any satisfactory method exists at present, beyond that of assuming a distance and correcting the subsequent shots, by noting whether they go over or fall short; while for determining the time to fire, the gun captain, keeping the pupil of his eye on the line joining the front and rear sights, waits until this line intersects the target. The inaccuracy of this latter method lies in the fact that it is impossible for a gun captain to balance himself in a seaway, and, at the same time, to keep the pupil of his eye exactly on this line.

Lieutenant Fiske, of the United States navy, in endeavoring to overcome these two sources of error, has perfected a range finder and an elevation indicator which we describe below. The first determines the distance, and the second substitutes for the uncertain line of the gun sights the optical axis of an accurate telescope. This telescope is so secured that it does not recoil with the gun. The gun captain, therefore, can brace himself in position, and keep his eye exactly against the eye piece, and recognize with positive certainty the precise instant when the line of sight of the telescope intersects the target.

The range finder is shown in Fig. 1, and consists of a fairly powerful telescope mounted on a standard, which can be rotated round a vertical axis, corresponding with the center of the large disk shown in the engraving. One-half of the edge of this disk is graduated to 90 deg. on either side of a zero point, and below the graduation is fixed a length of platinum silver wire. This wire only extends to a distance of 81.1 deg. on either side of zero, and is intended to form two arms of a Wheatstone bridge. The sliding contact is carried by the same arm as the telescope standards, so that it moves with the telescope. In practice two instruments are used, which are mounted at a known distance apart on the ship, as shown diagrammatically in Fig. 2. Here A and B are the centers of the two disks, C and D the arms carrying the telescopes, and E and F the platinum silver wires. Suppose the object is at T, such that A B T is a right angle, then

$$\frac{A B}{\sin A T B}$$

If the two sectors are coupled up as shown, with a battery, h , and a galvanometer, by the wires, a and c , then since the arm, c , on being aligned on the object takes the position c' while d remains at zero, the Wheatstone bridge formed by these segments and their connections will be out of balance, and a current will flow through the galvanometer, which may be so graduated as to give the range by direct reading, since the current through it will increase with the angle A T B. In general, however, the angle A B T will not be a right angle, but some other angle ϕ . In this case

$$A T = \frac{A B}{\sin A T B} \times \sin A B T$$

and hence it will only be necessary to multiply the range reading on the galvanometer by the sine of the angle A B T, which can be read directly by the observer at B. This multiplication is not difficult, but by suitably arranging his electrical appliances Lieutenant Fiske has succeeded in getting rid of it, so that the reading of the galvanometer always gives the range by direct reading, no matter what the angle at B may be. To explain this, consider the two telescopes shown in Fig. 2 in the positions, C and D; the whole current then has a certain resistance. Next suppose them, still remaining parallel, in the positions C' and D'. The total resistance of the circuit is now less than before, and hence if C', one of the telescopes, is moved out of parallel to the other, through a certain angle, the current through the galvanometer will be greater than if it were moved through an equal angle out of a parallel when the telescopes were in the positions C and D. The range indicated is, therefore, decreased, and by properly proportioning the various parts it is found that the range can always be read direct from the galvanometer, or in other words the multiplication of

$$\frac{A B}{\sin A T B}$$

by $\sin A B T$ is to all intents and purposes performed automatically. There is, it is true, a slight theoretical error; but by using a small storage battery and making the contents carefully it is said to be inappreciable. Each instrument is fitted with a telephone receiver and transmitter, as shown in Fig. 1, so that both observers can without difficulty decide on what point to align their telescopes. It will be seen that it is necessary that the lines of sight of two telescopes should be parallel when the galvanometer indicates no current. It has been proposed to accomplish this by sighting both telescopes on a star near the horizon, which being practically an infinite distance away insures the parallelism of the lines of sight. The range finder has been fitted on board warships belonging to the United States, French, and Italian navies, all of which have made very extensive tests of the accuracy and value of the instrument.

Although the Fiske range finder has been under the notice of the naval departments of different countries for so short a time, it has been very favorably received, the remarkable results obtained by the exhaustive trials carried out on board different United States warships having given a sufficient guarantee of the practical value of the instrument. The French government have bought the right to use it, while the Italian navy has tried it carefully.

