manner, and yet it would not make a good road metal.

Basalts of dark colour and close grain, should be selected. *Greenstone*, with similar characteristics, are good, as is also *Whinstones.*

Gneiss is inferior to granite; it is composed largely of mica, and is not a first-rate road metal.

Flints.—These, if tough, make excellent roads, but often they are too brittle for heavy traffic. Surface picked flints are better than those which are freshly quarried. They seem to harden with exposure.

Gravel.—This varies in character, but if of a flinty nature, and not too much mixed with earthy matter, makes very good roads for light traffic, and is much used. It should be screened through wire screens of about 1½-inch gauge, the larger stones being broken and used with it.

Pebbles.—These are found on sea-shores and river-beds. They are composed of very various rocks, and are much water-worn and rounded; when broken, and mixed with gravel to bind them, they sometimes make very fair roads.

Limestone.—The metarmorphic, silurian, and carboniferous limestones may be used if crystalline in appearance, but the lias and oxlitic do not make good roads. There are hundreds of miles of limestone roads in this country, and they often make excellent roadways, as such stones have a great power of binding together.

Limestone has, however, a strong affinity for water, and thus they are muddy in winter, and dusty in summer.

Clay-slate.—These do not make good roads, as they crumble on exposure, and quickly degenerate into mud.

Sandstones.—Some of these, if cherty, or containing a large percentage of iron, may be used, but, as a rule, they make a most inferior road.

In some districts it is almost impossible to obtain any natural stone for road metal. In these cases, slag from blast furnaces, or ordinary clinkers from furnaces, or even burnt earth, have been used as substitutes, but they are none of them to be relied on.

Oyster shells are used with very good results on the roads near the Gulf Coast, and charcoal has been used in Michigan, U.S.A. I have myself made an excellent road in Jamaica with a rough coral, and no doubt many strange materials have been pressed into the service.

It is a mistake to mix a soft stone with a hard one, the result is sure to be a "bumpy" road, arising from the fact of the soft stone wearing more quickly than the harder. The hardest stone should be kept for the top or surface layer of metalling.

Breaking stone into road metal was, until comparatively recent years, always done by hand; now machinery has taken the place of manual labour in this as in other industries. Hand-broken stone, however, is by some considered preferable to machine-broken, where it can be had at a cheap rate, as it is broken by a blow and not crushed.

When broken by hand the breaker first reduces the size of the pieces he is engaged upon with a heavy hammer, and then further breaks these pieces up into the required sized metal with a small, cast-steel, chisel-faced hammer, about 1lb. in weight, fitted to the end of a long flexible ash stick.

The size to which road metal ought to broken is often a matter of choice, but if each stone can pass all ways through a two-inch ring, it is, in my opinion, the right size. An old gauge used to be whatever the stone-breaker could put in his mouth, but this was not altogether satisfactory, as the gauge sometimes varied.

To the two-inch gauge a good stone-breaker will break about two cubic yards of hard limestone in a day of 10 hours, but with a very tough granite he cannot break much more than half a cubic yard in a day.

With a first-class machine stone-breaker, between 8 and 10 cubic yards of granite can be broken in an hour.

The following table gives some recent information in connection with Marsden's Stone Breaker, which will be of interest:—

Table of "Marsden's" Stone Breakers.

Size of mouth.	In use.	Users.	Material.	Product in 10 hours.	Object.
20 × 10	5	Buenos Ayres Corporation.		500 tons.	Road-making
20 × 10	2	Coverack Stone Company, Falmouth.		300 ,,	
24 × 13	2	John Mowlem & Company, Guernsey.		300 ,,	
12 × 8	1	Charnwood Granite Company, Loughborough.	Granite.	55 ,,	
15 × 10	1			75 ,,	Road metal
20 × 10	1			100 ,,	
20 × 10	2	Shap Granite Co., Shap.		200 ,,	
30 × 13	1	Ceiriog Granite Co., Chirk.		175 ,,	
20 × 10	1			100 ,,	
24 × 13	2	Lunedale Whinstone Co., Middleton-in-Teesdale.	Whinstone	300 ,,	
Various	40	Indian Government.	?	?	Road metal & concrete
15 × 10	1	Curragh Camp.	?	?	
15 × 8	1				
20 × 10	4	T. A. Walker, Esq. Buenos Ayres. Harbour Works.	Granite.	400 ,,	Concrete

A cubic yard of broken road metal, when properly spread, will cover an area of about 20 yards of roadway, and has the following weight :—

	Tons.	Cwts.	Qrs.
Cubic yards broken granite equals ...	1	3	2
,, ,, Flint, equals	1	1	3
,, ,, Pit gravel, equals	1	4	3
,, ,, Limestone, equals	1	2	0

The smaller the stone is broken the heavier a cubic yard will weigh, as the percentage of vacant space between each stone will be less. It has been found by experiment, however, that 55 per cent. of ordinary broken stone road metal is solid, so that the weight of a cubic yard of it can be easily ascertained as follows :—

Multiply the weight of a cubic foot of any stone by 27, and then multiply this by 0·55 ; the result will be the weight of a cubic yard of broken road metal.

Having decided the important point as to the metal which is to be used for the road, it is necessary to decide whether footpaths are to be provided, and if so, their width, height above roadway, and materials with which they are to be formed, and whether paved channels, gutters, or water tables (as they are called) are necessary ; and also the methods to be adopted for getting rid of the water falling upon the roadway and paths. Wherever a footpath is required, some description of edging or kerb is necessary in order to raise it above the level of the roadway, to retain the materials of which it is made, and to keep it from damage by vehicular traffic.

For country roads a border of turves on edge is sufficient. In some districts planks or old railway sleepers, set on edge and secured by wooden pins, are used.

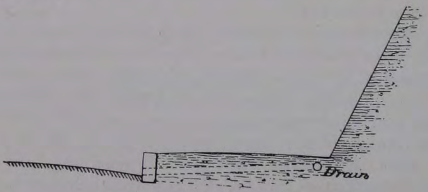
In France an L shaped cast iron kerb has sometimes been used.

Kerbs made of artificial stone or concrete are frequently made in this country, but where there is much traffic, a hard stone kerb, such as granite, should be used, as it is the only material which will stand the severe blows and abrasive action of the wheels of passing traffic, as well as exposure to great changes of temperature.

The dimensions of kerbstones vary in different localities, and their width should be somewhat regulated by the width of the footpath. As a rule, they should not be narrower than four inches or shallower than nine inches ; any kerbstone of less depth than this is likely to turn over on its bed. It should be in lengths of not less than three feet, and be hammer-dressed on top; and for five inches on the road side and three inches on the path side, a drafted edge about one inch in depth adds greatly to its appearance.

The kerbstone requires to be bedded in concrete or on clean gravel, and be beaten into place with heavy setting mauls, weighing about 50lbs., and be well packed or rammed with an iron bar on each side to prevent its shifting. To set heavy kerb correctly as to level and alignment requires considerable skill and practice.

The fall of the footpath between heel and kerb depends upon the material with which it is proposed to pave it. Gravelled paths should have an inclination of about half an inch to the foot (1 in 24), whereas paved footpaths may be reduced to $\frac{1}{8}$-inch to a foot (1 in 96), or $\frac{1}{4}$-inch to a foot (1 in 48). The foundation should be well drained, and where abutting on a hillside or retaining wall the path should be drained thus :—



The foundation may be made with large stones or coarse gravel, upon which may be laid three inches of fine gravel well rolled. Time will not permit me to do more than to give a list of some of the materials which are commonly used for the pavement of footpaths in this and other countries :—

1. Gravel, fine stone chippings, clinkers or ashes, and other similar materials.

2. Tar pavement, consisting of gravel, tar, chalk, and other similar preparations.

3. Natural asphalte, either mastic or compressed.

4. Slabs or flags of natural stone about two inches in thickness, such as the York stones, sandstones, Caithness, limestones, slates, etc., etc.

5. Concrete, or artificial stone, laid either in slabs about two inches thick, or in mass, or "monolith."

6. Bricks or tiles of different thicknesses and shapes laid either flat or on edge.

The channel or water table of your road, if paved, gives it great protection. Without some description of paved channel the haunches of a road may become seriously damaged during heavy rainfall, and if the path is kerbed it may eventually become undermined; a paved channel also acts as a "wheeler" for vehicles, and undoubtedly adds greatly to the appearance of a road.

Channels may be paved with concrete or stone. If the latter, it may be in flat slabs or in setts bedded solidly, and grouted with lime or cement grouting or bitumen. The channel should show from three to six inches of kerb, and have a longitudinal gradient of not less than 1 in 250. Where the road is of less gradient than this (or perfectly level), the necessary fall in the channel can be effected by showing less kerb at the top of the gradient and more at the foot near the gullies.

These gullies, protected by gratings where necessary, must be placed along the lines of channel at such intervals as may be found necessary, and be connected with the sewer or ditches which are intended to carry off the water.

A great number of different forms of gully have been introduced from time to time; the points to be considered in their design may be summarised as follows:—

1. To be of sufficient area to carry off all water.
2. Not to be easily choked by leaves or *débris.*
3. To have a sufficient pit to retain all sand and road detritus, to prevent it being carried into the pipe or sewer.
4. This pit to be easily accessible to facilitate cleansing.
5. If the pit is connected with a sewer it must be trapped.
6. The cover of the gully to offer no obstruction to the traffic.

All the foregoing points having been decided, it is necessary, before proceeding with the work, to prepare a specification, and I will, therefore, give you a specimen specification for the construction of a modern, macadamised roadway.

Heads for a Specification.

The ground to be excavated to the required depths and to the proper contour and grade of the proposed roadway, and thoroughly and repeatedly rolled until perfectly solid and hard. Any deficiencies which appear after this rolling to be filled with good material and again rolled until the whole is compact and firm. On the road-bed thus formed and compacted, a layer of stone, six inches in depth, is to be set by hand, so as to form a close, firm pavement. The stones are to be set with their largest side down, in parallel lines across the street, breaking joint as much as is practicable. The width of the upper part of the stone not to be more than eight inches or less than six inches. No stone to exceed 15 inches in length. After being set closely together, the stones are to be firmly wedged together with a bar. Projecting portions are then to be broken off and the interstices filled in with spall or chips firmly wedged in with light hammers. The whole is to be thoroughly rammed and settled into place, and any irregularities of surface broken off.

Upon this bottom or foundation thus prepared, a layer of broken stone, four inches in depth, is to be laid and thoroughly well rolled without any addition of binding, though a little water may be sprinkled on it to facilitate the operation. The stones of this layer must have been broken so as to pass all ways through a $2\frac{1}{2}$-inch ring. Upon this layer must be evenly spread a layer of stone, broken to pass through a $1\frac{1}{2}$-inch ring for a depth of about two inches, and this must again be thoroughly rolled. Finally, a coating, about half-an-inch in thickness, of fine screenings or siftings is to be spread, and the rolling must be continued, working the roller gradually backwards and forwards from the gutter to the crown, with an occasional light watering, until the cross section is exact to the proper contour of the road, all interstices filled in, the roadway firmly compacted and solid, and ready for traffic after a few days' drying.

In setting out a road, the dumpy level, theodolite, ranging rods, and chains are necessary. The line is first carefully staked out and all the levels given, after which anyone who is skilled with the use of "boning rods" can keep a check on the work of the men.

I will not enter into any detail or description of this part of the work, as ocular demonstration on the ground is the only clear way in which such information can be imparted, and doubtless you are all well able to use the instruments I have mentioned, and setting out work of any description is only acquired by practice on the ground ; I will, therefore, pass on to make a few remarks upon the maintenance of a road after it has been constructed.

In former years sufficient importance was not given to this question of maintenance, and many a good road was ruined from want of care, and the application of a "stitch in time."

It used to be considered that almost anyone was good enough to take charge of a road after its construction, and the result was not successful.

I will not weary you with describing the methods that used to obtain in this country for the repairs of roads, they were left in the hands of parish surveyors who had no practical or technical experience, and even now there are many miles of roadways in this country which are in a disgraceful condition owing to the mismanagement or ignorance of those who are responsible for their maintenance.

Time will not permit me to enter into many details upon this part of my subject, so I will content myself with referring you to Mr. Codrington's excellent book upon *The Maintenance of Macadamised Roads*, published by Spon, of 125, Strand, and many pamphlets which have been issued from time to time, some of which no doubt you have seen, especially that by Mr. W. H. Wheeler, which was written at the request of the Cyclists' Union, a body of gentlemen who are well able to speak as to the goodness or reverse of nearly all the roads throughout this country.

In France, the maintenance of the roads is managed on so excellent a system that a description of the method there employed will, I think, be of interest and use to you.

For many years past the roads in each department (equivalent to our county) have been under the supervision of the Engineers of the Ponts et Chaussées. The main roads are divided into two classes, viz., *National Roads*, which pass through two or more departments, and connect large cities ; and *Departmental Roads*, which connect the principal cities of the department.

The local roads are divided into three classes :—the important local roads ; the ordinary local roads ; and the bye-roads. Each road is thus classed according to its use and the amount of traffic it bears as verified by actual observation.

Some of the national roads are paved like streets, others are macadamised.

The local roads are generally gravelled.

The Engineer-in-Chief has charge of all the roads in his department, and he has under him a staff of assistant engineers, who, in their turn, have under them superintendents and overseers, each in charge of certain lengths of road, and with a force of labourers, and the necessary plant and tools for keeping all the roads in good order.

The fundamental principles, as laid down in the "Manual of Instructions," which is issued from the head office, are :—

First, the removal of the daily wear of the road, whether mud or dust.

Secondly, the prompt replacement of this wear with new materials.

Each road is divided into sections called "cantons," varying from 100 yards where the traffic is heavy to a mile or more where it is light. Each canton is under the charge of a "cantonnier," a workman who is responsible for the condition of the road in his canton. He works in summer from five to seven, and in winter from sunrise to sunset.

His duties are as follows :—

(1). To keep the gutters and channels clear so that all water may run off freely.

(2). To scrape off the mud, or sweep off the dust, as the case may be, so as to keep his road always clean.

(3). To pick up all loose stones, break them, and stack them in heaps at the sides of the roads, so as to be ready for repairing ruts and holes.

(4). When it snows, to clear it off so far as possible, and to break any ice that forms on the road or in the gutters.

(5). To take care of the trees bordering the road.

(6). To keep the milestones and direction posts in order.

He is provided with the following tools in order to execute this work, viz., wheelbarrow, shovels, pickaxes, scrapers, rakes, brooms, crowbar, hammer, and measuring tape.

Six adjacent cantonniers form a brigade under a foreman known as a "cantonnier chef." Several brigades are under a "conducteur," or superintendent, who may have charge of 40 or 50 miles of road, which he has to inspect and report on in detail twice a month to an engineer, who has charge of several sections, including all the roads in an "arrondisement" or parish, and he has to inspect every part of his roads once in three months, and report to the "Ingénieur-en-chef" who has charge of all the roads in his department or province, of which there are in France eighty-seven.

For special work, or heavy falls of snow, extra men are, of course, engaged.

Such is the method employed in France, and it might well be followed in this country, for, with the exception of Italy, no such splendid roads can be found in any quarter of the globe.

Before closing this point of my lecture on road making, a few words upon the subject of rolling the surface of the roadway are necessary.

In the early days of macadamised roadways it was the practice to allow the traffic to consolidate the newly laid metal, the grinding action of the wheels, and the blows of the horses' hoofs, breaking off small particles or chippings from the stones, and thus forming a binding with which the road eventually becomes made.

This has, however, been found to be a wasteful, as well as a cruel practice.

Horses suffer when travelling on newly metalled, unrolled roads.

The wheels of vehicles are injured by the grinding action.

The traction required on so rough a road is very considerable.

The loss of stone is great.

The effect of rounding off the edges of the stones is very detrimental.

Altogether the practice was not successful, and rolling was introduced. At first horse-rollers, and then steam-rollers, were used. The use of horse-rollers for road making is not satisfactory. They are expensive to use, as a large team of horses and many attendants are necessary. The horses' feet, in pulling the roller, do as much harm as the roller does good, and they are clumsy and difficult of manipulation.

Steam-rollers were consequently introduced about 25 years ago, and like many other inventions which are evolutions from a lower type, the first steam-roller was an ordinary horse-roller drawn by a traction engine.

From this first attempt the finished and perfected steam road-roller has emanated from the workshops of Messrs. Aveling and Porter, the well-known steam road-roller makers of the neighbouring town of Rochester, and of whose handicraft I now draw your attention to certain diagrams and photographs which illustrate this part of my lecture.

The following points in connection with this subject will be of use to you :—

(1). Rollers must not be too heavy, or otherwise they may injure the foundation of your road, or crush the stones of which it is made, or break gas or water-pipes, or even fall into a cellar, or break into a culvert. From 10 to 15 tons has been proved to be a good margin of weight.

(2). Do not have the rollers too wide, or else they will press unevenly on the contour of your road.

(3). Roll the haunches of the road always *before* you roll the centre.

(4). Do not attempt to consolidate the metal without the use of "binding," such as gravel, sand, chippings, or road drift, and a certain quantity of water.

(5). The following should be the method employed in repairing a road with the steam-roller :—

Lift the existing metal with pick-axes for a depth of from two to three inches ; then spread the new metal evenly about three inches in depth ; then roll about twice whilst dry to get a settlement ; then spread the binding evenly over the surface, and sprinkle sufficient water to prevent the binding or metal adhering to the roller ; then roll till the road is right. A steam-roller will put in order from 500 to 3,000 square yards of road surface in 10 hours, according to gradients, class of stone, attention, &c. Keep men constantly sweeping lightly the surface of the road whilst rolling. Give the road a day or two to dry before letting the traffic on it.

Before proceeding to a description of paved roadways, a few words upon what are known as tar macadam roadways will be of interest.

The road bed and foundation are prepared in a similar manner to that required for ordinary macadamised roadways.

The macadam, or metal, broken to the usual size, must be heated so as to drive off all moisture out of the stone, either by spreading the metal on hot plates, or stacking it with small coal intermixed, and letting the heap burn itself out.

Ordinary coal-tar is then heated and poured on to the heated road metal, which is turned over and over until the tar is thoroughly incorporated with the stone. When cold, the tarred metal is taken to the roadway and spread upon the foundation in the ordinary way, and well rolled to the proper contour. A finishing coat of smaller stone or chippings, prepared with tar in a similar manner, is then spread about two inches in thickness, and well rolled to the finished contour of the road.

This class of roadway requires some care in its construction, as the quality of the tar often varies, and it is also essential that every particle of stone should be thoroughly coated and slightly impregnated with the tar.

When, however, care is taken, an excellent roadway for light traffic results.

Such a road, however, requires careful watching and attention after construction, and when the crust is worn through it soon goes to pieces.

Facing the roadway with a coating of tar and sand about once every two years helps greatly, however, to maintain it.

I will now pass on to say a few words on the construction of what are known as paved roads.

When the traffic along the road is either very excessive or very heavy in its character, it becomes exceedingly difficult and expensive to maintain the surface of that road as a macadamised roadway, and consequently a more durable surface has to be instituted.

The following is a list of those materials which are known at the present time as suitable for the purpose of paving roadways, viz. :—

(1). Stone blocks, setts, or cubes.

(2). Asphalte, compressed or mastic.

(3). Wooden blocks, plain or chemically treated.

(4). Bricks.

(5). Indiarubber.

It is unnecessary to trouble you with the history of stone-paved roadways, how they have grown out of the Roman or archaic methods to the present state of perfection, and how even now road engineers are somewhat divided as to the best details for their construction. It will, I think, suffice to say that as with the macadamised roads, so with all paved streets, the foundation is of the utmost importance ; and where an expensive, stone-paved surface is to be given to a roadway, no expense or trouble should be spared in securing the best possible foundation.

Time will not permit me to describe to you the different methods of providing this foundation ; how in some districts rolled clinkers or ashes are used ; in others macadam, well matured and rolled ; in others concrete of lias lime or cement ; but I will pass on to describe to you how this work is carried out in Liverpool, where, under the heaviest traffic in the world, the streets are paved with the best granite, setts or cubes, and present the appearance of uniform surface, free from ruts or depressions, and carry a traffic of 360,000 tons per yard in width per annum, with a minimum of wear and expense for maintenance.

The method of construction is as follows :—

The ground having been excavated, thoroughly consolidated, and properly graded to the requisite depth and shape, a layer of broken stone is spread evenly over the surface and thoroughly wetted. A stratum of fine concrete is then laid on this, about two inches in depth, composed as follows:—one part by measure of cement, and five parts fine gravel, thoroughly mixed and incorporated together, when dry, and then turned over at least three times, when slightly wetted. Upon this stratum a second layer of stone is added, which is then beaten down with a heavy flat beater. Other layers of concrete and stone are added till the foundation is six inches to eight inches in thickness. Constructed in this manner it forms a strong, flat-arched wall of random stone or betôn, and is more powerful to resist compression than ordinary concrete.

On the foundation thus prepared, and allowed several days to get thoroughly set, is spread a layer of about half-an-inch in thickness of fine gravel, on which are laid granite or syenite setts in regular straight and properly bonded courses with straight joints. Setts, cubes, and blocks, vary in size as follows, according to the class of traffic they have to bear, the following being some of the sizes used in Liverpool :—

Setts	... ...	$6\frac{1}{4}''$	×	$3\frac{1}{4}''$	×	5″ to 7″ long
,,	.. ..	$7\frac{1}{4}$	×	$3\frac{1}{4}$	×	5″ to 7″ ,,
Cubes	... ...	$3\frac{3}{4}$	×	$3\frac{3}{4}$	×	$3\frac{3}{4}''$
,,	... ...	4	×	4	×	4
Blocks	... ...	4″	×	4	×	6″ deep
,,	... ...	$3\frac{1}{4}$	×	$3\frac{1}{4}$	×	$6\frac{1}{4}$

The joints between the setts are then filled with hard, clean, dry shingle, the setts being rammed with heavy setting mauls, and additional shingle added as it shakes down into the joints until all the joints are full of shingle. Hot coal pitch and creosote oil in proportion of three to one are then run into the joints, until they are quite full and overflowing. The pavement is then covered with half-an-inch of sharp gravel and is ready for the traffic.

The objections that have been raised to stone-paved streets are that—

(1). They are noisy.

(2). They are slippery.

(3). They wear out horses' legs and carriage wheels.

These objections have to some extent been met in Liverpool.

The bitumen joint and less width between the setts have diminished the noise, and the narrow setts give a better foot-hold to the horse; the hoof has but a little way to slip before being assisted by a joint.

In designing a stone-paved roadway the following points must be considered :—

(1). Foundation to be the firmest possible.

(2). Stone setts to be granite or syenite.

(3). Width of setts to be not more than $3\frac{1}{4}$ inches.

(4). Joints to be as close as possible.

(*a*). To deaden noise.

(*b*). To give strength.

(*c*). To prevent stones turning over.

(*d*). To prevent the edges or arrises of setts wearing off.

(5). Joints to be run with bituminous composition, not cement grouting.

(6). Select stones that are hard, but which will not wear slippery.

(7). Be careful that your setts are all of equal width and depth, and not more than three inches variation in length.

It was in order to meet some of the objections to stone-paved streets (especially that of noise) that wood blocks were proposed as a substitute, but although the first trial of this material was made in London upwards of fifty years ago, it is only within recent years that wood pavement has been scientifically and systematically laid in the metropolis and some of our provincial towns.

The advantages of wood pavement may be summarised as follows :—

(1). It is quiet. Wheels make scarcely any noise upon it, and there is no clatter of horses' shoes.

(2). It is safer than either granite or asphalte pavement for horses travelling on it, and if a horse falls he can rise more easily.

(3). The traction upon it, though slightly in excess of asphalte, is compensated for by better foothold.

(4). It is easily kept cleansed.

As with stone-paved roadways, so with wood-paved roadways, the foundation must be made to carry the weight of the traffic. Concrete makes the best foundation, and as the wood blocks can be made much more of an even size, one with the other, than stone setts, the concrete must be finished smooth on the surface.

Very little sand is necessary as a bed, and the wood blocks may be laid on the finished surface of the concrete, though this is somewhat objectionable on account of jarring.

In some cases the blocks are laid close together without any joints, but the following may be taken as a good description of a well-made modern type of wood pavement.

Lay the blocks on the concrete foundation in transverse courses with their butt joints in contact, and with a $\frac{3}{8}$-inch joint between the courses; this is maintained by means of three iron studs driven into the face of each block. Sometimes this is done with laths or raps, which are afterwards withdrawn. With a little practice, however, a paviour can set the blocks the proper distance apart without either studs or raps, thus saving expense. The joints are then run with cement grout (three of sand to one of cement); after this has set for about seven days the whole surface of the pavement is covered with sharp gravel, and the traffic is turned on. The stones of the gravel are crushed and driven into the road by the traffic, which protects the face of the road.

As wood swells very much when wet, an expansion joint must be left between the blocks and the kerb filled with clay; each of these joints should be at least one inch in width for a 30-foot roadway.

The depth of blocks now used is generally five inches, breadth three inches, by nine inches in length, and yellow deal is the timber selected.

Some hard woods, such as beech and oak, have been used, but experience shows that hard wood causes a rumbling or trembling to vehicles running on it, and the blocks seem to wear unevenly, whereas the softer woods wear more evenly and are pleasanter to travel on.

Jarrah wood, an Australian wood, is now, however, being used for the purpose, and has been down nearly three years in Westminster Bridge Road with good results; it is a hard wood, with a longer life than yellow deal—which only lasts about eight years under conditions where a granite paved roadway would last 50 or 60 years.

One great objection to wood as a pavement is its capacity for absorbing moisture, and this is apt to render it insanitary unless most carefully cleansed and scavengered, as the horse dung and urine are apt to saturate its fibres with very unpleasant, if not dangerous, results.

In order to meet this objection the blocks have been treated with creosote, that is to say, the wood has had the air expelled from its cells and fibres, and then creosote has been forced into every particle of it, with very good results if properly carried out, and not less than 16lbs. of the creosote oil forced into each cubic foot of wood. This process has not, however, found much favour with engineers, as unless each block can be examined before being so treated, it is impossible afterwards to detect inferior or sappy wood, which, if existing, very soon shows itself by the rapid deterioration of the pavement.

Great care must be exercised whilst any work of wood pavement is in progress to see that sappy wood is rejected, and for this purpose it is well to have a skilled foreman on the job, who should have power under the specification to split into two pieces any blocks which he rejects as unfitted for the purpose, owing to their sappy, knotty, or otherwise imperfect condition.

Asphalte.—Were it not for its slipperiness, asphalte would undoubtedly be the universal pavement of modern times. It has so many advantages over other descriptions of pavements, notably the following :—

Durability.—Take for instance Cheapside, where, under a most trying traffic, a life of at least 15 years is secured.

Appearance.—It is uniform in colour (which is a sober grey), and has no joints.

Cleanliness.—No pavement can compete with it for cleanliness ; foot-passengers can walk in the roadway just as conveniently as on the paths.

Healthiness.—No pavement is so thoroughly impervious to moisture, hence it is the healthiest, for not only can the organic matter be quite removed from its surface, but no moisture can soak through to the subsoil, and thus basements and cellars are kept dry.

Noiselessness.—With the exception of a slight clatter from the iron-shod horses' hoofs, there is no noise of traffic on asphalte.

Economy.—Taking its life into consideration, asphalte is the cheapest pavement that can be laid.

Ease of Traction.—No known pavement offers so little resistance to traction as asphalte.

With all these advantages, it seems a pity that it should be so objectionable on the ground of slipperiness, especially in this climate, where it is seen at its worst on a moist day, when a greasy, sticky mud appears on its surface, and then the horses may be seen sliding and slipping in every direction.

I believe that in Berlin, where there are many miles of streets laid with asphalte, this objection is being somewhat overcome by the fact that the horses and drivers are getting more used to it, and by keeping the asphalte scrupulously clean. This is a most important point. If perfectly dry and clean, or thoroughly wet and clean, asphalte is by no means a slippery pavement. As a proof of this, showing what greater care in this direction will effect, it appears that in the year 1885, in Berlin, 4,403 horses fell on 400,000 square yards of asphalte ; in the year 1887 there were only 2,456 falls on 490,000 square yards of this pavement; and the large horse owners of this city petitioned that more streets should be laid with this material, as the ease of traction was so great a saving to them.

Asphalte, as you are probably aware, is a natural lime-stone rock, intimately combined and impregnated with bitumen (carbon, hydrogen, and oxygen). It is principally derived from Val de Travers, Seyssel, Auvergne, Lobsann, and Limmer. It is used in two manners: melted or *mastic*; and ground into powder heated and rolled, or *compressed*. Compressed asphalte is more generally used for road making; mastic for footpaths or streets where there is but little traffic.

I will content myself, therefore, with giving you a short description of a roadway formed of compressed asphalte.

The foundation must be made, as in the case of stone or wood pavements, of the best and hardest concrete, the top surface of which must be floated up to a smooth and perfect contour.

The asphalte rock must be crushed in a stone-crusher, such as I have already described to you, and then pulverised in a "disintegrator," until it is reduced to a fine powder, so that it will pass through a sieve of 0·1 square inch mesh. This powder is then heated up to between 240 degrees and 250 degrees, Fahrenheit, in cylinders, which are kept revolving so that each particle may become heated without burning, and still remain separate from its neighbour. The powder is then carefully transported to the street where it is to be laid in iron-covered carts, in order that it may not lose more than 20 degrees of heat during transit.

The powder must then be spread upon the concrete in an even layer, about $2\frac{2}{5}$ inches in depth, and be carefully raked so as to have regularity of depth and surface. Great care must be exercised to ensure that the face of the concrete shall be perfectly dry before the asphalte powder is laid on it, otherwise the moisture is sucked up into the powder, turned into steam, which tries to escape through the heated powder, and fissures are formed, which may not appear until after the roadway has been made some little time. Such a result will lead to the disintegration of the mass, with the consequence that the material breaks up.

After the powder has been laid and raked, it must be well rammed with iron punners, weighing about 10lb., heated so as to prevent the adhesion of the powder. This ramming must be done lightly at first so to ensure equality of thickness, and afterwards augmented to heavy blows. After being thus rammed, the pavement must be smoothed by a suitable curved hot iron tool, after which it is again vigorously rammed and rolled until it is quite cool. The roller must weigh about 1,100lbs.

Within a few hours of the completed compression of the asphalte, the road is ready for traffic, a light sprinkling of sand being first applied to its surface.

Bricks.—Brick pavements have not been largely used in this country. They might be adopted instead of stone or wood blocks in cases where they were easily procurable, and where neither of the latter could be had.

They should be laid on edge, with their joints grouted in cement or bitumen, on a proper concrete foundation. As, however, their edges or arrises are somewhat brittle, it might be better to lay them close together without joint.

There is danger, however, that such a pavement would wear unevenly owing to the varying quality of the bricks, and this has been found to be the case where they have been used on footpaths, notably at Brighton, where this class of foot pavement is rapidly dying out in favour of flags, asphalte, or concrete.

In San Francisco a new street pavement has been tried; it is called "hydro-carbolised brick," and consists of bricks of a soft porous nature boiled in coal tar, which, it is *said*, renders them tough and hard. On the prepared road bed a layer of bricks is placed flat-wise, each brick being dipped in boiling tar as it is laid. This is overlaid by a second course of prepared bricks, placed close together edgeways. The interstices are then filled with boiling tar, and the whole covered with a thin layer of screened gravel.* I cannot recommend this form of pavement.

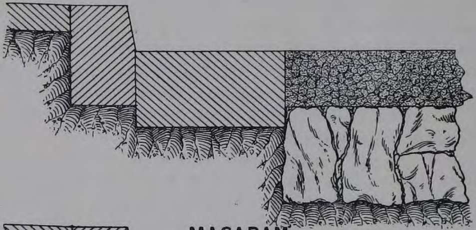
Indiarubber in large sheets, about one inch in thickness, has recently been introduced in Hanover as a material with which to pave roadways, but I have not seen it, nor can I give you any particulars of the manner in which it is laid. It is said to be as durable as granite, perfectly noiseless, and unaffected by either heat or cold, and that it is not in the least slippery, all of which is possible, but it must be very expensive.

There is a small sample of indiarubber pavement to be seen at the entrance to the L. & N.W. Euston Railway Station. These sheets of indiarubber are held down at their sides upon a concrete foundation

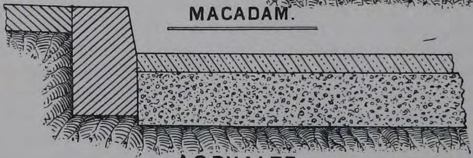
* *Journal of the Society of Arts*, Vol. XXII., page 123.

by strips of iron, which clasp the edges tight on each side. The effect of these small pieces of indiarubber pavement is excellent, and if it could be applied in a more general manner at a price which was not prohibitive, perhaps the road pavement of the future is to be found in this material.

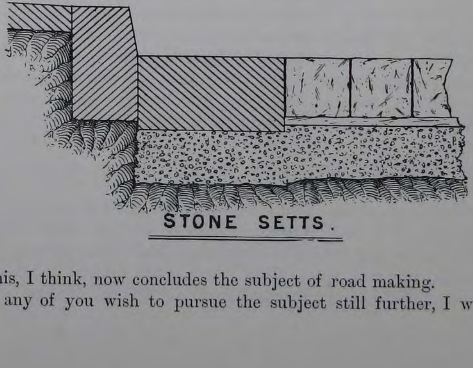
The following diagram shows some sections of various street pavements :—



MACADAM.



ASPHALTE



STONE SETTS.

This, I think, now concludes the subject of road making.

If any of you wish to pursue the subject still further, I would beg to suggest the following books to your notice, which deal with the various branches of the work more in detail than could be given in this lecture :—

Pavements and Roads (reprinted from the *Engineering and Building Record* of New York), by E. G. Love ; sold at 92, Fleet Street, E.C. (R. I. Bush). *The Maintenance of Macadamised Roads*, by Thomas Codrington ; Spon, 125, Strand. *Report on Steam Road Rolling*, by Frederick A. Paget ; Phœnix Printing Works, Doctor's Commons. *Repair of Main Roads*, by W. H. Wheeler ; Spon, 125, Strand. *Municipal and Sanitary Engineers' Handbook*, by H. Percy Boulnois ; Spon, 125, Strand. *Roads, Streets, and Pavements*, by Q. A. Gillmore ; published in America ; and *A Treatise on Roads*, by Sir Henry Parnell, published in 1833, and now out of print. And, of course, numerous valuable papers in different reports and transactions of societies and associations, which are not easily procurable.

In conclusion, let me thank you for the close attention you have given me. Your future careers will probably be of a warlike nature, but I know how often Royal Engineers are engaged in more pacific pursuits, and I trust they may some day find that the two lectures I have had the honour to give, may be of service to them.

(The lecture was accompanied by several diagrams, models, and samples of the various materials mentioned, which were explained during the course of the lecture).

APPENDIX A.

On the Valuation of Road Metal and Setts for Paving.

(*By* W. F. R. Stock, F.C.S., F.I.C., *Public Analyst for the County of Durham and the Borough of West Hartlepool*).

The subject which forms the title of the present communication is one that does not often, perhaps, come before any single investigator in its complete aspect. The problems which are involved in deciding upon the relative merits of different rocks for the construction and maintenance of different roadways are threefold in their nature, and for their solution make calls upon the analyst, the physicist, and the engineer. The writer has been unable to find any account of comparative experiments on road metal embracing the various points which he has found necessary to a thorough inquiry into the subject.

It is quite true that a good deal of useful work has been done, notably by Walker, Fairbairn, Mallett, and others, the first-named signalizing the thoroughness of his intention by laying down samples in the form of setts under actual street traffic, and determining the loss of weight and bulk after 17 months of exposure ; an experiment admirable in its way, but impossible of imitation where the question before the expert is one bearing upon the purchase or opening out of quarry property, and requiring an immediate answer.

Some ten years ago the attention of the writer was first attracted in the direction indicated, and it appeared to him that the salient features of such inquiry might be enumerated as follows :—

(1). The chemical analysis.

(2). The specific gravity.

(3). The porosity, or capacity for absorbing water.

(4). The crushing and breaking strains.

(5). The duration under abrasion.

(6). The nature of the surface retained under wear.

The last would apply to setts only.

Since that time opportunities have presented themselves for the application of these ideas, and the object of this paper is to show the bearing of the points thus laid down, and to give details of a method by which the duration value of road-making material can be obtained by a moderate expenditure of time and trouble, and, more important still, under constant conditions.

It will be convenient to take each of the six items separately, and in the order in which they appear above.

(1). *The Chemical Analysis.*—This should be of very complete character. Its main object, however, is to give the proportion of protoxide of iron, protoxide of manganese, bisulphide of iron, lime, magnesia, potash, and soda.

The first three constituents contribute to the destruction of rocks, by the absorption of oxygen ; the remainder, by their solution in carbonic acid, and probably some organic acids produced by the decomposition of excretal matters, always present upon roadways under traffic.

(2). *Specific Gravity.*—From this determination is deduced the relative weight of equal bulks of stone, or conversely, the relative bulks of equal weights.

It constitutes the factor for estimating the relative covering or spreading value.

(3). *Porosity, or Water-absorbing Capacity.*—This item is of considerable importance. There is, perhaps, no more potent rock disintegrator in nature than frost in the presence of water, and it may at once be accepted as a fact, that of two rocks which are to be exposed to frost, the one most absorbent of water will be the least reliable in wear.

(4). *Breaking and Crushing Strains.*—Although the knowledge of the resistance to gradually applied weight stresses appears to form part of every inquiry into the quality of road metal, the present writer has never been conscious of such knowledge possessing any definite value.

It is an elementary fact in mechanics that a body may bear enormous crushing force gradually applied, and yet be readily broken by a smart blow from a light hammer.

It may be said, without hesitation, that direct pressure or strain, as applied in a break-test machine, has no resemblance to quick blows from horses' hoofs, much less to grind or abrasion arising from wheel traffic.

Further, taking ascertained breaking and crushing strains as lying between $3\frac{1}{2}$ and 7 tons per square inch, it may be as safely said that no such strains are ever brought to bear upon any single inch of roadway in practice, not even during the passage of a 10-ton steam roller; the very nature of the foundation or core of a road makes such a supposition idle. These considerations have led the writer to look upon any statement of breaking or crushing strain in connection with the valuation of road metal as a mere conventionality.

What is really required is some test of easy application that shall show within reasonable time, and under constant conditions, what a rock will lose by the combined action of light blows and abrasion, and, at the same time, exhibit the nature of the face retained by the sample under wear, by the fifth and sixth tests already quoted.

To effect this, the writer has constructed a simple machine, which has already proved itself both convenient and efficient in use. The following is a brief description of the same:—A cast-iron cylinder is provided, of which the internal dimensions are—length, 12 inches; diameter, 6 inches. It is flanged at both ends, and fitted with two blank discs of $\frac{1}{2}$-inch plate-iron. Both flanges and blank discs are turned up in the lathe; they are secured together by six bolts;

a thin greased string serves as packing; the joints must be watertight. The cylinder is intended to be rotated end over end; it is, therefore, grasped in the middle by a strong clamp collar, which is furnished with nicely-centred, elongated trunnions, forming the axis around which it rotates. These trunnions run in bearings placed on the top of wooden uprights; these, in turn, are morticed firmly into a strong wooden base board. The whole of the frame is rigidly bound together by battens and strut bolts. The cylinder rotates between the uprights; one trunnion carries a pretty heavy fly wheel; the other a winch handle having a 10-inch throw. A stud on the axle actuates a revolution counter indicating to 100,000. This is placed in sight of the operator, and completes the machine.

(5). *The Duration Test.*—The rock to be tested is worked carefully into inch cubes, the faces of which must have a smooth finish; any skilled mason will undertake this. Nine of these cubes are dried in the water oven for two hours or so; they are carefully weighed; they are then placed in the cylinder of the test machine along with nine cubes of hardened steel of $\frac{8}{10}$ in face. A number of these cubes should be forged and hardened to their best.

Their faces must be smooth, their angles perfectly sharp, and they must scratch crown glass with ease. Forty ounces of distilled water are now added to the cubes in the cylinder; the disc or cover securely packed and bolted up. Since the dimensions of the cylinder already quoted give a nominal travel of one yard for every revolution, 1,760 turns will give a travel of one mile.

The writer has found that twice that distance will give a loss of from 7 to 12 per cent. on very hard material, and has, therefore, adopted 3,520 turns as standard.

The machine must be steadily worked at 40 revolutions per minute; no variation in this respect is permissible.

At the end of the run the stones are removed, washed in distilled or rain water, dried again in the water oven, and re-weighed.

The loss is calculated into a percentage.

The sixth test is got from the worn cubes.

For the information of the reader, it may be well to state that the duration test machine may be constructed at a cost of £5. The steel cubes cost from 8d. to 9d. each, and the rock cubes about 6d.; the steel cubes cannot be used twice over.

To give a comprehensive review of the results of such an inquiry as is embraced in the foregoing, the writer appends details of the examination of four specimens of rock recently tested by him.

Tabular Results of Examination of Samples of four Road Metals.

Nature of Determination.	No. 1. Granite.	No. 2. Granite.	Quartzose Slate.	Basalt.
Silica	72·52	67·57	62·97	51·22
Alumina and Titanic Acid ...	13·09	15·52	15·52	16·48
Peroxide of Iron	1·71	1·71	2·50	4·32
Protoxide of Iron	1·86	2·70	4·30	8·73
Protoxide of Manganese ...	·07	·17	·47	·16
Lime	1·47	1·47	1·97	8·33
Magnesia	1·74	2·24	2·58	4·42
Potash	1·42	1·38	1·31	1·25
Soda	3·25	3·64	3·40	2·55
Bisulphide of Iron	trace	trace	trace	·49
Carbonic Acid	·45	·50	·75	·19
Water	2·18	2·45	4·23	1·28
	99·76	99·35	100·00	99·42
Specific gravity	2·692	2·694	2·732	2·980
Weight of cube feet in lbs. ...	168·25	168·37	170·75	186·25
Porosity of Water Absorption...	·096	·070	·118	trace
Breaking Strain, tons, sq. inch	4·50	4·40	—	3·75
Crushing Strain, tons, sq. inch	5·75	7·00	—	7·00
Duration Test, loss weight p.c.	7·64	7·17	12·03	6·90
Duration Test, loss of vol. p.c.	7·63	7·11	11·98	7·03
Face retained under wear ...	Bold, rough	Fine, sharp	Smooth	Smoother than No. 2

PAPER V.

POWER OF GUNS AND ARMOURED DEFENCES,

AND

SHIPS *VERSUS* FORTS.

BY CAPTAIN C. ORDE BROWNE, LATE R.A.
(*Lecturer on Armour to R.A. College*).

THE three lectures given in December, 1890, on the powers of guns and the armour of forts and ships, necessarily dealt largely with matter contained in the lectures on the same subject two years ago. It is only desirable, therefore, to note such features as are new, chiefly the results of some important experiments which have been conducted abroad recently, and their bearing on the present condition of armour and its powers of resistance.

For many years past no competition has taken place between British compound, or steel-faced armour,* and foreign solid steel armour. The trials on the *Nettle* at Portsmouth were carried out with compound and solid steel plates, but the latter, as well as the former, were made in England, and it has been naturally questioned

* A competitive trial of English and foreign steel-faced plates took place in Denmark in November, 1889, but no solid steel plates figured in the trial.

whether the product of makers who are comparatively new to the work, represents solid steel as manufactured by Schneider. Consequently the two competitions which took place at Annapolis, in America, on September 18th and 23rd, and at Ochta, near St. Petersburg, on November 11th, last, in which Schneider's solid steel was tried in comparison with the compound armour of Cammell in the former trial, and the compound armour of Brown in the latter, as well as the English solid steel of Vickers, are of special importance at the present time. These trials were conducted on very similar programmes to that of our own *Nettle* tests, but were more severe. That of Annapolis is naturally the first to consider. *Figs.* 1, 2, 3, 4, 5 and 6 (*Plate* I.) show the fronts and backs of the plates after the conclusion of the trial. The plates were supplied by Messrs. Schneider and Cammell, and were each 8ft. by 6ft., and above 10·5 inches thick. The Cammell plate is said to have been 10·7 inches thick in one report, but its weight would probably be rather under than over that of the solid steel plates, which we may take at 9·4 tons. The Cammell plate was of steel-faced or compound armour, made on Wilson's process. Schneider submitted two "all steel" plates, one made of steel of his usual quality, the other of steel containing 5 per cent. of nickel. The plates were bolted on to a thick structure of wood, consisting of three layers of baulks one foot thick, strongly strutted at the back, so that it was a firm but soft support, such as would favour perforation rather than fracture. On September 18th four rounds were fired at each plate, each with a 6-inch forged steel Howitzer projectile, weighing 100lb., with a velocity of about 2,073 feet per second, and a calculated perforation equal to 13·20 inches of iron, or 10·56 inches of steel; or supposing the plates to yield by fracture instead of being perforated, the energy per ton of plate would be 34·4 foot-tons for each round. The four rounds thus fired at each plate were delivered near the corners. On September 23rd one round with 8-inch co-forged steel projectile, by Firth on Firminy's system, was delivered on the centre of the plate, which would have 14·72 inches perforation of iron, 11·78 perforation of steel, and 530·2 foot-tons energy per ton of plate. This naturally perforated the 10·5 inch plates in every instance, being broken up in the backing in the case of both of the Schneider plates, and passing entirely through the backing unbroken in the case of the steel-faced plate. The 6-inch projectiles last fired had also passed through the steel-faced plate and backing, while all had been stopped by the steel plates. The steel-faced plate had suffered from its face breaking away (see *Fig.* 1), the Schneider all steel plate had been broken into four pieces through the points of impact in an "x" shaped tear (see *Figs.* 2 and 5). The nickel steel plate had held together wonderfully well. Before commenting on this trial it is well to give the facts of the Russian competition, so as to deal with the whole question.

*The Russian trial took place at the Polygon at Ochta, near St. Petersburg, on Tuesday, November 11th last, under Vice-Admiral Kaznakoff, Director of Naval Artillery, and Rear-Admiral Kuprianoff, President of the Test Committee. The firing commenced soon after half-past nine in the morning. During the night the weather—previously mild—had become cold, and there was a sufficiently sharp frost to enable the soft mud to bear walking on. The programme was as follows:—Three plates, each 8ft. by 8ft. by 10in. thick, to be tested each by five rounds fired from 6-inch Obuchoff breechloading gun 35 calibres long, discharging forged steel projectiles, made by the assistance and direction of Holtzer's men. The weight of each projectile was 99lb. Russian, equal to 89·38lb. English. The length was 40·5 cm., or 16in., the head being of the usual ogival form, apparently struck with a radius of about two diameters. The first two rounds fired were intended to be with a velocity of about 1,980ft. per second; and, as a matter of fact, were fired with an average striking velocity of 1983·9ft. The last three were to be fired at 2,080ft., and actually their striking velocity averaged 2079·9ft. The average striking energy was therefore 2,414 foot-tons for each of the first two rounds, with a calculated perforation of 11·93in. of iron, or 9·54in. of steel or steel-faced armour, and for each of the three last rounds a striking energy of 2,682 foot-tons, and a perforation of 12·50in. of iron and 10·00in. of steel or steel-faced armour. So much for perforation. As regards work done by shattering, the steel plates may probably have weighed about 11·7 tons each, taking the metal to weigh 0·22 tons per cubic foot. Brown's compound plate actually weighed 11 tons 12cwt. 3qrs. 14lb., or 11·644 tons, though slightly thicker than the steel plates. Taking the weight of each plate at 11·7 tons, the shock per ton of each of the first two rounds would be 206·3 foot-tons, and of the last 229·2 foot-tons, the total of the five amounting to 1100·2 foot-tons per ton of plate. The range was about 130 yards, which

* The notes of this experiment were made by the lecturer on the ground, he having attended this trial. The figures are taken from a report he wrote in the *Engineer*.

was enough to insure steadiness and a direct hit. Next, with regard to the plates and their erection. Brown's plate was made on Ellis's patent in the usual manner. It was held up by eight bolts.

Schneider's plate was presumably hammered and oil hardened in its face on his usual system. The analysis of fragments picked up show it to contain about 3 per cent. of nickel. This plate was held up by twelve bolts.

The Vickers plate was of solid steel, rolled and hydraulic pressed, but not hammered or hardened by oil. The original face had been removed in finishing. Like the Schneider shield, this one was held up by twelve bolts, the compound differing, as noticed above, by having only eight bolts. Each plate was bolted to 12in. timbers of pine, backed by an iron skin, made up of three thicknesses of thin plate iron, the whole being supported by six heavy iron brackets. The backing is thus firm, but not hard, as in the case of Annapolis, being calculated to favour perforation to the fullest extent, for the soft pine would be very little hindrance to the forcing back of the moulds torn and bent back by the shot, while it would form a fair cushion against fracture of bolts and racking.

Figs. 7, 8 and 9 (*Plate* II.) show the fronts of the Brown, Schneider, and Vickers' plates respectively, after receiving the first rounds laid down in the programme. It appears that there were only ten projectiles passed as thoroughly good, consequently nine of these were reserved for the three last rounds at each plate, which were fired with the higher velocity, the two first rounds being with projectiles which were rather softer. This explains the fact that the projectile fired in the first two rounds set up more than those fired subsequently with a higher velocity.

As to the effect on the plates; the through steel resisted perforation much better than the compound, the three projectiles fired at the higher velocity completely perforating the compound plate and backing, and passing on intact. The penetration in the Vickers plate was slightly deeper than in Schneider's, but in no case did the projectile do more than get four inches of its point through into the backing. As regards racking or shattering effect, the Schneider suffered most.

Figs. 10, 11 and 12 (*Plate* II.) show the backs of the plates being taken from photographs made on the ground by the Russian Government after the plates were dismounted. The compound Brown plate has more "through fracture" than is usual, but its face plate has adhered well, and it may be observed that there is no tendency for the cracks to run to the bolts. The Vickers plate has come off best as regards shattering, requiring no frame to hold it up. The Schneider plate has stopped the projectiles most completely, so that the supporting structure would not have suffered, which would be important in the case of a ship's side whenever repairs should be made and broken plate replaced.

The analysis of the results of the Annapolis and Ochta trials is a little difficult, owing to the circumstance that the nickel and plain steel plates stood in opposite relation to each other in the two trials, that is to say, at Annapolis the nickel plate was the softer, resisting penetration less well, but holding together much better than the plain all steel plates, while at Ochta, the Vickers all steel was softer and resisted fracture much better than the Schneider plate which contained three per cent. of nickel. The natural conclusion to be drawn from this is to rather throw doubt on the value of nickel.* In both cases the English compound plate was perforated much more easily than the all steel plates. One Russian Kolprino plate, at all events, appears to have behaved very well indeed, but it is impossible to speak accurately as to its powers because the quality of the projectiles are not known. It seems, however, that the Kolprino plate shown in *Fig.* 13 (*Plate* II.) had resisted successfully eight blows, two of which were with 8-inch and six with 6-inch projectiles, three of which were reported to have had 2,140 feet velocity. The 8-inch shot were fired at a comparatively low velocity, and most, if not all, the projectiles were softer and inferior to those fired in the competition. Making all allowance for this, however, the plate must have been a very good one. To return to the competitive trials under conditions which are well-known; both at Annapolis and at Ochta the compound plates were badly beaten. No naval officer could prefer a plate which might allow the entrance of projectiles into a ship to one which stopped them. Is this because the compound system is altogether bad? Or can it be accounted for by faults which can be obviated? It is suggested that the latter is the explanation. When steel plates first displayed this great power to stop projectiles at the expense of fracture of the plates, our naval authorities took up the question, and then decided that while they would welcome any additional hardness and resistance to perforation, it must not be obtained at the cost of "through fracture."

* The fact that Schneider expects good results from nickel after many trials is, of course, in its favour. It is under trial by our own authorities.

The words reported to be said were that they would not have the armour stripping off the sides of the ships. Thus compound armour came in with very soft iron backs and hard faces. Sheffield makers endeavoured to substitute soft steel for the back, and the resistance of plates with hard steel faces and soft steel backs to perforation was very good, but the through fracture to which such plates were liable was objected to. However wise this may have been at the time, it has followed that the improvement of projectiles has led to the present state of things, when our compound plates are much more easily perforated by a certain class of fire than the solid steel used in France. The class of fire thus referred to is direct attack with "unbreakable" Holtzer projectiles; projectiles which are capable of striking steel at over 2,000 feet velocity, and after penetrating as far as their energy will take them, rebounding almost uninjured and undeformed. Other forged steel projectiles resemble Holtzer's more or less, and may possibly equal them, but on the whole Holtzer's have the best established reputation. It is curious that this form of soft armour with hard face should owe its existence to the navy, for while it is now shown to be faulty for naval purposes it is perhaps the best for land defences. It gives back at the front of impact and so allows of perforation unless very well backed, but when mounted on granite it has shown extraordinary resisting powers, as exhibited in experiments instituted by the Royal Engineers at Shoeburyness, in 1883. Forts, it is submitted, do not suffer from perforation to the same extent as ships. Further, a land front must expect to be exposed to breaching attack, when accurate fire from guns of medium size will be continued for a long period, when the armour will probably be destroyed by shattering, while there will be little danger of direct injury from perforation. A sea front is not liable to long continued breaching attack, but rather to a few blows from heavy powerful ships' guns. Nevertheless, the plates being at times backed by granite, and also a leak not being a serious matter, it may be questioned whether for forts the soft compound armour at present in use may not be as good or better than any other. Then again the land face of compound armour must tell more in its favour in oblique attack, and as Schneider himself admits, has a great power to break up projectiles of medium quality. Altogether it may, perhaps, be considered safely, that while no very serious injury has yet been done, it is necessary to make a change at once in our ships' armour, which is England's first need. So long as a land face can be defended to hold on to a softer foundation to which it has been united, it appears as if the compound principle ought to be a sound one; for whatever quality is thought best for the foundation of a plate, it must surely be an advantage to give it a harder face, seeing that the shot is resisted to much better purpose before it begins to penetrate and receive support from the plate surrounding the head as it drives its way on into the metal. Difficulties in rolling and working compound plates will be decreased most likely when the quality of the face and back approach each other more nearly than has been the case hitherto; a great improvement ought to result in resisting power if through cracking is to some extent allowed, and a good system of bolts depended on to hold up the fractured plates. Ships would be much more secure in action and the change of plates effected more easily when necessary, because the plates being not perforated and very little bulged and deformed at the back, the supporting frames would suffer little injury.

Gruson carried out a programme of experiments at Buckan and Tangerhütte, near Magdeburg, in September last, commencing on September 22nd (Monday). Major Clarke, R.E., as well as other officers, attended the trials on behalf of the English War Office, and a full official report drawn up by them furnishes the best information; it is, therefore, only desirable to refer briefly to a few principal features.

The different classes of designs under trial may be grouped in more than one way, but are fairly included under the following heads:—(1). Mountain and field quick-fire guns. (2). Fortress guns on casemate carriages. (3). Fortress guns in shielded mountings. (4). Naval guns. (5). Turrets. These are taken in the order followed by Gruson in his printed list. The special use of a mountain or field quick-fire gun is to pour in a fire of extraordinary rapidity at any required moment; its relation to an ordinary field gun being, in fact, the same as that of a magazine rifle to a single loader. This valuable power is obtained at the cost of the additional weight, inconvenience, and expense entailed by the use of fixed ammunition, in which projectile, charge and detonator are held in a copper case, which can be thrust into the breech with great speed, and which itself acts as an obturator at the breech joint. The scope for this action is limited in the field by the power of stopping, or very nearly stopping, the recoil; for if it is necessary to run up and relay the gun, the quick-fire speed in entering the charge is of little use. Hence it naturally follows that in the field, where carriages with hydraulic buffers cannot conveniently be used, quick-fire guns will be of very limited size, their value depending on the efficient action of their brakes. It is well to be clear on this point, in order to avoid any false application to quick-fire guns of what would be sound reasoning in considering the value of field guns. Quick-fire, to be efficient, must not be interfered with by recoil, and it is obvious that even a moderate recoil repeated every few seconds must interfere most seriously with it. At a supreme moment, however—as in the case of a rush at the battery, when accuracy is not necessary—a small recoil may be disregarded. A very fair instance of this may be seen in Tuesday's firing, September 23rd, at Tangerhüte, when a 5·7 cm. (2·24in.) gun fired case at cavalry targets at 1,800m., discharging 11 rounds in 51 seconds. At the end of the 11 rounds the piece had run back $6\frac{1}{2}$m.; but the gunner firing had been able to keep close to the trail, and to see that the gun pointed fairly enough in the desired direction, so that the cavalry targets were well riddled, and more careful firing with shell on any special point might be carried out with a field piece with less recoil. This rapid discharge at a critical period is a function of sufficient importance to have secured the adoption of quick-fire guns; and, keeping this in view, there is a value in a maximum rate of speed such as may otherwise appear to be unnecessary and unpractical. No doubt such speed will seldom be called for, but when called for it will be at a moment when everything may depend on it. The same provision for rapid continuous fire is carried out in fortress and naval guns by recoil and automatic recovery of position between each round, or by absolute absorption of recoil on a rigid mounting, and to correspond to the critical moment of a sudden rush of an enemy on field guns may be taken the case of assault of a fortress, or at sea of torpedo boat attack. In the case of heavy shielded mountings and turrets, whether with quick-firing or ordinary guns, the main consideration is protection against heavy fire. In fortresses there exist points where in limited space it is very desirable to place a piece which plays an important part, and on which a besiegers' fire will be concentrated. In such a case, a gun in a disappearing shielded mounting or turret may be of great value. The difficulty is mainly one of space, weight, and expense. A powerful gun means a long piece with strong recoil, and this being awkward to deal with, the tendency of guns on disappearing turrets and mountings is to be lighter than would be expected, and hence no doubt it is necessary to watch against the expenditure of means out of proportion to the power obtained. Thus there are places where, as an alternative, a gun might be fairly concealed, especially with smokeless powder, but in a regular siege, concealment soon comes to an end, continued practice discovers everything, and protection is then better than concealment. Here turrets and disappearing mountings have their field for action. A few definitions may be desirable to distinguish the classes of shields apart. In a *turret* the entire structure, walls and platform, as well as guns, generally revolves on trucks. In a *shielded mounting*, the shield or dome and gun revolve on a centre pivot. A *disappearing shielded mounting* only rises above the surrounding wall or glacis plate in coming into action, and after firing descends into the position of eclipse. In a *shielded emplacement*, the shield is a fixture, a mortar with a spherical body moves in a central hole in the shield, forming a ball joint on the top of a supporting pillar.

Lastly, special attention is invited to the *movable shielded mounting*, which consists of a gun in a sheet steel cylindrical structure with an armoured roof, which is placed on wheels, and can be brought into a gun pit, where it assumes an extremely strong position. Thus, in the defence of a fortress fresh ground might be taken and a gun placed in a spot which might greatly annoy besiegers and prove a valuable element in defence.

It may be noted that in all the trials smokeless powder was used, supplied by the United Rothweil Hamburg Company, from whom we in England obtained our first cocoa powder. The composition of the powder is a secret; it is almost wholly smokeless, and may be conjectured to resemble others which consist of guncotton in some form with a proportion of nitro-glycerine.

Passing by the trials of quick-fire guns, certain specimens of shielded designs may be noticed as included in the subjects of the lectures.

The 5·7 cm. (2·24in.) 25-calibre quick-fire gun in disappearing shielded mounting, shown in *Fig.* 14 (*Plate* III.), was exhibited to show its working and powers. It is aimed and worked by one man, and another to assist and change round when required. He sits on a saddle so contrived as to set gear absolutely checking the recoil of the gun when turned down. In this position, he works the turret with his feet, and when the gun is run back, the hood with gun in it is raised or lowered very easily indeed, being well balanced by a counter-weight. Practice was made with ring shells against a line of twenty skirmishers with supports at 1,300m. (1,640 yards) range. Twenty rounds were fired—ten with slow and ten with quick-fire; 277 hits were made on the skirmishers and 22 on the supports.

The whole structure of this mounting is balanced upon the pivot column, which moves up and down in the cone, and rests upon a lever, such as is shown in *Fig.* 14, whose counterweight balances the mounting. The gun rests with its trunnions in a frame, sliding backward and forward in guides. Bolts, which hold the gun from recoil, enter grooves in these guides, and are connected with a lever, on which the seat of the gunner pointing the gun is made fast. When the bolts are drawn back the seat is raised, and when pushed forward it is lowered. The effect of firing is to press the armoured ring against the glacis armour, after which it recovers its position again immediately, owing to its situation of the centre of gravity. The glacis ring is of chilled iron, resting on sheet iron plates and girders. In the position of eclipse, the flatness of the dome causes the top of the mounting to be very difficult to see or to strike with artillery fire, and the roof or dome resting on the glacis ring, the impact of projectiles can produce very little injury to mounting or armour.

Fig. 15 (*Plate* III.) is the movable shielded mounting for the 5·7 cm. (2·24in.) 25-calibre quick fire gun, weighing in all 2·85 tons, which was driven about the ground with three horses and a detachment of eight men, and put into position in a pit dug by the gun detachment (see *Fig.* 16). The sheet iron sides of the chamber are covered by the walls of the pit, and only the flat armoured dome-shaped roof is exposed to attack. In the case of a smaller mounting, that for the 3·7 c.m. gun, very little effect has been produced on one occasion by the impact of three 8·3 c.m. (3·3in.) projectiles, slight indents only being made. The door and back of the mounting is of thicker metal than the sides and front, so as to resist a considerable blow from a piece of shell striking it at the opening left at the back of the pit, which, however, would not be a contingency likely to arise often. For firing permanently in one direction, the mounting is provided with a brake, and against skirmishers dispersion can be given by an arrangement limiting the rotation of the mounting to a certain angle. The ammunition is placed in tin boxes which stand on the floor of the chamber.

This 5·7 cm. (2·24in.) 25-calibre quick-fire gun, in movable shielded mounting, was drawn on wheels by three heavy horses abreast, the total weight of the load being 2,900 kilos. (2·85 tons), exclusive of the driver. It was driven a short distance along the range, when the word was given to halt and come into action with the horses still hooked in—action rear. The piece was then fired to one flank, the horses being still hooked in. The recoil consisted of a slight shock downwards on the end towards the horses, which was met as far as necessary by short thick legs which hung on hinges from the mounting. In 6 minutes 13 seconds the first round was fired, two men entering the cupola or mounting. The target represented 20 skirmishers, and supports in rear of each flank of ten men each. The range was 1,500m. (1,640 yards); 172 hits were made on the skirmisher targets, 90 of them falling inside the bodies of the men traced on the targets. Fourteen hits were made on the supports. The detachment, consisting of one non-commissioned officer and eight men, were next ordered to take up a temporary protected position. Digging began at 11.3, a shallow pit was made by 11.12, and the wood for sleepers to carry the mounting rails was laid by 11.17, and secured by pickets. The gun was in its pit at 11.21½, and the first round was fired at 11.23½—that is, 20½ minutes from the time the word was given to entrench. It may be seen in *Fig.* 16 (*Plate* III.) that the pit was a shallow one, only affording partial protection; also the ground was sand, and easily worked by spades without picks. This, however, is immaterial to the issue. It is apparent that this mounting is capable of being easily moved and put into a strong position in a very short time; and this, as noticed above, might make this mount very valuable in the general store of reserve pieces in a besieged place. The coming into action with the horses hooked in may be regarded more as fun than serious purpose. The skirmishers and supports would spread and shoot down the horses and men outside the cupola, especially in the case of "action" to "right" or "left." Moreover the piece could not advance, retire, or come into action at the rate required for a piece to work in the field.

A 3·7 cm. (1·46in.) 23-calibre quick-fire gun, in movable shielded mounting, was then limbered up and brought into a permanent position, consisting of a pit of full depth to cover it, lined with wood, and afterwards taken out of it. This design is shown in *Figs.* 17 and 18 (*Plate* III.). The hood of this mounting is the one which as mentioned above had been fired at with an 8·2 cm. gun at 1,500m. range and struck three times, slight indents only being made.

Saturday's work (September 27th), began with an operation on which the value of the heavier shielded mountings greatly depends, namely, the erection of one of them in a pit made for it. The one selected was that for 12 cm. (4·72in.) howitzer of thirteen calibres (see *Fig.* 19, *Plate* III.). The simplest mechanical means were purposely employed, consisting of a travelling crane made by an erection of fir poles in the form of a sort of gin, with four feet striding on to two trucks, which moved on parallel lines of rails. A differential pulley was suspended to lift the pieces of the mounting. The heaviest lift is 1,900 kilogs. (1·87 tons), being the hood or cupola roof pieces, of which there are two, the hood being in this case made in two thicknesses. The entire weight of the mounting is 17,000 kilogs. (16·73 tons). Six men performed the entire work. They commenced at 9·42, and completed it by 11·30, having occupied one hour and forty-eight minutes.

The main questions in all these designs are the ease of working and the strength of mounting. The large turret for the two 15 cm. guns, revolved once, when its momentum was overcome, in eleven seconds, but generally slower, as twenty-two to forty-two seconds. The 21 cm. mounting, two revolutions in twenty seconds.

The following remarks suggest themselves on the whole trial and exhibition of Gruson matériel. First as to the turrets and heavy shielded mountings. The mechanism is excellent. The ease with which the heavy shielded mountings are worked is only to be understood when it is borne in mind that they revolve on a central pillar, so that there is a great leverage against friction. Their behaviour under fire appears to be very good. There is a space between the edge of the hood, or cupola top, and the glacis plate or ring round it varying from about $1\frac{1}{4}$in. in the large turret for the two 15 cm. guns down to about $\frac{1}{4}$in. in small mountings. On firing, the hood is forced against the edge of the glacis ring, but there is little apparent violence or bad effect either on mounting or on the accuracy of the shooting. The 12 cm. mounting was erected very easily, and certainly might be despatched and put up at night under favourable conditions at any desired spot previously prepared for it. Where any kind of rails existed, the operation would be specially simple. The element of resistance of the cupola roofs was not tried here, but it has been tested at Bucharest and elsewhere. Smokeless powder is held by some to have rendered it so easy to conceal the position of a gun, and to have detracted so far from the value of protection, as to make it questionable if the money needed for the latter is a good investment. This in a measure is true, but it is suggested that it does not apply to the case of systematic attack such as is employed in sieges, when all positions become known and attacked almost as accurately as if seen. The partial destruction of the sluice completely concealed in the ditch in Strasburg, by curved fire in

1870, may be taken as an instance of this occurring in actual war. Here, then, it is suggested that protection is of even more importance than concealment, and the cupolas and mountings exhibited at Tangerhütte certainly afford very complete protection, as well as being difficult to see, and it would take so enormous an expenditure of fire to destroy them, that probably they would remain serviceable until they should be captured. It has been objected that the man directing the fire in the shielded emplacements is boxed up too closely, and that in some of these a small "Admirable Crichton" would be needed to work with success, and that it is a mistake to endeavour to afford absolute security to any one. This objection is reasonable, but it would be perfectly easy to give the smaller hoods manholes in the roof, so that if needed the man could raise his head and look out for an instant. They existed in the Bucharest cupola, and there is one in the turret for the pair of 15 cm. guns. It has also been objected that nuts and bolts exist, which might be dislodged and form dangerous langridge. This applies chiefly to portable steel constructions, but the impression that this is characteristic of Gruson's designs appears to be a mistake. Even in the 12 cm. shielded hood, which is made in two thicknesses, screwed together for the sake of portability, the bolts could not fly into the interior, seeing that they end in a decreased screw which hardly reaches to the interior surface of the inner cupola. Of course, this objection cannot be urged against chilled iron shields whose special characteristic is the total absence of langridge. Details, such as position of bolts, ventilating holes and the like, might be varied at any time. It may be noticed that the report of discharge of the gun is surprisingly little heard inside a shielded mounting. In the practice made at targets at Tangerhütte, there was, in the judgment of some of those best qualified to speak, great room for improvement, and the same is true of some of the operations, such as getting a portable shielded mounting out of its counter-sunk position. No one, however, would go all the way to Magdeburg merely to see accurate target practice, which is only material so far as concerns the efficiency of the guns. For example, if the oscillation or vibration of the guns fixed in the hoods had affected the practice, there would have been a valid cause of objection. This was not the case, and errors in setting fuses or time lost in getting the exact range do not concern us. In conclusion the most remarkable design and features exhibited may be repeated :—(1). Simplicity, efficiency, and speed of the quick-fire gear. (2). The power of the quick-fire field guns when the recoil was checked. (3). The nave brake employed. (4). The power of heavier guns on naval mountings, where automatic recovery took the place of non-recoil. (5). The behaviour of the movable shielded mountings dragged by horses, and got in and out of gun pits. (6). The erection of the heavier shield and gun mounting in $1\frac{3}{4}$ hours. (7). The behaviour of the heavier guns in the hoods or cupola tops, which were held on a centre pivot and rested loosely in their surrounding glacis or other rings.

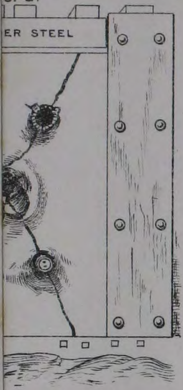
The questions involved in the engagement between ships and forts are almost the same as they were two years ago. The principal new features are the increase of quick-fire power, and the spread of this armour to resist it. This is specially seen in the new designs of ships commenced in 1889, in which the secondary armament of quick-fire guns is greatly increased and are protected by this armour. As mentioned in the lecture in 1888, the limited supply of ammunition carried on board ship is our principal element to consider in the naval attack of forts. Quick fire enables an increased quantity of ammunition to be carried, as is easily seen. Speaking roughly, the weight of gun carriage and slide amount to more than the ammunition carried for the piece. Thus a 6-inch gun weighs five tons. The carriage slide and carriage shield platform weigh 6 tons $12\frac{3}{4}$ cwt., while a hundred rounds of ammunition can hardly weigh $6\frac{1}{2}$ tons. Consequently 170 rounds could be carried for the same weight as a gun, carriage and mounting. Suppose then, that one quick-firing gun represents two ordinary ones, 170 rounds could be carried beyond the allowance for two guns, and there would be further saving in armour and in men.

ND ARMOUR. PLATE I.

COMPETITION.

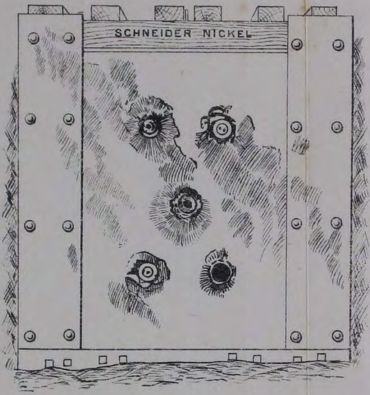
S OF PLATES.

G. 2.



AFTER FIVE SHOTS

FIG. 3.

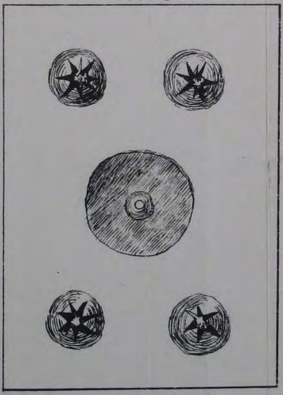


NICKLE STEEL AFTER FIVE SHOTS.

F PLATES

. 5.

FIG. 6.



PAPER VI.

MOBILIZATION OF THE FORCES.

A LECTURE DELIVERED

By Lieutenant-Colonel J. S. Rothwell, R.A.,

At the School of Military Engineering, 13th November, 1890.

Before entering on the subject of the mobilization of the forces, it is desirable to arrive at an understanding as to what is meant by the term "mobilization."

What is Meant by "Mobilization."

It is very likely that among those whom I am addressing there are many who, during the last few months, have had some shooting either on the moors, in the turnip fields, or in the coverts. The sportsman, in this case, carries a certain amount of ammunition himself; a reserve supply is carried for him; his midday meal is amply provided; his night shelter is found in the Highland lodge, or at the hall or manor house; and so far as the game he is in pursuit of is concerned, he is sufficiently mobilized, *i.e.*, he can follow it and shoot it down wherever it may be found within the prescribed limits.

It is also probable that some of those present have had an opportunity at some foreign station of going after large game. In this case the sportsman must be mobilized much more completely. To get within reach of such game he must have the means of moving freely over a wide extent of country, and must, therefore, carry with him not only arms and ammunition, but also his night shelter, supplies of food for himself, and possibly for his transport animals, and it is only when he is thus certain of being able, under all circumstances, to place himself face to face with the game he is in search of, that he can be said to be thoroughly mobilized.

The mobilization of an army is very similar, but here the game to be shot down is man.

The arrangements and preparations necessary differ in degree rather than in kind from those required for a large game expedition.

In each case the party has to be assembled; arrangements made for the supply of clothing, food, ammunition, medicines, and so forth; and for the provision of a sufficient quantity of suitable transport. But while two or three riflemen go out after the tiger or the antelope, two or three hundred thousand, or even larger numbers, must be ready to move against the enemy. They must be ready to shoot him down, or to pursue him over wide tracts of country; in fact, they must be prepared "to go anywhere, and do anything." When this can be truthfully said of a military force, its mobilization has been accomplished. I say "truthfully," for it is easy to be deceived as to the actual condition of an army, and many of you will remember how, in the earlier part of 1870, Marshal le Boeuf, then the French War Minister, assured the Emperor that the army was perfectly prepared for war, and would not want so much as a gaiter button for a year to come. "*Elle est archiprête*" was his expression.

The Germans are more cautious, and take effectual measures to ensure the different units of the army being in efficient condition when required. With this object they make each unit—say a battery of artillery—mobilize every year some portion of its *personnel* or *matériel*. Thus in a field artillery regiment one battery would turn out its guns, another its wagons, others their men and horses, exactly as for a campaign, so that a "mobilized" battery is put together complete in all particulars. This battery is then exercised for a short time, moved by train, etc., in presence of the officers and non-commissioned officers of the regiment, and then its constituent parts rejoin their proper batteries. The next year each battery mobilizes some different portion, those who turned out men this year supplying horses or guns next year, and so on. By this means all gain experience, and learn what a fully mobilized unit of their own arm ought to look like.

A military force, then, is mobilized when it is, as the Germans say, "*Marschbereit*"—ready to move and act—but no State attempts to maintain its army permanently in this condition. All are agreed that the army which is first able to move and act will thereby obtain the important advantage of the initiative in the subsequent operations, but even though wars do break out when they are least expected, it would be impossible to keep an army at all times ready for use. The London Fire Brigade is an example of a disciplined body kept in constant readiness for action, but to apply such a system to a modern army would ruin the State which tried the experiment. Moreover, wars break out less frequently than fires, and even Captain Shaw's firemen might get slack, and take more than 40 seconds to turn out, if they were kept on the alert for 20 years without any employment.

It thus comes about that under ordinary circumstances an army remains on a peace footing, and it is only when hostilities are imminent that it is converted into an efficient fighting machine by the process termed "mobilization."

Mobilization of Continental Armies.

We may now proceed to a consideration of the steps of which mobilization consists, but as our experiences in this country have been hitherto on a very small scale, we must make use of what has been done on the Continent as a guide for our action, in case of its being necessary for us to put out our whole military strength.

In speaking of the preparations required for a large game shooting party, I mentioned that the first thing to be done is to assemble the "*personnel*" of the expedition, and in mobilization this holds a similar place. You are aware that in time of peace nearly all the units of a Continental army have a weak or "*cadre*" establishment—approximately half the strength of the same units when on war footing—and that the extra men required are called up from the reserve. These men are, of course, engaged in the ordinary occupations of civil life, and the first portion of the mobilization machinery to be set in motion is that which has to do with recalling them, and ensuring their speedy arrival at the places where they are required.

Supply of Men.—In Germany, where localization has been carried out very thoroughly, a given unit, such as a regiment, has its own special recruiting ground, and under ordinary conditions is quartered at no great distance from this district. The reserve men for such a regiment are, therefore, within easy reach, as on the completion of their service in the ranks they, as a rule, had returned to their places of birth, and when the order to mobilize is received these men can rejoin the colours with a minimum of delay (certainly within two days after the receipt of the notice), and resume their military duty in the same regiment, and often in the same company in which they had served previously.

This German system of localization, on which a rapid mobilization to a great extent depends, is not carried out so completely in any other country, though all nations endeavour to copy it. France, especially, has made great efforts in this direction, and the existing mobilization arrangements in that country are a great improvement on the system of 15 years ago, and immeasurably above what went on in August, 1870.

At the time of the outbreak of the Franco-German war, the rule in France was that reservists, on being called up, should proceed first to the headquarters of their recruiting district, being sent thence to the regimental depôt to be equipped, and after that joining the regiment. As in many cases there was no connection whatever between the recruiting district, the depôt, and the station of the regiment, it resulted that men were travelling all over France before they could take their places in the ranks. For instance, in July, 1870, the 26th Regiment, belonging to the 6th Army Corps, which was in the east of France, had to draw most of its reservists from the department of the Moselle. But the depôt of this regiment was at Cherbourg, whither these reservists had to go to receive their arms and equipment, and by the time they had made their way there and back, Metz, where the regiment now was, was invested, and they never joined it at all.

The delay caused by thus sending men backwards and forwards was so great, that early in the French mobilization the War Minister issued fresh orders, cancelling those which had been in force, and directing men, when armed and equipped at the depôts, to join whatever body of troops happened to be nearest. This was very much what President Lincoln used to call "swapping horses while crossing a stream," and the result of the new order was greater confusion than ever. Regiments did not know where to look for the extra men required, and were sent to the front in many cases without having received sufficient reservists to bring them up to their establishment, while the depôts became crowded with men who could not be disposed of, for no one knew where they were to be sent. Thus we find the General commanding at Marseilles sending the following telegram to Paris :—" 9,000 reserve men here. Don't know what to do with them. I shall ship them all for Algiers."

On the other side of the Rhine things were differently managed. All had been worked out beforehand, and as each day arrived it had its appointed task, to be simultaneously carried out in each army corps. The story goes that a friend, meeting von Moltke in Berlin while the mobilization was going on, and saying: "You must be over-worked indeed at present," received the following reply : "Well, no, I am not, all orders have gone out, I have really nothing to do."

So much for the first step of a mobilization—the assembly of the men—and we may now suppose that the various units have received the extra numbers required to bring them up to war strength, and that these men are duly clothed, armed, and equipped, and that, so far as the men are concerned, the regiment or battery is complete.

Supply of Horses.—But such a unit is still a long way from being able to go anywhere and do anything, if it has not also been furnished with the means of regimental transport, and if there is no organization by which the supplies of food and ammunition carried in that regimental transport can be readily replenished ; and this brings us to the question of horses, harness, and wagons.

In the case of wagons and harness, it is only a matter of their first construction and of providing storehouses to protect them from weather. They don't eat anything, and with proper precautions may be kept in store for years, ready to be used at any moment they may be required. But horses cannot be stored in this way, and therefore all nations whose circumstances render it probable that they may require a large number of horses at very short notice, have instituted a periodical census and registration of all the horses in the country, and owners are by law obliged to produce the animals if required, and dispose of them to the Government on terms which are usually settled by a commission composed partly of military men and partly of civilians. The places to which the horses are brought to be inspected by these Commissioners are naturally spots which are convenient for despatching the animals to the regiments or batteries to be supplied.

The necessary number of horses having been furnished and fitted with harness, the various units may be regarded as complete in themselves, and till they are they do not move. The combatants are at war strength, fully equipped, and with the regimental transport efficient, and while the various steps for their mobilization have been in progress, similar measures have been taken with the departmental services, generally styled "the train," in Continental armies. The arrangements for food supply are completed, ammunition columns are organized, and provision is made for the conveyance of the sick and wounded. If all has been prepared beforehand on a thoroughly practical and decentralized system such as exists in Germany, the stores which the various wagons are to carry will be rapidly issued and packed, and there will be no clashing or interference. Each army corps district should be absolutely independent, with its own supply of warlike stores and medical appliances, besides having the men and horses necessary to make the fighting units efficient, and thus mobilization should proceed with equal steps in every district.

Appointment of Staff.—But, even though every unit of every army corps were complete in men, horses, and equipment, a great body of this sort would be like a giant smitten with paralysis without an efficient staff. Lord Wolseley has said that "the staff is to an army what steam is to a locomotive," and in Continental armies the provision of a good staff is regarded as a very important part of the mobilization process. In the first place, every army corps, division, or brigade takes the field under the same commander and with the same staff officers as it has been serving with in time of peace, so that at such a critical time as the outbreak of war there is no change of system. But the removal of all the staff would interfere very seriously with the work which must be done after the army has been moved off to the seat of war, and so for every post which would thus be vacated there is in Germany some unemployed or half-pay officer detailed, and on the order to mobilize these officers would at once join, and assist in the work till the regular staff move away, when they take their places.

When the whole work of mobilization is complete, a Continental army is concentrated and moved, generally by railway, to the place where it is required to act, and for such an operation the time-tables have, of course, to be most carefully worked out beforehand.

This, then, is the mobilization of a Continental army; in brief, the raising it from peace to war footing, making it capable of moving, existing, and fighting at a distance from home, and transporting it to the scene of the operations.

Time required by Continental Armies to complete their Mobilization.— As already mentioned, each State endeavours to reduce the time necessary to complete the mobilization of its forces, so as to forestall its adversary if possible. Thus most nations keep part of their cavalry permanently on war footing to send them across the frontier, and thus interfere with the enemy's preparations; Russia keeping, for instance, nearly 30,000 horsemen in Poland with this object.

In 1870, the orders for the German mobilization were issued on the night of the 15th–16th July, the telegram from Berlin being simply: "Mobilization according to plan. 17th July is first day of mobilization." It then took, on the average, seven days to mobilize an infantry regiment, but it is believed that this has now been reduced to five. It would take seven days to mobilize the field artillery, but the horse artillery would be sent off on the fifth day with the cavalry.

France made an experimental mobilization of one army corps in 1887 (17th Corps, at Toulouse), and the results seem to show that, under favourable circumstances, her infantry would be ready on the fourth day, field artillery on the fifth, and corps artillery and train on the eleventh and twelfth days.

In the case of both Germany and France, it is generally assumed that about six days would be sufficient, but that the German troops might be ready to move on the sixth day.

There is one point of interest in this mobilization race between France and Germany which I may perhaps refer to. The frontier line between these two countries being so strongly fortified on both sides, it seems by no means impossible that the line of collision of the field armies will pass through Belgium. In this case it would be the army that is first mobilized which would violate Belgian territory, and certainly if Germany were to do this she would have to reckon with the Belgian army on her flank, and detach a sufficient force to neutralize it. It might thus be that she would allow France to make the first move here, especially as the German railway system is not well suited for a large concentration on the Lower Rhine.

As regards the other European nations, none can approach France and Germany in rapidity of mobilization. Russia, for instance, would require 14 days to mobilize, and thus dare not attempt to concentrate her forces on the left bank of the Vistula, as long before the 14 days are over, the German armies will have moved a considerable distance into Poland. Italy in the same way requires about 21 days to mobilize.

We are not called on to compete in this race against time, but we must aim at results not very different from those which Continental nations have in view. Our conditions of life here are, however, so dissimilar to those of our neighbours, that a transition from a state of peace to a state of war means a much greater change to our military forces than it does to soldiers who are separated by no material obstacle from an enemy with whom they may be in collision in less than a week's time. For this precise reason, if we would avoid confusion and inefficiency when the time of action arrives, we must make our preparations in peace time with as great accuracy and completeness as is done on the Continent.

Mobilization of British Forces.

The mobilization of British forces may be undertaken under one or other of two conditions:—1st. For an expedition to be despatched for operations abroad (of which we have some experience); and 2nd, for the defence of the United Kingdom (of which we have none).

These conditions are very different, for while in the first case our preparations can be made comparatively leisurely, in the second there would always be a feverish haste to get the work completed, lest the invader should be upon us before we are ready to receive him.

Mobilization for Service Abroad.—Supply of Men.—When large operations are to take place in some distant land, our reservists are called up by orders which they receive from the officers commanding the regimental districts, who keep registers of the men and their addresses, and who have notices ready to send out. The notice papers, and railway warrants for the men's journey from their homes to the headquarters of the regimental district, are sent by post to the men, who are also warned by advertisements and placards that the reserve is called up. When the men are assembled at the regimental district headquarters they are medically inspected, and if found fit for service are sent to join some corps or depôt specified, where they are furnished with clothing, equipment, and arms.

Units in England are thus brought up to war strength in a manner analogous to that in use on the Continent; but whereas in a Continental army each battalion or other unit permanently belongs to some one brigade, division, or army corps, this is impossible with us. For if it were decided that one of our army corps should consist of certain definite regiments, batteries, departmental units, and the like, it would inevitably be found that when that division, or army corps, was required for service, many of its constituent parts would be out of England, some in India, some in the West Indies perhaps, or some at the Cape.

Organization by Stations and not by Units.—Our fighting formations must then be organized on the basis of stations, and not of units. That is to say, that a given brigade shall not be composed of four named battalions, but shall consist of whatever four battalions are, at the time, quartered at certain stations.

The reservist then joins the headquarters of the regimental district, and from it is sent, not to his old regiment, but to the regiment or corps which happens to be at the particular station which it is the duty of that regimental district to supply with reserve men. He is then clothed and equipped, the arrangements for this being as follows.

War Outfit of Troops.—The war outfit of troops is separated into three classes, viz. :—

The personal outfit—consisting of clothing, necessaries, arms, and accoutrements.

The first regimental outfit—consisting of cooking utensils, butchery implements, entrenching tools, signalling equipment, etc., and the vehicles in which these are carried.

The second regimental outfit—consisting of ammunition, vehicles for carrying it, supply wagons, ambulance wagons, and water carts.

Of the personal outfit, the clothing and necessaries are kept at Pimlico, and on the order to mobilize, the proper amount of these will be at once despatched to each of the mobilization stations ; the intention being that these articles shall be received before the reservists arrive from the regimental district headquarters.

The rest of the personal outfit, viz., arms and accoutrements, are kept at the mobilization stations in charge of the Ordnance Store Department.

The first regimental outfit is also at the mobilization stations, but the second, *i.e.*, the ammunition, etc., would not be so immediately required, and is, therefore, stored in larger quantities at other and more centrally situated stations.

When the various units are fully equipped, they are sent by rail to the port of embarkation.