In the American navy the range finder was installed on board the Baltimore, and from the extensive trials made with it there, during six months at sea, the writers of the official report state that it is accurate within 3 per cent. on ranges up to 5,000 yards. In France the range finder has been mounted on board Le Formidable, the flagship of the French Mediterranean fleet, and extensive trials were made in February last with the instrument to determine the distance between vessels having a relative motion of from 0 to 28 knots. Under these conditions the results were found to be accurate within 5 per cent. From experiments on fixed objects the commission in charge report that the instrument could be used by trained observers under the conditions of combat, and they remark that a specially valuable feature of the instrument is that it en-

ables the observer to record the distance—to within a very small percentage—between forts or ships, before firing grows heavy.

Difficulty in observation would, of course, be increased in a heavy seaway, but not so much as would the accurate pointing of the guns, so that the range finder can be always relied on to give more accurate work than the guns. The commission consider the instrument will be particularly useful at night, as the mere flash of a gun will be sufficient to give the range of the vessel firing it. Even more satisfactory experiments were made on board Il Terribile, of the Italian navy, at Spezia last month, when it was found that, with the ship moving, the distance of a moving target was ascertained with an error of only 1.3 per cent. per 1,000 meters range.

The annexed table gives a short *resume* of the results obtained in these trials:

Mean Distance. Meters.	Mean Per- centage of Error.	Percentage Error in 1,000 Meters.
2290	3.25	1.45
1565	1.8	1.22
1950	2.4	1.23
3240	6.8	2.10
3880	2.8	0.70
3640	4.0	1.10
2978	5.8	1.90

Per cent.

Hence mean error at 1000 meters is.....	1.3
“ “ “ 2000 “	2.6
“ “ “ 3000 “	3.9
“ “ “ 4000 “	5.2
“ “ “ 5000 “	6.5

The instruments were mounted 58.9 meters, 197 ft., apart; with a longer base, still more accurate results would be obtained.

Messrs. Elliot Brothers, of St. Martin's Lane, are the manufacturers of the instruments for Great Britain.

The second of Lieutenant Fiske's inventions is an

FIG. 2.

elevation indicator, also for use on shipboard, which we show in Figs. 3 and 4. It consists of a shield telescope, which can be mounted either on the shield, as shown in Fig. 5, or on the platform, or on the conning tower of the ship. In the former cases it rides on a horizontal axis parallel to the gun trunnions, moving with the gun, so that the telescope and the gun sights always point in the same direction, but by means of the graduated disk shown at the back of the instrument, the telescope can be set so as to make a greater or smaller angle with the horizontal plane than the gun does. The main difficulty in obtaining good results at sea is to fire at proper elevation, and the object of Lieutenant Fiske is to insure this. Thus suppose the range is such that an elevation of 2 deg. should be given to the gun. By Lieutenant Fiske's system the gun is trained horizontally, the elevation being given instead in an opposite direction to the telescope, which in the instance taken would be depressed 2 deg. The gun is then trained on the object and the officer in charge keeps his eye to the telescope till the line of sight is brought dead on the mark by the rolling of the ship, when he fires the gun by any suitable means. Should the water be so smooth that the vessel does not roll sufficiently to give the required elevation, part of it is given to the gun and the remainder to the telescope, and the gun fired when the line of sight is on the mark as before. Not the least of the advantages claimed for this instrument is that, by making the cross-wires incandescent by an electric current, as is done with many kinds of telescope, a night sight is produced, which is at once simple and exact. The device has been fitted experimentally on board the Yorktown with, it is stated, satisfactory results.—*Engineering*.

TESTS FOR STEEL USED IN THE MANUFACTURE OF ARTILLERY.*

By Dr. WILLIAM ANDERSON, Director-General of Ordnance Factories, Royal Arsenal, Woolwich.