It has been argued that the largest force which we can send across the sea for military operations will amount to two army corps, with a cavalry division and troops for the line of communications, in all some 89,000 men and 29,000 horses. These figures may seem small when compared with the numbers involved in a Continental mobilization, but it must be realized that they represent a greater effort than has ever been made at any time in our past history, and that they would tax our resources very severely. For the conveyance of a battalion or a battery of artillery a large steamer of some 3,000 or 4,000 tons is necessary, and for a cavalry regiment about three such vessels would be required; so that it has been calculated (and this calculation has been made by taking definite vessels, which were available on a given date, and allotting troops to them exactly as would be done for an expedition) that to convey *one* army corps, with the line of communications troops, and the cavalry division, to a distant port, would require 134 vessels of over 450,000 tons gross, or an average of 3,400 tons for each vessel.

Large as our mercantile marine is, it is unlikely that there will be much more than 134 such vessels available at the same time, and, therefore, the movement of our second army corps must be deferred till there has been time for the ships to complete the conveyance of the first corps, and to return for a fresh freight. Our mobilization scheme for a foreign expedition should, therefore, be prepared in accordance with these conditions, and as soon as the troops of the first army corps have left their mobilization stations, their places should be taken by the corresponding units of the second army corps, to be there equipped and despatched as the first corps had been.

Supply of Horses.—We have not yet touched on the question of the supply of horses, as for a foreign expedition this must be dealt with in a special manner. We naturally wish, as far as may be, to avoid carrying these 29,000 horses across the sea, and thus, while for the combatant units we must, of course, take troop horses that will stand fire, we generally try to obtain locally such animals as will answer for our regimental transport, or for the conveyance of stores. We also buy animals in other countries, and have them shipped direct to the port which is to be our base of operations, and so it happens that in any expedition of ours it will generally be some time after the arrival of any given unit in the theatre of war before it can be pronounced *marschbereit*—ready to go anywhere.

All these delays, the comparatively leisurely preparations in the first instance—the time required for securing and fitting up the vessels—the voyage—the waiting at the base—tend to make us regard mobilization as an end which is to be reached by slow and deliberate steps; but such a view would have a serious, if not a fatal, influence if it were applied to our preparations for an impending invasion.

Mobilization for Home Defence.—It is not within our province on the present occasion to discuss the question whether the invasion of England is or is not a feasible military operation, but we may be quite sure that one of the most direct ways of rendering invasion feasible is for us to neglect the measures which should be taken to meet it, if it were attempted. The most important step which can be taken in this direction is the preparation for mobilization, and this must be done in time of peace. If we ever are invaded, it will be without much warning, and by a considerable force, and when the invader has reached our shores it will be too late to begin to make plans for bringing up our forces to discomfit him.

Supply of Men.—In the event of a mobilization for home defence, the first step must be, as it was for a foreign expedition, the assembly of the men, and this brings us to a point of considerable importance, viz., the establishments of the various units. In France or Germany there is only one war establishment for any given unit. A battalion, a battery, or an engineer company, when on war footing, will always have exactly the same number of men, horses and carriages, whether the war is to be offensive or defensive; but with us there is hardly a unit in any arm which has the same war establishment, both for home defence and for service abroad. This is due to the difference between the conditions under which the war would be carried on in the two cases, the general result being that for home service troops have less train, as tents and a number of other impedimenta are dispensed with. An infantry battalion, for instance, when mobilized for service abroad has 16 vehicles with it, but when for home defence, has only nine; and in the same way an engineer field company has 10 at home instead of 13 for service abroad. The number of horses and drivers vary, of course, with the number of vehicles, and our mobilization arrangements are in this respect made more complicated than those of a Continental power.

The Auxiliary Forces.—But if ever we have to mobilize for home defence, it will probably be at a time when a considerable portion of our regular army is engaged abroad, and therefore our auxiliary forces—the militia and volunteers—would certainly be required to take a part.

It was in the year 1859 that the weakness of this country against invasion was so clearly recognized as to lead to the formation of the volunteer force, and since that date the enormous development of the armies of the Continent (see table below) has caused this force to be maintained and improved. The militia have always been regarded as a force available to replace or reinforce the regular army, but what position did the volunteers hold formerly? For the first twenty-five years of their existence, at all events, they were a force of some 200,000 men with no organization beyond the battalion, and without any definite connection with any scheme for defending the country.

In the happy-go-lucky way in which military affairs have sometimes been managed in this country, it was said "Oh yes, we have got the volunteers, and they will defend the country"; but how these 200,000 men with muskets, scattered over the length and breadth of England, were to be usefully employed against an invading army, seems to have been regarded as a problem which it was nobody's business to solve.

Problems like this do not solve themselves, and though public attention was aroused by the events of the Franco-Prussian War, and a good deal of interest excited by the picture of our unreadiness, as displayed in the *Battle of Dorking*, which appeared in 1871, it is only within the last five years that any real steps have been taken to remedy the state of things which then existed.

It is satisfactory to think that now each unit of the volunteers would know what is expected of it in case the prospect which called the force into existence should become a reality. For home defence we have now got a practical scheme in which the regular

Country.	Number of Army Corps (1st line).	Minimum number of days required for Mobilization.
Germany...	$20\frac{1}{2}$	6
France	19	6
Russia	22	14
Italy...	12	21

Approximate strength of an army corps—35,000 men, 10,000 horses, and 96 guns.

troops, the militia, the yeomanry, and the volunteers have each a definite place. The militia units would be equipped and mobilized so as to take their places in the field army, the volunteers would also be equipped and mobilized to an extent sufficient to enable them to occupy a given position, and to hold it for a long period if required.

The hero of the battle of Dorking, you may perhaps remember, began the campaign with a kit consisting of a mackintosh coat and a small pouch of tobacco, and he describes how at first his battalion was left for two days without food, and when at last the rations arrived by train, there were no carts to carry them to the battalion; how, though there was an abundance of bread, meat, and tea, there was not a kettle or a cooking pot, and they could not make any proper fires, as they had nothing but their penknives to cut wood with. This was by no means an exaggerated sketch of what would have been the result of calling on the volunteers to take the field in those days, but now the wants of the men have been, to a great extent, provided for, and many corps have had some experience of camp life.

At all events, the volunteers are now assigned a definite share in the defence of the country. They are not meant to manœuvre and fight in the first line, but they are intended to hold fortresses and field works, and thus set free regular troops to form the active army.

Supply of Horses.—In a mobilization scheme for the defence of England, the number of horses necessary is, of course, much less than is required for a force of the same size abroad; for instance, an army corps in the one case has 10,068, and in the other 6,763, but still it is absolutely necessary to arrange before-hand for the prompt supply of whatever numbers may be needed. We have seen that abroad this is managed by requisition, but as it is not desirable to impress horses, if it can be avoided, and as it might be difficult—if not impossible—to obtain horses by importing them from other countries, we have adopted the plan of inducing owners in this country to register their horses as for sale to the government, if required. For each horse so registered the owner receives 10s. a year, and at the present time we have over 3,000 riding horses and over 10,000 draught horses, secured for military use in this way, should an emergency arise.

The horses would be collected at certain stations selected by the Inspector-General of Remounts, and each unit would send to one of these stations a party to receive the horses necessary for its transport, and bring them by train or road to the station occupied by the unit—the battalion or engineer company as the case may be. The horses are here fitted with their harness, which forms part of the first regimental outfit, and then parties are despatched with the horses and their harness to the stations where the carts, etc., of the second regimental outfit are stored, and the carts are then moved away to join the unit, which will thus have its equipment complete.

It was formerly considered desirable to have most of the vehicles necessary for a mobilization stored at Woolwich, or else at some port at which troops would embark for foreign service, but it is now thought preferable to form numerous store houses at convenient inland points, so that the wagons and other stores may be easily accessible to the troops when they require them, whether it be for service abroad or for home defence.

Appointment of the Staff.—One other point remains to be referred to, viz., the Staff. In a Continental army every commander and member of the staff has a very good idea of where and how he will be employed should a war break out, but with us it is very different. If we engage in a foreign expedition, all is arranged specially for that occasion, and no one can foresee his share in the campaign and prepare for it by previous study. But for home defence something might be done in the way of preparation, and the country lying at our doors might be even more studied than it is, and its military features carefully observed. In connection with this part of the subject, I may refer to a point in which your corps is especially concerned—I mean the supply of maps.

The one-inch map is excellent, and if only the country would not change so fast, would be perfect, but the existence of the best map in the world is of no use, unless a sufficient number of copies are available on mobilization, and certainly every commander of a unit, such as a battalion, battery, squadron, or engineer company, should be so supplied. It is also important that the map issued should be that of the proper district. In 1870 the Depôt de la Guerre took great pains to furnish the French officers with maps, and immense quantities were sent to the troops when they were mobilized, but all the maps were of the country beyond the French frontier, and as no others were available, the French were absolutely without any maps of the country in which they were operating.

Conclusion.—In concluding this sketch of the mobilization of the forces, I would commend to your serious consideration all that would be meant by this term, if employed with reference to a hostile invasion of this country. Mobilization under these circumstances would be carried out under conditions of grave national peril, and the defensive strength of the country would largely depend on the manner in which the mobilization of the available force is carried out. There may be such things as Heaven-born generals who can lead troops to victory without previous study or preparation, but it may be safely affirmed that there is no such thing as a general capable of rapidly mobilizing an army if the details of the operation have been previously neglected. The study of these details comes within the province of all. While it is the duty of the staff at headquarters to prepare schemes of mobilization, these schemes cannot be intelligently carried out without the co-operation of the regimental officers. Every officer ought to realize what his duties and responsibilities would be in case of a mobilization for home defence, and if he belongs to a combatant unit, he should know in all its details how that unit is to be made complete in what it requires for taking the field.

It is, perhaps, too much to expect that officers generally will take so much trouble about what they regard as a very remote contingency, but if those who are among the representatives of the brain of the army wish fully to understand what is meant among Continental nations by a "mobilization of the forces," they should study in peace time the work which would fall to their personal share if an invasion of England were immediately impending.

PAPER VII.

HYDROGRAPHIC SURVEYING.

By Staff-Captain T. H. Tizard, R.N.

The principal difference between marine and land surveying is that the greatest part of the area requiring investigation in the former case presents a level, unbroken surface, so that no idea can be formed as to the time required, or the difficulties to be met with, in any particular piece of work, unless it has been already surveyed, and merely requires to be re-sounded to ascertain what changes are in progress. The laborious and monotonous work of sounding alone reveals the inequalities of the ground beneath the surface of the sea, and this is laborious not only to the men actually employed in the exercise of their physical powers in constantly heaving the lead, and hauling in the lead line, but also to the surveyors, for it is only by minute attention and watchfulness that cannot for a moment be relaxed, that soundings are obtained in the desired positions and with the requisite accuracy. I venture to say that no one who has not had personal experience of the labour and trouble required to sound accurately a given area can form an idea of the patience and watchfulness given to this work, and it must be borne in mind that it must be entirely executed by responsible officers, for mistakes cannot be readily rectified, and if made may lead to serious disaster. Even with the utmost care it is hardly possible to detect every inequality at the bottom; for instance, boulders or pinnacle rocks, even when known to exist, cannot sometimes be found by the ordinary process of sounding, and have to be swept for; and instances have been known where it has been necessary to send a diver down to place the lead on the top of a rock before the depth over it could be satisfactorily ascertained.

Soundings may, generally speaking, be divided under two heads: 1st, the ascertaining the depth of water; and 2nd, the ascertaining the precise position of the sounding.

The method of obtaining the depth depends greatly on the depth itself. It will readily be understood that the process of ascertaining the depth in shallow water is an easy matter, and that in ocean depths of above 1,000 fathoms it requires considerable care and skill, and, consequently, that the difficulties and time occupied increase with the depth. The usual method of sounding is to attach a weight called a lead to a line and lower it to the bottom. In all ordinary vessels the leads and lines are of two kinds, the hand and the so-called deep-sea. The hand lead weighs about 14lbs., and is attached to a line of about 25 fathoms in length, marked in the following manner:—At 1 fathom there is a piece of leather; at two fathoms, 2 pieces of leather; at 3 fathoms, 3 pieces of leather; at 5 fathoms, a piece of white bunting; at 7 fathoms, a piece of red bunting; at 10 fathoms, a piece of leather with a hole in it; at 13 fathoms, a piece of blue bunting; at 15 fathoms, a piece of white bunting; at 17 fathoms, a piece of red bunting; and at 20 fathoms, two knots.

It will thus be seen that there are no marks at 4, 6, 8, 9, 11, 12, 14, 16, 18, and 19 fathoms. The fathoms with marks at them are named marks, and the others deeps; and the leadsman in ordinary vessels calls the soundings accordingly, guessing the depths to quarter fathoms, thus by the mark five, or the deep six, at the even soundings, and calling the quarters a quarter less five, and a half five, quarter less six, etc.

This system of marking the hand line is far too rough for any surveying work, and accordingly we mark our lines to feet up to 10 fathoms, and afterwards at every fathom, but to simplify the markings for the leadsmen, who are all taught in their training the marks in use in ordinary vessels, we adopt, as far as possible, those marks, adding others; thus at the 1st and 2nd fathoms are the leather marks; at 3, 9, and 13 fathoms, blue marks; at 5 and 15 fathoms, white marks; at 7 and 17 fathoms, red and blue marks; at 4 fathoms, 4 pieces of leather; at 6 fathoms, a blue and white mark; at 8 fathoms, a red and yellow mark; at 11, 12, 14, 16, 18, and 19 fathoms, single knots; then every half fathom has a small piece of red, and the 1, 2, 4, and 5 feet between the fathom marks a piece of knotted marline ; and the leadsman calls the soundings to feet, thus three, two, means 3 fathoms and 2 feet ; five, four, 5 fathoms and 4 feet, etc.

The so-called deep-sea lead in ordinary ships consists of a weight of about 28lbs. attached to a line 100 fathoms in length, which is marked to every 10 fathoms above 20 fathoms, but which we mark at every fathom.

Various instruments have at different times been invented to ascertain the depth also. The three most useful and prominent of these are, for ordinary depths, Massey's sounding machine, Burt's nipper and bag, and a pressure gauge originally invented by Ericson and since modified by Sir W. Thomson and Mr. Bassnett.

Massey's machine, invented about 1820, is simply a clockwork set in motion by a rotator, which revolves freely as the instrument descends, but is caught by a catch when it is being hauled up. Like all other instruments it is not perfectly accurate, but should have its errors ascertained by being lowered to given depths, when it may be usually relied on.

Burt's nipper and bag is an excellent arrangement ; it is simply a roller with a strong spring kept at the surface of the sea by a bag full of air ; the lead line passes between the spring and the roller, and runs freely between them in one direction, but cannot be hauled back ; as the lead sinks the bag is kept perpendicularly over it, and registers the true depth.

Both Massey's machine and Burt's nipper were most useful in the days of sailing vessels, when it was almost impossible to get a good sounding in depths above 20 or 30 fathoms, owing to the drift of the ship, but they are not of so much use now, as it is easy to keep the line perpendicular from a steamer, and, moreover, hemp line for soundings over 20 fathoms has, of late years, been almost superseded by fine wire. Here the pressure gauge is of great use in ordinary navigation; of these there are two in use, Sir W. Thomson's and Mr. Bassnett's.

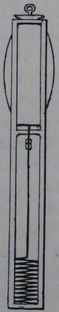
In using wire for sounding in ordinary circumstances the depth may be recorded by a clockwork arrangement attached to the spindle of the drum on which the wire is reeled; but as this requires the ship to be stationary, as in sounding with the hemp line, and as, moreover, unless the wire be prevented running out when the lead has reached the bottom, it is very likely to kink and part, in ordinary navigation the wire is generally used when the ship is steaming through the water, and a pressure gauge attached to record the depth. The ordinary pressure gauge of Sir W. Thomson consists of a glass tube chemically marked inside; as the

Sir William Thomson's Pressure Gauge.

depth increases so the pressure increases, and the water is forced up the tube, compressing the air inside, and washing off the chemical substance with which the tube is lined. When brought to the surface the compression of the air due to depth is shown by the amount of red washed off, and the depth ascertained by placing a prepared scale against the top of the tube. It will thus be seen that a fresh tube is required for every cast of the lead. To avoid this difficulty Mr. Bassnett, of Liverpool, invented a pressure gauge, which consists of an overflow tube inside a larger one; the water being forced up the overflow tube falls down into the surrounding tube when it reaches the top of the inner one, and consequently records the amount of pressure and the depth. When brought to the surface the outer tube can be emptied by opening a valve at the bottom, and the recorder is ready again for use. Sir William Thomson has lately invented another instrument, which he has named the depth recorder. This consists of an air-tight cylinder, in which is a moveable valve attached to a piston, the other end of the piston being fastened to a spiral spring at the bottom.

Mr. Basnett's Pressure Gauge.

The pressure of the water forces up the valve into the cylinder, but



Sir William Thomson's Depth Recorder.

the height to which it is forced is regulated by the spring beneath; the piston is graduated, and has a moveable index, which records the depth.

None of these instruments can, however, be considered as such a satisfactory method of recording the depth as a perpendicular cast of the lead. First of all, in water under 10 fathoms deep the soundings can be registered to feet by the lead line, and even to half-feet if necessary, and can be obtained as quickly as is compatible with hauling in and heaving the lead, thus saving any time required to read off an instrument, and secondly, the graduation of the pressure gauge allows such minute space for each fathom that it is not easy to tell the precise depth; moreover, in using them with the wire sounding line, when it is usually necessary to keep some way on the ship to prevent a kink, the ordinary method of knowing when the bottom is reached, viz., by touch, is not available, and the only means by which the navigator may be certain his lead has reached the bottom, and that his apparatus is consequently recording the true depth, is by bringing up a specimen of the bottom, which is usually done by fixing a bit of tallow called the "arming" to the bottom of the lead. When the ground is hard the tallow often comes up clean, and the result is consequently doubtful.

In surveying vessels, instruments for ascertaining the depth are seldom used.

The method of heaving the lead is for the leadsman to stand on a platform on the side of a ship, or boat, and throw the lead sufficiently far forward for the line to be perpendicular when the spot where the lead entered the water is underneath him by the time the bottom is reached. The speed of the vessel, and the distance it is necessary to heave the lead, are regulated by the officer in charge, and very slow speeds are kept up, or the depths would not be obtained in sufficient numbers. In depths of from 30 to 100 fathoms the ship is usually brought head to wind and stopped, so that a perpendicular cast may be obtained. The lead lines in use are kept constantly wet and are frequently measured—at least twice a day—and their errors, if any, recorded and allowed for before the soundings are plotted. At frequent intervals specimens of the bottom are brought up, and their nature also recorded for entry on the chart, so that the navigator may know what sort of ground he may expect. This is the usual method for depths under 100 or 150 fathoms, but for ocean depths special arrangements are required, and steam power absolutely necessary to ensure accuracy.

The plan originally tried by the early navigators to obtain soundings in the open sea was to prepare a reel of continuous spun yarn of from 5,000 to 10,000 fathoms in length, and to attach a number of shot to the end, and let it run out until the bottom was reached. Experience soon proved that no satisfactory results could be obtained from a sailing vessel itself, as the heave of the sea, or a breeze springing up whilst the weights were descending, caused the ship to drift away from the spot where the weights were let go very rapidly. After a time the experiment was tried from boats, the reel of line being placed in one boat with the men to attend it while it was running out, whilst a second boat took the sounding boat in tow and kept her in position over the descending weights. It seems, however, that the seamen of that day lost sight of the fact that the line would not cease to run when the shot reached the bottom, as its own weight was sufficient to cause it to run, and consequently reports were made that no bottom had been reached with 5,000, 7,000, and even 10,000 fathoms, giving rise to the poetical idea of the ocean's "unfathomable depths." The idea of "unfathomable depths" was by no means confined to the ocean, for some lakes were also said to be unfathomable. I remember, when employed in surveying the island of Pantellaria, in the Mediterranean, the Governor there said that a small lake on the island was unfathomable, and we resolved to test this statement, the result being that nowhere could we find more than seven fathoms.

Before long it was, however, discovered that by timing the rate of descent of the line at each 100 fathoms, or less intervals, the moment the weights reached the bottom could be ascertained with accuracy, as although the line did not cease running its rate was sensibly diminished, and Sir James Ross, in the *Erebus and Terror*, in 1840, made some excellent observations on oceanic depths, his deepest sounding being 4,000 fathoms. In none of the earlier attempts was any endeavour made to bring up a specimen of the bottom, the line being invariably cut after the shot reached the ground, but the bold idea, in 1857, of connecting England and America by a submarine cable, necessitated a knowledge of the depth of the ocean and nature of the bottom between the two countries, and various sounding apparatus were designed to accomplish the object, some of which I exhibit here—Brooke's rod, the "Bulldog" clamp, Fitzgerald's machine, the Hydra rod, and the Baillie rod, the latter being the instrument most generally used now by our surveying officers. All the instruments have one common object, *i.e.*, to disengage the weights or sinkers directly the bottom is reached, and to bring up as large a specimen as practicable for examination.

Up to 1874 hemp rope was entirely used to measure the depth and bring back the instrument to the surface, and the weight of the sinkers necessary depended greatly on the size of the rope, though not entirely, as it was found that by marking the line very carefully the friction in passing through the water was very much reduced, and that consequently less weight was required to get a given speed of descent.

About 1874, wire began to be used for deep-sea sounding, and as it requires far less weight of sinkers, it has gradually been adopted as the best means of ocean sounding, though the hemp rope has not been entirely discarded, for owing to the liability of the wire to kink and break if there is much motion on the ship, it is often not advisable to attach valuable instruments to it when other information in addition to the depth is required. For instance, it is always advisable to ascertain the temperature of the water at the bottom, and to sometimes bring a specimen of that water to the surface for examination; and it is also highly advantageous to ascertain the temperature of the ocean at different depths, which is done by attaching a number of thermometers at given intervals to the sounding lines. As these instruments are expensive, it is well not to risk their loss by any chance of the line parting.

In a former lecture, delivered here in February, 1886, I have described in detail the method pursued in the *Challenger* in ocean sounding and temperature observations, and, therefore, it seems hardly necessary to repeat that now, as the lecture is published in your *Occasional Papers*, but I exhibit some of the instruments used.

I may point out though that we are now beginning to have a fair knowledge of the depths all over the world, as the accompanying general chart shows; the deepest authentic sounding yet obtained is 4,600 fathoms, and there are but few places where the depth is of or above 4,000 fathoms; the general depths are from 2,000 to 3,000 fathoms. We are also beginning to have a fair knowledge of the deposits on the floor of the ocean. A considerable portion of the bed at the bottom consists of a white ooze, which, when examined, proves to consist of microscopic shells rained down from the foraminifera (principally globegerina); living in large quantities on the surface, the shells fall down to the bottom, when the animals die. But it is a curious fact that in depths above 2,500 fathoms few, if any, globegerine shells are found, although the animals are quite as numerous at the surface. There the bed of the ocean consists principally of a red clay.

Having thus described how soundings are obtained, I must point out that it is always necessary to reduce them to a common standard as the depth in every position varies constantly with the rise and fall of the tide. In the open ocean the tidal wave never exceeds 5 feet, and can consequently be overlooked, but directly the tidal wave meets with any considerable obstruction it becomes abnormal, and is heaped up to 10, 15, 20, and sometimes to 40 and 50 feet; therefore, in sounding coasts or harbours, etc., the condition of the tide must be constantly observed, and the depth obtained reduced to a common standard.

The standard adopted by the Hydrographic Department of the Admiralty is the low water of ordinary spring tides; this has to be ascertained for each particular survey, and the height of the tide registered at short intervals during the whole period the survey is in progress, so that tidal curves may be drawn which will allow the soundings as they are taken to be reduced to the adopted standard. In itself it would seem to be a very simple matter to ascertain the datum point of low water, but the rise and fall of the tide is influenced by such varying forces that it is by no means so simple as it seems. Theoretically, each tide rises and falls equal distances above and below a fixed line known as the mean level of the sea, which is always supposed to be constant, but in reality the mean level is subject to great variations; for instance, the atmospheric pressure influences it, for with a high barometer observation proves that the mean level will be lower than with a low barometer, varying about a foot in height for an inch of mercury, which is, of course, quite natural; again, the mean level is different at different seasons of the year, the difference in some places amounting to as much as two feet (notably in some parts of Australia); it is also greatly influenced, especially in estuaries or narrow seas, by the wind; in the Thames, for instance, a S.W. gale has been known to cause the tide to fall four feet below the calculated low water, and a N.W. gale produces a contrary effect, and there are other disturbing causes which produce some effect, though comparatively slight ones. The first thing we do, then, in original work, is to ascertain the mean level of the sea for the particular period of the year in which the survey is executed, then by applying half the range of a spring tide to the mean level, we have the low water of ordinary springs. Of course, to ascertain with accuracy the mean level of the sea at any particular place, tidal observations should be taken day and night for at least a year; this is unfortunately rarely practicable, but in order to make surveys executed at considerable intervals of times comparable, it is customary to refer the datum adopted for the reduction of the soundings to some fixed point on the shore; for this purpose a rock that covers and uncovers at a given height on the tide pole is valuable; sometimes a mark is cut in on the rocky foreshore, and in this country the datum is referred to a dock sill in the vicinity, or to one of the Ordnance bench marks, so that when re-sounding rivers and harbours in the United Kingdom, or banks close to the shore, there is no difficulty in reducing the depths to the standard used previously.

The tidal wave, or undulation, must not be confounded with the tidal stream or ebb and flow, which is quite a different thing. It is customary to name the tidal stream flood when the tide is rising, and ebb when it is falling, and in rivers and harbours the stream often does run in one direction with a rising tide, and in the opposite direction with a falling tide, but this is by no means the case on open coasts, or in estuaries and straits.

When sounding banks and channels at some distance off the coast, where it is impracticable to erect a tide pole, an empirical method of reduction has to be adopted; for instance, we have been in the *Triton*, for some seasons now, engaged in sounding the banks and channels between Flamborough Head and Cromer, and the method we have adopted to find the times of high and low water, and the rise and fall, are as follows:—At Flamborough Head it is high water at 4.30 at full and change of the moon, the rise and fall at springs being 16 feet, while at Cromer it is high water at full and change at seven o'clock, the rise and fall at springs being 15 feet. If a line be drawn from Flamborough Head to Cromer, and divided into five parts, assuming the progress of the tidal wave to be uniform, we have the positions where the times of high water at full and change will be at 5, 5.30, 6, and 6.30 o'clock, and the rise and fall may be considered the same along that line, as it is 16 feet at Flamborough Head and 15 at Cromer.

If lines be drawn at right angles to the line joining Flamborough Head, at the positions named, they will fall on the spot where, by calculation, the time of high water should be the same, and this they do almost precisely; for instance, the line along which the high water should be at 5.30 o'clock cuts the coast just south of Spurn Point, and the high water as observed at Spurn Point is at

5.26 o'clock, etc. To see if the rise and fall is as calculated, we take the depth by lead line at every hour from the ship whilst at anchor at night, or from a fishing vessel, which was used as a mark boat, in the daytime; but the irregularities of the ground prevent very accurate results being obtained by this means, as the lead does not always fall in the same place; the general result is, however, wonderfully like the calculated.

We had, also, in 1889, a further opportunity of testing the accuracy of our calculations, as a steam vessel sank, after collision, seven miles west of the outer Dowsing light vessel, and as her masts showed above water, the Trinity House Superintendent of the district, at my request, nailed a tide pole to one of them, and caused the people on board the light vessel placed to mark the position of the wreck, to record the tide every hour. By my calculation the rise and fall of the tide at springs at the wreck should have been $15\frac{1}{2}$ feet; it proved to be 15 feet.

To ascertain the precise height of the tide at any given moment when we cannot put up a tide pole, we use a method originally adopted by Sir Francis Beaufort; for instance, if the rise and fall of the tide at springs be 15 feet, the mean tide level is $7\frac{1}{2}$ feet. If a diagram of a tide pole be made, and at the $7\frac{1}{2}$ feet a circle be drawn with a radius of $7\frac{1}{2}$ feet, this cuts the pole at 15 feet high water, and zero at low water. If the circle be divided into 12 equal parts, or twelve hourly intervals, and lines be drawn perpendicular to the pole, they will cut the pole at the number of feet rise. Thus, at a spring tide which rises 15 feet, the height 1 hour before and after high water will be 14 feet; at 2 hours, 11 feet 3 inches; at 3 hours, $7\frac{1}{2}$ feet; at 4 hours, $3\frac{3}{4}$ feet; at 5 hours, 1 foot; and at 6 hours, zero; whilst at the same spot, with a neap tide which rises 12 feet above the low water at ordinary springs, the tide would be 11 feet 3 inches at 1 hour before and after high water; 9 feet 9 inches at 2 hours; $7\frac{1}{2}$ feet at 3 hours; $5\frac{1}{4}$ feet at 4 hours; $3\frac{3}{4}$ feet at 5 hours; and 3 feet at low water. By dividing the circle into as many time intervals as may be required, it is evident the height of the tide may be estimated at any moment, and experience proves with considerable accuracy.

Having shown how the depth is obtained, and how the soundings are reduced to the common standard of low water, I will now show how the position of each sounding is determined, as it is evidently of no use obtaining the depth unless its position can be accurately ascertained.

1. In sounding narrow rivers or channels the most convenient method is to stretch a line across, marked at given intervals, and to obtain a sounding at each mark. As a specimen of this method of sounding I produce the plan of Blythe Harbour on a scale of 25 inches to the statute mile. Here marks were set up on each side of the river at every 100 feet, and a line stretched

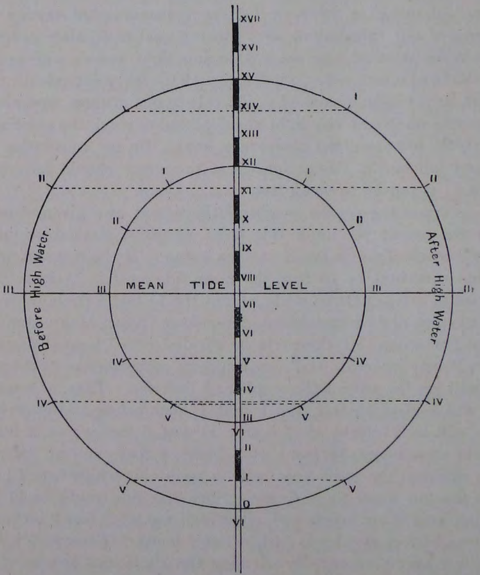


Diagram showing Sir Francis Beaufort's Method of Finding the Height of the Tide at Any Hour.

across from side to side marked at every 30 feet, two small anchors being used to secure the line to, one on each side. A seaman with one anchor is stationed on one side of the river to make fast the end of the line, and two seamen with an anchor on the other side to heave it taut. The sections are all numbered, and soundings taken at each mark on the line by the leadsman in the boat, the officer in charge recording the number of the section, the depth at each mark, and from which side of the river he begins and at which side he ends, the positions occupied by the anchors having been previously marked and properly fixed by angles. The hour and minute at which the soundings are taken is also recorded, and at the same the tide watcher records the height of the tide on the gauge. When the section is finished, the line is eased up and the anchors shifted to the next marks, and so on until all the sections required have been obtained. Care must be taken that at each sounding the boat is really on the straight line between the two anchors, as the tidal stream has a tendency to somewhat bow the rope stretched across the river.

2. When the river or channel is too wide, or has too much traffic moving on it, to permit a line to be stretched across, some sort of marks have to be used, and the position of the soundings fixed by angles between objects on the shore. As an instance of this method of sounding I produce the plan of Gillingham Reach, recently sounded on a scale of 20 inches to the nautical mile to ascertain the state of the dredging operations. Here it was necessary to sound the river very closely, and the width and traffic rendered the stretching a line across impracticable. We therefore took advantage of the spire of Hoo church, as a mark sufficiently far off to admit of the lines of soundings all converging towards it, especially as the curve of the river ran in such a direction that lines from Hoo spire crossed it nearly at right angles. Then as the foreshore was muddy and much broken, so that it was awkward to measure even distances on a straight line, we laid out a long rope just outside the low water line on the north side of the river, and marked it at every 60 feet, dropping an anchor at each end. A boat with a flag was then moored at each successive mark on the line, and the sounding boat kept this flag in line with Hoo spire. This ensured the sectional lines being run at regular intervals, but to fix the position of the soundings, angles were taken at frequent intervals between the objects on shore already plotted from the triangulation, viz., the Dockyard chimney, Hoo spire, Folly Fort flagstaff, Folly beacon, Darnett Fort flagstaff, Friday mill, Gillingham church, etc.

Two angles are sufficient to fix the position, and these angles are taken simultaneously with sextants by the observers and plotted by the station pointers, and, if correctly taken, should plot on the line of the boat and spire. Each sectional line was run from south to north, as it is easier for the steersman to keep two objects exactly in line when steering towards them than when steering away from them, and these objects made such a good transit that if they were in line from one side of the boat they were a little open on the other side.

The sextants used for observing angles when sounding are made especially for this service, without shades and fitted with powerful tubes, and they are graduated to minutes, as smaller divisions are unnecessary. The station pointer, which next to the sextant is our most useful instrument, has one fixed and two moveable arms, so

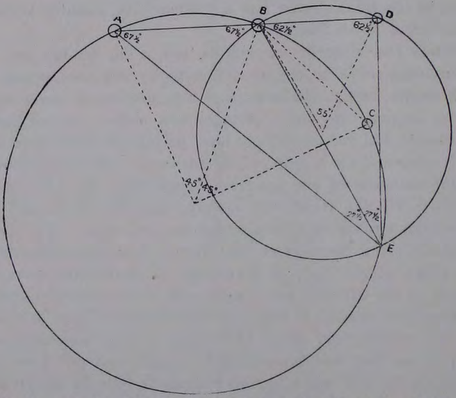
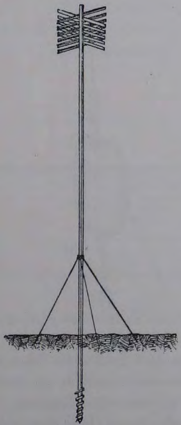


Diagram showing Method of Fixing Soundings by Station Pointer.

that the angles observed can be placed on it, and the arms placed over the points on the chart. It is constructed on the twentieth proposition of the Third Book of *Euclid*, that the angle at the centre is double the angle at the circumference upon the same base, *i.e.*, upon the same part of the circumference; for instance, in the diagram shown let A, B, D be three objects on shore, the positions of which have been ascertained by triangulation, from the boat the observed angle between D and B is 27° 30′, and between B and A 22° 30′; then, by doubling these angles and projecting we get two circles, which define the position of the boat at E. The objects selected for observation must be in such positions that the circles drawn cut each other sharply; this they will do if the centre object be nearer the observer than any point on a straight line joining the other two objects. If, however, the points used are in such positions as A, B, and C, and the angles observed be $22\frac{1}{2}°$, then the observer may be anywhere on the circle A, B, C, E. In actual practice we do not project, but use the station pointer, which gives the position of the boat at once.

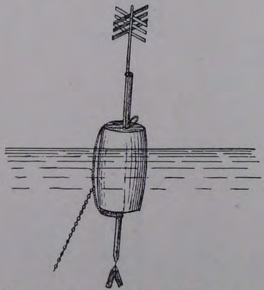
3. In sounding open coast or estuaries we endeavour to take the soundings in lines at right angles to the coast, or banks in the estuary, so as to contour the sea bottom in a similar manner to contouring the elevation of the land. When practicable we sound by keeping marks on the shore in line, but this is frequently impossible, and we then have no option but to steer by compass, and fix by angles between objects on the shore, as previously explained. The difficulty here is that we cannot always steer on the exact line we



Surveying Beacon used on the Sand Banks in the Thames Estuary.

wish to follow, as the varying strength of the tidal stream requires varying allowance to be made for it so frequently that it is impossible to tell exactly what course is required to maintain a perfectly straight line; consequently more time is used to cover a given area with soundings, than if marks were available which could be kept in line. When the estuaries occupy a considerable area, and are full of sand banks out of sight of land, it becomes necessary to erect beacons on the banks and connect them by triangles with the shore objects. In the Thames estuary, which the *Triton* re-surveyed last year, the work was greatly facilitated by the masts of vessels wrecked on the banks. A convenient form of beacon is an iron screw pole supported by stays and surmounted by a wooden pole, on the top of which are battens. These also serve to record the rise and fall of the tide, as they are marked in feet. When they dry at low water, another pole is used in addition.

4. In sounding banks out of sight of land, marks of some kind are absolutely necessary. In many cases it is impracticable to erect beacons on the banks, and we then hire a vessel and anchor her in position, and by her aid and anchoring beacon buoys, triangulate



Form of Beacon Buoy used in Surveying Banks out of Sight of Land.

and sound round the bank. The first thing to do is to ascertain the correct position of the mark vessel at anchor, and to place a watch buoy by her to guard against her drifting. If the position can be triangulated out from the shore, it is, perhaps, the most satisfactory way, but when that cannot be done, astronomical observation is the only alternative. Here we bring our chronometers into play, and connect the bank by meridian distances to the nearest point on shore, the longitude of which has already been determined.

In all surveying vessels we bestow great care on the chronometers. They are placed as nearly as practicable in the centre of the vessel, where they are less subject to jars than anywhere; they are wound carefully at the same hour daily; all iron is kept as far as possible from their neighbourhood, and they are kept under glass cases so that the faces may be seen without lifting the lid, and thereby causing variations in the temperature each time it is necessary to compare with the hack chronometer. The rates are always obtained by equal altitudes by the same observer with the same sextant and artificial horizon, and the errors shown on the mean time of the place where the observations were taken. Although it is necessary to have one standard meridian on the globe, which meridian is an arbitrary one, Greenwich being accepted by most nations, it is advantageous to have a number of secondary meridians which govern the longitudes of particular areas, and to which all meridian distances in that area are referred.

Every surveying vessel, therefore, is furnished with a standard secondary meridian by the Hydrographic Department, and to that meridian all her chronometrical distances are referred; our method of working these distances is that originally promulgated by Tiarcks,

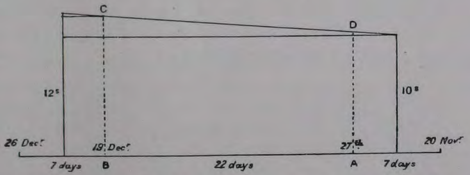


Diagram showing the Method of Ascertaining the Accumulated Rate of a Chronometer.

of which I show a diagram. If a chronometer be rated at A and again at B, and the error ascertained on the mean time of place at both places, then assuming any change of rate to be uniform, the accumulated rate is the rate at A + or $-\frac{1}{2}$ the difference between the rate at A and the rate at B multiplied by the number of days elapsed between the observations. In the case of a number of chronometers the result given by each instrument is recorded, and those which differ materially from the arithmetic mean are rejected, and a selected mean adopted. That this gives good results will be apparent when I mention that in the *Challenger* we were furnished with 12 chronometers, and carried a series of meridian distances round the world, the voyage occupying $3\frac{1}{2}$ years, and the chronometers undergoing many changes of temperature. The result of all the meridian distances added together gave 24hrs. 0min. 28secs., or seven miles of longitude out in the distance of 68,000 miles traversed.

In obtaining the meridian distance of a mark boat at anchor from a standard position on shore, the same system is pursued, but the equal altitudes for errors and rates of chronometers are obtained by the sea horizon.

To get the latitude, observations are either taken of stars at twilight north and south of the zenith, or the sun at noon by contact with the horizon both north and south. The difficulty in all sea observations is owing to our often not seeing the true horizon, owing to refraction. This is to a great extent remedied by taking the mean of observations to the north and south, but if the meridian altitude of the sun is less than 60° the angle becomes too large to measure in the opposite side, and meridian altitudes of stars on either side of the zenith, or double altitudes of stars at twilight, are necessary for accuracy. To give an instance of the close accordance of the results when the observations of the sun are taken with both horizons on the meridian, I may state that, in fixing the Ower and Leman light vessel, we found its latitude on

June 25th to be	... ...	53	7	56	N.
July 9th ,,	... ...	53	8	0	,,
July 11th ,,	... ...	53	7	54	,,
July 12th ,,	... ...	53	7	57	,,

an extreme range of six seconds of arc, or 600 feet in the latitude. Such a close accordance shows the value of this method originally recommended by Raper.

Having, either by triangulation from the shore, or by astronomical observation, fixed our mark boat, we sound round her, and fix the position of the soundings by compass bearings and masthead angles.

For observing with accuracy the masthead angle we use Rochon's micrometer, a telescope fitted inside with two prisms of rock crystal, the one cut parallel to the axis of the crystal, and the other parallel to one of the faces of the pyramid. These are placed one on the other in contrary directions, and cemented together in a cell, which slides in the body of the telescope, by means of a slit, in the direction of its length, so that the prism may be moved along the tube; this shows two images of the object in the field of the telescope, and the angle subtended by any object is measured by the contact of the images. Its graduation is corrected by moving the prisms to a point where the images cover, which is the zero, and by taking the diameter of the sun. It is, of course, only intended to measure small angles, and is rarely graduated to more than 40 minutes, but angles to one second can be read off by means of the vernier. By the help of this instrument we can sound accurately, in clear weather, for a radius of four miles round the mark boat. Having filled up the area round the mark boat with soundings, we anchor a beacon buoy from three to four miles from her, and fix it by obtaining a true bearing and distance, and then shift on the mark boat to three or four miles from the buoy and continue sounding. The distance is obtained by the micrometer, checked by measuring the distance by sound.

The rise and fall of the tide, and times of high and low water, are obtained by the lead line, if no better means offer.

The beacon buoys we generally use are specially constructed casks with a spar passing through a tube; to the bottom of the spar weights are attached, to make it float upright, and on the top is a light pole with cross-pieces. These can be seen about five miles in clear weather.

5. In sounding off the shore to the 100 fathom line of soundings, when land is lost sight of, the lines of soundings are run by compass and patent log, and checked by astronomical observation. The difficulty in fixing accurately the position of a ship at sea is that it is not often we are able to obtain observations for latitude and longitude at the same time. At night, when the stars are visible, the horizon is seldom accurately defined, and we are, of course, entirely dependent at sea on the visible horizon. The best time for stellar observation is just before sunrise and after sunset, when the horizon is yet well defined, and the bright stars just beginning to show; at such times, altitudes of two or more heavenly bodies on different bearings give accurate results. This is known as Sumners' method, and is based on the fact that circles of altitude may be drawn at any moment on the earth's surface for each particular star, so that the position of the observer is where the circles cut; for instance, if a line be drawn from the centre of the earth to a star, at the point where this line cuts the surface, the altitude of the star

will be 90°, whilst a plane from the centre of the earth, at right angles to this line, cuts the earth's circumference at those points

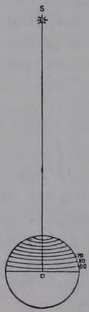


Diagram showing Circles of Altitude.

where the altitudes will be 0° ; 10° from this plane towards the point where the altitude is 90° the altitudes will be 80°, and so on; and, as the circles are large, any small portion of them may be taken as a straight line, and this line will be at right angles to the bearing of the star from the observer. Now, as you know that if we have the latitude, altitude, of a heavenly body, and its polar distance, we can calculate the time at place and azimuth of the star, and consequently, with the aid of chronometers, the longitude, and as we know the latitude always, say to within 20 circles, by calculating the longitude and true bearing of the star, we get a circle of altitude, on which the observer must be at that particular moment ; therefore, by observing stars on different bearings, we get as many circles of altitude as are necessary, and the point where these circles cut is the position of the observer.

This fact is also of value in many instances where an altitude of only one heavenly body can be obtained ; for instance, in making the land after many days thick weather, if an altitude of the sun can be obtained, although the latitude is doubtful to within many miles, still the observer knows he is on a circle of altitude, and that perhaps that circle of altitude will cut the land in some, or close to some, prominent point, therefore, by steering on the circle of altitude he is sure to make the land in some known locality. On the chart of the entrance to the English Channel you will see that if in the forenoon, when the sun is in the S.E. quadrant of the compass, an observation be obtained for longitude, the observer will be in a circle of altitude running in a S.W. and N.E. direction, and that this will meet the English coast in some point between Lands End and the Start; therefore, by steering on this circle of altitude the precise position of the ship can be ascertained by the soundings, even before the land is actually seen.

The only other means of obtaining both latitude and longitude simultaneously at sea is when either Venus or Jupiter passes the meridian in the forenoon or afternoon, when the skilled observer can get the meridian altitude, and also observations of the sun for longitude within a minute or two. But this requires very clear weather, and the planet must pass at least $2\frac{1}{2}$ hours before or after noon, or the brightness of the sun prevents its being seen with a sextant. In order to see the reflection of the planet it is necessary to screw the telescope in by the "up and down piece" as far as it will go, and the sextant must be held very steadily, and directed towards the meridian with the altitude nearly on. Practice enables the observer to get most excellent results, but I fear few sailors take the time and trouble necessary for this purpose.

The soundings in running off or on the shore out of sight of land are regulated by distance and the speed of the ship. A good plan is to proceed at a rate of about six miles an hour, and to stop and obtain a cast of the lead every 10 minutes; this will give soundings at distances of a little less than a mile between them. At each sounding the course the ship is steering, the distance run by patent log, the depth, the nature of the bottom, the error of the line, and the state of the tide are noted, as also whether any astronomical observations were obtained, and if so, of what nature they are. Too many astronomical observations cannot be obtained, more especially when sounding off shores where the tidal streams change every six hours, and where it is impossible to tell, excepting from astronomical observation, with what speed the stream is running.

In ocean sounding, the time occupied in obtaining the depth and bringing up a specimen from the bottom is so considerable that observations for latitude and longitude can almost always be obtained, as the ship is kept stationary.

It will be evident from the foregoing remarks that our chief dependence in nautical surveying is on the sextant. That is the instrument which enables us to perform our work accurately, and with it, and it alone, many valuable surveys have been made. The great disadvantage of the sextant is that it has to be put down each time an angle is registered, as it is not practicable to hold the instrument and write down at the same time; so that it is very convenient to have some one to register the angles as they are observed; otherwise, it is, I think, the best instrument there is for surveying, for the theodolite, altazimuth, or transit instrument, are only of use on shore, and the compass is subject to so many errors that observations by it alone cannot be relied on; but with a sextant the whole work of either a land or marine survey can be executed with the greatest precision.

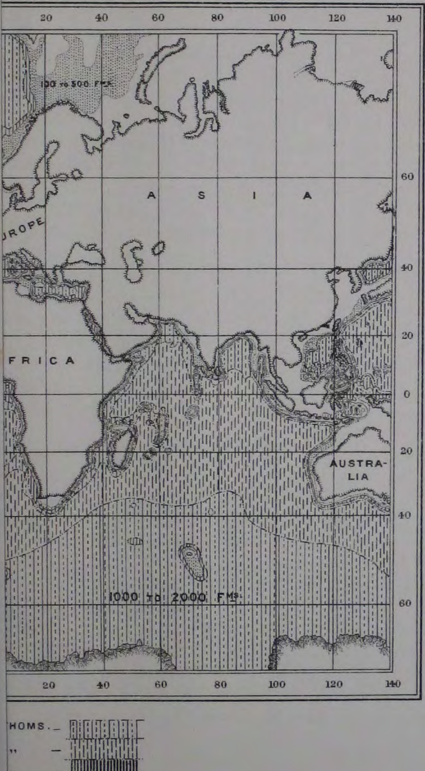
The instrument being then so useful to us, it is important to know its errors. Most of these are doubtless familiar to every one who makes use of the sextant, but there is one very important error which seems to have attracted very little attention, and that is the error of centering.

All sextants have an error of this description, and in good instruments it is usually progressive; being nothing at the zero of the instrument and increasing gradually with the angle, sometimes amounting to 50″ or 60″ at 120°. If it does not so increase, or if it varies, it shows that in all probability there is an error in the graduation as well. These two errors cannot be entirely separated, but the graduation can be tested by trying the vernier at different parts of the arc, when, if the graduation is correct, the zero and last division in the vernier will invariably cut lines on the arc simultaneously.

The plan I usually adopt to obtain the errors of centering is either to measure angles between objects on the land by it, and by Borda's repeating circle, or else to obtain a series of equal altitudes of the sun at all elevations, when the observations, worked as single altitudes, should agree with the results given by the equal altitudes. This is seldom the case, but it will be found that the mean result of the a.m. and p.m. sights always will agree. Consequently, by applying an error to the altitudes until the result agrees with that obtained by the equal altitudes, the error of centering at that altitude is obtained. Then by obtaining a series of results at different altitudes, and drawing a curve of errors, the amount at any altitude or angle can be tabulated. Lately, the authorities at the observatory at Kew have undertaken to test sextants for errors of centering by payment of a small fee, and it would be well before purchasing any instrument to ascertain that its valuation has been so tested, and to get a copy of the Kew certificate attached to the receipt.

ING.

the Ocean Bed.



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PAPER VIII.

MILITARY POSTS IN BURMA.

BY MAJOR A. R. F. DORWARD, D.S.O., R.E.

THE conditions under which the very numerous military posts in Upper Burma had to be designed and constructed were :—

1. The forts to be semi-permanent; to last about two years.

2. The forts to give sufficient interior space to allow of hut accommodation for all troops, and stabling for all horses and ponies, being built.

3. The following scale was adopted in settling amount of floor area to be given to each man :—

	In Barracks.		In Hospital.
British soldiers	... 50 square feet	....	90 square feet.
Native ,,	... 30 ,,	....	50 ,,
,, followers	... 25 ,,	....	50 ,,

Each officer was given a room $14' \times 14'$, with verandahs; and warrant officers, departmental conductors, sergeant-majors, and native officers were given half an officer's quarter each.

4. Cavalry horses were allowed $10' \times 6'$ of stable area; mules, $9' \times 5'$; and ponies, $8' \times 4\frac{1}{2}'$.

L

5. In addition to barracks and stables, the following buildings had to be erected in most posts :—

British hospital. Native hospital for soldiers. " " followers.	With quarters for medical establishment.

British cook-house.
Guard-room.
Night latrines and urinals.
Post and telegraph offices.
Bakery.
Commissariat go-downs.
Transport gear shed.
Officers' mess.

The forts, generally, were built to hold from 50 to 500 rifles. It was, as a protection against fire, and as a sanitary necessity, always arranged to keep the various buildings a considerable distance apart, the result being that the interior space and length of parapet was always out of all ordinary proportions to the strength of the garrison. The shape of fort usually adopted, as requiring fewest night sentries, was as shown in *Plate* I.

Generally, the materials available for the construction of the posts were bamboos, jungle-wood, giant grass, and thorns of great ferocity. In some cases the whole post, with the exception of the earth parapet, was made of bamboo.

The floors of the houses were raised from four feet to six feet above ground level. In some of our earlier posts neglect of this precaution was the cause of much fever.

The barracks and other buildings were carried on large bamboo uprights, or rough jungle-wood posts, spaced about $7\frac{1}{2}$ feet apart. *Plate* II., *Fig.* 1, gives a section of a barrack for British soldiers.

For native soldiers no rear verandah was given, and for followers no verandah at all; but, to keep off wind-driven rain, the eaves were strutted out about $3\frac{1}{2}$ feet from the side walls, as shown in *Plate* II., *Fig.* 2.

Cane, which was nearly always obtainable, was used for the lashings.

The floors were formed of bamboo wattle laid on small whole bamboos placed a few inches apart at right angles to the large bamboo or jungle-wood joists. Owing to the elasticity of the bamboos, the floors moved very easily when walked on. The sunk passage in the centre, up which men walked to their beds, was, therefore, necessary, to prevent men being disturbed in their rest. It also provided a very convenient seat for the men.

The roof covering always consisted of long fans of grass, or bamboo chips, strung together, the ordinary roofing material in Burma.

In hospitals, where rigid floors were necessary, planking was used; also in commissariat go-downs, where the floors were designed to carry a weight of 400lbs. per square foot. Stores in them were generally packed six feet high, with a wide central passage. One-third of the space in them was allowed for passages, weighing room, etc. A very useful formula was used in settling the floor area of a godown.

Let

n	=	number of	British troops	consuming	4lbs.	of food daily,	
n'	=	,,	natives	,,	3 ,,	,,	
n''	=	,,	horses	,,	8 ,,	,,	Without grass,
n'''	=	,,	mules	,,	6 ,,	,,	Without grass,
n''''	=	,,	ponies	,,	4 ,,	,,	Without grass,
n'''''	=	,,	elephants	,,	15 ,,	,,	Without grass,

then the floor area in square feet necessary for a six months' supply godown

$$=4n+3n'+8n''+6n'''+4n''''+15n'''''.$$

This formula was arrived at by assuming the average weight on the floor as 240lbs. per square foot.

The floors of godowns were generally raised about two inches from the ground, and, to guard against fire, the roofs were of corrugated iron.

The gates of the forts, nine feet wide, were generally swung (in two halves) on wooden pintles, as in *Plate* II., *Fig.* 3.

The tops of the gate-posts worked in an iron band firmly tied back to posts sunk in the parapet. Generally, the gates opened outwards, clapping against a large post sunk in the middle of the roadway. If they opened inwards, they were secured against outside pressure by a large beam dropped across them from post to post in slots fixed to the posts. If an iron band was not available for the tops of the posts, a wooden cap was used (*Plate* II., *Fig.* 4).

As most of the attacks by the Burmese on our posts were made during construction, it was important that the defences should take as little time in completion as possible. Our chief difficulty, owing to the want of skilled labour, was in the revetments. Bamboo hurdle revetments could be quickly made, but were very temporary, and the heavy rains washed the soil through them, and planks and bricks were only occasionally available.

Plate II., *Fig.* 5, shows a section very generally adopted when we had to rely on bamboos and thorns, as was often the case; in it revetments are done away with altogether.

The Burmese are particularly skilful in running up very quickly any form of bamboo stockade, and the small amount of earthwork necessary in the pattern section was usually done by the garrison.

The bamboo spikes are placed about a span apart, and are from nine inches to one foot long, with about half their length stuck in the ground. When sharply pointed and charred, they present a formidable obstacle to even British troops with boots on. They would be useful in any campaign, and could be easily carried in bundles. They are destruction to horses.

The commonest thorns in Burma are sharply curved, and resemble the "Wait-a-bit" of Africa. They are particularly obnoxious to Burmans, whose flowing garments and loose slippers are sure to get inextricably hooked up in them. They form the common defence of almost every village in Upper Burma.

It was at first thought that the thorns in rear of the bamboo stockade would catch fire from rifle flashes, but they never did, although they burned readily when set fire to and dry. They can very well be replaced by bamboo spikes.

A few strands of barbed wire in the upper part of the bamboo stockade greatly increases its use as an obstacle, and in savage warfare the obstacle is of chief importance.

A very useful and permanent revetment can be made of the great river grass (Kaing grass) of Burma. This grass has the power of throwing out roots at each node, which occur at distances of from nine inches to one foot six inches on the stem; its average height is from 9 to 10 feet. The grass is made up into fascines, and placed in the revetment in the ordinary way. The foundation roller, or fascine, is generally made about two feet thick, the other ones about 10 inches.

To make a roller, or fascine, take a bamboo from 18 to 20 feet long, and from two to three inches thick. At lengths of about 18 inches on the bamboo attach strings of grass or coir rope, or cane, and arrange the strings on the ground at right angles to the bamboo, and spread over them a thin layer of the thinner stems of grass at right angles to the strings (*Plate* II., *Fig.* 6). The layer should not be thicker than is necessary to hold up a very thin layer of damp clay, which is spread over it. Now place men along the bamboo as close together as they can stand, and also place a man at the end of each string. The men holding the bamboo proceed to roll it up, care being taken that they move evenly, and that the men at the ends of the strings keep them tight and parallel; the strings are then racked off, and the roller is ready for use. If properly made, when the clay dries it will be found very difficult to drive a peg into them. The grass will grow in any soil, even pure sand, if it be moistened at first. The roots soon extend into the parapet, and knit the rollers firmly into it. It is only necessary to water it from time to time, and to keep the grass cut. I feel sure that if large rollers were used this revetment would be very useful in the embrasures of fieldworks.

The Royal Engineer officers in Upper Burma were also largely employed in the construction of more permanent works, *e.g.*, in the construction of permanent barracks and their subsidiary buildings at Mandalay and Bhamo, the fort at Bhamo, and the drainage of Mandalay city; also in the construction of hill roads to the Ruby Mines and the Shan Plateau.

In the hill forts, where the cold forbade the use of bamboo wattle work, the walls were made of timber, brick-in-mud, or mud. Kerosene oil tins, or ghee tins placed on small iron tripods and bored full of holes, were used as charcoal burning stoves, or brick fire-places of the Indian Military Works pattern were built at the ends of the huts, the chimney being increased in height by the use of ghee tins to carry the sparks well into the air, there being great danger from fire caused by sparks falling on thatched roofs.

In the fort at Bhamo, the parapet, made of earth with a brick revetment, was about a mile and a quarter in perimeter, the crest of the parapet being at one level throughout, and always 16 feet above the bottom of the ditch.

The height of the parapet, of course, varied with the ground level, the minimum being $4\frac{1}{2}$ feet.

The site was fairly level, but intersected freely by deep nullahs from 15 to 20 feet deep.

These nullahs provided completely for the site drainage, and for that of the ditch. They were crossed by iron spiked railings, 10 feet high, stepped down the nullah sides. The railings allowed ample passage for the drain-water, and were a fairly efficient obstacle. The nullahs outside the fort were searched by timber blockhouses and crows' nests about 20 feet high.

The permanent barracks in Mandalay and Bhamo were built entirely of teak wood with iron fastenings, and so also were the various out-houses, with the exception of the cook-houses, which were built of rubbish or brick-in-mortar, or, at Bhamo, of corrugated iron. The roofing was formed by teak shingles 10 inches by 5 inches.

At posts, generally, along a line of communications, where it was only necessary to establish a few men, timber blockhouses were erected. These were very efficient works, the credit of the design being chiefly due to Mr. Richard, of the Burma P.W.D. This design is shown on *Plate* III.

Both in our permanent and temporary works concrete was largely used. It was important to find an efficient but simple system of moving and laying it, owing to the totally unskilled labour available, and the want of machinery of any sort. The mortar consisted of one lime to two sand. Small conical heaps, consisting of alternate layers of sand and lime in the above proportion, were made on some fairly hard, clean platform. These heaps were then turned completely over by native hoes, and other heaps formed with the material completely reversed, *i.e.*, the sand and lime at the apex of the first heap now formed the base of the second. These second heaps were again similarly pulled back into their original positions, and a section of the cone always showed the materials to be thoroughly mixed. The mortar was then given 60 turns in an ordinary bullock mill, and was ready for use.

Over all the spaces on which concrete was to be laid, except six feet at one end, which was kept clear, little heaps of two baskets of broken stone were laid with their bases just touching; on these heaps a basket of mortar was next put, and above the mortar another basket of stone. The whole of the heaps were then pulled through a space of six feet, and back again to their original position, and the mixture was found to be very thorough.

The concrete was then rammed for about four hours with light wooden rammers. It is important that the ramming should be done continuously, as any ramming after the lime has begun to set tends to shake up and loosen the mixture. It is best to keep the three processes of laying, mixing, and ramming perfectly separate.

The old city, now the cantonment, of Mandalay is surrounded by a thick brick wall, about 20 feet high, and by a moat about 150 feet wide, and from 7 to 17 feet deep. Inside and against the wall was a broad earthen rampart. It was necessary to carry the city drainage water under the wall and moat, and then down one of the Mandalay streets to a large drain called the Shoay-ta-Choung.

Inside the city the drainage water was carried by open earthen drains, running into a tunnel, which extended from the city rampart down to the Shoay-ta-Choung, a distance of about half-a-mile. The section of the tunnel was as shown in *Plate* II., *Fig.* 7. It was built entirely of brick and concrete, the bricks being procured from the numerous walls that had to be pulled down inside the city.

The bricks were of the very poorest description ; the inside of the tunnel was consequently plastered.

The information regarding the annual rainfall in Mandalay was naturally very meagre, and none whatever was obtainable about the maximum fall in a day. Such information as was obtainable indicated an annual fall of from 30 to 40 inches, and it was decided to make the tunnel capable of carrying off a $\frac{1}{4}$-inch of rainfall over the whole drainage area in one hour. Manholes, 4 feet by $1\frac{1}{2}$ feet, were placed along the tunnel about every 200 feet.

The occupation of the Ruby Mines Hills and the Shan Plateau rendered hill roads necessary. At first only mule tracks were attempted. The minimum width of these tracks was seven feet, and the maximum gradient 1 in 7. The great difficulty on the Ruby Mines road was the laying of it out. The undergrowth, principally cane and bamboo, had to be cut as the work proceeded, as it was in places perfectly impenetrable, and the high trees prevented views of any saddle or other landmark where the road must pass being obtained, except from a few and far distant points. The consequence was that many trial lines had to be run before a feasible one was obtained, many days of labour simply resulting in the knowledge of the uselessness of running the line in one particular direction.

The Ruby Mines road, almost throughout, ran through an intensely feverish country, and dreaded by the Burmese, so that the greatest difficulty was experienced in procuring labour, and the death rate among the coolies was very high. The length of the road was about 60 miles. Much of it ran through soil, and its execution was rapid. Near the Sanitarium of Bernardmyo there is a large forest where the rainfall is about 200 inches per annum, and the soil is the richest leaf mould, from five to seven feet deep, lying on a sandy substratum. The mistake was made of cutting away only enough of the soil to form a 7-foot track, and the result was that it became, after a little traffic in the rains, simply an impassable bog. Some transport mules were actually drowned in the slush when attempting to use it. The road was then cut down to the hard sandy bottom, and afterwards answered its purpose very well.

Only one river of any size had to be crossed, and this was done at a narrow place by a suspension bridge of 50 feet span. The joists carrying the roadway were suspended by $\frac{1}{2}$-inch iron rods from an old telegraph cable found in Mandalay on our arrival there. The time available was far too short to allow of the construction of a stronger timber bridge, and the old cable was used of necessity, not from choice, but with much apprehension of failure, as our only chance of getting the bridge completed in the time available. It did its work, however, very well.

The hill roads to the Shan Plateau were much easier to lay out owing to the comparative absence of undergrowth, but much harder to construct, as much blasting and building up was necessary. Guncotton, dynamite, and powder were all freely used, dynamite proving to be far the most satisfactory blasting agent.

The cart road to the Shan Plateau was a work of considerable magnitude. The maximum gradient was 1 in 20, and the minimum width 15 feet. Much of it ran through very hard limestone, and in one place it passed for 80 yards along the face of a precipice about 50 feet from its foot. The precipice was about 300 feet high and nearly perpendicular, and that portion of the road kept a company of Madras sappers steadily boring and blasting for about six weeks.

The bridges on the road were made 13 feet wide. Suitable trees were felled so as to fall across the larger nullahs, and the roadway, formed of teak-wood joists and 3-inch planking sent from Mandalay, was laid on them. The smaller streams were passed through dry stone culverts, or pipes made of sheets of corrugated iron. The sheets can be rolled into pipes of about two feet diameter, and make very efficient drainage pipes. They are easily carried, and will always prove useful on active service, as they save so much time in bridge construction. For cart traffic, to prevent injury to the pipes, it is well to have at least two feet of soil above them.

By far the most convenient clinometer for laying out the hill roads was found to be De Lisle's (I am uncertain about the spelling of the inventor's name). It can be set to the required slope, is very simple, is not liable to get out of order, and admits of very rapid work.

Part of the cart road on the plateau ran through a somewhat extraordinary formation, a bog on a steep hill side. This part, about a quarter of a mile in length, gave much trouble. The bog was found to consist of a peaty soil, of depth varying from six inches to six feet, lying on hard blue limestone rock, and possessing a uniform surface slope. Two deep side drains were first blasted through the rock, and the metal got from the blasting laid between them for the road surface. In a very short time the metal disappeared, and the bog resumed its place. A further deepening of the side drains, and the addition of more metal, did very little good. A small portion of the bog was then carefully examined, and the limestone substratum was found to be pitted with conical holes, which did not connect with each other, and from which the water could not escape. Some of these holes were five or six feet in depth, and the proper method of making the road would have been the complete removal of the overlying soil, and the filling up of the pockets with good soil or broken stone, or by the blasting away of the partitions and bridging over the cross drains so formed.

As regards the military operations, the most marked points were the value of mounted infantry for all day work in pursuit of dacoits, and of night marches for infantry. The dacoits rarely dared to meet our troops in the open country, but preferred a prepared position in jungle. Our chief losses occurred in coming unexpectedly on one of these positions on the march. These positions were rarely at any time surprised, our want of knowledge of the ground round the position, and the absence of any but one or two paths, militating against success; but when news arrived of dacoits having occupied a village, a night march was often employed with success. The conditions necessary for success were the employment of good guides, of a small force, the absence of all baggage, the stationing of officers at fixed points along the column to look after the keeping of the track, the marking of the track to be followed at cross roads by torn paper, and absolute silence.

In an advance through jungle in the day time, it was found necessary, for the protection of the guide (frequently only one could be obtained), to have flankers in the jungle on both sides of the path considerably in advance of the leading men in the centre of the advanced guard. The dacoits usually prepared a position at a bend in the path, from which they opened fire at short range on the leading files of the advanced guard, and frequently succeeded in shooting the guide, always one of their great objects. The forward flanking files were useful in turning this position, and causing its instant evacuation. This formation of an advanced guard seems to me to have certain advantages in all cases over the authorized one. When used, delay at villages, woods, etc., is lessened, all such positions being turned in the ordinary course of the march.

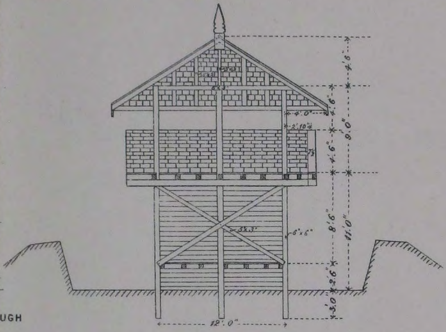
Its disadvantage consists in the advanced flankers being at a considerable distance from the central support. A special support placed in rear of them has difficulty in keeping up in a broken or wooded country, and unduly increases the number employed with the advanced guard. In impenetrable bush, the whole force was obliged to move on the paths, often in single file, and the position of the leading man was very trying. The guide, of course, should never be allowed to occupy that position. In such cases the dacoits often cleared a position in the bush parallel to the line of march at about 10 yards distance, and opened fire from it as the column passed. If artillery accompanied the force, they generally waited till they heard the mules, and opened fire on them, with the hope of creating a stampede along the narrow path. On such paths even a small force occupied a considerable length, and any individual control of the whole force was out of the question. The tendency of the men was to lie down and blaze aimlessly away into the jungle, and in such cases the most valuable officer was the one who would do something, it hardly mattered what, with the object of getting into the bush, and at the back of the enemy's position. If firing could be prevented, and perfect silence kept, it had an intimidating effect on the dacoits, who in such cases rarely remained long in position. If dacoits were known to be in ambush near such a wood, which the force had to pass through, it was best to send a few native troops accustomed to jungle work, such as the Ghoorkas, to explore in front of the force. Twenty men were generally sufficient, and, being much scattered, such a small body rarely suffered loss. European soldiers, who never seem to be able to advance quietly, and whose dress is unfitted for movement through thorny bush, were not of much use for such work, but the Ghoorkas, nearly naked and armed only with their kookries, delighted in it, and the training acquired in youth in their own jungles, their silent and yet combined movement, together with their native propensity to creep up and kill, rendered them peculiarly suited for it.

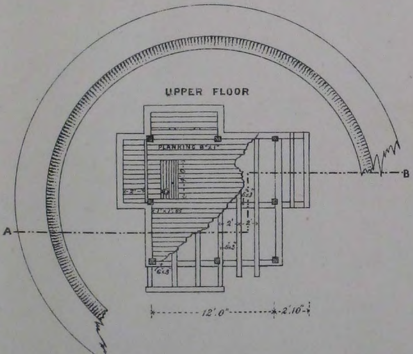
These jungle marches were often, indeed generally, carried out by very small forces, from 50 to 100 men or so, under the command of very junior officers, who, in the endeavour to surprise a body of dacoits, had to plan and carry out the whole operation. The lessons in mimic strategy and tactics so gained will certainly bear fruit in our future wars, many of our junior officers having so acquired a confidence and readiness of resource, which will be invaluable to our army when they are employed in higher positions and more important operations. I do not believe that any war of late years has been so valuable, from an educational point of view, to the younger officers of the army than the Burma Campaign.

PLATE I.

DETAIL PLAN.

CROSS SECTION ON A.B.





PAPER IX.

ELECTROMOTORS AND THEIR APPLICATION TO ELECTRIC TRACTION.

By G. Kapp, Esq., M.I.C.E.

The subject which I have the privilege of bringing before you forms a special branch of electric power transmission, and let me state at once, as far as this country is concerned, the most important branch at the present time. The transmission of large powers between fixed points is of paramount importance in countries like Switzerland, Italy, or the United States, where water power is abundant; but this is not the case with us. Here the most important problem of transmission is that between a fixed point (the generating station) and moving points (the cars), and electricity as the vehicle of power is adopted, not because it affords the best means of utilizing hitherto unaccessible sources of natural power, but simply because it is the most convenient and flexible transmitting agent we at present possess. Electric traction may, therefore, be described as power transmission in small quantities over constantly varying but generally short distances. Hence, before entering upon the details of the various methods employed for utilizing electric power for traction purposes, it will be necessary to briefly glance at the general problem of electric power transmission.

The general principles of this are based upon two experimental facts: the one discovered by Oersted, and the other by Faraday.

Oersted found that an electric current passing along a wire in the neighbourhood of a compass needle will, under certain conditions, deflect the needle, the deflection being due to a mechanical force acting between the wire and the needle. Faraday found that it was possible to produce a transient current in a closed conductor if a magnet was moved in its neighbourhood; in other words, that relative motion between a magnet and a conductor produced an electromotive force, for it is impossible to obtain a current without previously setting up an electromotive force. The compass needle and the magnet may be regarded as the sources of a magnetic field, that is, of a space through which flow magnetic lines of force, and we may, therefore, state the laws revealed by Oersted's and Faraday's discoveries as follows :—

Production of Mechanical Force.—A wire passing across the lines of force of a magnetic field, and traversed by a current, is acted upon by a mechanical force tending to displace it parallel to itself, and at right angles to the lines of force. The magnitude of the force in dynes is given by the product $\mathrm{H}lc$, where H is the strength of the field in C.G.S. measure, l the length of the wire in centimètres, and c the current, also in C.G.S. measure. It is assumed that the wire is straight, and placed at right angles to the lines of the field.

Production of Electromotive Force.—If a straight wire passing at right angles across the lines of a magnetic field be displaced parallel to itself, and at right angles to the lines, an electromotive force is set up in it, the magnitude of which, in C.G.S. measure, is given by the product $\mathrm{H}lv$, where v is the velocity of the wire in centimètres per second.

The dyne is too small a unit for practical work, since in our latitude no less than 981,000 dynes are required to represent the force of one kilogramme. The C.G.S. unit of electromotive force is also too small, being the hundredth-millionth part of a volt, whilst the C.G.S. unit of current is 10 ampères. All these units are more or less of inconvenient magnitude, but we can easily transform the formulas so as to obtain the results in practical units. We thus find that the force in kilogrammes, and the electromotive force in volts, are given by the following expressions :—

$$\text{Kilogrammes} = \frac{\mathrm{H}lc}{9,810,000}.$$

$$\text{Volts} = \mathrm{H}lv10^{-8}.$$

We have seen that the electromotive force is due to the movement of the conductor across the lines of the field; in other words, to the fact that the conductor cuts lines of force. Let us now illustrate this by an example. You know that the earth is a magnet, and has, consequently, a magnetic field surrounding it. Any conductor moved along the surface of the earth so as to cut its lines of force must, therefore, become the seat of an electromotive force. If the conductor is horizontal and we move it parallel to itself, it cuts the vertical component of the earth's field, and if we let the ends of our conductor slide along two fixed parallel metal bars we can collect from them a current flowing under the electromotive force produced in the moving conductor. The rails on an ordinary railway may very well represent our fixed bars, and the conductor sliding over them, which I shall in future call the slider, may be simply a crow-bar thrown across the track (*Plate* I., *Fig*. 1). Now attach the slider to a train and haul it along the line. What electromotive force will be produced between the two rails? This depends, of course, on the speed of the train, on the gauge of the line, and on the vertical components of the earth's field. Taking the latter at ·87, the speed at 45 miles per hour, and the distance between centres of rails at 4 feet 10 inches, we find that the electromotive force is very nearly the one-thousandth part of a volt. If the earth's field were 10,000 times as strong, that is to say, 3,700 C.G.S. lines per square centimètre, then we should have 10 volts between the ends of our slider. Now it so happens that the strength of field in modern dynamos and motors is about 3,700, and that the circumferential speed of the armature ranges between 2,000 and 6,000 feet per minute, or, say, averages 4,000 feet, which is almost exactly the speed of our train, namely, 45 miles per hour. As each armature wire may be considered to be a slider in the sense I have defined before, we see that, under the conditions stated, the electromotive force of every foot of active armature wire is about two volts. Let us now return to our railway over which a slider is made to move by being attached to a train. We have seen that the electromotive force of the slider is exceedingly small, but let us for the moment assume that by strengthening the field, or by some other device, we can get any electromotive force we like. Let the train itself be insulated from the rails so that there shall be no leakage of current, and let at some other part of the line be a second slider, to which a train is attached. Here you have the most simple imaginable system of electric propulsion. The electromotive force produced in the slider dragged along by the first train causes a current to flow along the rails to the other slider, to which the second train is attached. Since the second slider is also in a strong magnetic field, and is traversed by a current, there will be a mechanical force acting upon it tending to displace it parallel to itself, that is to say, the slider will move forward, dragging its train behind it. The second slider is, in fact, an electric locomotive. Now let us examine this very simple system of electric traction a little more closely. We have seen that where we have to deal with conductors and magnetic fields, movement produces electromotive force, and current produces mechanical force. In moving the first slider, our object is to generate an electromotive force which shall cause a current to flow. We get it, but we get something else besides, namely, a resisting force which has to be overcome by the propelling machine. This means expenditure of power, but it is important to note that, apart from frictional losses, this expenditure is strictly proportional to the current. If there is no current, we may move the slider as fast as we like, and generate any amount of electromotive force, but we spend no power. This would be the case if we lift the second slider off the rails so as to interrupt the flow of current. Now let us put the second slider back, and a current immediately flows. What we desire to get is a mechanical pull which shall haul the second train along. This we get, but we get something else besides. The second slider, when in motion, generates also electromotive force which, it is obvious, must oppose the electromotive force generated by the first slider, and thus to a certain extent check the current. Thus, as the speed increases, we get a reduced pull, and that is just what we want. To start the train, we must have the greatest pull, and to keep it in motion a smaller pull will do. Now what is the power expended in the first and that recovered from the second slider. For the sake of simplicity, let us assume that the strength of the magnetic field is the same in both. Then the pull will be also the same in both, and the electromotive force will be proportional to the speed. It is obvious that the electromotive force of the first slider must exceed the opposing electromotive force of the second slider by just that amount which is required to overcome the electrical resistance of the circuit. The product ratio of pull with speed is the mechanical energy for each slider, and since the pull is the same in both, we find that the ratio of the speeds gives the efficiency of the system.

Thus far our investigation is mere theory, not realizable in practice. We cannot spread a strong magnetic field over miles of railway, nor would the rails be capable of transmitting the prodigious currents which we would require to get a sensible mechanical effect with the low electromotive force which a single slider can develop. Now let us see how we can make our transmitting system more practical. In the first place, we get over the difficulty of the field by carrying it with us on the train. Instead of employing a slider moving in a straight line, we can use a revolving slider, and collect the current from the centre of a circular conductor, as show ninthe diagram (see *Plate* I., *Fig.* 1). We might produce the motion by gearing this slider with the wheels of the first train, but this would be a clumsy device. We would do better to connect it by a pulley and belt with a fixed steam engine established at some convenient spot near the line. As regards the second slider, this must, of course, be geared with the wheels of its train. By using a revolving slider, or, in technical language, a non-polar dynamo, instead of the progressive slider, we have got over the first difficulty I mentioned, but not over the second, since the electromotive force of non-polar dynamos is, as you all know, far too small for our purpose. We may, however, employ a whole series of revolving sliders suitably combined, and thus get a sufficiently high electromotive force. In other words, we may employ ordinary dynamo machines to act as generator and motor, and thus at once arrive at a practical solution of our problem. In *Plate* I., *Fig.* 1, N S represent the magnetic fields of each machine, and the circle its armature. The dotted lines are the conductors along which the current is transmitted from the generating dynamo to the motor dynamo. As far as the latter is concerned, it is obviously immaterial how the current is generated. So long as we supply the motor with current flowing under a suitable electromotive force, it will rotate and give out power. If, therefore, we find it inconvenient to have these connecting wires between the motor and the generator, we can replace the latter by another source of current carried on the train. Such a source of current is a storage battery, and we thus arrive at what is known as storage cars, which are in use on several tram lines in this country and abroad.

I have here given you a rapid sketch of what may be termed the evolution of electric traction from first principles, and must now bring before you some of the details required in its practical working. The subject naturally divides itself into four headings: the generating dynamo, the connecting link (conductors or batteries), the motor, and the gear, both mechanical and electrical. As, however, time will not permit to treat all these matters exhaustively, I must content myself with putting before you the theory of the electromotor only in so far as it concerns the application of the motor to traction, and a general description of the most important methods of conveying the current to the motor and the accessory appliances used in practice.

The Electromotor.

The primary object of the electromotor is to produce a propelling force, or to produce a twisting couple on the wheels of the car, by virtue of which the car is propelled. It is therefore necessary to begin the investigation by determining the twisting moment or torque produced in the armature of the motor. Having found this, we can determine the torque on the car wheels from the speed ratio between them and the armature, taking due account of the losses in the gear. Take as an example an ordinary Gramme machine as shown in *Plate* I., *Fig.* 2. The current entering at one brush splits in two halves, which traverse successively the coils on either side of the diameter of commutation and unite again at the other brush, where they leave the armature. If you follow the current, you find that all the wires between the armature and one pole-piece carry current in one direction, and all the wires under the other pole-piece carry current in the opposite direction. Since on the two sides both the direction of current and the sense in which the lines of force flow are reversed, the mechanical effects are added, both tending to rotate the armature in the same direction. The currents flowing through the inside wires produce no torque because they are shielded from the poles by the intervening mass of the armature core, and we may, therefore, neglect to take into account these inside wires, or we may wind the armature drum fashion, which is in so far preferable, as we save some wire and avoid certain disturbing effects, due to the internal turns, about which I shall have something to say later on. For our present purpose it suffices to note that the torque is only due to the outside wires, and that the same theory applies to Gramme, or, as they are also called, "cylinder armatures," and "drum armatures." Before entering into the theory, let me say a few words about the methods of representing drum windings. As a general rule, diagramatic representations are more easily understood than written instructions, and in text-books on dynamos, drum windings are always illustrated by diagrams, but care is taken to make the illustration very simple by assuming that there are only a very few conductors on the armature. In practical work we have, however, to deal not with 6 or 8 conductors, but with 100 and more, and if you attempt to draw a diagram for such a number, say to serve as an instruction to the winder, you will get such a maze of lines all crossing one another as to make the diagram quite unintelligible. I have found it possible to get over this difficulty by substituting a written table for the diagram. Say we have an armature with 100 conductors. Looking at the armature from the commutator end the winding may be thus described :—Down wire No. 100, then across back and up wire No. 49. Then across front, then down wire No. 98, across back, up wire No. 47, and so on. This is shown in the table, where D and U represent down and up wires respectively, and F and B the front and back connections. A glance at the table will

DRUM WINDING.

F	B	F	B	F	B	F	B	F	B	F
D	U	D	U	D	U	D	U	D	U	
100	49	98	47	96	45	94	43	92	41	
90	39	88	37	86	35	84	33	82	31	
80	29	78	27	76	25	74	23	72	21	
70	49	68	17	66	15	64	13	62	11	
60	9	58	7	56	5	54	3	52	1	
50	99	48	97	46	95	44	93	42	91	
40	89	38	87	36	85	34	83	32	81	
30	79	28	77	26	75	24	73	22	71	
20	69	18	67	16	65	14	63	12	61	
10	59	8	57	6	55	4	53	2	51	
100	49	98								

show you any connection far clearer than would a diagram. Thus, if you take for example wire No. 15, you find that it is connected in front with 64, and at the back with 66. The table also shows how the pressure increases from wire to wire. Thus assume that the current enters at the commutator strip, to which wires 49 and 98 are connected. The current must, therefore, leave the armature at the commutator strip between 99 and 48, and in going through the table to the right of 98 and to the left of 49 (the latter is reproduced at the bottom of the table), you will see how the pressure increases wire by wire. You will also see that the pressure is a maximum between neighbouring wires on the diameter of commutation, a fault common to all systems of drum winding, necessitating great care in the matter of insulation.

After this excursion into the practice of winding armatures, let me go back to the theory of the torque produced by the current. Let, in *Plate* I., *Fig.* 3, N S represent the poles of a motor, and let O O be the diameter of commutation. The active wires on the armature are seen end on, and fill the space enclosed between the two circles. The current in all the wires to the left of O O is downwards, or into the paper, whilst that in all the wires to the right of O O is upwards. The individual wires are of course insulated from each other, but the insulation is not shown. The total effect of the currents is as though we had on the left of O O a semi-circular sheet of current flowing down, and on the right a similar current sheet flowing up. Let τ be the total number of wires counted all round the armature, and R the radius of the armature, then the space occupied by one wire is $\frac{2 \pi R}{\tau}$. To find the torque we have now to add the pull exercised by the current on each wire, and multiply with the radius. If the distribution of magnetic lines of force were perfectly uniform over each semi-circle, each wire would contribute the same amount to the total force, and our calculation would be simple enough. The distribution is, however, not uniform, and what is worse, we do not know in what manner it varies. In the first place, the pole-pieces do not embrace a half circle, and even if they did, it by no means follows that from each square centimètre of their area there project into the armature the same number of lines of force. In the second place, the configuration of the field magnet circuit, which is not even represented in the diagram, must to a certain extent influence the distribution of lines. On this head we make no assumption whatever beyond saying that all the lines coming out of N enter the armature somewhere on the left of O O, and all the lines coming out of the armature to the right of O O enter S. Designate the length of the armature by l and consider one wire. Through this wire flows the current c. The pull $\triangle$ P exerted by this wire is the product of $l\ c$, and the strength of field in that particular place. The latter we do not know, but let us call it H. Now it is evident that the number of lines which pass into the armature through the space covered by this wire is

$$\triangle F = \frac{2\,\pi\,R}{\tau}\,Hl\,;$$

and since

$$Hl = \frac{\triangle P}{c}\,,$$

we can also write

$$\frac{2\,\pi\,R}{\tau\,c}\triangle P = \triangle F.$$

Now imagine the same equation written out for every wire on the left of O O, and all these equations added. We would thus obtain on the right the sum of all the small fields $\triangle F$, which is obviously nothing else than the total flow F of lines out of N ; and on the left we get a constant multiplied with the sum of all the pulls of the wires, that is, the total pull P of all the wires, or in symbols—

$$\frac{2\,\pi\,R}{\tau\,c}\,P = F.$$

The total torque is 2 R P, and this is found from the previous equation in dyne centimètres—

$$2\,R\,P = \frac{F\,\tau\,c}{\pi}.$$

You see that it is not necessary to know the exact manner in which the field is distributed ; all we require to know is the total strength of the field, the number of armature wires, and the current flowing in one wire. If we have to deal with two-pole machines (which are mostly used for traction work), the current in one wire is half the total current, and we can, as a matter of convenience, insert this instead of c. At the same time, we may bring the formula into a more practicable shape, giving the torque in kilogramme-mètres or foot-pounds. I need not waste time by going through the arithmetical operation, but simply state the result, which is

$$\text{Torque}\begin{cases}\text{Kilogramme-mètres} = 1{\cdot}615\,F\,\tau\,c\,10^{-10}.\\ \text{Foot-pounds} \qquad\quad = 7{\cdot}05\,Z\,\tau\,c\,10^{-6}.\end{cases}$$

In these formulas the current is given in ampères, and F is the total strength of field in C.G.S. lines. You will notice that in the second equation a new symbol Z has been introduced instead of F.

This is merely for convenience when we are obliged to use English measure. The C.G.S. unit of magnetic flow is so very small that millions are required to represent the strength of field found in modern machines, and although the beautiful simplicity of the C.G.S. system renders the use of large figures quite easy, this is not the case when we are compelled to use the inch instead of the centimètre. To meet this case I have adopted a unit for field strength, which is 6,000 times greater than the C.G.S. unit, and Z in the formula here given represents field strength in these English lines.

I would invite your attention for a moment to a practical lesson which may be learned from an inspection of the torque formula. You will see that nothing occurs in the formula relating to any particular shape of armature. At one time it was thought that the great thing to aim at in a motor was to make its armature a strong magnet, and many would-be inventors have wasted time and money in devising all sorts of peculiar shapes intended to give the armature strong poles so as to get a powerful mechanical effect. All these devices are useless. What we want is a strong current, many wires, and a strong field. Even the diameter is not directly of influence, but indirectly it is of influence, namely, in so far as a larger diameter enables us to get more wire on to the armature, and may enable us to use a stronger field.

We have seen how to calculate the torque of a motor, or, what comes to the same thing, the propelling force on a car to which it is geared, but before we can apply the formula we must know what value to take for F, the field strength. The number of wires you can count, the current is either determined by the source or by the capacity of the armature to pass it without undue heating, and as you are all familiar with Ohm's law I shall not go into this matter further, except to point out that you may allow in electromotors used for traction a greater rise of temperature than would be safe with motors or dynamos which work in a room. Experience has shown that the rise of temperature above that of the surrounding air in stationary machines is given in degrees Fahrenheit by the formula $T^{\circ} = 65 \frac{W}{S}$, where S is the external surface of the armature in square inches, and W the number of watts transformed into heat.