THE physical and mechanical properties of steel depend upon so many conditions, that the greatest difficulty exists in devising tests which shall give the user of steel reasonable certainty as to the intrinsic qualities of his material, as well as some idea of its condition

* From a paper recently read before the Iron and Steel Institute, London.

with reference to internal stresses. At first sight it would appear that chemical analysis ought to provide the most certain indication of the nature of a specimen. The purchase and manufacture of very many substances are guided by chemical tests alone, and the results are eminently satisfactory. Why should not chemistry, in its present advanced state, render equally certain indications as to the qualities of steel? The answer, I think, lies in the circumstance that the mechanical properties of steel, and of alloys generally, are affected in a remarkable manner by extremely minute quantities of substances associated with the dominant metal, by the relative proportions of these substances, by the changes in some, or in all, of them, produced by more or less rapid changes of temperature, which influence dissociation and reveal their effects by the singular phenomenon known as recalescence, which also indicates, though to a less degree, allotropic changes in some or all of the components.

Chemical analysis sufficiently minute to detect even traces of every substance associated with iron would be so tedious and costly as to be impracticable, and I fear that many years must pass away before chemical and physical science together will succeed in determining the laws which govern the mechanical properties of alloys. Some advance has already been made by Professor Roberts-Austen, who has shown that there exists a relation between the mechanical properties of some alloys and of the atomic volumes of the substances of which they are composed, and I do not doubt but that farther investigations in this direction will enable metallurgists to predict with some certainty the effects of ingredients upon the mechanical properties of the substances to which they are added, but it is only those who have attempted such systematic work as Professor Roberts-Austen is now doing for the Alloys Research Committee of the Institution of Mechanical Engineers who can have any idea of the difficulties which surround the inquiry, chiefly arising from the practical impossibility of obtaining pure materials in sufficient quantity, owing to the liability to oxidation of the metals which are most used in the arts, to the disturbance caused by the occlusion of gases, and to other causes. The time which must necessarily elapse before a sufficient number of facts can be established to enable unassailable laws to be laid down, and the corresponding expense, are sufficient to deter the most enthusiastic investigator. But assuming, even, that the laws are discovered, and that the effect of each constituent of steel can be foretold, there will still remain the necessity of determining by analysis the exact constituents of the sample, which will involve expense and loss of time that cannot be conceded.

For these reasons, and acting under the advice of the president, the specifications of gun steel used in her Majesty's service exclude all definitions of chemical composition, in so far, at any rate, as the proportions of the ordinary ingredients of steel, such as carbon, manganese, silicon, phosphorus, and sulphur, are concerned. The introduction of new material, such as chromium, aluminum, or nickel, is, indeed, not forbidden, but special care is taken to ascertain their effects upon the mechanical properties of the metal before their use is sanctioned.

With respect to steel for lighter work, such as small arms, and especially for use in the production of swords and bayonets, some restrictions in chemical composition are imposed. In the former case, however, the percentage of carbon is defined with a view to the hardening which some portions of the components of a rifle have to undergo, and with reference to the durability of the barrels in regard to erosion by powder gases and abrasion by the bullets. In the case of swords, the difficulties of framing a satisfactory specification are so great that the subject was specially referred to Sir Frederick Bramwell and to Sir Benjamin Baker, and by them the nature of the steel to be used was, indeed, defined by its chemical composition, but with the sole view to secure uniformity in supply, the sword maker being permitted to vary the components of the steel he proposed to use within certain limits.

Once, however, the quality supplied is found suitable by the mechanical tests imposed, the chemical composition so selected is not to be departed from beyond reasonable limits of toleration; and I think that I may venture to affirm that the chemical tests for sword steel were adopted only because it was found impossible to define the qualities required by physical tests alone, seeing that sword blades have to be hardened and tempered, and are, therefore, subject to internal stresses, the nature and intensity of which certainly depend upon the chemical constituents of the steel, as well as upon the form of the blade and the mode of treatment.

It is not, I think, sufficiently realized that metals, and, indeed, most substances, are incapable of appreciable cubical compression, that is, change of volume under any stress that can in practice be brought to bear on them, under whatever conditions they may be, whether fluid, in the pasty state, at forging temperature, or cold.