There remains yet to determine the strength of the field. This you may either roughly estimate or calculate carefully. Generally you do both ; you estimate first what will be the strength of field which may be reasonably expected with a given armature, and then you calculate what exciting power in ampère turns you must employ on the field magnets to get this strength of field. The induction in armature cores, that is, the number of lines of force passing through one square centimètre of core, varies between 12,000 and 20,000. If you employ a smaller induction you get too large a machine for its power, and if you employ a larger induction you require too much exciting wire and too much exciting energy, thus increasing the first cost and decreasing the efficiency of the machine. What particular induction should be chosen in each case is a matter which must be determined for each case, but it would take too much time were I to attempt to discuss this subject fully. To do so would mean giving a complete theory of the magnetic circuit and its application to dynamo electric machines. I will, therefore, merely state that for each machine there exists a definite relation between the exciting power and the field produced, which is most conveniently represented by a curve, such as shown in *Plate* II., *Fig*. 5, which represents the characteristic of magnetization of a motor intended to be used on an electric locomotive. The points of the curve are obtained by plotting exciting power in ampère turns on the horizontal, and field strength on the vertical. Though such a curve can be predetermined from calculation, this particular curve has been found from experiment with the finished machine, and to explain how this is done I must refer for a moment to the relation between field strength and electromotive force, for it is by observing the latter that we arrive at the former quantity when making such experimental investigations.

Just as all the mechanical forces acting on the armature wires on one side of the line, O O (*Plate* I., *Fig*. 3) are added, so are also added the electromotive forces generated in these wires by virtue of their cutting the lines of the field at a certain speed. With some slight modifications, the method which I used for arriving at the total pull will, therefore, be suitable for arriving at the total electromotive force. These modifications are so simple and obvious that I need not go through the mathematics a second time, but may at once state the result. Calling E the electromotive force in volts and n the speed of the machine in revolutions per minute we obtain

$$E = F\tau \frac{n}{60} 10^{-8}.$$

$$E = Z\tau n 10^{-6}.$$

Before discussing this equation, let us for a moment go back to the torque formula. We have seen that the torque is proportional to the strength of field and to the current. Now torque multiplied by speed represents mechanical energy, and the latter is, therefore, proportional to the product ZCn. But the two factors Z and n occur also in the formula for the electromotive force, which is proportional to their product. We thus find that the product of current and electromotive force represents energy, a result in perfect accord with the fundamental conception of the slider, as given in the beginning of this lecture. In practical measure the electrical unit of energy is the volt-ampère, or "watt," and this represents the 746th part of a horse-power, or 746 watts make up one horse-power. To find the H.P. represented by a current, we multiply it with the potential difference under which it flows, and divide by 746. For greater convenience—making the reduction from watts to H.P.—Mr. Reckenzaun has devised a graphic method, which is shown in *Plate* I., *Fig.* 4, and which is self-explanatory.

Now to return to the electromotive force formula. We know the number of turns on the armature, and we observe the speed and electromotive force at various exciting powers. This gives us the strength of field corresponding to those exciting powers, and we can thus plot the curve of magnetization, or, as it is also called, the characteristic of magnetization (*Plate* II., *Fig.* 5). I should have mentioned that in making these experiments we must only allow a small current to flow through the armature, in order that the observed pressure at the brushes may truly represent the internal electromotive force. If the current is large some electromotive force will be lost in resistance, and in addition there will be produced a certain alteration and distortion of the field, due to the armature current. The latter effect is more particularly noticeable in machines having cylinder armatures and small field magnets. The wires inside the cylinder produce a magnetic field of their own, and this is a cause of sparking at the brushes, additional to the other causes of sparking, which we find in drum machines. To get rid of sparking, we must shift the brushes backward rather farther than would be required in drum machines, and thus we lose some of the lines which would otherwise help in producing electromotive force. In other words, the F or Z in our formula will be somewhat decreased as the current and the work done by the motor increases. Another effect of the inside wires in a cylinder armature is that the internal field produces heating in the shaft and other metal parts between the shaft and the armature core. This, of course, means loss of power. Nevertheless, cylinder armatures are generally preferred for traction work because the insulation is more easily obtained, especially in small machines, wound for high pressure currents. An important practical lesson may be learned from analyzing the expression which I have just given. Suppose we have to do with a shunt machine worked on a constant pressure circuit, then the exciting power will be constant, and F would be constant if the disturbing effect of the armature, of which I have just spoken, were absent. But since this distributing effect can never be entirely avoided, it follows that as the current increases, F will be slightly decreased. If we wish to preserve the speed constant we must arrange for a slight drop of electromotive force. Now this is exactly what happens in actual work. The electromotive force E must be overcome by the pressure in the supply circuit, and is, therefore, equal to the difference which remains, after deducting from the constant supply pressure the electromotive force required to overcome the ohmic resistance of the armature. The greater the current, the less electromotive force remains for the armature, and if we can so design the machine that the electromotive force lost in resistance equals the electromotive force lost in armature re-action, we obtain a motor which, on a constant pressure circuit, will run at a constant speed, though its mechanical load may vary within wide limits. It so happens that this condition can be easily fulfilled in ordinary shunt machines, the resistance loss in which can be kept within five per cent., whilst loss of electromotive force due to armature re-action need not much exceed this limit. A shunt machine forms, therefore, a very good self-regulating motor, a fact first discovered and published by Mr. Mordey some years ago. I come now to consider

The Application of the Electromotor to Traction Work.

Shunt machines are not of much value in traction work. Their constancy of speed, to begin with, is not required, and, in fact, not desirable. We do not want to tear up hills at the speed of level running, but are content to go a little slower, and thus keep the expenditure of power within reasonable limits. The great drawback to shunt machines is, however, their want of starting power. If we have a series machine, the conditions of working are far better. At starting, when there is the first rush of current, we at once obtain the strongest possible field and a maximum torque, whilst as the car gets under way and requires less power and, therefore, less current, the field strength decreases and causes an increase of speed, as will be seen on inspection of the formula for E. Thus on gradients where we want more power we get it, but at a lower speed and on the level where we want more speed we also get it, but at a smaller expenditure of power, all of which is just what we want. The series machine has, however, one drawback, and that is in running down hill. As no power, or only very little power, is required to propel the car down hill, the current must be small. The field must consequently be weak, and if we are working on a constant pressure circuit the speed must be excessive to get the counter electromotive force up to the value required by the supply electromotive force. We must, therefore, check the car by either putting resistance into the motor circuit, or by lowering the supply electromotive force. The former is done where the current is derived from a conductor, the latter where it is derived from a storage battery. In neither case can the energy of running down hill be recovered. We may briefly sum up the advantages and disadvantages of the two types of motors as follows :—

A shunt motor is a bad starter, and runs too fast up hill ; down hill it runs at a safe speed, and may even be made to yield up part of the energy of the car running down hill.

A series motor is a good starter and hill climber. On the level, and on down grades, its speed is apt to become excessive. The latter effect is avoided in practice by inserting artificial resistance, or applying the current only periodically.

You see that neither of the two methods of winding field magnets gives a perfectly satisfactory result, but as the faults of the one are not the faults of the other, it might reasonably be expected that a combination of both methods—in other words, a compound wound motor—would be satisfactory in every respect. This question I propose to investigate in some detail by means of a graphic method, but to make you familiar with the method, I shall first show its application to the more simple case of a series motor. This course is the more justifiable, as at present the series motor is more generally used than the compound motor. Let the weight of the car when in service be nine tons, the supply pressure be constant at 300 volts, and the maximum current which the motor can take for a short time be 100 ampères. The current which will actually flow through the motor depends upon the propelling force required by the car at any particular moment, or, in other words, on the gradient. We could, therefore, plot a curve representing the current as a function of the gradient, or if we have a profile of the whole line, we could insert the current corresponding to each section. I have, however, as a matter of greater convenience, reversed the process in the diagram (*Plate* II., *Fig.* 6), and plotted the gradient as a function of the current. The heaviest gradient I have assumed as existing on the line is 100 per 1,000, or a rise of ten per cent., but I need scarcely say that such a steep bit would not be found on any line. I have taken ten per cent. as the maximum in order to allow for the increased resistance to traction on a curve which may occur just at the steepest part. Thus the line may have no gradients steeper than 40 in 1,000, but the resistance of curves and the necessity of sometimes starting on a gradient will have the same effect as if all the gradients were steeper. If we assume the efficiency of the gear between the armature spindle and the axles of the car wheels to be 75 per cent., the resistance to traction on the level at 27lbs. per ton, and the resistance of the motor to be ·6 ohm (which figures may be taken as fair average values), then we find by an easy calculation that the speed of the car on the heaviest part of the road will be four miles per hour. The power actually represented by the moving car amounts to 24 horse-power, and that supplied to about 40 horse-power, showing an efficiency of 60 per cent. You will, perhaps, be astonished at the large amount of power required by a 9-ton car, when you consider that an ordinary 6-ton car is worked by two horses. It would, however, be misleading to judge of the power by the number of horses, because a horse will, on an emergency, exert a tractive effort far in excess of that corresponding to a mechanical horse-power, just as a man will for a short time be able to exert considerably more than a man-power. If you set a man to work steadily at a crank for the whole day, he will not develop more than an eighth part of a horse-power, but if the same man runs upstairs he will, for the time, develop very nearly one horse-power. The mistake made by most beginners in electric traction work is that they under-estimate the power required. There is no use blinking the fact that we must provide plenty of power in order to give a satisfactory service. Returning now to our problem, you have seen that one condition of working has been established. For this purpose we need not know the speed of the motor, nor its speed ratio as regards the car wheels; these are details of design which do not require to be specially considered in the general theory. We assume, however, that the speed ratio, whatever it may be, for the heaviest gradient is the same for all gradients, and that the efficiency of the gear also remains constant at all loads. By efficiency I mean the ratio of the torque, produced by the current in the armature and the torque of the car wheels effecting propulsion. The latter is obviously proportional to the tractive force, or the stress, in a rope, if the car were hauled along by it, and this force is the sum of the frictional resistance on the level, and the component of gravity acting against the motion on a gradient. Let W represent the weight of the car in tons, p the frictional resistance per ton on the level, and g the gradient in feet rise per 1,000 feet, then the tractive force in pounds is given by

$$T = W\ (p + 2{\cdot}24g).$$

Since this is proportional to the armature torque, and since the latter is again proportional to the product of field strength and current, we have also

$$T = K_1 ZC,$$

in which formula K_1 is a co-efficient depending on the constructive data of motor and gear. As regards the speed of the car in miles per hour, which we will denote by the letter M, this is, of course, proportional to the speed of the motor. As I have shown before, the counter electromotive force of the motor is proportional to the product of field strength and speed, so that we have the relation

$$E_2 = K_2 MZ,$$

in which K_2 is a co-efficient, and E_2 the counter electromotive force. The latter is, of course, the difference between E, the electromotive force of the supply current, and cR, the electromotive force lost in ohmic resistance, or in symbols

$$E_2 = E - cR.$$

By means of these four very simple equations we can now determine the condition of working on any part of the line. We suppose that the current is turned on and the car left to run as the balance of power between the propelling current and the retarding forces of friction and gravity determines. On the level the speed will be a maximum and the current a minimum, and as the gradient increases the speed will decrease and the current will increase. Thus to each current corresponds one particular gradient and one particular speed, all of which can be represented diagramatically, as I have done in *Plate* II., *Fig*. 6.

In this diagram the current is plotted as abscissa, and gradient and speed are plotted as ordinates. If the gradient be given we need only look out on the gradient curve the particular point, the height of which above the horizontal represents the given rise per 1,000, and find below it the current which is required on this gradient. On the same vertical we also find the speed in miles per hour.

There are also shown in the diagrams lines representing the electrical power supplied and the power actually utilized in propulsion, and a curve below the horizontal which gives the efficiency, that is, the ratio between the power supplied and utilized. The diagram gives us all the information required to find the conditions under which the car will run on any part of the line. Thus you see that as the gradient decreases, the current also decreases, and the speed increases. When the gradient is 12 per mille the speed is 7 miles per hour, and on the level the speed would increase to 10 miles per hour if we kept the current on and allowed the car to run uncontrolled. Now so high a speed would not be permissible on a tramway. The Board of Trade provides regulations, according to which the speed must never exceed 6, or at the outside, 7 miles an hour, and must be reduced to 4 miles in passing points and crossings. In our diagram the speed curve for gradients below 12 per 1,000 is, therefore, represented by a horizontal line, and to get the speed down to this limit, or rather to prevent it rising beyond it, we must insert a resistance into the supply circuit. The curve marked ohms gives the amount of resistance which must be switched in, according to the gradient. Thus, on the level, we must insert about two ohms, on a down grade of 3 per 1,000 we must insert 10 ohms, and on a down grade of 12 per 1,000, we must insert an infinite resistance, that is to say, we must cut off the current completely. On such a grade the component of gravity would just balance the frictional resistance, and the car ought to continue running down the incline with whatever speed it had on entering it. I need hardly tell you that in practice such a nice balance of power is out of the question. If the incline is very steep, well and good. We can then cut off the current and run down on the brake, but if the incline is not steep enough for this, then we must help the car on by electric power. Now there are two ways of doing this. We can turn on the current and insert all the available resistance, at the same time checking the descent by the brake, and this is the way which you or I, who have no experience as to the driving of tram-cars, would adopt. It is, however, a wasteful way, for by it we produce power in the motor and destroy it again in the brake. The other way is to put the brake on as little as possible or not at all, and manipulate the switch so as to give the car a little push from time to time. This is by far the more economical method, but it requires care and experience on the part of the driver. As in ordinary town tramways most of the running is made on the level or slight up or down grades, you see at once that the greater or less skill of the drivers must have an important bearing upon the economy of the system. As an illustration of this I may mention what the engineer to a large American tram company told me. The company work storage cars, and consequently the conditions are a little worse than with conductors, because the pressure derived from cells increases as the current decreases, and there is consequently a greater tendency to racing than where the pressure is kept constant. My informant found that an intelligent, well instructed, but inexperienced driver will invariably run more charge out of the battery than an experienced driver. If the man has been on the road for a few weeks he begins to know it, and to acquire confidence, with the result that he saves 25 per cent. of the charge which he at first found necessary to run out of the battery over a given distance. Thus, by superior skill, he can make up for what is an inherent defect of the series motor. To recapitulate. If we make the motor large enough to overcome the worst part of the road which can possibly occur, then it will be too large for level parts and cause the car to race unless checked by the brake, which is wasteful, or by a continuous manipulation of the switch, which requires great attention on the part of the driver. If, however, the driver should lose his head at the critical moment, then the current will not hold the car at a safe speed, as is the case with a shunt motor, and an accident is very probable. That such accidents do happen occasionally cannot be denied. Some months ago we read in the papers of a runaway car in America, and the accident near Florence is no doubt still in your memory. It should, however, be noted that in this respect the electric car is no worse than any steam locomotive, which also will run away on a down grade if the driver does not shut off steam and apply the brake.

Now let us see whether the electric car can be made safer than a steam locomotive by using a compound instead of a series motor. The answer to this question depends in a great measure on the ratio between the series and the shunt winding. If the shunt winding preponderates we get almost perfect safety, but impair the starting power and the power to get over bad parts of the road with a reasonable expenditure of energy. If the series winding preponderates we get great starting power, but at the cost of reducing the factor of safety. I can best explain this by reference to the two diagrams (*Plate* II., *Figs.* 7 and 8). The former diagram represents the running condition of a car fitted with a compound motor, in which the series winding is more important than the shunt winding. The construction of the diagram is the same as that of *Fig.* 6, and I need not, therefore, stop to explain it. Of the maximum exciting power of 20,000 ampère turns required for the production of the strongest field, the shunt only supplies 4,000 ampère turns, the series winding supplying the remainder. To make this matter clear, I have drawn the characteristic of magnetization on the lower part of the diagram, and placed the origin of the running diagram over the point corresponding to 4,0C0 ampère turns. All the excitation beyond that is given by the main current and measured to the right of O. The gradient and speed curves are inserted as before, in full lines. You see that on the level the speed is still safe, but on a down grade it becomes excessive. I would invite your attention to the turn at the bottom of the curve representing the gradient. At a down grade of 12 per 1,000, the speed might be 9·6 miles per hour and the current zero, that is to say, there might be an exact balance between the supply electromotive force and that produced in the armature of the machine which is being worked by the descending car. I say advisedly "might be," because you will see from the diagram that there is a second point on the gradient curve for which the descent is 12 per 1,000, namely, on the extreme left. For this point the current is negative, and amounts to 25 ampères, the speed is infinite, and the motor has no magnetic field at all, as you will see by looking at the curve of magnetization. This point is of so much importance that I will stop for a moment to explain it in a different way. We have started with the assumption that we have to do with a compound wound machine, in which both the shunt and main coil act in the same sense. This, however, only applies to the condition of working for which the machine has been designed, namely, to absorb electrical energy and give out mechanical energy. Now, if the car is running down hill and driving the motor (instead of the motor driving the car), then the motor absorbs mechanical and gives out electrical energy, becomes, in fact, a generator giving current to the line. The direction in which the current passes through the machine has now been reversed, and we must consider the current as negative and plot it to the left. The direction of the shunt current has, however, remained the same, and we see, therefore, that the main current tends to demagnetize the field instead of helping to magnetize it. The greater the main current the greater is the demagnetizing force, until with 25 ampères the demagnetizing force of the main current is exactly equal and opposite to the magnetizing force of the shunt current, and no field at all is produced. By referring to the formula for counter electromotive force, you will see that the product of field strength and speed must be a constant for any given supply condition, and the weaker the field, the faster must the machine run to get the required balance between the supply electromotive force and counter electromotive force. This explains why the speed increases as the up grade decreases, and why, on a down grade, if this is steep enough to cause the motor to work as a generator, the speed tends to become infinite. The mischief, you will observe, is entirely due to the demagnetizing power of the main current, and the remedy is obvious. We need only take away this demagnetizing power when going down hill, and the current will keep the car at a safe speed. In other words, we must cut out the main coils and work the motor as a plain shunt machine. Arrangements for strengthening or weakening the power of the shunt are frequently used in motors, and if we fit some such arrangement to our car motor which will enable us to keep the excitation of the shunt alone at 20,000 ampère turns whilst the main is cut out, the speed will remain nearly constant on all grades, as seen from the dotted speed curve in the diagram. The gradient curve is also shown dotted. You see that we can now run down a very steep grade without any danger of excessive speed, but to obtain this result we had to depart in a certain measure from our original programme, which was to use a compound wound motor pure and simple. We use such a motor for the up grades, but on down grades we transform it into a pure shunt motor.

Without going into details, you will easily understand that this transformation may be effected only partially if desired, so that the speed at which we run may be between the limiting values given by the two speed curves. If we use the brake we can, of course, run at any speed we like, but if for the sake of saving power we aim at running free, we can alter the speed within the limits shown in the diagram, and we can do this without wasting power. We can do even more; we can give back power when running down hill. Here you have a point of superiority of electric cars over steam locomotives. A locomotive running down a hill cannot in any way assist another running up a hill on another part of the line. With electric cars this is possible. The descending car gives current to the line, which at another point may be used in helping a car to ascend. We must, however, be careful not to over-estimate this advantage, and to help you to form a correct estimate I have put on the top of the diagram a line representing the power which corresponds to the current. The line to the right of the origin gives by the height of its ordinates the power expended, and that to the left, the power recovered, or rather the power recoverable, for it is necessary to bear in mind that power can only be obtained from the car running down hill if the road is clear, so that the full speed can be kept up. This condition is, of course, not found in tram lines in towns, but there is no reason why in an electric railway running across country a portion of the power required by ascending trains should not be furnished by the descending trains.

I have shown you that the compound motor pure and simple (at any rate, a motor in which the main preponderates over the shunt) is very little safer as regards racing than the plain series motor, but can be made safe by the addition of certain coils and switches, which must be handled by the driver. Now let us see how the case stands with a compound motor, in which the shunt is very strong in comparison with the main. *Fig.* 8 is the running diagram of such a motor. The constant excitation of the shunt is twice as great as before, and produces 80 per cent. of the total field strength. I need not explain the diagram at length, since its construction is identical with that of *Fig.* 7, but I would draw your attention to the gradient curve, which dips down much lower than before, showing that the unstable or dangerous region occurs at a much steeper down grade. If we had made the shunt stronger still, the unstable region would have been pushed out correspondingly farther, and you see, therefore, that by a judicious design of the magnet coils we can indeed make a machine which will be *safe under all circumstances*, and never allow the car to run away even if the driver should lose his head at the critical moment. In *Fig.* 8 the dotted lines refer to a pure shunt motor as before, and the power spent and recoverable is given at the top of the diagram.

Before leaving the subject of speed control, we must for a moment go back to the series motor, and see whether it could not be improved in some such way as will allow us to keep the speed within safe limits without the wasteful device of artificial resistances. You will see from *Fig.* 6 that the best efficiency is obtained on gradients of about 10 in 1,000, and that on steeper grades the efficiency is still very fair. On gradients below 10 there is a rapid fall in the efficiency curve, and since most of the running is done on more or less level parts, or at any rate since there must be as much down hill as uphill work, it becomes important to reduce, if possible, the waste of power inseparable from the use of a simple series wound motor. Now what is the reason of this waste? It is that on the level we want very little current to propel the car, and this current is not large enough to fully magnetize the field magnets. What we lack in magnetism we must make up in speed, or we must check the current by inserting an artificial resistance. If we could, however, so arrange the winding of our field magnet that the small current will develop as much magnetism as the large current, then the speed on the level will also remain within safe limits, and we need not insert a resistance. You will easily see how this can be done. In *Fig.* 6 we want a current of 100 ampères to develop the full strength of the field, which requires 20,000 ampère turns. We have, therefore, 200 turns of wire on the magnets. Now let us wind 800 additional turns of wire on the top of the 200, making in all 1,000 turns, and you see immediately that a current of 20 ampères will produce as much field strength as was produced formerly by a current of 100 ampères. We combine with this additional winding a switch which enables us to either send the current through the whole of the winding or through only the 200 turns first put on. If we are running on the level we put in all the field winding, and if we are running on a steep grade we put in only the 200 turns. In either case the speed will be about the same. In practice it is customary to sub-divide the field winding into more than two portions. We might, for instance, have the following divisions:—200, 400, 700, and 1,000 turns, and correspondingly four contacts on our regulating switch. It is important to note that the wire need not all be of the same size. There would, in fact, not be room for it, since the available winding space is always a limited quantity, but especially so on motors for traction work, which must be made compact. The first 200 turns, which are always in circuit, and have to carry the heaviest current, are of the stoutest wire; the next 200 turns are made of smaller wire, the next 300 of smaller still, and so on, it being obviously permissible to reduce the gauge of the wire, since the additional coils are only used for small currents. This system of winding has first been used for electric traction work by Mr. Sprague in America, but is now also employed here and on the Continent. Time will not permit my bringing before you the many interesting details which have been worked out in connection with the Sprague system during the last few years, but I would draw your attention to *Fig.* 9, which shows the running diagram obtained with a series motor, whose field coils are sub-divided in the manner I have just explained. There are four speed and four gradient curves shown, corresponding to the four positions of the regulating switch. The abrupt steps connecting those parts of the curves, which are shown in full lines, correspond with the shifting of the switch from one contact to the other, and you will see that by properly handling this switch we can, even on slight down grades, keep the speed within the seven-mile limit. We can, in fact, notch up the switch lever very much in the same way as a locomotive driver notches up his expansion gear, and thus prevent waste of power. The effect of this notching up you can observe in the efficiency curve E, shown in the same diagram. You will see that in no place does the efficiency fall below 60 per cent.

There are other devices for controlling the speed without sacrificing economy of working, and of these I will mention the two most important. The one was originally introduced by Mr. Reckenzaun, and consists in the employment of two series motors, the armatures of which can be coupled in series or in parallel, whilst the field excitation can also be varied within certain limits. If the armatures are in series, each gets only half the supply electromotive force, and the speed is reduced. If the armatures are in parallel, each gets the whole supply electromotive force, and the speed is increased ; or if on a heavy part of the road, the power is increased at the same time, the excitation can be varied to give the finer adjustment of speed. All this is done by means of one single handle, working a very ingeniously contrived switch. As regards the employment of two motors instead of one, it may be objected that this entails additional complication. On the other hand, however, it affords greater safety against a complete breakdown. The strain on motors in tramway work is exceedingly heavy, and the motors from their position under the car, where they are exposed to mud and dust, are more liable to break down than stationary machinery. I have not been able to obtain from English companies any reliable statement as to the average run before a breakdown occurs, but from information supplied by American and Continental companies, who, be it remarked by the way, are far more liberal in this respect than our own countrymen, I find that 1,500 miles is about the average distance run without a greater or lesser mishap. It is, therefore, highly important not to be dependent on one motor only, and Mr. Reckenzaun's lead as regards the employment of two motors has now been extensively followed by other designers and makers of electric cars.

The second system of speed regulation to which I desire to draw your attention is only applicable to storage cars, and was first employed by M. Julien on the Bruxelles tramway. It consists in subdividing the battery into two or other even number of sections and grouping these in series, compound parallel or simple parallel, so as to vary the supply of electromotive force, and therefore the speed and power in accordance with the requirements of the road. This system is in use at Birmingham and on the Barking Road tram line.

The Gearing of Electromotors.

A point of great practical importance is the mechanical connection between the spindle of the electromotor and the axle of the car. In order to have a motor of small weight and bulk, we must run it at great speed, whereas the speed of the car axle cannot exceed a certain limit depending on the travelling speed and size of wheels. There is consequently required some kind of speed-reducing gear, the ratio of which varies for the usual run of tram car between 6 to 1 and 10 to 1. Whatever type of gear is employed, it must be as far as possible noiseless, light, occupy little space, waste little power, and it must not be deranged by the vertical motion of the car. The most perfect gear would of course be one in which the speed ratio could be varied at will, so that the motor might be kept always running at a constant speed; but no such gear has yet been practically successful, and meanwhile we must be satisfied to keep the ratio of the gear constant and vary the speed of the motor. All kinds of gearing have been tried, belts, both solid leather and links, silk cords, cotton ropes, flexible metallic spiral cords, link chains, spur gear, helical gear, and worm gear. Of these only the last three have stood the test of every-day use on electric tramways.

For electric railways the necessity of a speed-reducing gear is not so great. The locomotive can be specially constructed for a large motor, and the speed is generally much higher, which facilitates direct coupling. At the same time, the road is much better, the gradients are easier, and consequently the tractive force per ton is much smaller then on a tramway, so that the ratio between the torque, which can be developed by the armature, and the dead weight of the train, becomes more favourable. There is no time to go into the details of the various methods of gearing used in actual practice, and I must content myself with giving you merely a sketch of three types which have been successfully applied. These are :—

Direct Driving.

This is the system adopted in the electric locomotives designed by Dr. E. Hopkinson, and made by Messrs. Mather & Platt for the City and Southwark Railway. There are two motors, the armatures being mounted on the axles, by which means the use of gearing has been entirely avoided. The supply electromotive force is 450 to 500 volts, and the speed attainable is 25 miles per hour when the armatures make 310 revolutions per minute. Each armature can develop 50 horse-power. By virtue of the inclination given to the field magnets, the available space below the axle has been utilized to the fullest possible extent, whilst at the same time the yoke part of the field magnet can move up and down with the frame of the locomotive without altering the position of the pole-pieces, which are supported in bearings on the running axle.

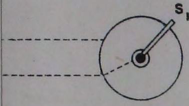
Spur Gearing.

This is used by Sprague, Westinghouse, Thomson & Houston, and several European firms. In the design adopted by the General Electric Power and Traction Company the motor, which is of the cylinder type, is mounted on a cast-iron frame, and the latter is supported partly in bearings on the car axle, and partly by a spring at the other end. This end of the frame participates to a certain extent in the up-and-down motion of the car frame, but any jerk is taken off by its own spring suspension, whilst at the same time the hinging of the frame on the car axle ensures correct gearing under all circumstances. The motion is transmitted by means of a countershaft, and there are two motors, each working its own car axle independently of the other. The pinion on the motor spindle is made of grey vulcanized fibre to prevent noise and jarring.

Worm Gear.

If engineers were entirely guided by the standard text-books on machinery, they would never have given worm gearing even a trial, for it has long been an axiom laid down in these text-books that the efficiency of a worm and wheel cannot exceed 50 or, at the outside, 60 per cent. So low an efficiency would, of course, preclude the employment of this particular gear for all purposes in which waste of power must be avoided. In this particular the standard text-books are, however, wrong, and the experiments of the Research Committee of the Institution of Mechanical Engineers and many other experiments have shown that the co-efficients of friction previously adopted were far too high when the surfaces were bathed in oil. The pitch of the worm has also an important influence on the power wasted in friction, and by a long series of experiments with different materials, different shapes of teeth and different pitch, Mr. Reckenzaun has succeeded in designing worm gearing which in point of efficiency is almost, if not quite, as good as spur gearing, whilst it has the additional advantage of being absolutely silent. The worm is cut out of solid steel, and has a double thread (sometimes a treble thread) which gives it a pitch sufficiently large to allow of its being driven by the wheel, so that the car can freely run down hill. The whole gear is boxed in, partly to protect it from dirt and partly to allow an oil bath to be applied, by means of which the friction is materially reduced. When two motors are employed, each is mounted on a bogey independently of the car body, but for small cars carrying only one motor the latter is fixed under the car frame, and geared with one or both of the axles by short lengths of shaft with flexible couplings.

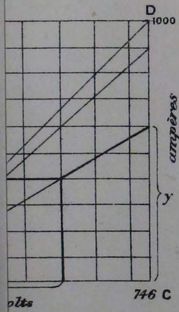
ELECTROMOTO PLATE I.



E.

ig. 4.

H.P. DIAGRAM.



h = H.P.

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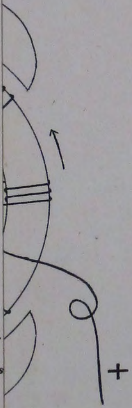

PAPER X.

PETROLEUM AS A PRODUCER OF ENERGY.

By H. Graham Harris, M. Inst. C.E., M. Inst. M.E., Etc., Etc.

LECTURE I.

In December, 1888, when I before had the honour of lecturing in this room, the matter with which I had to deal—that of "Continuous Brakes"—was one depending for its success almost entirely on the description of minute detail, not only in the machinery and apparatus constituting the brakes, but in the theory involved in their use and application.

The subject, however, upon which I have to talk to-night and to-morrow night is one of which no such complaint can be made. "Petroleum as a Producer of Energy"—the title chosen by the authorities here—embraces within it a field so vast as to render it almost impossible for me to deal fully with it in the time at my disposal.

As we consider it, you will find that there is involved in this title an almost limitless field for speculation and consideration, even in theory alone. Further than this, practical commercial results are only recently being attained, and all sorts of suggestions for improvement and for alteration arise in one's mind when the subject is at all fully considered. I do not propose, however, to trouble you with much theory, as, luckily for me, my audience is a technical one, and one therefore which I may well assume is, to a large extent, acquainted with the various theories involved. You will find, therefore, that on many points I simply suggest, and of many I take it for granted you are cognisant.

I should not propose to trouble you at all with any remarks as to what petroleum is, or as to its origin, were it not for the fact that within very recent times the great Russian chemist—Professor Mendeleef—has propounded a theory of the origin of petroleum which is most ingenious and beautiful. This suggestion differs to a large extent from all others that have hitherto been propounded, with the exception of that of M. Berthelot. As I have said, however, I do not propose to trouble you with these, but will refer such of you as are interested to the book by Mr. Benjamin J. Crew, published so recently as 1887 by Messrs. Sampson Low, Marston & Co. This book discusses very fully the whole question of the origin, production, chemistry, and ordinary utilisation of petroleum.

Professor Mendeleef's theory was published in England by Dr. Anderson—now Director-General of Ordnance Factories—in his presidential address to Section G of the British Association, at Newcastle last autumn. Paraphrasing from this address—which may be found printed at length in *Engineering* for the 20th and 27th September, 1889—the origin of petroleum may be shortly stated as the following :—

It is universally agreed that in the depths of the earth there are fluids or soft substances at a great heat and of great specific gravity, among which molten iron and other metals, either pure or existing as carbides, would certainly be found. Now the crust of the earth is very thin in comparison with its diameter, and as, in the course of time, this thin crust cools, cracks or fissures are developed in it from shrinkage; and through these cracks, surface waters find their way down into the molten masses below. When these waters and the molten masses, which are composed chiefly of metals, come into contact, the oxygen of the water combines with the metals, forming an oxide, and the hydrogen from the water is either set free as hydrogen, or, combining with the carbon which had hitherto been associated with the metal, the volatile substance—naphtha—is formed ; but not in its liquid state, because of the heat of the molten masses with which the water had come into contact, but naphtha in its vapour form. This vapour rising either through the fissures down which the water had come, or through other fissures, reaches the cooler crust, and is there condensed into a liquid, collecting in large volumes in the crevices or strata, which will hold or absorb it.

It is obvious that the constituents of a liquid thus formed would vary through very wide ranges, and would depend upon the relative quantities of water and of metal, or of carbon, and to some extent on the heat at which the combination took place, or of the mass with which the water has come into contact.

This is roughly the theory of the great Russian chemist, and if it is correct—and petroleum can be, and has been, artificially produced in such a way as to justify our belief in it—then we may rest content that our store of petroleum will not be exhausted for some considerable time at least, in spite of the vast quantities which are yearly used.

It is, perhaps, hardly our business to consider whether this suggestion as to the origin of petroleum is correct or not, but it seemed to me one which might well be stated to you; first, because of its intrinsic beauty, but mainly because we shall directly have to consider the mode in which petroleum is, in practice, used to obtain energy, and we shall then find that its properties of easy evaporation and of condensation to the liquid form are those upon which some, or all, of the modes by which energy is produced from it are dependent for their success.

I should here just like to call your attention to the statistics of the petroleum trade for the year 1888, which have been recently published :—

Number of Barrels of Petroleum Annually Imported into Great Britain.

Year.	American.	Russian.	Total.
1883	1,329,004	502	1,329,506
1884	927,919	11,078	944,997
1885	1,367,720	70,149	1,437,869
1886	1,363,801	46,814	1,410,615
1887	1,444,350	88,467	1,632.811
1888	1,286,148	549,126	1,835,274

You will see from this table that the quantity imported has increased from a little over 1,250,000 barrels in 1883, to 1,835,000 for 1888. Now as each of these barrels contains 40 gallons, and weighs, roughly, about 3cwt.—if the specific gravity of the whole is taken as about 8·50—then this means that there were shipped to this country, and used in the year 1888, over 275,000 tons of petroleum. Further, as the calorific value of petroleum may be taken as 50 per cent. greater than that of the best Welsh coal, it means that this quantity was equal, in heating effect, to about 412,000 tons of coal.

As a fact, the year 1889 shows a large increase in the quantity imported.

Again referring to the table you will further see that while the quantity from America has practically remained stationary, the shipments from Rüssia have increased from 500 barrels in the year to 55,000 in the year. This increase is largely due to the less cost of freight, for Russian petroleum is now brought over in bulk in ships consisting of tanks, into which, and from which, the oil is pumped, thus enabling a very much larger quantity to be carried, besides saving the cost of barrels and of their freight to and from England. This mode of carriage, however, has, during the year 1889, been introduced into the American oil business, the new petroleum tank steamer *Lux*, with a capacity of over 2,100 tons of oil, having, within the last few weeks, discharged her cargo at South Shields.

Professor Mendeleef—to whom I have already referred—has recently stated that the prospects of the increase in the Russian trade are enormous, and that the Baku wells are not, as was erroneously stated, showing signs of exhaustion.

I shall have again to refer to this table when I point out to you how much "energy" in the way of horse-power could be obtained from such an amount of petroleum as this.

Let us now come to the second part of our title, and let us consider what it is that petroleum is called upon to produce; why it should be possible to produce energy from it; and how, in practice, energy is produced from it.

The word "energy," when used in the connection (to use an Americanism) in which it is used in our title, may be said—broadly speaking—to mean power; and you, all of you, know that the production of power must, of necessity, be accompanied by motion, or by the tendency to motion. Further, you know that heat and motion are convertible the one into the other; and as it is upon this question of heat that the ability of petroleum, or in fact of coal or of gas, to produce energy depends, let us take some little time to consider the way in which heat can be converted into motion or into energy. For, unless we are fully grounded in this portion of our theory, it will be impossible for us to comprehend the true causes of this energy production.

I have told you that heat is convertible into motion or energy, and that these are re-convertible into heat. Let me try and prove this to you by that which is, to my mind—although it has been used before by others, as well as myself—the most common-place and yet complete illustration with which I am acquainted. This illustration is, perhaps, more appropriate when addressing a military audience than any other which I could possibly use.

In the year 1798, Count Rumford, one of the earliest of those who investigated and propounded the true philosophy of heat, stated that some 20 years before he had proved by direct experiment that if a gun was fired with a bullet or shot in it, the gun would not be heated to such an extent as it would be if it were fired with a blank charge alone in it, and he concluded, therefore, that a portion of the heat developed by the combustion of the gunpowder was absorbed or dissipated in some way (unexplained by him at that time) when the force of the explosion was used to drive the bullet from the gun.

A little consideration will show you that if heat and motion are convertible, the one into the other, this is what should arise : that is to say, some of the heat of explosion should be transformed into motion in the bullet, and should not appear in raising the temperature of the gun. Now, if this is that which arises when a bullet is fired, it evidently should be possible, by suddenly arresting the motion of the bullet, to reproduce the heat which has been in it transformed into motion.

If I were not dealing with a military audience, it might be necessary for me to show some experiments to prove this, which could be very simply performed, but I do not think I need labour the point in the least, because you are all aware that when a bullet strikes the target, the rapid motion of the bullet being thus suddenly arrested, heat is developed, and if the bullet were made of a metal fusible at a very low temperature it would be melted.

I think, therefore, we may take it for granted that that extremely interesting work of Professor Tyndall, entitled *Heat a Mode of Motion*, has, in that title, irrefutable truth contained, that is to say, that it is true to its uttermost meaning.

Let me try to impress this truth more fully upon your minds, and let me try also to enable you more easily to realise the modes which we use for comparing the relative amounts of work to be obtained from various sources of heat. And in order to do this I will ask you to look at the following figure (*Fig.* 1). A big gun being one of the

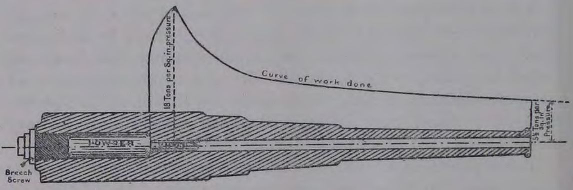

FIG. 1.—*Big Gun.—The Simple Heat Engine.*

simplest and most elementary machines for the production of energy from heat, I have shown you here a section through such a gun ; at the left hand, the breech end, is shown the powder, with the shot in front of it. You will see that there is drawn from the base of the shot practically a vertical line, which reaches a point some distance above the centre line through the middle of the gun, and this point is marked "18 tons per square inch pressure ;" that from this point a curved line is drawn towards the muzzle, curved so as to approach more nearly to the horizontal centre line as the muzzle is reached ; and that at the muzzle there is another verticle line, marked "$5\frac{1}{4}$ tons per square inch." Now, the space enclosed between the horizontal centre line of the gun and this curved line above it is supposed to represent the work developed by the explosion of the powder, that is to say, if at any point you measure up the distance between the horizontal centre line and the curved line above it, the length of the line thus obtained will tell you, when applied to the proper scale, how many tons to the square inch pressure there are existing in the gun when the base of the shot has advanced to this point, and you will realise from this that in order to obtain these pressures the gas produced by the explosion must, if I may so put it, have a desire to occupy so much larger space, or to have so much greater volume, as will cause the pressure to exist.

Now, the pressure and the temperature of a gas, if the volume or space occupied by it is kept constant, are measures, the one of the other; that is to say, with a volume kept constant, increased heat means increased pressure. If this is true, then we see it must follow that the greatest heat exists in the gases just after the shot has started into motion, and at the time when the pressure has attained the 18 tons on the square inch, which is marked on the diagram; and that because the shot is advancing along the bore towards the muzzle, the space between the back of it and the front of the breech-piece is increasing, and that the gases generated by explosion are having their volume increased and, therefore, their temperature lessened, and their pressure also lessened.

What has our big gun diagram now taught us? Let us consider. It has taught us, first, that a large volume of gas at a high temperature is produced on explosion; it has also taught us that as this gas is allowed to expand, because of the forward motion of the shot, the heat of the gas has lessened; and it has also taught us that as work is done in imparting to the shot the velocity with which it leaves the muzzle, heat has been extracted from the heat developed by explosion; that that heat has been converted into motion, and as I have told you, and as you know from experience, we can re-convert some of that motion into heat by suddenly arresting the motion of the shot.

I think if I have succeeded in rendering all this plain to you, and if you will bear the big gun diagram and its lessons in mind, many of the more abstruse points upon which I must of necessity touch will be largely simplified.

Now I have talked generally of heat and of motion, but it is necessary, in order that we should be able to make a comparison between the efficiency of various machines, to have some standard or unit which will enable us to define quantities or amounts of heat. The standard commonly employed varies in different countries, but in England a "unit" of heat is that amount which is necessary to raise 1lb. of water one degree Fahrenheit, that is to say, from 39·1 to 40·1 degrees Fahrenheit, this being the temperature of greatest density of water.

Before I go any further I must give you one caution, that is to say, not to confound the true meaning of the words "heat" and "temperature." As I shall have to show you directly, these words really signify two different things; and that depending entirely upon what body it is we wish to raise or lower in temperature, we shall have to put different quantities of heat into it, or take out different quantities of heat from it, in order to make given variations in its temperature.

Now, we found that our big gun diagram taught us that the addition of heat to a gas caused that gas, if its volume were kept constant, to increase in pressure; that is to say, gave the gas the desire—if I may so put it—to expand or increase its volume. It also taught us that the abstraction of heat caused the gas to lower in pressure. Of course you will realise that if the temperature of a gas is in excess of that of the surrounding atmosphere (which is practically a perfect gas as far as expansion is concerned), there will always be a tendency on the part of that gas to increase its volume until its temperature becomes normal with that of the atmosphere.

Now all bodies (or almost all bodies, for there are some exceptions), be they solid, liquid, or gaseous, have a tendency to increase their volume when heated. If we take a cast iron pipe, 800 feet long, and we vary the temperature of that pipe 200 degrees, that pipe will either expand to 801 feet long, or contract to 799 feet, according as we increase or decrease the temperature; that is to say, a cast iron pipe, 800 feet long, at the temperature of 32 degrees Fahrenheit, or freezing point, will expand to nearly 801 feet if you fill it with boiling water, or raise its temperature in some way or another to 212 degrees.

Mr. Benjamin Baker—the joint engineer with Sir John Fowler, of that magnificent monument of engineering skill, the Forth Bridge—tells me that he has there made an allowance of three-fourths of an inch for every 100-feet length of girder in each span, this being sufficient to provide for the difference between summer and winter temperature, or say, 100 degrees Fahrenheit.

All of you, of course, know of the variations produced by heat and cold, as shown by the expansion and contraction of the mercury in a mercurial thermometer; and you know, also, that the mercury expands and contracts to a much greater extent than either cast iron or the steel of which the Forth Bridge is composed. Further the contraction and expansion of gases with variation of temperature—steam, air, or whatever gases they may be—are very much greater than those of either mercury or any solid or liquid.

Now, I have given you, as an illustration, the expansion of cast-iron and of steel for certain increases of temperature, and I have reminded you of the excess of expansion of mercury over these, for an equal increase of temperature, and have told you that the expansion of gases is greater even than that of mercury, but I do not mean you to understand from this that equal increments of heat, dded to different bodies, will cause even approximately equal incre-nents of temperature, for, in order that this should be so, the pecific heat of all bodies would have to be the same. This you now it is not. You know—or at least many of you do—that qual increments of heat with different bodies will only cause varying ncrements of temperature.

This quality of the variations in the quantity of heat necessary, n order to cause in different bodies an equal variation of temperature, s the quality known as "Specific Heat," the specific heat of the body.

Water is taken as the standard for comparisons of specific heat, nd this is done because water, of all bodies which we know, is he one which presents the greatest resistance to a change in its emperature, or, in other words, is the one which requires the reatest amount of heat put into it, or taken from it, in order to ary its temperature through any given range. The specific heat of vater is, therefore, termed "one," or unity, and it of course follows rom what I have just said that the specific heat of all other bodies, vhether solid, liquid, or gaseous, must be expressed in fractions, or n some terms less than unity. The specific heat of water, however, s not constant at all temperatures, becoming slightly increased at oiling point, or 212 degrees Fahrenheit. We may, however, ignore his variation, as it is so slight as not to affect any calculations or rguments with which we shall have to deal.

The definition of specific heat is, as you will realise from what I ave said, the ratio of the quantity of heat necessary to raise, or to ower, a given weight of any body through a given variation of emperature—say one degree—to the quantity of heat required to aise, or lower, an equal weight of water through the same variation f temperature.

Let us now recapitulate that which we have learnt.

First, we know the measure used generally to define a given uantity of heat, that is to say, we know what a "unit of heat" is. have cautioned you also, and have shown you the reasons for that aution, as to the difference between "heat" and "temperature." Further, we have learnt what is meant by "specific heat."

Let me now tell you what is meant by "Latent Heat"—the "latent heat" of liquefaction, and the "latent heat" of vaporisation; nd in respect of this quality of bodies, let us consider only the ody with which we have to deal, namely, petroleum, in its various orms. We must, however, first generalise, in order that you may ully understand what is meant by the term "latent heat."

All bodies, whatever they may be, exist in three different forms, or rather, it is possible that they *will* exist in these three forms—the solid, the liquid, and the gaseous—and their condition at any time, that is to say whether they are solid, liquid, or gaseous, depends entirely upon the pressure and temperature at which they are existing at that time. For instance, atmospheric air is a gas at ordinary temperatures, and at ordinary pressures, but if atmospheric air is subjected to a very low temperature, and a very high pressure, it is possible to liquefy it, and it is almost certain—if we could increase the pressure, and lower the temperature sufficiently—it would be possible to solidify this liquid. Let us, however, take the most familiar instance; let us take water. At ordinary temperatures and pressures, water is, as you know, liquid. At lower temperatures it is solid, that is to say, it is ice; and at higher temperatures it is gaseous, that is to say, it is steam. Now, all bodies in changing from the one state of being to the other, either absorb a certain amount of heat, which does not become sensible, that is to say, is not realisable as an increase of temperature, or, in passing from the higher to the lower state—say from the gaseous to the liquid, or from the liquid to the solid—give off a certain amount of heat, and they do this without their temperature varying. Ice, in changing from the solid, ice, at 32 degrees Fahrenheit to the liquid, water, at only the same temperature of 32 degrees, will absorb for each pound weight 146 units of heat; that is to say, will absorb sufficient heat to raise its temperature, supposing it already existed as water, from the 32 degrees, by a further 146 degrees, or sufficient heat to make it 178 degrees; and if you go on further, and turn that pound of water into steam, it will absorb, in passing from water to steam—even although the water may be at the boiling point of 212 degrees, and the steam may be no hotter—as much as 966 units of heat for each pound weight of water.

These absorptions of heat when the state of the body is changed from the solid to the liquid, or from the liquid to the gaseous, are termed the "Latent Heat of the Body," the "Latent Heat of Liquefaction," and the "Latent Heat of Vaporisation," and the various forms of petroleum vary not only in respect of their specific heats, that is to say, in the amount of heat which they will absorb or give off, in order that their temperature may vary through a given range, but they vary very largely in the temperature at which the vaporisation of the liquid petroleum takes place; that is to say, in that which is technically known as their flashing point.

Many of you will doubtless think that I have, to a large extent, laboured in endeavouring to put before you in sequence, although I hope very briefly, the various properties of bodies generally as regards heat, and the various properties of heat itself; but I hope before I have done you will agree it is necessary you should have fully before your minds all the various points which I have emphasised, and that you will thereby realise the more readily the many ways in which energy is produced from the heat contained in petroleum.

You will also find that although, apparently, the modes by which energy is produced from petroleum are various, yet they are all based upon the same properties or qualities to which I have referred, possessed by petroleum in common with other bodies, and I must ask you kindly to remember these. I will endeavour to refer to each of them when, in succession, I describe the various practical modes which are adopted.

Let us now return for a little while to the property of expansion by the addition of heat, which we dealt with to some extent when considering the big gun. This property of expansion is common to all gases, and let me ask you to consider *Fig.* 2, which shows you a section through the power cylinder of an ordinary steam, or gas, or petroleum engine.

You see you have here in this cylinder a disc or piston capable of movement from end to end of the cylinder, and steam or vapour-tight at its outer circumference between itself and the walls of the cylinder. From the piston you have a rod passing steam-tight through a stuffing-box in one of the cylinder covers; and, further, you have, by means of valves (which I have purposely left out of the diagram in order not to complicate the description), the means of admitting steam or any other vapour, under pressure, to either side of the piston, between it and the cylinder cover at that end. You will see that if we let in the steam alternately at one end, and then at the other of the cylinder, and alternately exhaust the steam from the cylinder by allowing it to escape, we shall cause the piston to travel backwards and forwards.

Now let us consider what are the economical advantages to be derived from utilising the property of expansion in gases. Suppose that we let in to one end of the cylinder steam having a pressure of, say, 100lbs. on the square inch. It is evident that the piston will be moved towards the front end of the cylinder by an effort represented by the area of the piston in square inches, multiplied by

100lbs. for each square inch. If we then exhaust that steam, admitting steam at the same pressure to the other side of the piston,

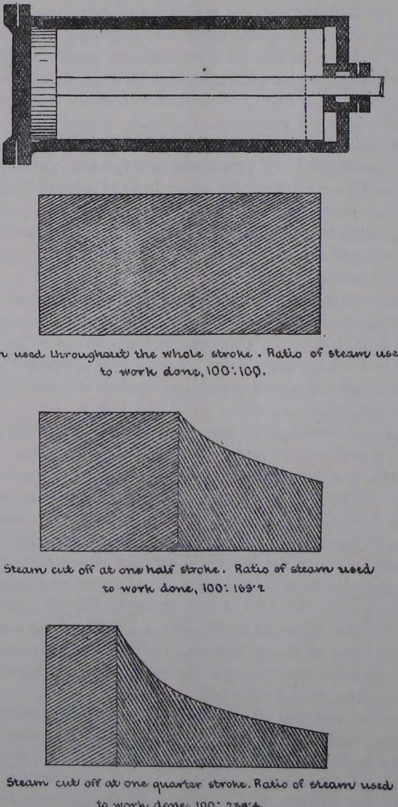

Fig. 2.—*Elementary Cylinder of Heat Engine.*

the piston would be driven backwards with an equal effort—less that due to the small area of the piston rod ; but it is evident that we should have used for each backward and forward stroke of the piston a cylinder full of steam at the maximum pressure with which we are dealing, *i.e.*, 100lbs. on the square inch. But supposing now we take the same cylinder and piston, and only let in steam for one-half of the stroke of the piston, and for the remainder of the stroke we allow the steam which is already in the cylinder—that is to say, the one-half cylinder full of steam at 100lbs. pressure—to expand, then the pressure would gradually fall along the curved line which I show on *Fig.* 2, and we should obtain from this half-cylinder full of steam not only the work which it does in driving the piston for the first half of its stroke, but the work represented by the area of this part of the diagram contained between the base line at the bottom and the curved line at the top ; and if you make the necessary calculations, you will find that if the work done when the steam is let in for the whole length of the stroke is represented by 100, the steam also being represented in each case by 100, then the amount of work done during the whole stroke of the piston, when we cut off at half-stroke, would be represented by 169·2. Let us carry this a little further, and suppose that we cut off the steam at one quarter of the stroke, and that the remaining three-quarters of the stroke have been done by the expansion of the steam ; then you would find that if the steam let in was again represented by 100, the amount of work done during the whole stroke would be represented by 238·4. You will see that the right-hand end of this last diagram is much lower than the end of the preceding diagram ; that is to say, the pressure has fallen in this case to a lower point, more of the heat contained in the steam having been transposed into work in driving the piston.

I should like to spend some little time upon this question of expansion, but the clock warns me that I must not. I will only tell you that James Watt was one of the earliest to realise the value of this property of expansion of gas. In the year 1782, he took out a patent for "Certain Improvements for Steam or Fire Engines, for raising water and other mechanical purposes." In this you will find the very earliest diagram of energy with which I am acquainted, showing also the economy that may be derived from the use of expansion. You will remember that in the big gun diagram the curved line of work done fell towards the base line as the shot moved forwards, showing, therefore, that work was to a large extent performed by the expansion of gases generated by the rapid combustion—practically explosion—of the solid body, the gunpowder. This body containing as it does within itself the necessary ingredients for producing upon combustion a large volume of gas at a very high temperature, in the big gun (as we shall find is the case in the petroleum engine), the whole of the work is practically performed by the expansion of a very hot gas.

But you will say to me: "It is all very well to show us these diagrams, theoretical as they are, and to tell us that these are the pressures which exist at the varying points of the forward or backward movement in a cylinder of such size as this." You will say that these are only theoretically constructed diagrams, and you will say: "How can we tell that theory is correct, or that the theoretical results are at all approached, even in practice?" Well, it is again due to the genius of James Watt that the engineer has had the means of ascertaining what was transpiring in the cylinder of any engine with which he has to deal, and of ascertaining precisely the pressure of the gas existing at any and every point of the stroke of the piston.

I have here (*Fig.* 3) (kindly lent to me for the purposes of these lectures by Mr. H. Wollaston Blake, of the firm of Messrs. James Watt and Co., the successors to Messrs. Boulton and Watt, of the Soho Works, Birmingham) the original steam engine indicator made and used by James Watt, according to the date upon it, some 105 or 106 years ago, an instrument which constructs for us, as the engine is working, a diagram of that which is taking place in the power cylinder. If I explain this apparatus to you, you will realise the principle upon which all steam engine indicators work, even the most recent of them.

Let us first look again at our elementary diagram of a power cylinder of an engine (*Fig.* 2). You will, all of you, realise that if a pipe were connected to the space between one side of the piston and the cylinder cover, and if that pipe made connection with a smaller cylinder having a piston in it capable of movement, this piston would be subjected, during the whole length of the stroke of the main piston—both away from and back towards the cylinder cover—to the same pressure, whatever that might be, as existed in the main cylinder. Now, if this small piston is normally kept at one position in its cylinder by a spring, and if the pressure in the main cylinder tends to move the small piston against the pressure of the spring, the strength of which is accurately known, then the position

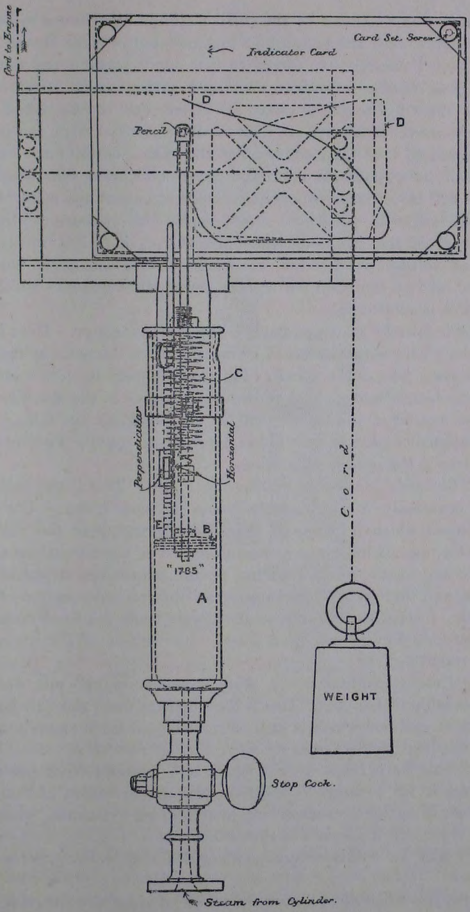

FIG. 3.—*Watt's Indicator.*

assumed at any moment by the small piston in its cylinder will show us exactly what is the pressure at that moment existing in the main cylinder. Further, if we attach to this small piston a rod working through a steam-tight stuffing-box, and having on its outer end a pencil marking upon a piece of paper, and if we cause this paper to move backwards and forwards in contact with the pencil, and in accord with the movement of the main piston of the engine, we shall have produced upon the paper a diagram, the length of which will be in exact proportion to the stroke of the main piston, and the height of which will show exactly the pressure existing at any part of the stroke of that piston; or, in other words, the diagram will tell us what the pressure is which exists at any moment in that end of the main power cylinder of the engine, to which the indicator is connected.

This is exactly what you have in the Watt indicator. Here is the cylinder; here is the means of connecting it to the main cylinder of the engine; here is the pencil. The paper is fixed upon this moving frame, which is moved backwards and forwards in the one direction by the motion of the engine, and in the other by the falling of a counterbalance weight which has been lifted by the movement of the plate in the opposite direction.

A "Richards'" indicator is shown in *Fig.* 4. This is the indicator most commonly in use by engineers at the present day. The principle upon which it works is exactly the principle of the "Watt" indicator, and its only improvements consist in the alterations which reduce the weight of the moving piston, reduce the stroke of this piston, and thereby reduce the error arising from momentum of this piston. In fact, the alterations are merely those rendered necessary or desirable by the increased speed of revolution of the engines of the present day.

A "Crosby" indicator is a more recent form, and one which I very much prefer myself. This is a refinement upon the "Richards" indicator, and one which is still better adapted for high speeds, and is lighter and handier in every way.

It would be perhaps as well—although I would have preferred to leave it till to-morrow—to show you the operation of taking a diagram from the oil-worked engine of Messrs. Priestman, which we have here. (A diagram was then taken).

We will have this diagram enlarged for us in our lecture to-morrow.

Now, you will want to know, when we have got this diagram, how we are able to say how many horse-power our engine is developing, and you will also want to know what is meant by "horse-power."

The term "horse-power" was originally devised by James Watt in order that his customers should understand, or should get some idea of, the amount of power which any engine he was selling should be capable of developing, and as in his time engines were mainly used directly to supersede horses, it was a measure of power which was readily adopted. He tried a good many experiments in order to determine what was the value of the continuous work of a horse, and he found that the average was equal to a weight of 22,000lbs. lifted one foot high, in one minute of time, and he therefore, in

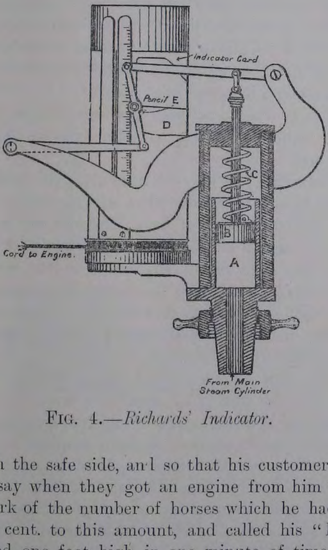

FIG. 4.—*Richards' Indicator.*

order to be on the safe side, and so that his customers should not grumble, and say when they got an engine from him that it would not do the work of the number of horses which he had told them, added 50 per cent. to this amount, and called his "horse-power" 33,000lbs. lifted one foot high, in one minute of time, and that is what an engineer *should* mean when he speaks of a "horse-power." I am sorry to say, however, that it is only within very recent days that this definition of a horse-power is becoming the absolutely universally used definition of a horse-power. I am sorry to say the engineer has had five different kinds of horse-power, and unless you pin him down to "indicated horse-power," that is to say, work in the cylinder equal to the above, he will manage to confuse you, and very probably himself.

There is one more theoretical question with which I must trouble you before I begin to describe the modes which are practically in use for obtaining energy from petroleum.

Let us again come to our big gun diagram (*Fig.* 1).

Here, you will remember, we proved that a portion of the heat developed by explosion was turned, or converted, into work in moving the shot, and we proved it by showing that if the motion of the shot were suddenly arrested, the heat would be re-produced. Now, if this is so, it follows that if we knew the weight of the shot, the specific heat of its metal, and the rise in its temperature due to its sudden arrestation, we ought to be able to measure the number of units of heat which in it had been converted into work; that is to say, we ought to be able to say so many units of heat mean so much work; or, we ought to be able to state what is the "mechanical equivalent of heat."

If Count Rumford, in his experiments, had realised this, he should have been able to record what was the value in mechanical work of any given quantity of heat. He did not know, however, of that which is known as the dynamical theory of heat. It was not until the year 1849, when Dr. Joule, as the result of experiments which had extended over the seven previous years, was able to state before the Royal Society that which has since been universally accepted as the mechanical equivalent of heat, perhaps now-a-days more commonly known as Joule's equivalent.

It has always seemed to me that there is no instance of which I know where the description of apparatus used in discovering a scientific truth has tended to render the explanation of this truth more easy than it has in the case of Joule's equivalent. I therefore propose to trouble you with a diagram of this apparatus.

Fig. 5 shows the very simple apparatus with which Dr. Joule experimented, which he used for many years, and by which he demonstrated with absolute certainty that the amount of heat necessary to raise 1lb. of water from 39 to 40 degrees Fahrenheit—that is to say an English unit of heat—would be sufficient to raise a weight of 772lbs. one foot high in one minute of time; and he did it by showing that if this weight were allowed in this time to fall the one foot, when the friction of the apparatus was eliminated there would be a sufficient amount of heat generated to raise the 1lb. of water through 1 degree Fahrenheit.

Let us look at the diagram. Here you have a close-topped vessel, in which water is contained, having in it fixed vanes, and also a revolving paddle, the object being that when the paddle is revolved the water shall be churned up, as it were—that is to say, subjected to the friction produced by the revolving of the paddle between the obstructing vanes. From the paddle a vertical shaft goes upwards, and at the top of this there is a reel, around which a fine twine or cord is wound. The other end of this twine is carried round a pulley, and upon the shaft carrying the pulley another cord is wound, and to this cord a weight is attached. The result is that if the weight is allowed to fall it revolves the pulley, the cord is unwound from the reel at the top of the vertical shaft, the paddle is revolved in the water, which is churned up in the manner I have said.

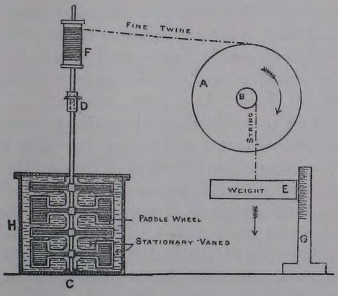

FIG. 5.—*Joule's Experimental Apparatus.*

Dr. Joule's communication to the Royal Society wound up with the following conclusions:—

1. The quantity of heat produced by the friction of bodies, whether solid or liquid, is always proportional to the force expended.

2. The quantity of heat capable of increasing the temperature of 1lb. of water weighed in vacuo, and taken at between 55 and 60 degrees Fahrenheit, by 1 degree Fahrenheit, requires for its evolu-

tion the expenditure of a mechanical force represented by the fall of 772lbs. through the space of 1 foot.

It follows from what I have told you, therefore, that if 33,000 foot-pounds exerted in a minute of time are equivalent to one horse-power, and if 772 foot-pounds, are equivalent to one British unit of heat, then 42¾ British heat units expended per minute, or 2,565 heat units expended per hour, is the equivalent of an indicated horse-power.

Let us now see, therefore, whether it is possible for us to realise from that which we have learnt the various modes by which energy should theoretically be obtained from a material such as petroleum.

You all of you know that at ordinary temperatures, and at ordinary pressures, petroleum is a liquid, and you also know that when heated by external heat, or by its own combustion, it will be gasified, and can be consumed as a gas. You also know, from what I have said, that if a gas has its volume kept constant, while the heat it contains is increased say from external sources, this external heat will cause the gas to desire to expand, or, in other words, will increase its pressure. You will observe, I said from some external source ; but ordinary day-to-day experience tells you that petroleum is one of those materials like gunpowder, which has within it the constituents enabling it to be used as fuel. Take an ordinary petroleum domestic lamp. In the reservoir you have the liquid oil, you have the wick up which that oil is drawn by capilliary attraction, you have the oil gasefied by the heat of the flame, and you have the oil burning with an infinitesimal consumption of the carbon of the wick, burning with a luminous flame, and in its burning producing great heat, which is communicated to the surrounding atmosphere.

A little consideration of all the facts to which I have called your attention, will show you that it follows petroleum may be used to produce energy in at least three different ways :—

1. It may be used as a fuel in an ordinary steam boiler, its heat being imparted to the water in the boiler, and thus converting it into steam under pressure.

2. The petroleum itself may be used to replace the steam, that is to say, it may be gasified, as water is gasified when it is turned into steam, the petroleum taking the place of water in the boiler, and the petroleum vapour taking the place of the steam in the boiler and in the steam engine.

3. The petroleum may be gasified, and the gas thus produced may

be burnt in the cylinder of the motor itself, thus heating the atmospheric air, and producing power by the expansion of the air thus heated, as gas does in a gas engine.

We have, up to the present, talked generally of petroleum containing the constituents necessary to produce heat, but I have not given you the calorific value of petroleum; that it is to say, I have not stated to you, except incidentally, the number of heat units existing in a given weight of petroleum; but you will have realised that there are various sorts of petroleum, and that, therefore, these must have various calorific values.

If time had permitted, I should have much liked to go into the various relative values of the various sorts of petroleum, but for these I must refer you to the course of lectures given here by Mr. Marvin last year, and to the literature of petroleum generally.

I always find it is an advantage to have in my mind some well-known standard on which to base the comparisons which it is almost invariably necessary, as well as possible, to make when one is dealing with values. I always remember that good Welsh coal—say Nixon's Navigation, or Powell Dufferin—when burnt to destruction, has for each 1lb. weight a calorific value of, roughly, 14,500 heat units; and I always remember that, ordinarily speaking, petroleum is 50 per cent. better; that is to say, 1lb. of petroleum contains, roughly, 22,500 heat units.

As you will remember, I troubled you with some words as to the latent heat of liquefaction, and the latent heat of vaporisation. I do not think it is well to trouble you with the exact figures in respect of these changes of state in petroleum, I only want you to remember that at ordinary atmospheric pressure and temperatures petroleum is a liquid (and there it has further advantage, in addition to its extra calorific value, over coal, for coal at these temperatures and pressures is solid), and I also want you to remember that the temperature of vaporisation or gasefication of petroleum varies between say 72 degrees Fahrenheit and 220 to 230 degrees Fahrenheit, but that, generally speaking, it is very low as compared with water.

I should like just to remind you, however, that the latent heat of liquefaction and gasefication of coal is obtained when coal is turned into gas—ordinary lighting gas, such as can be used in a gas engine—from the coke burned in the gas retorts; and that when a gas engine is compared, as regards economical working, with a steam engine, the heat imparted to the coal to gasefy it by this coke should be taken into consideration.

I do not propose to trouble you at all about the "Carnot" theory of the efficiency of any heat engine, which demonstrates the utmost possible work to be obtained from any given amount of heat—a theory which, just at present, is very largely discussed, mainly, I am sorry to say, because that which Carnot said and contended is misunderstood—and I will not trouble you with this because, although to some extent it is germane to our subject, yet I should then have to enter into questions of absolute zero of temperature, and into many other intricate heat questions, but I will hope that which I have told you—which I have purposely told you in the roughest, though I hope the simplest, way—will enable you to advantageously grasp the practical modes adopted for the production of energy from petroleum, the reasons of success of these modes, the possibilities there are of greater success, and the limitations on these possibilities which are inherent to the petroleum itself.

For all these heat questions, I would refer you to Dr. Anderson's lectures, he being our great living authority on heat questions; to the books by Professors Goodeve, Tyndall, and Rankine; and for the fringe of the subject, to the lectures which I myself delivered at the Society of Arts last year.

As I have now cleared the ground, I will hope that to-morrow night I shall be able to tell you many things which will be of greater interest to you, because they will describe to you the results which have, up to the present, been practically obtained.

LECTURE II.

If you will remember, at the close of my lecture last evening, I pointed out to you that as the result of the consideration we had given to our subject we had found that it was possible to use petroleum to produce energy in either one of three ways.

The first of these ways was to use it as liquid fuel, and by this means to generate steam in the boiler of an ordinary steam engine, using the steam thus obtained to drive the steam engine.

I may say, at once, that the largest use of petroleum for energy production is (at present) by such means.

When the crude petroleum is obtained, either by its spontaneously flowing from the holes bored in the earth to tap the petroleum-bearing strata, or by its being pumped from such strata, that which is produced is not the petroleum that we know as the petroleum of commerce, nor is it petroleum in the form of the thickish petroleum lubricating oils, and it is certainly not petroleum in the form of the volatile spirit used in the ordinary domestic lamp ; but it is a thick treacle-like viscuous fluid, having a high flashing point, that is to say vaporising only at a high temperature, even as compared with water, and this flashing point is rapidly raised if the oil remains exposed to the atmosphere, that is to say, as the more volatile portion of it evaporates. It is this thick fluid which, when subjected to the process of refining, gives us the various petroleum products, from the water-white oil, used in the domestic lamp, to the jelly-like odourless "vaseline," and it is the refuse of all the refining which is commonly used (and is, in many respects, the most suitable to be used) for liquid fuel—this treacle or tar-like material being burned in specially constructed furnaces to produce steam in an ordinary steam engine.

Directly you consider the burning of this material in quantity, the mind naturally concludes that the proper way to do it would be to turn the fluid into minute particles, in fact to spray it, that it may be intimately mixed with the atmospheric air necessary for combustion ; may be so intimately mixed that each particle of fluid will be itself infinitesimal, and will be surrounded by the necessary film or portion of air. If you can imagine this treacly fluid pulverised, as it were, you can realise that which is done, and that which is found to be the most successful way of burning petroleum refuse. Remember, this petroleum refuse has had, in the course of the refining operations, all the lighter and a great many of the heavier portions of the oil separated from it, and that, therefore, the temperature at which this refuse will fire—that is to say, its flashing point—is, as I have said, high ; so that in this respect its use and storage for fuel purposes is not, as it would at first sight appear to be, attended with danger. I want you, please, to bear this point thoroughly in mind when I explain to you the mode of burning petroleum refuse as liquid fuel.

As this material is the refuse product of the refineries situated, as these are, near the wells where the petroleum is produced, it follows that the use of this liquid fuel has made the greatest progress in those districts where the petroleum wells are to be found.

English inventors, it is true, have considered and have experimented with various kinds of apparatus for successfully burning this fuel. The names of Aydon and of Inglis are inseparably connected with these inventions, but in Russia we find that petroleum has been used, as the only fuel, in many of the largest steamers trading on the Caspian; that all the Russian Black Sea fleet have their boilers so arranged as to be able to use this fuel, and that the majority of the Russian locomotives burn it, and nothing else; and with this Russian locomotive work, the name of an Englishman, resident, however, in Russia—Mr. Urquhart—is connected.

The whole of the various modes employed or suggested depend for their success upon the principle of pulverisation to which I have referred. I think if I describe one or two of the modes which are adopted, it will enable you to understand the general principle underlying the whole of them.

In England good work has been done by Mr. Holden, the locomotive engineer of the Great Eastern Railway, and, due to his kindness, I have here, on the table, one of the injectors which he uses for injecting the fuel into the fire-box, and for there pulverising it, and mixing it with the necessary quantity of air (see *Fig.* 6); and you have upon the wall an enlarged diagram of this apparatus, and a section through a locomotive fire-box, and through the oil tanks in which the fuel is carried on the locomotive itself or on the tender.

Of course, it is unnecessary for me to emphasise to you the reason why so little has been done in England in this direction. You, of course, appreciate that it is because of the price of this petroleum refuse in England, and because it is found that directly the demand for it increases, this price also increases, so that the cost of the liquid fuel will not favourably compare with that of coal.

If you will look at *Fig.* 6, you will see that there is a series of cones or pipes, one inside the other, and that into the outer one of these, free steam from the boiler is allowed to pass; that this steam rushing to the nozzle outlet of the injector, induces a strong current of air through it, and induces, or "sucks" (if I may use the word) with it an annular stream of liquid fuel, supplied to the injector by this branch and connecting pipe to the oil tanks to which I am now pointing. The steam, in rapid motion, coming in contact with the oil, pulverises or sprays it, and the mixed steam and oil spray is discharged into the fire-box of the locomotive through the openings at the mouth of the nozzle. The steam is supplied direct from the boiler through the pipe shown, and the oil comes from the oil tanks in the tender, and through this pipe. You will see that there is a ring jet surrounding the injector towards its front end, and through this ring jet, when the injector is at work, a large volume of air passes into the fire-box with the mixed jet of steam and oil. There is a steam pipe for warming up the oil in the tank in very cold weather, so as to make it sufficiently fluid to readily work, and provision is made for blowing steam through all the oil pipes to prevent their becoming clogged.

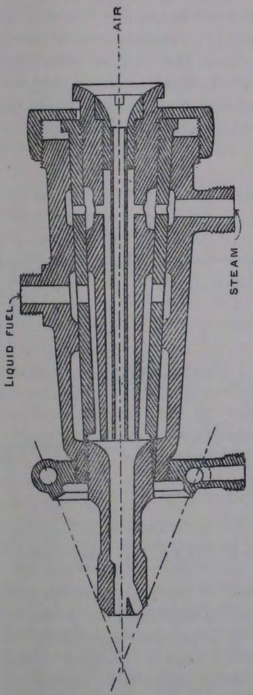

FIG. 6.—*Holden's Injector—Locomotive Pattern.*

Mr. Holden has worked out the apparatus, which I here show you, in a very practical way.

He felt that the possibilities of obtaining this petroleum refuse in England were at present so small, and the supply was so limited under present conditions, that it would not do to make his locomotives so that they were capable of burning petroleum alone; and, therefore, the only alterations which he made were in the way of addition. He takes an ordinary locomotive with its ordinary fire-box and brick arch, and keeping on the fire bars a very thin fire—only sufficient to raise steam in the first instance—and only keeping that fire very thin during the whole course of a run, and having in his fire-box a good body of fire-brick, or other refractory material, to act as a reservoir of the heat produced, he uses the oil fuel as an adjunct to the coal, and finds by this mode of using it a very great economy and saving in his yearly coal bill.

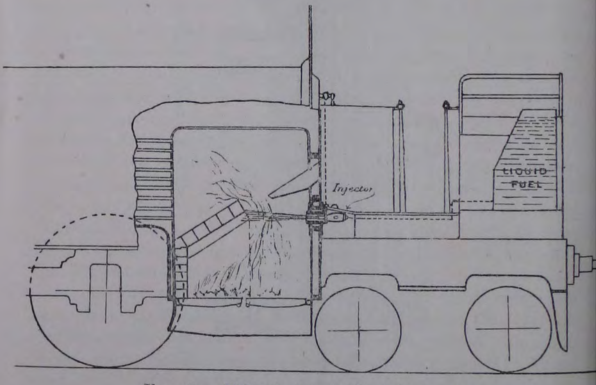

FIG. 7.—*Holden's Liquid Fuel Locomotive.*

This is a description of the way in which oil fuel is used in locomotives, or, with slight modifications in the boilers of land or stationary engines; but among the many applications which seem to me to bid fair to be—even in England—extremely successful, is that for its use in small steamers or launches, such as torpedo boats.

Let me describe to you the way in which it has been used by Messrs. Doxford & Sons, of Sunderland, and let me also enumerate to you the advantages which they claim are derived from the use of liquid fuel, *per se*, and also from their particular mode of using it for torpedo boat purposes.

They have fitted it to a torpedo boat, provided with an ordinary locomotive boiler, which has, however, instead of the ordinary fire-bars and ash-pan, a "wet bottom" or water space. It is, of course, possible to have this, as there is no ash to be removed and no need for the injection of air in order to consume the fuel. In the stokehole there is an air-compressing pump for the liquid fuel. This fuel is carried in tanks which are built into the bottom of the boat, between its double skin, and it is possible to fill these tanks either with oil or with sea water at will, maintaining the weight constant, or in other words allowing the space occupied by the fuel which is consumed in propelling the vessel to be utilised for water-ballast.

You see one of the advantages of the use of the liquid fuel for torpedo boats is that it can be carried in a place where its weight, or the weight of the water which replaces it, is an assistance to the stability of the boat, rather than a lessening of that stability as when coal (which has to be consumed) is carried in bunkers at the side of the boat. Further, the oil is stored in a place which is ordinarily incapable of being used for stowage purposes at all, or, if at all, then to a very slight extent.

The fuel pump in the stokehold of which I have spoken is also arranged to draw in a new store of fuel (when necessary) from a wharf, or from a boat alongside. When under steam, this pump draws the petroleum from either one of the many tanks in the boat's bottom, and delivers it into a small reservoir placed up under the deck, above the level of the boiler furnace, from which pipes connect into the boiler furnace. The air-compressing pump also delivers into this same reservoir air at a pressure of about 30 to 40lbs. on the square inch, and on opening cocks placed in the pipes to the burners, in the fire-box, the mingled air and oil rush out, and are lit here. Each jet gives a clear, bright, flame of about 6 feet 6 inches long and nine inches diameter, if burning alone. There are some ten of these burners, and, of course, when they are all alight, the consumption of oil and air is equalised over the whole of them, and the flame resulting becomes a vast body the whole width of the fire-box, and completely filling it.

The consumption of oil can be made to vary for each burner from about 25lbs. to 70lbs. per hour, and, of course, each burner, or the whole, or any number of them, can be shut off, thus giving a most perfect regulation of the quantity of fuel consumed.

The advantages claimed for this mode of using liquid fuel for torpedo boat purposes are, first, that a number of stokers are not required, one man being sufficient to do the whole of the work ; all that he has to do is simply to turn on, or turn off, as the case may be, the oil and air as the steam pressure rises or falls in the boiler ; second, that the oil can be carried in a space which is ordinarily unused for stowage purposes, and that, therefore, the available room in the boat is very much increased ; third, that owing to the greater calorific value of the oils as compared with coals, for a given bulk or given weight, a greater quantity of effective fuel can be carried; that is to say, that the boat is capable of steaming for a very much greater distance before it is necessary for her to return to port to replenish her store.

It is claimed that the boat in which this apparatus is fixed could steam for a distance of 1,800 miles, at a rate of 10 knots an hour, before her store of fuel would be exhausted ; that, as I have said, the weight of the oil where it is carried adds to the stability of the boat instead of lessening it, as does coal when carried in bunkers at the side in the ordinary way ; that with proper care there is no soot formed ; that there are never any ashes, and that, therefore, these have not to be got rid of ; nor do the boiler tubes require sweeping.

All these advantages are obtained, but, as you will understand from what I have already told you, at a much increased cost of running, owing to the cost of the fuel in England.

You will see from what I have told you that, in addition to the difficulty of uncertain supply of the oil refuse, which it is alone economical thus to use as liquid fuel, there are the practical difficulties due to want of steam to drive the oil into the boiler at starting when the water in that boiler was cold. This is met by using a small coal or wood fire at lighting up, and further, there is the difficulty that the heat produced is very intense, and is at its maximum the moment the burners are lit up, and ceases directly they are turned out. It is, therefore, necessary to line the fire-box nearly completely with fire-brick, or some other refractory material, in which the heat can be stored, and by which its intensity and lasting power, if I may so put it, may be regulated.

The second way in which we agreed petroleum could theoretically be used for the production of energy was to take that product of petroleum, which is, if I may so put it, at the other end of the scale from the petroleum refuse, with which we have just dealt; that is to say, to take the freely volatile portion of it, to put that in a closed system consisting of a boiler, an engine, and a condenser; vaporise it in the boiler; use the vapour in the engine as steam is used in a steam engine; condense the vapour in a condenser after it has done its work in the engine, and return it to the boiler in a fluid state, to be there again heated, and vaporised, and re-used.

This mode of using petroleum spirit for the production of energy is one of the most interesting one can imagine, and is now being exploited—to use an American expression—by Messrs. Yarrow and Co., the torpedo-boat builders, of Poplar. You will have gathered from what I have already told you as to petroleum, that some of the products obtained from it vaporise at a very low temperature; indeed, the extremely volatile petroleum spirit which Mr. Yarrow uses has a temperature of only some 100 degrees Fahrenheit when its vapour pressure is at about 60lbs. on the square inch.

Now, to describe the apparatus he uses; if you will imagine an ordinary steam engine, wherein the water and steam in the boiler, and the steam in the steam engine, are absent, but are replaced by a very volatile petroleum spirit in the boiler, and by the vapour of this spirit in the engine, you can realise that which is done by Messrs. Yarrow. They take an ordinary steam engine, with very slight modifications, and an ordinary steam boiler. In the boiler they put this petroleum spirit, vaporising, as I have said, at a very low temperature; a fire is lit under the boiler, or rather some of the petroleum spirit itself is burnt under the boiler; petroleum vapour is generated under pressure; this vapour is taken to the steam engine, and is there used in a way absolutely similar to that in which steam is used in an ordinary steam engine. When the vapour has done its work in the engine, it is taken to a surface condenser, is there condensed into a liquid, and is then returned to the boiler by means of a pump, so that it may be re-evaporated there; the whole arrangement being absolutely similar in arrangement, though not in detail, to that which is adopted with the water and steam in a condensing steam engine.

An extremely interesting series of comparative experiments have been tried by Mr. Yarrow, experiments which compare the advantages to be derived from such a use of petroleum spirit with those obtainable from water in an ordinary steam engine, with the result that he says he finds that if "nine" represents the value to be obtained in work done from any given amount of heat put into the petroleum spirit in his boiler, "five" represents the value in work done to be obtained from the same amount of heat put into the water, or into the steam, in an ordinary steam engine boiler; or, in other words, he says he can obtain nearly twice as much benefit from the use of an equal amount of heat by using this apparatus as is obtained in the ordinary steam engine.

These advantages are obtained mainly from the following causes:—

First, the temperature at which vaporisation of the petroleum spirit takes place is low, as compared with the temperature required for water, and therefore there is not so much loss by radiation of heat from the petroleum spirit boiler and engine, etc., into the atmosphere, there not being so great a difference between the temperature of these, as there is in the case of the steam engine; second, the latent heat of vaporisation of the petroleum spirit is low as compared with water, that is to say, there is not so much heat lost in that vaporisation as there is in the case of water; and third, the specific heat of the petroleum spirit is low, that is to say, it requires smaller increments of heat to increase its temperature through any given range than does water.

I have not a doubt that many of you will say, "If all this is true, why is not the apparatus more largely used, especially as there are other advantages derivable from its use in this way?"

Well, there are many reasons for this scanty use.

1. That it has only within very recent times been devised and practically used.

2. That it is extremely unsuitable for large powers, and for the reason that this spirit is extremely difficult to "contain," and I must here explain what is meant by this.

In the case of many liquids, when comparing them with water, one finds that in practice it is extremely difficult to make a satisfactory "joint" in the various portions of the metal forming the apparatus in which they are contained under pressure, such a joint as shall absolutely prevent leakage; that is to say, many liquids and vapours will, although their pressure may not be great, leak through a joint which would contain or hold water or steam. This is more especially the case in practice with the vapours of such liquids as petroleum. Steam, when escaping from a leaky joint, shows itself by being at once condensed in the atmosphere, and there becoming a visible vapour; and further, steam, when it has escaped at once loses its pressure, and becomes practically harmless. But the vapours of petroleum, and of many other liquids, are invisible, and it is not possible to discover a leak, unless by the smell of the vapour, and it is very often by that time too late to prevent accident. The vapours of most of these liquids will, as I have told you, and as we shall find petroleum vapour does, explode or burn with very rapid combustion when mixed with a given quantity of atmospheric air, and therefore it would be extremely unsafe that engines and boilers worked by such a spirit as this, should be placed in a closed engine or stokehold. Further than this, there is one great practical reason why water and steam have such advantages over other liquids, and the vapours from them, for power production. Those of you who have had anything to do with the inspection of new boilers for instance, will often have seen, when these are under hydraulic pressure (their hydraulic tests), that in spite of the caulking having been properly done—or rather the fullering, as it should be in these days—there are in places, at the joints, slight "weeps," or signs of moisture exuding; and you are also aware that if the manufacturer knows his business, and is left to himself, he will prefer to leave these (which may perhaps be termed leaks), alone, knowing very well that they will "take up" when the heat due to the steam pressure is on the boiler, or when, after a little time has elapsed, a slight rust or oxide forms in the almost infinitesimal spaces through which the moisture has come; and it is this capability of rusting or oxidising the metals with which engineers most frequently deal, which is possessed in so great a measure by water or steam, that renders their use so much more easy and satisfactory in practice.

One notable instance of failure of a theoretically satisfactory scheme for obtaining a greater percentage of effect from a given quantity of heat by the use of a vapour other than that of water, is afforded by the ether engine. This was a combined vapour engine, that is to say, it was a steam engine wherein when the steam had done its work in its engine, it was condensed in a vessel where its heat was transferred to liquid ether, which, vaporising as Mr. Yarrow's petroleum spirit does, at a very low temperature, was used in an engine similar to the steam engine and to assist that steam engine, the ether being afterwards condensed by being passed through pipes surrounded by cold water, and then returned to the vessel in which the exhaust steam from the steam engine was condensed, this vessel acting, therefore, as the steam engine condenser, and, at the same time, as the ether vapour boiler. These engines are associated with the name of an eminent Frenchman, M. du Trembley, and were in use about the year 1850.

Many large engines were made, and employed in mail ships carrying the mails from Marseilles, but although they were for years in use, and although most careful experiment and practical tests showed an economy of fuel consumption, yet these engines had to be removed and to be replaced by steam engines, almost entirely because of the difficulty of containing the ether vapour.

Some of the incidental advantages of which I have spoken above, and which Mr. Yarrow obtains by the use of his apparatus, are that the weight of his engine and boiler, and of the fuel which he must carry necessary to drive the boat for a given distance, are small as compared with the weight of a steam engine, a steam boiler full of water, and the similar necessary quantity of fuel. Further, he has the advantage that he can obtain a pressure sufficient to start his engine into motion in a very few minutes—two or three—from the time of lighting up ; in fact, I have seen a pressure of 40lbs. on the square inch obtained in a small launch boiler within three minutes of the time of lighting up. This is an advantage well worth having in the case of the machinery of a launch, or of a yacht's small boat, cases for which, as I have told you, Mr. Yarrow is at present alone using this apparatus.

You will see that I have upon the wall several diagrams, showing sections through a "Zephyr" launch, "zephyr" being the name by which Messrs. Yarrow's boats of this class are known.

Time will not admit of my fully describing them to you, but you must take it from me that all that is done is to use the vapour of this petroleum spirit in an engine in the same way as steam is used in a steam engine. Ordinary petroleum oil is used as the fuel, burnt with an ordinary wick, similar to that of the ordinary domestic lamp or oil stove.

You will, of course, understand that the largest of these boats is only of some 10 to 15 indicated horse-power, and that, for the reasons I have given you, they are all "open" boats, *i.e.*, the engine is not contained in a closed stokehold.