Like ice and water, steel and cast iron have a greater volume in the solid than in the liquid state, and, therefore, red hot solid cast iron or steel floats on the surface of the molten mass, and hence, to some extent, is due the sharpness with which the metal takes the form of the mould in casting. The molecular motion in the metal, which results from the continued application of heat, culminating in producing a change from the solid to the fluid state, although it must constantly increase in energy, does not necessarily imply a greater mean distance between the molecules; in fact, the distance often becomes less, since the liquid is often more dense than the solid; hence it is probable that the motions of the atoms in the molecule are affected, which view certain other changes due to thermal influence seem to support.

In the process of solidification the outer surface sets first and becomes rigid, but as the cooling proceeds, in spite of the slight swelling of the mass due to solidification, the loss of volume arising from cooling asserts itself, and since the outside cannot be drawn in altogether on account of its being set and comparatively cold, the inside of the mass is broken up into porous places or into hollows, so familiar in large castings of unequal thickness; and even if solution of continuity does not occur, the casting is in a condition of internal stress which a trifle may develop into rupture. As the cooling proceeds, the inside contracts, and the outside, which had set in a stretched state, becomes violently

compressed, while the inside remains in a state of tension; and if the material yields, the sudden release of the outside surface causes the parts to spring asunder with such violence that the stress, which was originally compressive, is suddenly turned into tension high enough to cause rupture with such energy as to be generally accompanied by a report.

In the case of wrought steel cooling suddenly from forging heat, similar action takes place. When annealed from below the temperature, *b*, of Chernoff, that is to say, below the temperature from which, in cooling gradually, crystallization can take place, the fall of temperature on the outside and in the inside proceeds at nearly the same rate, and the contraction is consequently uniform throughout, and no internal stresses arise; but if heated to the same point and quickly immersed in oil or water, the surface is rendered rigid in every direction, and contracts upon the heated core, and this being incompressible, the surface has no alternative but to stretch. If it does this without fracture, the mass of metal is apparently uninjured; but should the tenacity be unequal to the stress, rupture takes place at once. Should the metal survive the violence it has been subjected to, the subsequent cooling will gradually relieve the tensile stress on the surface, and substitute a compressive one in all directions, while the core will be in a state of tension also in all directions, and in some cases these stresses become so severe that a slight disturbance of temperature, or the application of mechanical force, will determine rupture with more or less noise. This has been frequently observed in hardened armor-piercing shot, in steel coining and stamping dies, and even in oil-treated gun hoops and tubes, though made of mild and tough steel; and in these the late General Kalakoutsky succeeded in accurately measuring the strains in a great number of instances, and in calculating the intensity and direction of the stresses which produced them. In consequence of the conjugate nature of the stresses, the fractures are generally of a serrated, branching and diagonal character. As there is no such thing as an absolute elastic limit, time, to some extent, obliterates the internal stresses; the metal slowly yields under them till a sort of armed neutrality is produced, so that after a few months' repose spontaneous fracture need hardly be dreaded; and for this reason dies and armor-piercing shot are kept in store for some time before being issued for service. The proper way, however, to restore neutrality, when hardness need not be retained, is to heat the steel to about the temperature, *a*, of Chernoff's scale (about 900° Fahr.), and suffer it to cool slowly. This is found to obliterate the internal stresses, while retaining, in a great measure, the so-called high elastic limit and ultimate strength, which oil-hardening undoubtedly communicates. If, however, the process of hardening has set up fissures or cracks, however minute, in the interior of the mass, and these are just as likely to be longitudinal as transverse, no subsequent annealing can repair the mischief done, and in this lies the great danger of oil-hardening. I attribute to it most of the failures which have occurred in artillery; and although all nations are in accord in practicing the oil treatment of gun steel, it is a remarkable fact that civil engineers do not feel justified in taking advantage of the undoubted increase of elastic and ultimate resistance communicated to steel by the process, on account, I presume, of the risks attending it. There is no contesting the fact that the effects above described do follow sudden changes of temperature; but the action is by no means regular, because both the allotropic and chemical changes in the material are influenced not only by changes of temperature, but also by the state of pressure or tension which such changes tend to produce, so that certain combinations of pressure and temperature may develop much more marked effects than others. This is well illustrated by the changes which take place in drawing and rolling metals and their alloys; they are rendered hard and brittle by mechanical tensions and pressures alone, and often to the same degree as by sudden cooling.