There is much more that I could tell you about the details of these two modes which we have considered for producing energy from petroleum, but I am warned by the clock that our time is getting short, and we have yet to consider the third mode, that which is, to my mind, pre-eminently the mode which will, in the near future, be most largely used.

That which I have termed the third mode, is the one where energy is produced by the burning of petroleum in the cylinder of the motor itself in a way similar to that adopted for obtaining power from coal gas, where the coal gas, with its proportion of air, is burnt with rapidity, or exploded, in the engine cylinder.

You will remember that the first mode was that wherein the petroleum was used as a liquid fuel burned in the fire-box of the boiler of a steam engine, thus producing steam to drive the engine; and in this indirect way, if I may so put it, power was produced. And you will remember that the oil used for fuel was that having a high flashing point, and being practically the refuse of the refineries. And you will also remember that one of the principal practical difficulties in connection with this mode of using petroleum in practice, of which I told you, was that due to the regulation and conservation of the heat so as to "average" it, and thus to prevent the local effects of over-heating.

You will also remember that the second mode was that wherein the lighter, or more volatile part of the petroleum, that is to say, the petroleum spirit or naphtha, was used in an engine similar to the ordinary steam engine; this spirit, and the vapour from it, replacing the water in the boiler, and the steam in the engine and condenser. And you will remember that the principal practical difficulty here was the difficulty of "containing" the volatile vapour of the spirit, and that I told you how the danger of explosion, when leakage occurred, was guarded against.

The third mode by which we agreed in our first lecture that energy might be produced from petroleum, was that where the petroleum was gasefied, and the gas thus produced was burnt, or exploded, in the cylinder of the engine itself, thus heating atmospheric air, and giving energy by the expansion of the hot gases thus produced.

You, of course, all of you, know that the ordinary gas engine may be scientifically termed a hot-air engine, as may be the form of petroleum engine I am about to describe; that is to say, a gas engine is an engine wherein a volume of air is heated by the rapid combustion—call it explosion, if you will—of coal, or other gas, and power is produced by the expansion of this heated air, and of the gases produced by the explosion.

You will have realised from what I have told you that the burning of petroleum is accompanied by the development of great heat, and you will say to me, if the evil effects of the great local heat had to be guarded against where petroleum was burned in a boiler furnace, and where, therefore, it was surrounded by the water to be heated, surely these effects will have to be guarded against where you burn the petroleum in the cylinder of your motor, and to a much greater extent, because, in order to avoid the evils due to leakage, which are evils common to the two modes, you must preserve the bore of your cylinder perfectly true and smooth, and you must also preserve the exterior surface of your piston, which is in rubbing contact with that cylinder (this rubbing contact making the joint as against leakage) perfectly true and smooth.

I do not know of any experiments which have been tried, and which give, with accuracy, the temperatures produced when petroleum vapour and air are mixed and exploded, or rapidly burned, as they are in the motor cylinder of a petroleum engine such as we have here. It is generally accepted as a fact, however, that when common coal gas and air are exploded in a similar manner, a temperature of some 3,500 degrees Fahrenheit "absolute" may be reached. If this is so, you may well ask how it is possible to find any material, of which to make your cylinder, capable of withstanding such great heat. You know that the temperature at which cast iron melts is some 2,200 degrees absolute, or nearly 1,500 degrees less than that stated above; and, as it is fair to assume that in consequence of its higher calorific value, a mixture of petroleum, vapour and air will at least attain as high a temperature as that which experiment has shown is attained by the mixture of common coal gas and air, when these are exploded, you would at once conclude that cast iron cannot be the material used for the cylinders of petroleum engines. If you did so, you would be wrong, for it is the material used not only for the cylinders, but for the pistons, and these cylinders and pistons do maintain an extremely bright and true surface over long periods of working when they receive proper attention.

Now, as the whole working of petroleum engines of this class is arranged so as to meet this difficulty of overheating the cylinders, I think if we spend some little time in considering how this difficulty is dealt with, it will be of advantage. It was the difficulty which was first overcome in those successful gas engines (which are practically similar to the petroleum engines) which have, of late years, commanded such great attention, and have had so great a sale.

The earliest of these gas engines was that known as the "Otto" Silent Gas Engine, manufactured in England by Messrs. Crossley Brothers, of Openshaw, near Manchester. Owing to the kindness of Mr. Crossley, I have here a working model, which shows by the successive colours appearing through the section of the cylinder, the sequence of operations taking place there through a succession of strokes of the engine.

I will work the model, and you may take it that that description which is good for this engine is in respect of its "cycle," or sequence of operations, good for such a petroleum engine as this, which is called the "Priestman" engine. This sequence of operations occurring in the motor cylinder, is, in gas and petroleum engine parlance, termed a "cycle." Please remember that when I speak of the "cycle" of a gas engine or of a petroleum engine, what I mean is the sequence of operations occurring in the motor cylinder of that engine. Further remember that these are not all exactly similar in sequence for different classes of engines, but the principle underlying them is the same throughout.

You will remember that when I showed you the diagram of the elementary cylinder with the piston moving from end to end of it, I suggested that the steam might be let in behind the piston as it went forward, might be exhausted as it returned, then again let in as it went forward, again exhausted, and so on. This if the engine were single acting. If it were double acting, these operations would be repeated in succession on the opposite sides of the piston, and, therefore, at each end of the cylinder.

Most gas engines, and all petroleum engines, as far as I know, are only single acting, that it is to say, there is only an impulse to move the piston in one direction, and the front end of the cylinder is open to the atmosphere, which passes freely in and out as the piston moves backwards and forwards. We may, therefore, leave one end of the cylinder out of consideration altogether, dealing only with the other, and with the space between the cylinder cover and the side of the piston at this end.

You have here a section through a gas engine cylinder, or rather, I will call it a petroleum engine cylinder, for these two engines—"Otto" engine and the most common form of petroleum engine, the Priestman—are alike in the sequence of operations taking place in the motor cylinder; or, in other words, they are alike in the "cycle" of their working. You will see that the model shows, by the varying colours displayed in succession in the cylinder as the model is worked, the "cycle" which occurs.

Let us commence with the first outstroke of the piston. When this is taking place, the valve admits the charge of petroleum in the form of spray with a charge of atmospheric air, the proportions of these being so adjusted as to give an explosive mixture when the petroleum has been vaporised, and the two are fired. You will see, as I move the piston forward, this charge is drawn, or sucked, into the cylinder, and that then the further motion of the engine closes the slide valve, and stops the admission of the mixed air and petroleum spray. The engine going on, the piston returns, making its first instroke, the inlet slide valve and the exhaust valve remaining closed; the mixed charge of oil and air are compressed between the back of the piston and the cylinder cover. The charge is then ignited, explodes, forcing the piston outwards, the motion being made because of the combustion of the mixture, this stroke being the "power" stroke. The further revolution of the engine, due to the impetus conveyed to the fly-wheel, carries the piston inwards, the exhaust valve being at this time opened, the products of combustion produced in the power stroke are expelled into the atmosphere. You will see that our model engine is now in the same condition as it was when we started, for the next forward movement will open the inlet slide valve and draw in a charge of petroleum and air.

You will now remember, therefore, that the "cycle" of a petroleum engine, such as the Priestman engine, really consist of two *out* and two *in* strokes of the piston; the first out-stroke being the suction stroke; the next in-stroke being the compression stroke; the next out stroke the explosion stroke; and the next in-stroke the exhaustion stroke.

Now, look what the practical result of this is. You devote the whole of one stroke of the piston to sweeping out the products of combustion or explosion which have been formed in the previous out-stroke; you allow time whilst these various successive strokes are being made for the heat of the cylinder to be communicated to the water in the water jacket, and to be thus carried away; and you thus ensure that the cylinder shall not get so hot as to cause premature explosion or firing when its next charge for giving the impulse is drawn in, and before this charge can be compressed.

I want to avoid, if I possibly can, complicating that which I have to tell you with questions of that which is known as "stratification of the charge," or of the advantages derivable from compression of the charge, and I will only point out the practical difficulties, and the practical modes of overcoming these, with the practical results obtained, feeling that for your particular purpose this is the proper thing to do.

As the mode for obtaining energy from petroleum with which we are now dealing is one comparing most favourably with the ordinary steam engine, I have had prepared, in order that you may have graphically before you some idea of the mechanical efficiency obtained in these petroleum engines, these three cubes.

The larger one, the black one, is supposed to represent a definite amount of heat, let it be represented by the figure 100; and these two smaller red cubes represent--the one the efficiency obtained in a good compound condensing steam engine, say burning 2lbs. of coal per indicated horse-power per hour; the other, which, as you will see, is only slightly smaller, the efficiency obtained in a petroleum engine such as this which we have here.

To give you the illustration in percentages :--If the large black cube is represented by the figure we have taken, viz., 100, the steam engine cube would be represented by 11, and the petroleum engine cube by 10; that is to say, the steam engine usefully utilises 11 per cent. of the total heat contained in any given amount of fuel, and the petroleum engine usefully utilises practically 10 per cent. of a similar quantity of heat. If you compare either of these efficiencies with that of the gas engine, please remember that the fuel for gasification of that used in the gas engine is not taken into account, as it is represented by the coke used in the retorts for distilling the coal from which the gas is produced.

Other forms of petroleum engines, which I shall presently describe, do not utilise quite as much as this, that is to say, their mechanical efficiency is not quite so high.

In considering the relative efficiencies of the steam engine and of the petroleum engine, you must remember, however, that the steam engine is a machine which has been in use for many years; which has been studied and improved, and experimented with by thousands of able men; and that the petroleum engine, for practical purposes, has only very recently been considered and come into practical use.

The petroleum engine is not yet quite as efficient, nor is its cost of working so low, as that of its great rival—the gas engine; but the petroleum industry is one which is, day by day, increasing, and there are no theoretical reasons, of which I am aware, of sufficient importance to justify us in thinking that the petroleum engine will not, in the near future, be at least as efficient, as handy, and as simple as the gas engine. Further, we must remember that the petroleum engine has one advantage, at least, over the gas engine, which arises from the fact that there is no need to turn its fuel into gas before it is delivered to the engine, and there is no need, therefore, to incur the expense of the costly apparatus necessary for the gas engine, in those cases where its fuel cannot be obtained directly from the gas company's mains.

Further, petroleum engines are now made of the portable type—that is to say, are mounted on wheels as is a portable steam engine; the tank of oil fuel being carried on a separate set of wheels, or upon those carrying the engine, so that the whole may be moved easily about from place to place; and you will realise that this portability is a great advantage for agricultural purposes, and is an advantage not possessed by the gas engine.

I have now shown you what are the practical advantages derivable from the use of petroleum for the production of energy in engines such as this, and I have at some length described to you that which is the greatest practical difficulty that had to be surmounted, that due to the heat developed by the combustion of the petroleum vapour in the motor cylinder itself; and, further, have told you how this difficulty is met. You must remember, however, that the fuel in petroleum engines is a liquid; that this liquid has to be automatically delivered at regular intervals into the working cylinder of the engine, and must be delivered in such a manner as will render it capable of easy vaporisation in those cylinders. This is usually obtained by pumping the petroleum into the cylinder, delivering it there as a spray; a regular quantity being supplied for each explosion or working stroke of the engine.

You will realise that this need for the vaporisation of the liquid fuel involves a certain amount of theoretical loss of efficiency—that is to say, you will remember that there is a certain amount of heat which disappears, or becomes latent, in every case where liquid is turned into a vapour; and although the oil used for working these petroleum engines is very volatile, yet this theoretical loss is an appreciable one.

We shall find that in Mr. Priestman's engine—the one we have here—efforts are made to utilise some of the heat of the exhaust (which would otherwise be wasted) by causing this heat to vaporise the liquid fuel before it is delivered to the working cylinder.

Other difficulties in practice are those connected with the firing, at the right moment, of the explosive mixture, and with the necessity of so regulating the quantity of oil and the quantity of air that perfect combustion shall be ensured; for if this is not done, then carbon deposits are formed in the internal portions of the engine, and these clog the small inlet passages and block the working faces of the valves, etc.

To show you how recent is the practical development of this form of petroleum engine, I may say that the earliest record of such an engine that I have been able to find is the one suggested by the late Sir William Siemens, in 1868; but this was only a suggestion, and no practical work was done until, in 1873, Brayton, an American, patented a petroleum engine which, with very slight modifications, could be used with either petroleum or gas.

We have upon the wall a diagram showing a section through the working cylinder of a Brayton petroleum engine, and a section through the oil pump of this engine (see *Fig.* 8).

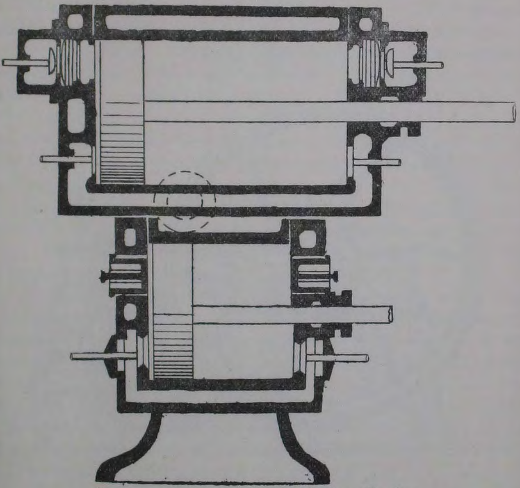

FIG. 8.—*Brayton's Hydro-Carbon Engine.*

In the earliest engines of Mr. Brayton, he used the explosive force of a mixture of air and oil to compress atmospheric air in a separate vessel, and this compressed air was made to act upon a piston connected to a crank shaft, and thus to obtain rotary motion.

This form of engine was abandoned, however, and the engine, of which we have the diagram, was designed.

I must be very brief in describing this, and may tell you that air was forced by a pump through a chamber containing felt, or a similar fibrous material, this felt being kept supplied with the requisite quantity of oil. The air thus became charged with petroleum vapour which was compressed in the working cylinder, and was there fired by means of an external flame connected through passages, at the right moment, with the oil mixture in the working cylinder.

Although many engines on this principle were manufactured and sold, yet the engine was not practically a success, mainly because it was impossible to ensure the correct strength of the explosive mixture by forcing the air through felt charged with oil, as Mr. Brayton did.

Fig. 9 shows an elevation of a Knight's petroleum engine, which is one of those at present made and sold.

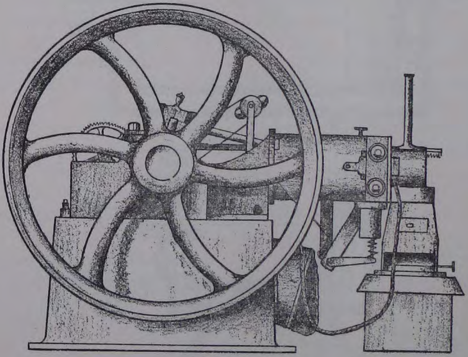

FIG. 9.—*Knight's Petroleum Engine.*

This engine is horizontal, and is single-acting. One capable of developing, say, one horse-power, would run at about 300 revolutions per minute, and would consume about one-fifth of a gallon of oil per hour. Its cylinder would be four inches in diameter, and its stroke eight inches. At the back of the cylinder there is this vaporising chamber, and the cylinder and the vaporising chamber are separated by a steel plate about $\frac{3}{16}$in. thick. To this plate ribs are attached, projecting into the vaporising chamber—these ribs acting as those in an ordinary slow combustion stove, to transmit the heat from the cylinder to the oil in the vaporising chamber. Under this chamber there is placed an ordinary oil heating stove, by means of which the chamber can be made so hot that when a small quantity of oil is pumped into it for starting purposes, this oil is vaporised, and the fly-wheel being turned by hand, the vapour, with the necessary quantity of atmospheric air, is sucked or drawn into the cylinder through the inlet valves, and is fired in the manner which I shall presently describe, and the engine starts to work. After a time, and when the cylinder has got sufficiently hot, so as to enable the ribs in the vaporising chamber to deliver sufficient heat to the oil pumped into that chamber by the engine at each stroke, the heating stove can be extinguished. The firing of the explosive mixture is done at the requisite moment by means of heated platinum wire carried in a small slide valve, worked by the engine. This valve has a hole in it, in which is the small spiral of platinum wire. This platinum wire is exposed to the blow-pipe flame from an oil lamp—the air blast for this blow-pipe flame being obtained from a bellows fixed on the bed plate of the engine and being worked by it. The igniting slide valve is worked by a cam, which at the proper moment draws the slide with the white-hot platinum wire in it into a position where there is connection through a hole in the cylinder-side, with the compressed charge of vapour and air in the cylinder. The oil is, as I have said, automatically pumped by a small pump worked by the engine into the vaporising chamber, being delivered there in the right quantities and at the right moment. The governing of the speed of this engine is done by stopping the supply of oil to the vaporising chamber, with the result that an explosion is missed out, when the speed exceeds the normal. No lubricating oil is required in the cylinders of these engines, because a small quantity of the oil vapour used for working the engine is condensed at each stroke, and thus acts as a lubricant.

There is another engine which I should have liked to describe, had time permitted, which is that known as the "Weatherhogg" engine, but it only differs from those which I have described and from the one which we have here in certain small details, and I must leave it.

As you see, we have here a "Priestman" oil engine, which I suppose is, at the present time, the most successful oil engine in the market.

Due to the kindness of Messrs. Priestman, who have sent this engine here, and have put it to work, I am able to show you the actual machine.

Here is the motor cylinder corresponding, as you will remember, with the cylinder shown in section in the model, where I described the "cycle" of operations occurring in this cylinder. In this motor cylinder is the piston which, by rods, communicates its reciprocating motion to the crank on the crank-shaft, thus causing this shaft and the fly-wheel and pulley attached to it to revolve. From this shaft by means of gearing and the way-shaft, the inlet valve for admitting the petroleum and air is worked, as is also the exhaust valve through which the products of combustion are expelled at the exhaustion stroke of the piston. The firing is done, as I have told you, electrically, contact being made at the right moment, so as to cause an electric spark to pass through the mixed charge of petroleum and air, when it has been compressed by the instroke—the compression stroke—of the piston. Below the cylinder is a vessel. into which the oil is delivered in successive charges, there being heated, while the engine is working, to vaporisation, by the heat of the products of combustion from previous explosive strokes.

If you will consider this, you will see that it is necessary, when the engine has to be started, to generate sufficient heat in the vessel into which the petroleum as liquid is delivered, to ensure the vaporisation of that petroleum. This heat is obtained by means of a lamp, the flame of which is urged by the air blast worked by a hand-pump, and as soon as the vessel, into which the charge of petroleum is delivered at each successive stroke, is sufficiently hot, the engine can be started.

I should like, if time would permit, to explain to you the modes by which the electric firing is done at the exact moment required; the modes by which the proper quantity of oil and of atmospheric air are delivered into the cylinder, and at the right times; and also to describe to you exactly the mode by which the speed of the engine is governed, but the clock warns me that I have already exceeded the time allowed for the delivery of these lectures.

I must ask you to pardon me for this, and to remember how difficult it has been to condense sufficiently that which I had to tell you, and yet to be certain that I have told you enough to enable you to appreciate the theory of working; the difficulties; the modes of overcoming these difficulties; and the possibilities of energy production from petroleum. It now only remains for me to thank you for the courtesy you have shown, and for the attention with which you have listened to that which I have had to say.

PAPER XI.

BRIDGES IN THE BENGAL PRESIDENCY.

By Sir Bradford Leslie, K.C.S.I., M.I.C.E.

I was very reluctant to undertake to lecture on Indian bridges, because the subject is of such great importance that it deserves to be treated by someone who has had better opportunities of studying it than myself. My practical experience of bridge construction is confined to Lower Bengal, and my acquaintance with the bridges of the Punjab, the North West Provinces and Oude, is very limited. I, therefore, cannot pretend to give any approach to a complete account of bridges in the Bengal Presidency, as I have neither the recorded data nor the personal knowledge to treat in a comprehensive manner so interesting a subject. I can only offer such general observations on bridge construction as have occurred to me during the period, from 1858 to 1887, that I spent in Bengal, illustrating my remarks by reference to special works typical of the various styles of design that have been adopted. As I have, to a great extent, to draw upon memory for what I have to say, I must claim your indulgence for any inaccuracy in matters of detail.

Of the great bridges in the Bombay and Madras Presidencies I have no personal knowledge, but judging from the numerous instances in which bridges in those Presidencies have failed, and have had to be replaced by new bridges, it appears probable that the rivers of Southern India present quite as great difficulties to the engineer as those of the Bengal Presidency. Before the British era, some of the minor rivers in Upper India were bridged by the Moguls, near their large cities, and these old Mussulman structures are very remarkable. As an example, may be taken the elevation of the bridge over the Goomtee, at Jaunpore City (*Plate* I., *Fig.* 1). They are high narrow bridges of brickwork or masonry, founded on a continuous masonry platform, with very massive piers and small pointed arches, more resembling a perforated dam than a bridge—in this respect they are not unlike many old bridges in Europe. Whether intentionally or as a necessary consequence of their practice of building their arches on earthen centring, which was not very reliable, the piers of these bridges are sufficiently massive to act as abutments, so that the failure of one arch would not involve the destruction of the remainder, as in the case of an arched viaduct, in which the thrust of an arch is sufficient to upset the pier. In the case of the Jaunpore bridge, the floods of ages have poured through, and in one case at least, in 1871, 10 feet over the top, carrying away all the shops that were erected on the piers (somewhat after the fashion of old London bridge) without finding a weak point, and this bridge is valuable as an example of the stability of platform bridges, provided they are efficiently protected from under-scour.

Since the establishment of the British dominion in India, the great majority of the bridges have been constructed for effecting railway communication over rivers and watercourses, and these structures are interesting, especially in the Bengal Presidency, owing to the heavy floods and inundations to which they are subjected in the rainy season, and the generally unstable character of the river beds in which the abutments and piers have had to be founded.

The quickening effect of railway communication on the backward provinces of India has been most marked wherever these highways have penetrated. Unfortunately, the proposal to run a line of railway through an isolated district is too often nugatory, for the simple reason that the probable traffic will not pay interest on the capital outlay.

The cost of embankments, cuttings, permanent way, stations and rolling stock is fairly constant and proportionate to the traffic. The cost of bridging, however, depends on the nature of the country, but the bridging of a railway must be a thorough job, and it generally aggregates a heavy addition to the capital outlay. For these reasons economical bridge construction is of vital importance to the future of railway extension in India.

Characteristic Features of Indian Rivers.—In the vast extent of the plain country of the Punjab, the North-west, and Bengal proper, the land is an alluvium of sand and clay of unknown depth, with occasional deposits of "kunker," a kind of limestone gravel, which occurs in thin beds, and which, when burnt, yields excellent hydraulic mortar.

The lowest level of the plains is generally that most remote from the great rivers, the land rising gradually thence to the banks of the rivers where the large towns and villages are situated. The centre of these extensive depressions is usually covered by a swamp or jheel, which never dries up, and is connected with the rivers by watercourses, "nullahs or khals," through which, in the flood season, the water charged with deposit, flows from the river into the swamp, extending the limits of inundated land until, in very wet seasons, only the high land at the margin of the rivers is above water. As the water in the river subsides the current in the nullah is reversed, and it gradually drains the land, leaving it fertilized by the river deposit.

The watercourses or "nullahs," which draw off the flood spill of the main streams, are often ill-defined, and in extraordinary floods an enormous volume of water is spilled over low portions of the river banks, which finds its way to the interior over a wide area, and necessitates flood openings in railway embankments.

The large rivers in the Punjab and upper India discharging sudden and concentrated periodic floods through alluvial plains have commonly a very erratic character, and this is especially the case in the Punjab.

The rivers in the plains generally occupy broad shallow valleys, varying in width, but in some cases as much as seven or eight miles broad. These valleys are termed the "kader" of the river, and through them the dry season channels, generally fordable, meander in a tortuous course, leaving wide sand banks or "churrs" on one side or the other, and forming islands in the centre. In some cases the low-lying lands of the banks and islands, afford valuable crops and pasture, in others it is overgrown with elephant grass and jungle, giving cover to tiger, wild pig, and other game.

When the monsoon rains are light it may happen for several years in succession that the rivers do not greatly exceed their dry season channels.

The heavy inundations are less frequent, but when they do occur, a great part, sometimes the whole width, of the kader valley is filled with a turbid flood, which does not, however, flow in an uniformly direct course, but influenced by the turns and bends of the dry season channels, runs in some portions at a velocity of 10 miles or more per hour, with, in other places, large areas of comparatively still water; while frequently in the wake of islands or under projections of the permanent banks the stream eddies back and flows in the opposite direction. It also escapes through the lateral nullahs before described, and fills the depressions in the interior of the plains. Besides raising the level of the water in the river, a heavy flood gets relief by scouring and deepening the channels, and forming new ones by cutting away the sand banks and islands, so that sections taken in the dry season are of very little use in calculating the discharge, or as a guide to the regime of a river in the floods.

On the occasion of a heavy inundation, it not unfrequently happens that owing to some local obstruction caused by drifting jungle, a deep channel may be cut through portions of the kader valley, which, a few days before, were cultivated fields.

The high permanent banks are in fact the limits of deviation, within which the channels may occupy almost any position, sometimes at right angles to, and sometimes even in the opposite direction to, the general course of the river.

During a heavy inundation the surface breadth of these rivers is so great that the tops only of the highest trees are visible from one side to the other. On the subsidence of such extraordinary floods, great changes are frequently found to have occurred in the location of the dry season channels.

The net width of waterway to be given in bridging such rivers is one of the most difficult questions that have to be decided by engineers in India.

A remarkable instance of the sudden alteration of channels caused by the floods, occurred in Lower Bengal, in 1861 (*Plate* I., *Fig.* 2). Previous to that date, and as far back as the memory of the oldest inhabitant, the main channel of the Ganges flowed close under the high bank at Kooshtea; but no sooner had the Eastern Bengal railway built their terminal station at this apparently permanent and favourable reach of the river, than in a single flood season a new channel was scoured two and a-half miles to the north-east, and the old channel silted up so completely, that within a month a crop of indigo was growing on the new land, where the main channel of the river flowed 50 feet deep before the floods—representing a thickness of 80 feet of solid earth deposited in a few weeks, and that over an area of many square miles. It is to be noted that the Gorai river, an outlet of the Ganges, taking off a mile or two below Kooshtea, was not choked by the silting up of the old channel of the Ganges, but adopted a portion of that old channel to maintain its connection with the new stream of the Ganges, consequently reversing the flow of the water in that portion of the old bed of the Ganges.

Since 1861, the bed of the Ganges has gone much further to the north-east, and the course of the Gorai river has been lengthened by fully five miles above its old mouth previous to 1861 (*Plate* I., *Fig.* 3).

A similar instance occurred at Rajmahal, to which point the East Indian railway was opened in 1860, and where also extensive terminal buildings were erected on the banks of the Ganges, and sanguine anticipations were formed of the traffic to be derived from tapping that great highway of inland navigation. Here also in a single season the floods entirely altered the course of the river, and the railway terminus was left miles inland, so as to be utterly inaccessible to steamers and country craft.

A more recent case may be mentioned when the navigable channel of the Ganges, which flowed close to the Patna Ghat station of the East Indian Railway, suddenly silted up, and the railway had to be extended about a mile to the new channel.

These instances refer to Lower Bengal, where the Ganges is navigable, and where no proposal has hitherto been made to bridge it, and are quoted because they came under my own observation, but changes similar in character constantly occur in the rivers up country.

In the Punjab, Oude and Rohilkund, and the North-West Provinces, the floods are seldom more than ten days or a fortnight in duration, though this is long enough to carry away bridges and embankments and to do a vast amount of damage to the railways.

In Eastern Bengal, swelled by its numerous tributaries, and owing partly to the influence of the Brahmapootra river, the Ganges and its Nuddeah effluents may remain in full flood for a month or more, and during such periods the railways of this district south of the Ganges are sorely tried by the flood spill, and often severely punished.

Numerous important rivers, tributaries of the Ganges and the Jumna, take their rise in the southern slopes of the Himalayahs and in the elevated plateaux of Rajputana, the Central Provinces, Chota Nagpur, and the Rajmahal hills, while others, like the Damoodah and Mahanuddy, flow direct into the Bay of Bengal.

In the hills these rivers generally have a well defined channel with a steep slope and a rocky bed, covered with a greater or lesser thickness of sand; but where they debouch on the plains they assume the ordinary characteristics of rivers in the plains.

Some of these rivers, like the Teesta and the Coosy, with a comparatively short course and rapid fall, drain vast areas of snow-clad mountains, the highest in the world. Their floods, which are more distinctly affected by the melting of the snow, carry with them an exceptionally large amount of detritus from the hills, which chokes their beds and results in spreading them laterally over a wide extent of country. To carry a railway over the Coosy, would, I have heard, require some twelve miles of bridging.

Further to the eastward are the fertile districts of Assam and Cachar, which for many years to come must be severed from the railway system of the rest of India by the great Brahmapootra river. With the hills in close proximity on either side, and with a very heavy rainfall, the rivers of these districts are numerous and formidable; the plains are covered with a network of creeks and water-courses, which make it a very amphibious sort of country in the rainy season. Should it become necessary in the future to carry land communications across the Ganges or Brahmapootra rivers in Lower Bengal, the question will arise whether tunnelling may not be cheaper than bridging. In the case of a tunnel, a great portion, if not the whole length, would have to be made through permeable strata. Any permanent structure for crossing these rivers involves the necessity for fixing and controlling its course at the site of the structure. Although not impossible, this might prove a costly undertaking, and it therefore seems probable that the present system of working the railway traffic across the lower reaches of the Ganges and the Brahmapootra by ferries must continue.

Flood Openings.

Having thus, in a very imperfect and cursory manner, recalled the general features of the rivers and inundations in the Bengal Presidency, I will proceed to make some observations on the various types of bridges adopted to effect railway communication. Excepting the objection to the use of timber on account of its liability to decay in the Indian climate, there is nothing special that I am aware of in the superstructures of Indian bridges; my remarks, therefore, will treat rather of the conditions affecting the stability of the piers and abutments, and I will in the first instance deal with the subject of flood openings.

It was not to be expected that railway engineers, fresh from England, where a moderate rainfall over comparatively restricted areas with a short course limits the volume and force of the floods, and where, as a rule, a good foundation can be secured, should at once realize the conditions of the problem before them in providing for the drainage of such a country as India.

The floods that previous to the throwing up of a railway embankment passed with an almost imperceptible flow over a wide expanse of level country are checked by such an embankment, and have to be concentrated at the lowest depression, where a sufficient area of waterway has to be provided to give vent to floods that were previously diffused over miles of country. The result is that in high inundations the strain caused by the concentrated current with a considerable afflux on the upper side of these flood openings is very severe, and there is developed a tendency to scour out channels at such openings, which was not foreseen by the engineers.

On the Eastern Bengal Railway, which was commenced in 1858, in a district where no roads excepting fair weather tracks existed, and no previous experience was available, it was supposed that a good foundation could be secured by cast iron cylindrical screw piles sunk to a depth of 20 feet; the amount of waterway provided was determined on insufficient data, and in many cases has proved to have been quite inadequate, and the abutments or retaining walls at the ends of the viaducts were founded a few feet only below the ground level.

In 1867, a flood opening of three spans of 30 feet, near Bugoolah, at 61 miles from Calcutta, was damaged by a flood which scoured a depth of seven feet, and undermined the south abutment.

The structure was then lengthened by four additional spans, making a total length of 210 feet. In 1871, the flood spill from the Ganges, obstructed by the railway embankment, rose to an extraordinary height, and in a few days swept the whole bridge away, and scoured a hole 1000 feet wide, and 90 feet deep below ground level, as shown on *Plate* II., *Fig.* 1.

To increase the waterway two flood openings of 250 feet each, one on each side of the gap, were built; these consisted of 35-feet spans carried on brick piers, and were properly floored with a thickness of 12 inches of concrete for a width of 75 feet, to protect them from scour. A sclid embankment was thrown across the gap on the site of the original screw pile bridge, and the railway was restored on its original alignment; a wide channel, parallel to the railway, was also cut through high ground on the west side of the line to give an outlet for the flood water to the south. With this large increase of waterway and these precautions the line was considered safe.

In 1879, another high flood topped the railway embankment a depth of six or eight inches for a distance of three miles south of Bugoolah, and scoured a deep hole at the down stream side of the south bridge at 61 miles, but fortunately the flood subsided without further damage. The part of the railway that had been overtopped was raised three feet, and the south bridge protected by filling in the scour outside the drop wall of the flooring for a breadth of 30 feet, and laying on top of the berm so formed a rubble stone apron three feet thick of the same width, at the level of the flooring of the bridge.

After an interval of six years, in 1885, another extraordinary flood overtopped the line at Bugoolah, and for two miles north, and the line was breached in two places for a total width of 680 feet. The floored bridges stood the rush of the water with an afflux of 19 inches uninjured, but the rubble stone at the south bridge dropped down; this was restored and made up to an uniform slope. As the waterway was still evidently insufficient, two new bridges of 400 feet, and one of 200 feet in length, were built between the 55th and 59th miles.

With this additional waterway it was hoped that the line would be safe, but in 1890 the floods again overtopped the line by five inches, though the head of water was reduced from 19 inches to 12 inches, and consequently the current was not so strong. One of the new bridges was damaged by an eddy, caused by the lateral flow of the water round the end of a training embankment on the up-stream side, which undermined the flooring and caused two of the piers to cant up-stream; however, the mischief was checked by throwing a few truck loads of rubble stone into the hole. At the south bridge, at 61 miles, where the current was strongest, the stone apron stood well, the outer edge only dropping away.

These details give a very imperfect sketch of the struggle that has to be maintained with the flood spill of the Ganges, at one place only out of many, where the Eastern Bengal Railway has sustained damage by the overflow of that river. At present I believe that all of the important flood openings on that line are protected by a flooring either of concrete, brickwork, or rubble stone. But whenever an inundation is threatened the engineering staff has to be on the alert; all weak points are anxiously watched night and day, and the appearance of the turbid flood-water from point to point is reported hourly by telegraph. Trains loaded with rubble stone and coolies are ready to proceed to fortify and protect any structure that may be attacked, and in danger of being underscoured.

On such an occasion the whole country is a wild waste of waters 15 to 20 feet deep; the villages on the higher grounds forming islands cut off from all communication excepting by boats. The railway is only visible by the difference of level of the water rippling over the rails, and washing away the ballast, or on higher parts of the line the top of the embankment, thronged with cattle and villagers taking refuge, may be seen, while the girders of a flood-opening with a ballast train standing in the water, appear as it were in the middle of an inland sea. At such a period it requires an engineer who knows every yard of the line, and whose experienced eye, as he trollies along the line, can detect indications of mischief in the treacherous eddy or incipient washing away of the ballast, or the discoloration of the water at the abutment of a bridge, to direct the operations of the material train and avert danger. And these duties have to be performed at the most trying season of the year, when the heat and glare of the sun reflected from the water soon knock the toughest constitution out of time.

I have seen spans of 30 feet wide completely choked by floating islands of grass and weeds, and with a strong stream it was no easy matter to clear the constantly accumulating obstruction, especially as not a few cobras and other vermin had taken refuge in the drift weed and bushes.

Where the height of an inundation is 15 or 20 feet above the level of the plain, it does seem extraordinary that the flood, having once effected a breach in the railway, should excavate a hole over 100 feet below the level of the flood surface, instead of confining itself to getting relief by cutting away a few miles of the embankment, which it could easily do. I believe, however, that such deep holes are the result rather of the boring action of the eddies, caused by the flow of water from various directions converging on the breach, than of the direct scouring action of the current through the opening, and it is probable that beyond a certain depth such holes are not effective to help the discharge of the flood water.

The boring action of an eddy is a very remarkable phenomenon. I have seen a hole of 180 feet deep scoured out at the end of a stone spur by an eddy, where the direct scour along the face of the spur was less than half that amount. We have seen how, in 1890, one of the new Eastern Bengal flood openings was damaged on the up-stream side by an eddy caused by the lateral flow of the current, and my experience of flood damage to bridges is that in nine cases out of ten the mischief is the result of the boring action of eddy water.

These considerations show how important it is in designing flood openings to guide the converging flow of the water by easy curves through the opening, without requiring it to take any sudden bends, or opposing any unnecessary obstacles to excite eddies.

It is remarkable that every severe flood has a character of its own, and differs from preceding floods in direction, level, and duration, so that is is impossible to predicate the locality and nature of the danger to be encountered.

On the North Western Railway the usual type of flood opening was originally 40 feet span girders on piers, consisting of a couple of wells nine feet diameter sunk 40 feet below ground level, but it was soon found that such a depth of foundation was no good to prevent failure from scour, and a trench about 10 feet deep and wide, filled with rubble stone, was made the whole length of the flood opening. A hole 60 feet deep was scoured out just below some of the flood openings. The width of these holes was double the width of the flood openings, and the stuff scoured was deposited on the edge of the hole. The latest type of flood opening on the N.W. Railway consists of 40 feet span girders on wells or blocks only 12 feet deep, but the whole area of the flood opening pitched with rubble for the full width of the embankment.

The cast-iron screw pile viaducts, if protected by a proper flooring from scour, are a very good type of flood opening, and if the ends of the embankments are formed conical, and protected by stone pitching or concrete, no brickwork is required, which in some districts, where bricks or bricklayers are not locally available, may result in saving a working season.

On the whole, the best and most economical type of flood opening for the plains, according to my experience, is a structure with girder spans of suitable width carried well above the probable highest flood level, as affected by the railway embankment (this it will be remembered may be higher than the flood level before the throwing up of the bank) on brick piers, founded at as low a level as possible without well-sinking, the foundations depending on a sufficient extent of base for their stability, and protected from under-scour by flooring the entire area of the flood opening for the full width, or nearly so, of the embankment by a platform of concrete, laid a few feet above the level of the pier foundations. The outer edges of the concrete flooring should rest upon curtain or drop-walls of brick-work or concrete founded at the same level or rather lower than the piers.

In such a flood opening, without going to any extraordinary depth, the flooring platform should be laid at a lower level than the surface of the ground, which on each side of the opening should be excavated to form a gradual incline down to the platform.

The best termination of a flood opening is one of the ordinary piers with the embankment thrown up round it, in the form of a cone, the conical end of the bank being protected by stone pitching, or a layer of concrete like the flooring.

It is not necessary that the concrete flooring should be of any considerable thickness, 15 inches, or even 12 inches, if well laid, is sufficient, as it is a mere skin to protect the earth erosion.

Where there is no well defined channel, curved training embankments, forming a sort of trumpet or bell mouth to the opening, should be thrown up to check the lateral currents and to guide the stream, and cause it to flow in a direction normal to the flood opening. Similar training embankments are required on the down-stream side, to prevent the formation of eddies that might cut back into the embankment. The length of such training embankments, both above and below bridge, as well as their direction, must depend upon circumstances. They should be above the flood level where they abut on the railway embankment at the end of the viaduct; in fact, the outer slope of the training embankment should be in line with the end of the viaduct. The top of the training embankment should be inclined, gradually sloping down from the viaduct until it merges in the plain. This formation, if the training embankments are of sufficient length, allows the converging flood waters to flow through the flood opening without giving rise to eddies. For want of such training embankments, I have known an instance where the brick piers of a bridge were taken in flank by a high flood flowing parallel with the railway and thrown over by its momentum.

Instead of terminating the viaduct by coning the ends of the embankment and protecting them by concrete, the more usual plan is to cut the embankment square off by a brick abutment with battering wing walls, and this plan gives the greatest sectional area of waterway for a given length of superstructure, or the wing walls may be made with a convex curve in plan, so as to give a sort of trumpet or bell mouth to the opening. The exact mode of treating the ends of the flood opening is not a matter of much importance, provided the whole of the wetted perimeter of the opening, whatever shape it may be, is protected by brickwork, concrete, or stone-pitching, and that no salient angles are opposed to the smooth flow of the stream.

It is, however, impossible to avoid some slight eddies on the down-stream side in the wake of each pier, and these, combined with the general rolling action of the water in a strong flood, are almost certain to eat away the earth adjoining the drop-wall on the down-stream side of the opening. To obviate this, the earth beyond the curtain or drop-wall should be excavated for a depth of three or four feet and a breadth of 20 to 30 feet, and replaced by heavy rubble-stone or random concrete blocks. If, as probably will be the case, the earth is scoured away and a hole formed, beyond the rubble stone so deposited, it will roll down, and gradually adjust itself to a condition of stable equilibrium, care being taken to refill any places where the washing away of the rubble-stone or concrete blocks may have left the curtain or drop-wall exposed.

Where a flood opening is subject to a flow in both directions, acting both as inlet and outlet, the stone or concrete block protection may be required at both the curtain or drop-walls.

It might be supposed that the rubble-stone apron should be sufficient to protect the edge of the concrete flooring, and that the curtain or drop-wall is unnecessary. In very strong soil this might be the case, but in the ordinary alluvium the curtain walls are required, their function being to act as water-tight diaphragms to prevent the formation of land springs beneath the foundations, which might gradually undermine the flooring or even the piers of the bridge.

Floored flood openings, properly designed and constructed, are practically indestructible while the railway embankments stand, and provided the spans are wide enough and of sufficient headway not to get choked with floating jungle or wreckage. In certain cases in high embankments, where, owing to back waters or other causes, floods of great depth occur at rare intervals, it may be expedient to cover the flood openings with brick arches, with a good height of embankment over them; such openings, if properly floored, will not suffer damage through being submerged.

The Kurnowtie culvert (*Plate* II., *Fig.* 2), on the East Indian Railway, a short distance above Mirzapore, is an arched bridge of 20 feet span in an embankment 40 feet high, and may be quoted as an example of a flood opening that has been severely tested by floods in both directions. This culvert admits the flood spill of the Kurnowtie river to a large valley of depression between it and the Ganges, and on the subsidence of the river passes a portion of it back again. The drawing shows the ponds that have been scoured out on both sides of the embankment. It will be observed that the bridge foundations are many feet above the flood excavations. The bridge is no doubt much too small for the work it has to do, but the fact that it stands shows the perfect security of a well-built floored structure.

For small bridges, inverted arches are frequently used between the abutments, but I prefer a plain flooring of concrete. The soil in Bengal is more or less compressible, and the seat of a heavy embankment may sink gradually to the extent of five per cent. of its height. In building the abutments and wing walls of a bridge the earth should be filled in and rammed solid as the work progresses, but in spite of this, in the case of arched bridges it sometimes happens, owing to the pressure of the bank at the bridge site being less than on either side, that a longitudinal crack occurs in the crown of the arch. To allow for the settlement of a heavy embankment, it is necessary to build long-barrelled culverts with a considerable camber, making the arch at the centre of the embankment higher than at the ends, so that the settlement may bring it level. When once the settlement has taken place, any cracks that may have shown can be repaired, and no further damage occurs. These are minor points of practical detail, perhaps hardly worth referring to, but they may be useful to those who have to carry out work in Bengal.

Bridges Over Rivers.

I shall now proceed to make some observations on bridges over rivers, as distinguished from bridges over flood-spills or drainage waterways. Where a river has a rocky bed, on which it is possible to found the abutments and piers without great expense, there is no risk of settlement, and in such cases a careful investigation would probably show that an arched structure of masonry or brick would be the most economical, as it certainly would be the most durable and convenient.

There can, in fact, be no comparison between the beauty and repose of a masonry arch, and a noisy rattling iron girder, constantly giving trouble by its expansion and contraction, difficulty of securing the permanent way, and liability to deteriorate by corrosion.

There are numerous beautiful masonry arched bridges on the East Indian Railway, which have never cost a sixpence for repairs since they were built.

The expedition and facility of erecting girder bridges, however, and the convenience of uniform types, leads to their use in many cases where a more deliberate mode of procedure would result in the adoption of the more permanent and economical masonry arch for the superstructure.

Where the height of the piers is extraordinary, advantage may be taken of the absolute stability of rock foundations to adopt girders continuous over two or more spans, by which a considerable saving of material can be effected, and which can be built on one side of the river and rolled over the piers into position. I ought, however, to mention that the practice of making girders continuous over two or more spans is seldom adopted in India, the only instances of which I am aware being on the Oude and Rohilkund Railway, in the bridges over the Ganges, at Rajghat and Cawnpore, and I think in the bridge over the Saie river. Continuous girders, combining a saving of material and in the cost of erection, ought to be adopted for all moderate spans where the foundations are undeniable. The want of confidence in them is probably due to the vague idea that piers founded in sand or silt must always be liable to settlement which might cripple or destroy the girders, and where the borings show a great or unproved depth of sand or silt it is generally considered safer to adopt an ordinary girder bridge. Of course, the same objection applies to arched viaducts; the settlement of one pier involves the failure of at least two arches.

Bridges in the Plains.

Site and Waterway.—A principal object of railways being directness of route, there is seldom much choice with respect to site for bridging rivers. Generally speaking, the best reaches of the river, *i.e.*, where the main channel is most permanent and most frequently concentrated into a single stream, have been selected for the ferries or boat bridges on the old road routes, consequently the railway bridges are often located near these old crossings. For the sake of minimizing the cost of the bridge and protective works, large bridges are located as nearly at right angles to the general direction of the river as possible.

The problem of determining the waterway to be given to a bridge by calculating the area of the basin drained, and the fall of the river bed, is one that I never had occasion to attempt practically. The rivers of Lower Bengal, such as the Hooghly, Echamuttee, Koomar, Gorai, Chundanah rivers, act principally as spill channels for the overflow of the Ganges, and therefore admit of no such calculation. In ordinary circumstances, however, the contour levels necessary to calculate the area of the basin do not exist, and the problem is so complicated by variations in the average inclination of the land, and in the fall of the river channel, as affected by the scour of its bed, also in the quantity of spill into adjacent depressions, and retardations of momentum, caused by bends and elbows in the course of the river, to say nothing of the soil, tillage, conditions as to saturation, and evaporation, all of which affect the discharge, that any attempt to co-relate the drainage area with the maximum flood discharge can lead to no reliable result. The tendency of all empirical rules for calculating the flood discharge of rivers is to err so very much on the safe side, that a dependence on them must inevitably tend to the affording of an extravagant amount of waterway.

In practice it is very difficult to lay down any general principle for the determination of the width of the waterway to be given. The first object of every engineer is, of course, the stability of his work, but in every branch of engineering the desire to be on the safe side may be productive of extravagance. Rivers have to succumb to the control of natural gorges, of which I need not quote instances, and although engineers cannot rival the works of nature, I think it may be affirmed that engineering experience in India has solved the problem of making the piers and abutments of bridges equal to sustaining uninjured the heaviest floods. We have seen that the mere surface breadth of many rivers in flood has no direct relation to the quantity of water passing a given site. The floods also in Upper India are of comparatively short duration. There seems, therefore, no reason for making a bridge wider than is necessary for discharging the net quantity of water passing the site. This would be very much less than most of the large bridges now existing, notwithstanding that more than one of them have already been considerably shortened.

It is very rarely in the plains that a river flows in a compact channel between well-defined banks; generally we are obliged to be content with a permanent bank on one side, and low ground with shelving banks on the other. In dealing with a "kader" valley many miles wide, it is evident we can only use one of the permanent banks as an abutment, and it may happen that we cannot avail ourselves of either. On the high bank the abutment may be slightly retired behind the line of the river frontage, but on the low side the location of the abutment is a more difficult matter to decide. In some cases where the conditions appear to be permanent or can be fixed at a moderate cost, the bridge over the main stream is supplemented by a less expensive viaduct over the low ground on the shelving side, as at the Dufferin bridge over the Ganges, at Benares, and at the Gorai river bridge on the Eastern Bengal Railway (*Plate* III., *Figs*. 1 and 2). Every bridge site has its special and peculiar features involving suitable treatment, but it appears to me that the security of the abutments and the cost of protective works are the most important considerations in determining the minimum width of waterway to be given, the piers being founded at such a depth as to permit the river to adjust its sectional area to the discharge by scouring away its bed without endangering their stability.

It may be objected that to effect any considerable contraction of the waterway would, in many cases, involve training works above bridge, the cost of which would be greater than the saving due to the shortening of the bridge. Where the abutment or abutments of a bridge are in low inundated ground, training embankments, such as those described in my observations on flood openings, to prevent the formation of lateral currents and to guide the stream in a direction normal to the bridge, are necessary; these embankments require to be very strong, and should be pitched with stone and with a rubble-stone apron, but they need not be very long. The utility of the more remote training works, embankments, and spurs of earthwork, brushwood, and stone is not so certain. It may no doubt be objected that in the absence of such training works to bring all the channels of the kader valley under the bridge, the river or a branch of it may impinge on the embankment at some point of the kader valley remote from the bridge, and if it tops the embankment the line may be breached; even if the flood does not rise above the level of the embankment, its momentum where it impinges on the embankment being checked, is expended in forming dangerous eddies, which take effect in boring out deep holes, before the stream acquires a new direction parallel with the embankment, and until it finds a vent by the bridge; this may necessitate the protection of a great length of embankment from under-scour, and for this reason it is generally considered necessary to construct training works to concentrate the flow of the flood in the direction of the bridge. It is, however, difficult to make good the defence of extensive and remote training works; they may be outflanked, and then the strain may come on the railway embankment. However that may be, the limitation of the waterway to that required for the direct discharge of the floods must favour the ultimate formation of a deep and well-defined channel in the direct course of the river, and thereby have a beneficial effect in establishing a permanent regime of the river at the site of the bridge.

In crossing many of the large bridges in Upper India, one is struck by the fact that while the water may be rushing through some openings at a high velocity, at others, if flowing at all, it is moving only at a very gentle rate, and in such cases it is, at least, a fair question, whether some of the waterway is not superfluous. If we can guarantee the stability of our work, it does not seem necessary to afford the river a wide range over which to select its point of attack. If anything approaching the full waterway is to be given to these erratic rivers, it is better to treat them as flood openings and make a floored platform bridge, and thus save the expense of deep foundations.

In submitting these views on the extremely difficult question of waterway, the point for which I contend is that considering the absolute stability of bridge construction with the deep foundations now adopted, we are warranted in taking credit for a considerable increase to the waterway by scour, and that in determining the waterway, allowance should be made for such potential addition to the flood discharge. In drawing attention to this phase of the question, it is necessary to repeat that the infinite variety of conditions affecting bridge sites makes every case a special study, and that no general rules of universal application can be laid down.

As in the question of waterway, so with respect to the width of spans and the design of the abutments and piers, and depth of foundations; the circumstances and conditions of every bridge of importance are so special and peculiar, that it is impossible to frame rules of universal application. I, therefore, propose to give a brief, and I fear a very imperfect, review of what has been done, trusting that such a review may be of some assistance in the investigation of the principles affecting the economy of bridge construction.

The earlier bridges of any magnitude built over rivers with alluvial beds were those built in 1860, over the Tapti and Nerbudda, on the B.B. and C.I. Railway, the piers of which consisted of cast iron cylindrical screw piles, screwed to a depth of 20 feet, carrying 60 feet Warren girders. The Tapti bridge, I believe, is still standing, but gives trouble through the corrosion of the ironwork of the piers in the brackish tidal water. The Nerbudda bridge, after repeated failure of the piers from flood scour, was replaced in 1881 by a structure generally similar to the Gorai bridge, as shown on *Plate* III., *Fig.* 2, consisting of 183 feet spans, carried on piers of two iron cylinders, sunk to a depth of 76 feet below low water. The total length of the Nerbudda bridge is 4,688 feet, and the cost $37\frac{3}{4}$ lakhs of rupees.

In 1861 the Eastern Bengal Railway bridges over the Echamuttee and Koomar rivers, consisting of 80 feet span plate-iron girders on piers of double cast iron cylinders, eight feet diameter, sunk by the pneumatic process to a depth of about 40 feet below low water, were erected. There has been some 20 feet of scour at the Echamuttee bridge without affecting the stability of the structure. I may observe that in using the pneumatic process for cylinder sinking, the air pressure is that required to overcome the head of water in the rivers, and the cylinders have to be strong enough to sustain the internal pressure. The plant is expensive, and the heat caused by compressing the air is very trying in the climate of India. Generally speaking, cylinders or wells can be sunk by open dredging, but when compact clay or other strata that cannot be dredged have to be passed through, it is possible to lower the level of the water in the cylinder to some extent with safety by pumping, so that divers working in the diving dress have not to bear so much air pressure as if the pneumatic process were adopted. For these reasons the pneumatic process has not been much used in Bengal.

The adoption of iron cylinders for these earlier bridges facilitated the erection of the piers in rivers which carry a considerable depth of water at all seasons, and the great convenience of iron cylinders or caissons in this respect has led to their continued use in such cases, as at the Benares Dufferin bridge, where iron caissons were used for the lower portion of the piers that had to be pitched in water, and at the Gorai bridge, where iron cylinders were used throughout. In Upper India it is generally possible to pitch the brick cylinders on the dry bed of the river in the cold season, or to form islands for pitching them in the shallow dry season channels.

The first great typical bridge in India was the East Indian Railway bridge over the Sone river, completed in 1862. The total length is 4,731 feet, consisting of 28 deck spans of 162 feet centre to centre of piers, which are 12 feet thick, carried on three brick wells of 18 feet diameter in line, sunk to a depth of 32 feet below low water into a bed of stiff yellow clay. There has hitherto been no difficulty in limiting the scour by depositing rubble-stone round the piers from time to time as required.

According to the original design, each pier 60 feet long was to have been founded on 12 brick wells, of 10 feet in diameter ; ranged in two rows of 5, with a central well at each end of the pier. One pier was finished on this plan, but the design was then altered by the adoption of three wells of 18 feet diameter. The area of the 10 wells which really carried the pier was 785 feet super, with an aggregate circumferential measurement of 314 feet. The area of the three 18 feet wells was 763 feet, with an aggregate circumference of 170 feet. As the resistance to sinking is in proportion to the aggregate circumference, the superiority of the three 18 feet wells to the 12 wells of 10 feet diameter is evident. This bridge has been completed for double line of rails—the cost is stated at Rs. 33 lakhs, but I am not quite sure whether this includes the girders for the second line of rails.

With piers founded at a greater depth, it is probable that the waterway at this bridge might have been safely reduced to a considerable extent.

The bridge over the Tonse river, with seven spans of 162 feet centre to centre of piers, carried on group well piers, sunk to about 15 feet into the river bed, was finished in 1864. This bridge does not appear to have given trouble by scour. The girders are deck spans with, as in the case of the Sone bridge, a roadway below. In 1875, an extraordinary flood rose half-way up the girders to within 10 feet of the rails. The lattice girders got choked with drift jungle, but no damage was sustained—the flood level, in this instance, appears to have been aggravated by a simultaneous Ganges flood damming up the mouth of the Tonse river.

The Allahabad Jumna bridge finished in 1865, has 14 deck spans (with roadway below) of 200 feet each, the piers founded on groups of 12 brick wells 13 feet 6 inches diameter, giving a bearing surface of 1716 feet super, with an aggregate circumference of 509 feet, sunk to a depth of 42 feet below the water; total length of bridge, 3,235 feet. During the sinking of the up stream well at pier No. 11, it was thrown over by a flood. The fallen well was incorporated with the pier, and the whole protected from scour by rubble-stone. At this bridge there is no considerable amount of scour, a few loads of stone thrown in as occasion demands limit the erosion of the river bed. The cost of this bridge was Rs. $44\frac{1}{2}$ lakhs, or Rs. 1,374 per foot run. The girders are for single line only.

Then followed the Delhi Jumna bridge, of 12 deck spans of $211\frac{1}{2}$ feet with roadway below, carried on piers founded on groups of 10 brick wells, 12 feet diameter, giving a bearing surface of 1,131 feet super, with aggregate circumference of 377 feet; total length of bridge, 2,640 feet. The 10 wells of each pier are arranged in two rows of four, with a central well at each end. The two abutments and piers No. 1 and 2, at the west end, are founded on the rock which crops up at Delhi; the other pier wells are sunk to a depth of about 40 feet below low water into a bed of stiff clay. There is no trouble from scour at this bridge, although, owing to the configuration of the rocky promontory on the right bank, the stream seldom is normal to the bridge. The bridge is for single line, and cost Rs. $16\frac{3}{4}$ lakhs or Rs. 629 per foot. All of these bridges are on grouped well piers, and are fortunate in resting on good solid clay beds. The channels of the rivers are fairly well defined, and excepting the obstruction of the piers, there is no contraction of the waterway, and consequently scour is easily controlled.

We come now to the Punjab and Delhi Railway bridges over the Jumna, Beas, and Sutlej, which were finished in 1869. I regret I am unable to give a complete account of these bridges, as it would be very instructive. The superstructure of all these bridges consists of deck spans of 110 feet, centre to centre of piers, carried on single well piers $12\frac{1}{2}$ feet in diameter, giving an area of 123 feet super, with a circumference of $39\frac{1}{4}$ feet. The wells are sunk to depths varying from 40 to 50 feet; about the same depth as the East Indian Railway bridges, but without meeting with any clay bed. The Punjab rivers flowing in ill defined and unstable channels in broad kader valleys, are also quite different in character from the rivers crossed by East Indian Railway bridges.

The length of the Jumna bridge is 2,664 feet, cost Rs. 15⅓ lakhs or Rs. 500 per foot; the length of the Beas bridge is 3,820 feet, cost Rs. 26 lakhs or Rs. 600 per foot run; and the Sutlej bridge, after the removal of 12 spans, is 5,193 feet long, cost Rs. 33½ lakhs, or about Rs. 600 per foot run. If I remember rightly after the Sutlej bridge was partly finished, the river altered its course and left the finished bridge high and dry, the bridge was then extended by 28 spans at the south end, to include the new channel of the river. In the first heavy flood which occurred in 1871, after the completion of these bridges, each of them was more or less damaged by under-scour of the piers and abutments. So unforeseen was the disaster, that at the Beas bridge a passenger train dropped through the broken bridge into the river. The failure of these bridges so soon after their completion caused great consternation, and it was at one time supposed that the piers would have to be abandoned, and the superstructure shifted to new piers sunk on a line parallel to the old structure. I regret that I have not at hand the particulars of the failure of these bridges in 1871, or of the measures taken to restore them. It is sufficient to observe that the failure of the piers was caused by under-scour, and that the fact of their falling up stream shows that they were not forced over by the pressure of the stream; the abutments were also damaged by under-scour. The damage to these bridges in 1871, was made good by sinking some new piers where necessary, and by the liberal use of rubble stone and block kunkur protection. In fact, it was at this time and at these bridges, that the efficacy of loose rubble stone or boulders in checking and limiting the scour round the piers of bridges was first brought prominently to notice. Large sums of money were also spent in training works above bridge to regulate the flow of the rivers.

In 1876, the Sutlej bridge was again breached by the floods. It appears that three or four years before that date eight or nine spans at the south, or Loodhiana, end of the bridge were partially blocked to check the set of the stream on the left bank of the river, and this seems to have had the desired result, in so far that in the commencement of 1876 the channels were fairly thrown over towards the centre of the bridge. Subsequently, however, the channel changed, setting against the left bank and hugging it until it reached the bridge, where it was deflected, and ran along the blocked up openings until it reached the clear part of the bridge, where it set in full force against the first three or four piers. The lateral current along the revetment of the blocked openings in swinging round under the bridge must have created formidable eddies. However, the space between pier No. 50, at the end of the blocked openings, and pier No. 48 had been protected by some 63,000 cube feet of rubble stone, and as pier No. 49 was one of the deepest of the old piers, 48 feet below low water level, no danger was apprehended.

On 7th and 8th August, there was some slight settlement of the rubble stone, but this was made good by throwing in a few truck loads of stone. Pier No. 49 was at that time embedded to a depth of 26 feet. On the 9th, there was a sudden settlement of the whole of the stone of 12 feet, reducing the depth of the pier embedded to 14 feet, and exposing over 60 feet to the force of the stream. Train loads of heavy block kunkur, to the extent of 15,000 cube feet, were thrown in around the pier as fast as possible, without however making any impression in reducing the depth of scour. The pier began to settle down, vibrating dangerously with the force of the stream, and canting over, until on the night of the 10th it fell over carrying with it two spans of girders. The force of the current at piers Nos. 47 and 48 was enormous, and seemed centred at pier No. 48, which fell over on the afternoon of the 11th August, after which the flood abated.

The damage to the bridge was made good by deflecting the stream by three spurs above bridge, and silting up the site of the fallen piers. Then a platform of block kunkur was made, on which piers of cast iron columns filled with concrete and three spans of girders from the blocked openings were erected. The entire space between piers 47 and 50, was floored with stone and kunkur to prevent scour. Practically the piers are erected on a *pierre perdue* foundation. The security of this mode of repairing the damage seems to depend a good deal on the continued efficacy of the spurs above bridge in deflecting the stream, and on the forbearance of the river itself. It is remarkable that in the flood of 1876, when piers 48 and 49 were under-scoured, the whole of the flood water was passing through five spans at the north end and seven spans at the south end of the bridge, and through only a few of these with great violence, *i.e.*, 12 spans only out of 50 carried the river in a high flood.

The panic caused by the failure of the piers of the Delhi Railway bridges in 1871, led to the appointment of a committee for the considering the design of the Punjab Northern Railway bridges over the Ravi, the Chenab, and the Jhelum, then under construction. The decision of the committee in the matter of the piers was to adopt triple well piers, consisting of three $12\frac{1}{2}$ feet wells in line, sunk to a depth of 75 feet below low water.

The wells are united above low water by corbelling to form a single pier. The idea that led to the adoption of the triple wells, apparently was that the greater depth which the experience of the Delhi Railway bridges had shown might possibly be laid bare by scour, required increased support to sustain the pressure of the floods, and that this could best be afforded without decreasing the waterway by using three wells in line. The fact, however, is that at the Delhi Railway bridges, the piers failed not by yielding to the pressure of the stream, but through the wells being undermined by scour under the up stream side, and falling over against the stream. Thus the committee failed to realize what, in my opinion, is the only good feature of the Delhi Railway bridges, viz: the single well piers. The triple wells which cannot be sunk close together, and are only united above low water level, are not nearly so stable as a single well of the same area (21·66) diameter, while they have 74 per cent. more aggregate circumference or resistance to sinking. The design of the triple wells is also ill-adapted to the Punjab rivers. In spite of the most perfect training, it is very rare that the course of the stream in these rivers is exactly normal to the bridge. A very slight obliquity in the direction of the current, acting on a triple well pier, must produce greatly increased scour, as compared with a single well pier, to which the direction of the stream makes no difference. However, the triple well piers were adopted for the Punjab Northern bridges, over the Ravi, the Chenab, and the Jhelum, and led of course to largely increased outlay. These bridges were finished in 1875–76.

Ravi.—The bridge over the Ravi is 3,217 feet long, in 33 spans of $93\frac{1}{3}$ feet, and cost Rs. 16 lakhs, or at the rate of Rs. 450 to the foot run.

Jhelum.—The bridge over the Jhelum is 4,875 feet long, in 50 spans of 90 feet, and cost Rs. 17 lakhs, or Rs. 334 to the foot run.

Chenab.—The bridge over the Chenab is 9,088 feet long, in 64 spans of $133\frac{1}{2}$ feet, and cost Rs. $53\frac{1}{2}$ lakhs, or at the rate of Rs. 484 to the foot run. The cost of the protective or training works at this bridge has been Rs. 940,336. These are on a very extensive scale, extending fully $1\frac{1}{2}$ miles above bridge, and some considerable distance below.

An instance of the effect of a lateral current taking the triple well piers in flank was not long delayed. In 1874, during the construction of the Chenab bridge, a quantity of material was deposited in some of the finished spans at the north end of the bridge, blocking these spans. The main stream setting towards the north side of the river, on reaching the bridge, was deflected southwards, and flowed along the blocked openings until it arrived at the clear part of the bridge. The momentum which the current had acquired, exerted itself in scooping out a channel in the line of the bridge. The obstruction caused by the triple wells aggregating 42 feet in breadth, resulted in a deep scour, exposing a height of the wells to a force of stream that overthrew the upper two wells of three piers. These wells were sunk to the full depth of 70 feet below low water. There is no instance on record of a single well standing by itself, sunk to such a depth, having been overthrown by scour. From this it may be inferred that in the case of the Chenab wells, an extraordinary depth of scour was caused by the stream striking the triple well pier in flank.

The disaster was very similar in character to that already described, which occurred at the Sutlej bridge in 1876.

The length of the Chenab bridge has now been reduced from 9,088 feet, to about 3,500 feet, by the closing of 17 spans on the right bank, and 22 spans on the left bank of river, which have been filled in with solid embankments. To confine the river within these reduced limits, training embankments extending 1,200 feet above bridge on the right side, and 3,400 feet above bridge on the left bank, and about 500 feet below bridge on both sides, are proposed to be made. The banks are about 12 feet high, 20 feet wide at the top, and 90 feet at the base. The outer slope of the bank, with an additional width of 40 feet at the base, to be pitched with rubble stone about $2\frac{1}{2}$ feet in thickness.

The question suggests itself, whether this bridge might have safely been limited to the reduced length in the first instance, and further, assuming the stone protected training embankments in the immediate vicinity of the reduced bridge to have been provided, whether a great part of the outlay incurred on the more remote and outlying training embankments and spans might not have been saved. This is a question that it would be presumptuous to attempt to answer, without full information. Evidently, however, if the railway embankment was strong enough to resist the flood spill, the river proper, having no other outlet than the bridge, would be compelled to adopt that channel.

I believe that the stone-protected training embankment, if located so as to effect a judicious contraction of the waterway, forming, as it were, a bottle neck at the site of the bridge, are the real abutments of such bridges—merely to carry the ends of the girders a pier of the ordinary type is sufficient.

The contraction of the waterway is necessary to steady the stream through the bottle neck, and by confining it, to prevent it from cannoning from side to side.

The direct scour of even a very strong stream parallel to the embankments will not do much damage when once the apron pitching stone has adjusted itself to a natural slope. The points at which these embankments are most likely to suffer damage, are the extremities. The common practice of forming what is termed a "head" to such training embankments is, I believe, a mistake. From my own experience I am of opinion that such training embankments should be curved back to form a trumpet mouth, and should slope down at the ends by a very gradual incline, and should be protected by a wide apron of rubble stone (*Plate* IV.). The ends of the training embankments, both above and below bridge, should, in short, gradually sink down and spread out to the level of the plain in such a manner as not to excite the formation of eddies, but to let the flood glide round without feeling it.

About the same time that the Punjab Northern bridges over the Ravi, Chenab and Jhelum were in progress, the Oude and Rohilkund Railway Company were constructing bridges over the Ganges at Cawnpore, and at Rajghat, near Aligurh.

The Cawnpore Ganges bridge (*Plate* III., *Fig.* 3) has a length of 2,830 feet, with 25 spans of 100 feet, and two of 40. It was originally intended that the piers of this bridge should be carried on two brick wells, of 10 feet only in diameter. Great difficulty was experienced in sinking the small 10 feet wells beyond a certain depth, and they had to be heavily weighted with rails ; a number of them that were partially sunk were caught by a flood, under-scoured, and fell over, the rails with which they were weighted settling down into the river bed. The mistake of multiple small well piers for deep foundations was then realized; the design of the piers was altered to a single 18-feet well, and the centre line of the bridge was shifted down stream to allow some of the 10-feet wells, which were securely sunk to the full depth, to remain standing, forming, as it were, cut-water wells on the up-stream side of the large 18-feet wells. The sunken rails and the material of the overthrown 10-feet wells obstructed the sinking of the large wells, and in some cases rails that were found under the cutting edge of the large 18-feet wells had to be blasted with guncotton. Besides, a stratum of agglomerated kunkur had to be passed through. However, all obstacles were eventually overcome, and the 18-feet wells were founded at a depth of 65 feet below low water, in a bed of hard clay.

This bridge was finished in 1875, and cost Rs. 17½ lakhs, or Rs. 561 to the foot run.

The design of the Rajghat Ganges bridge, 3,040 feet long, with 33 spans of 80 feet clear, or 92½ feet centre to centre of piers, carried on single wells of 12½ feet in diameter, sunk to a depth of 55 feet, was very similar to that of the Delhi railway bridges over the Jumna, Beas, and Sutlej, that had failed. When the disaster occurred to those bridges, some of the 12½-feet wells at Rajghat, and some of the 18-feet wells at Cawnpore were sunk, and others in progress. Influenced by the decision of the committee on the Punjab northern bridges, the Government Engineer was desirous of altering the designs of the Oude and Rohilkund bridges from single to triple well piers, and revised estimates for the increased outlay were submitted, and received the sanction of Government. Fortunately, however, the confidence of the Company's engineers in the piers of the single well type was not shaken, and owing to their persistence, these bridges were completed in accordance therewith, the only alteration being that those wells of the Rajghat bridge, the sinking of which had not been commenced, were increased from 12½ to 16 feet in diameter. The Rajghat Ganges bridge was finished in 1874, and cost Rs. 8 lakhs, or at the rate of Rs. 227 to the foot run —the cheapest bridge over the Ganges.

The Ramgunga bridge, near Bareilly, total length 2,260 feet, 34 spans of 66 feet centre to centre of piers, carried on single wells, 14 to 16 feet in diameter, sunk 85 feet below low water, was finished in 1874, and including Rs. 8 lakhs for protective works, cost Rs. 14 lakhs, being at the rate, for the bridge alone, of Rs. 267 to the foot run.

The Oude and Rohilkund Railway Company erected two other bridges over the Ganges, both finished in 1887. The Dufferin bridge over the Ganges at Benares, with seven spans of 356 feet centre to centre, carried on elliptical piers, of which Nos. 1, 2 and 3 are founded in hard clay at various depths, and Nos. 4, 5, 6 and 7 are founded in sand, at a maximum depth of 140 feet below low water, and nine spans 114 feet centre to centre on piers carried on double wells of 13½ feet diameter, sunk to depths varying from 114 to 24 feet below low water. The total length of the bridge is 3,571 feet, and the cost Rs. 52 lakhs, at the rate of Rs. 1,432 per foot run; the rise of river in the flood season is 50 feet, and a maximum velocity of 15 miles per hour has been recorded. This bridge is one of the most perfect specimens of engineering work in India, and I regret that time does not admit of my describing its erection in detail.

The other is the "Balawali" Ganges bridge, near Hurdwar. It has eleven spans of 264 feet centre to centre, total length 2,904 feet; the piers are carried on double wells of 20 feet diameter, sunk to a depth of 100 feet below low water in sand. Including Rs. $6\frac{1}{2}$ lakhs for protective works, the total cost has been Rs. $27\frac{1}{2}$ lakhs; the rate per foot run, exclusive of protective works, is Rs. 724. This is also a very fine work. Comparing it, however, with the Rajghat Ganges bridge, it does seem that a less expensive design might have been adopted. Excluding protective works, the cost of the bridge has been Rs. 21 lakhs. By the adoption of 18 spans of 160 feet centre to centre, with piers on single wells of 20 feet diameter, the cost of the superstructure would have been Rs. $6\frac{1}{2}$ lakhs, and the cost of piers and abutments Rs. $7\frac{1}{2}$ lakhs, total Rs. 14 lakhs, there effecting a saving of Rs. 7 lakhs.

The 160 feet spans would have been nearly double those of the Rajghat bridge, and the 20 feet pier wells would have had 57 per cent. greater area, sunk to nearly double the depth to which the Rajghat wells have been sunk.

It may be asked, why not revert at once to the Rajghat design, and effect a still greater saving? On this point I would observe that the wells at Rajghat, sunk only to 55 feet below low water, might, in the event of extraordinary scour, be difficult to protect, and that where excessive stone protection is required in short spans, it practically forms an irregular weir, tending to develop dangerous eddies, and scoop out deep holes on the down-stream side.

The principle of deep foundation bridges is to give room for depth of scour; to permit of this, while allowing for a cone of rubble protection at each pier, the spans should evidently not be too small.

I have now referred to the most important bridges with which I can claim personal acquaintance, though, in some instances, my knowledge is limited to an inspection in passing over them.

There are numerous other important bridges, which I know only by report. I will not refer to the great bridges over the Indus, because these structures are founded on rock, and I have been treating more especially of bridges in the plains. The most interesting bridges, from my point of view, are the Empress bridge, over the Sutlej, at Adamwahan, the Kaiser-i-Hind bridge, over the same river, at Ferozepur, and the Sher Shah bridge, over the Chenab, near Mooltan.

The Empress bridge is 4,200 feet long, in 16 spans of 264 feet centre to centre of piers. This bridge was finished in 1878, and cost Rs. 51 lakhs, or at the rate of Rs. 1,210 to the foot run, with an additional outlay of Rs. 20 lakhs for protective works.

The piers are founded on triple wells, of 19 feet diameter, pitched in line and sunk to the depth of 103 feet below low water. The aggregate area of the wells is 850 feet super, and the aggregate circumference 173 feet.

The abutments of the Empress bridge are similar in design to those of the Punjab Northern Railway bridges. They have a T head on well foundations protected by rubble stone. The peculiar feature is that one span at each end of the bridge, between the abutment and the nearest pier, is blocked by a rubble stone filling a little above low water level, extending round the pier. This stone embankment thus forms a spur of the length of one span plus one pier, nearly 300 feet, projecting from the abutment into the river, and judging from the disasters at the upper Sutlej and the Chenab bridges, which have been described, is just the kind of obstruction to deflect the flow of the river in the direction of the bridge, causing eddies that might endanger the other piers. I have no information as to the nature of the protective works on which the heavy outlay of Rs. 20 lakhs was incurred at this bridge.

The bridge over the Sutlej, near Ferozepur (*Plate* IV.), is 4,293 feet long, and has 27 spans of 144½ feet clear. The piers are on wells, sunk to a depth of 78 feet below low water. The bridge was finished in 1887, at a cost of Rs. 30 lakhs, or at the rate of Rs. 699 to the foot run, with an additional outlay of Rs. 11 lakhs for protective works.

The valley of the Sutlej at the site of this bridge is about five miles wide; the main bridge is located about a mile from the left bank of the valley. On the right side a branch stream, called the "Demu" creek, takes off some distance above bridge, and is crossed by the railway about three miles beyond the main bridge. The Demu creek runs under the high bank, which appears to be the permanent boundary of the kader valley on the right. The protective embankments between the Demu creek and the main bridge cover a space of about three square miles in extent. On the left side an embankment of about three miles long extends from the left abutment to the high bank of the valley. The general plan of these protective embankments form a bell-mouth or funnel, with the object of guiding the main stream through the bridge. These embankments are of earth, and are covered by stone-protected spurs or groynes, projecting obliquely into the river at intervals of about 700 feet.

A maximum flood does not appear to have been experienced since the completion of the bridge, but in July, 1889, the protective works were severely tried by a flood rising to within three feet of a maximum; on this occasion some of the spurs were destroyed, and the main protective banks were breached for about 1,200 yards on the right side, and about 600 yards on the left side of the river. On the right the flood water seems to have forced its way through the protective works as far as the railway embankment, and was finding its way back into the main river through an outlet in the training embankment near the right abutment of the main bridge. The flood apparently commenced to attack the protective works on the 8th or 9th July, and did not begin to fall until the 14th idem. It was only by extraordinary exertions of the engineering staff that the main river was prevented from getting behind the protective bank. The work of throwing in stone to resist the attack of the river commenced on the 9th, was continued day and night without intermission till the 22nd, and extensive operations were subsequently required to make good the damage, and protect the sand embankments from the wash of the waves, which seems to have been very destructive.

The hand-to-hand struggle required to hold these outlying protective works, and the ease with which the flood breached them, seem to indicate the desirability of confining the operations to strengthening the railway itself where necessary, and to making the bottle-neck of the bridge secure by stone-protected training embankments, extending some 1,200 yards above bridge, and leaving the river to settle its own course beyond. Of course, in such a case the flood water might reach the railway embankment throughout the kader valley, and even the main channel of the river might work its way in that direction, but it would have to return round the upper end of the stone training bank, and it is very improbable that any considerable stream would continue to flow by such a circuitous route long enough to do any serious damage. The probability is that the flood would fill the space behind the training embankment with still water, which would quietly drain off round the upper end of it.

In the flood of 1889 there was a scour of 35 feet maximum at piers 1, 2 and 3, on the left bank of the river; this still left 37 feet of wells in the ground. It is remarkable that such a considerable flood should only have affected three piers out of 26.

It is, I believe, now intended to remove the spurs or groynes from the protective embankments for a length of 3,500 feet above bridge on both sides of the river, and to fortify the outer slopes of these embankments by a layer of rubble-stone, with a stone apron extending some distance beyond. This will give a clean run for the stream through the bridge.

The Sher Shah bridge, over the Chenab river, near Mooltan (the combined Chenab and Jhelum rivers, crossed by the Punjab Northern Railway higher up), is 3,650 feet long, in 17 spans of 200 feet clear. This bridge was finished in 1890, and cost Rs. $20\frac{1}{3}$ lakhs, or Rs. 558 to the foot run, a rate of less than half that of the Empress bridge. The protective works have cost in addition $7\frac{1}{2}$ lakhs. The piers are founded on a couple of united hexagonal wells, forming a single block, $28\frac{1}{2}$ feet by 18 feet, with re-entering angles at the centre, somewhat like the numeral 8 in plan; the area of the block is 370 feet, and its perimeter is 84 feet. A circular well of 22 feet diameter would have given the same area, with a circumference of 69 feet, and probably no greater resistance to the stream. The block wells are sunk to a depth of 75 feet below low water. At the site of the Sher Shah bridge the permanent banks of the Chenab are only about 6,000 feet apart, though the river widens considerably above. Through the bridge the river is controlled by training embankments on each side, extending 3,000 feet up-stream and 600 feet down-stream; these embankments are faced with a layer of rubble stone, and have in addition a stone apron; a large quantity of stone has been deposited round each pier to limit scour.

The success of the stone-faced training embankments in forming a bottle-neck at this bridge has been so satisfactory that it is intended to adopt this system of controlling the Chenab at the Punjab Northern bridge, and, as just stated, at the Ferozepur bridge over the Sutlej. In my opinion, success greatly depends on limiting the waterway to what is actually necessary. It will, of course take time to get the stone slopes thoroughly adjusted to the stream, and the exact length and right direction of the embankments may not be hit off in the first instance. The ends also of these training banks will require special study. My view is that they should slope down so gradually that it should not be possible to say where they end, and that a broad apron of stone should be provided.

At the Sher Shah bridge, a step in advance has no doubt been made in the matter of contraction of waterway. The flood discharge of the Chenab at Sher Shah is said to be 50 per cent. more than that of the Sutlej at the Empress bridge, while the waterway is 50 per cent. less.

I have stated my opinion that the absolute stability of the piers and abutments of bridges in the plains can be ensured by deep sinking of foundations, combined with rubble stone or random concrete block protection.

With respect to deep sinking, the most recent example is that of the Dufferin bridge over the Ganges at Benares, the elliptical piers of which are sunk to a depth of 140 below low water. At the Balawali Ganges bridge the piers are sunk to 100 feet, and at the Empress bridge over the Sutlej at Adamwahan to 103 feet below low water, while there are numerous instances of sinking to depths of between 75 and 90 feet below low water.

The well curbs are frequently made of timber, but iron is very superior, especially for forcing the well through hard strata or any obstructions that may be encountered. The vertical tie bars should be strong enough to suspend the curb, and at least one diameter of the well in depth. In the event of a well canting, the tie bars impart a certain amount of transverse strength to sustain any pressure necessary to right it. The diameter of the inside of the well is generally half that of the outside, so that the thickness of the brickwork is a quarter of the external diameter.

A smaller hole in the middle would give more dead weight, which is an advantage, but in case of a deep well getting out of upright, a small internal diameter makes it difficult to work the vertically suspended dredgers.

The resistance to sinking caused by side friction varies with the depth; in brick wells it may roughly be taken at 1cwt. on the total area embedded for every 20 feet in depth; with iron cylinders it is less.

The effective weight of a cylindrical well depends on the height of the water inside, consequently, dewatering a well increases its effective weight, but this involves risk of a sudden irruption of sand and water from below, without getting any run or descent of the well.

Generally, wells after sinking to a depth of $1\frac{1}{2}$ to 2 diameters require loading to overcome side friction. The loading is usually done with rails, a very tedious and expensive business.

When sunk to the full depth, the wells are sealed with a certain thickness of cement concrete, after which they are dewatered and hearted with ordinary lime concrete or brickwork. The stability of such wells depends of course on the reactive power of the soil on which they stand, assisted more or less by the friction of the earth in which they are embedded. In sandy or permeable strata, about one-half of the weight of the well below the water line is water-borne. In clay soils and impermeable strata, even allowing for a certain amount of support from side friction, a pressure of 8 or 10 tons per square foot of base is not uncommon. This seems a large amount to impose on alluvial soil, but it must be remembered that the normal pressure of the superincumbent earth and water at a depth of 90 feet is probably not less than $3\frac{1}{2}$ tons, and it is the difference only between this pressure and the actual weight on the base that takes effect in tending to cause displacement of the foundation. A pier cannot punch its way down without squeezing the earth from beneath it, and the pressure of the surrounding earth is effective in resisting such displacement. The side friction also helps to distribute the pressure for a certain distance round the well.

In single well piers the limit of resistance to the horizontal pressure of the stream depends on the dead weight, plus the assistance derived from the collateral support of the earth in which it may be embedded, but is diminished to any extent that, owing to the permeable nature of the earth, the pier may be water-borne.

In designing piers it is necessary to assign a limit to which scour should be restricted, by the use of rubble stone if necessary.

In a river with a flood rise of 20 feet, if we limit the scour at the well to 40 feet below low water, the greatest depth of water at the well will be 60 feet.

Assuming the maximum height of the pier to be exposed to the stream at 3 diameters of the well, this will be $\frac{60}{3} = 20$ feet in diameter. The pier above low water may be reduced to say 14 feet in thickness, and may be formed with cutwaters. As, however, the current may set obliquely to the pier, in considering its power of resisting the horizontal pressure of the stream it is better to assume that the cylindrical well extends up to the highest flood level.

If the scour is limited to leave a minimum of 2 diameters $= 40$ feet embedded, the total depth will be $60 + 40 = 100$ feet below flood level $= 80$ feet below low water.

With a stream of 12 miles per hour at the surface, which is a very high velocity, the horizontal pressure due to a depth of 60 feet on a 20 feet well may be taken at 50 tons, acting at a depth of 30 feet or 70 feet above the base.

With 100 feet of pier below the flood level, 10 feet of pier above, and 150 feet spans, the effective weight on the base of such a pier would be 1,120 tons; this is assuming that the pier is pitched in sand, and is therefore partially waterborne.

The pressure of 60 tons at a height of 70 feet above the base would alter the incidence of the effective weight about 3 feet; this shifting of the centre of pressure might or might not be more than the earth under the base of the pier could sustain.

Assuming that the earth at the base of the pier is not capable of sustaining the inequality of pressure caused by the horizontal force of the stream, or taking the case of a hollow cylinder of plate iron, planted 40 feet in the river bed, subjected to a horizontal pressure of 50 tons at a height of 70 feet above the bottom, it is evident that such a cylinder, having no bottom, must depend on the lateral support of earth in which it is embedded for stability. A cylinder under such conditions would tend to revolve about a point in its axis a certain height above the base; roughly assuming the reactive power of the earth below the centre of revolution as double of that above, this point would be about 17 feet above the base, and the pressure on the earth above the centre would be half-a-ton, and below the centre one ton, to the square foot, upon the plane of the diameter of the cylinder.

These pressures are so moderate that there could be no doubt about the stability of the cylinder, without reckoning on any assistance from the earth beneath the base.

I am not aware of a single instance in the case of a well that has canted during sinking being righted, or even moved in the slightest degree by the greatest pressure applied at the top. It is only by horizontal pressure applied during sinking that wells can be gradually righted. This fact confirms our confidence in the value of the support afforded by the reactive power of the earth in which a cylinder is embedded, and proves the necessity of limiting the depth of scour so as to leave a considerable length of the well embedded.

With respect to limitation of scour by rubble stone, the Gorai bridge is a good instance of what can be done in a river, 40 feet deep in the dry season with a three mile current, and 90 feet deep in the flood season with a five or six miles current. The scour at the deep channel piers of this bridge is limited to a depth of about

40 feet below low water by an average quantity of 6,000 cubic feet of stone per annum. At the No. 5 pier, the top of the stone is 30 feet higher than the deepest scour between 5 and 6 piers. This bridge was built before the great depth of scour in Indian rivers was known. With our present experience the cylinders would have been sunk to a greater depth. It is, however, satisfactory to find that it is possible to limit scour at the piers by a moderate expenditure for rubble stone.

The flood stream in the rivers of the Punjab and Upper India is often much stronger, but it seldom affects any pier for more than a fortnight, and, excepting in instances like that which occurred at the old Sutlej bridge in 1876, where, no doubt, the rubble stone dropped into a deep hole, bored by the violent eddy, I am not aware of any difficulty in limiting the scour caused by the normal action of the stream.

In Upper India, where the rivers carry but little water in the dry season, a thick layer of stone is deposited round the pier at that period. The flood stream scours the sand or earth round the edge of the stone, which rolls or slips down gradually, forming a stone-cased mound, which is maintained at the fixed level by an annual supply of stone as required.

Water-worn boulders are not approved for resisting floods, as they are easily rolled away, but the rounded form, which is supposed to facilitate this, makes them less liable to be lifted by the stream than angular fragments. My own experience is that the most important object is to get heavy large-sized stone, and that the form of it is of less importance than the weight. There is an old musjid or mosque on the edge of what was formerly the right bank of the Ganges, at Rajmahal, which is protected by a bank of very large rounded boulders, standing at a slope of about $1\frac{1}{2}$ to 1. About 14 years ago I saw the river in flood setting full on the musjid point without dislodging the rounded boulders. I should prefer angular fragments of rock, but as in many cases these are more costly than water-worn boulders, it is well that the objection to the latter should not be overrated.

I have now touched upon some of the principal points of importance peculiar to Indian bridges in the plains; points, however, which may not be void of interest in other alluvial countries subject to be visited by exceptional floods. In treating of these subjects I have simply and without reserve laid bare to you the notions and ideas that have grown up in my own mind, from the formation and experience I have gained during my Indian career. ersonally, I have to regret many lost opportunities of making and cording valuable observations, and of trying interesting experi- ents. In railway construction it is generally the case that every- ing is sacrificed to pushing on the work at high pressure. I trust, owever, that what I have said will influence some of my audience, ho may have better opportunities than myself of studying the oints touched upon, to make a better use of them, and thus add our stock of knowledge of the methods and devices for bridging d controlling Indian rivers and floods.

LIST OF PLATES.

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PLATE I.