The difficulties which surround the framing of a specification for gun steel were enhanced by the circumstance that till quite lately the steelmakers did not manufacture guns, at least for her Majesty's service, while the gunmakers did not produce the steel which they required. Hence it became necessary to test the material practically in the rough-forged state, and by a process which aimed more at ascertaining what the steel was likely to do when ultimately treated in the recognized manner than to determine its properties in the particular state in which it was tested, which was consequently not the condition in which it was to be built into the gun. The specification now in force in her Majesty's service lays down that the specimens, which are to be cut from the components of the guns in a carefully specified manner, are to be 1 inch diameter by 4½ inches long; they are to be heated to 1,525° Fahr., or a bright red, and quenched in oil of 65° Fahr. temperature, and left in the oil till cold. They are then to be turned down for a length of 2 inches to a diameter of 0.533 inch, and tested by tearing asunder. Bending tests on specimens 4½ inches long, and 0.75 inch wide, and 0.375 inch thick, cut to these dimensions after being oil-hardened, are also prescribed. In samples so small the probability is that the internal stresses set up by the oil treatment, even though it is not followed by annealing, are not very severe, and they are greatly relieved, in the specimens tested by tension, by turning off nearly a quarter of an inch all round the operative part. But the temperature at which the hardening is effected lies between two temperatures at which important molecular changes take place in the material. The researches of Gore, Barrett, Osmond, Professor Roberts-Austen, and others, show that at about bright red heat, or 1,500° Fahr., iron undergoes a molecular change, made manifest by the evolution of heat sufficient, if not actually to raise the temperature of the metal, at any rate to retard its rate of cooling. Such evolution of heat must be due to molecular or atomic change, which is clearly reversible. In heating a bar, the rate of absorption must be momentarily increased at the point of recalcence; in other words, the specific heat of the material is increased at a particular temperature; or, rather, as a molecular change has taken place, the heat absorbed or evolved would be more correctly called latent. We have no information as to whether a change in specific gravity takes place also; but since liquid iron is more dense than solid,

it seems probable that increase of density commences at the point of recalcence, and is maintained when the metal passes into the fluid state. A similar phenomenon is apparent in water, which attains its maximum density at 39° Fahr., and then commences to expand as the temperature falls, and maintains that expansion till converted into the ice into which it ultimately turns. Water colder than 39° Fahr. appears to be an allotropic form of water warmer than that temperature.

The allotropic change which takes place in iron at 1,500° Fahr. is probably accompanied by a change in physical properties, producing what Osmond has called α and β irons. Apparently, when the change takes place in gradual cooling, the β iron, that of the higher temperature, and which Osmond conceives to have hard molecules, passes into the α state, in which he supposes the molecules to be soft. Cooled rapidly, in either state, soft iron results; but in the presence of carbon or of some other substances, the β iron is supposed to retain some of its hard nature, and to be the cause of hardening in steel.

In addition to this change in the iron, which forms the main component of steel, it is now demonstrated by the researches of the president, Akerman, Osmond, and others, that the carbon, at any rate of steel, exists in two conditions, namely, either in the form of a definite compound of carbon and iron dissolved in an excess of iron, or as greatly subdivided carbon diffused through the mass, and that at certain temperatures association and dissociation take place, the combined carbon becomes diffused, and the diffused carbon combines.

The act of combination being a chemical process might be expected to declare itself in the evolution of heat, and the researches of Osmond laid before this institute last year abundantly show that at about the temperature of 1,200° Fahr., or red heat, such an evolution of heat does take place.

Struck by the importance of the researches to which I have drawn your attention, and imagining that the methods pursued by Osmond opened up the possibility of arriving at a knowledge of the condition of large masses of steel with respect to their uniformity of composition and physical condition, I suggested to the Institution of Mechanical Engineers that it could not do better than institute a systematic research into this matter.

The proposal was adopted with the utmost readiness. A strong committee, of which our president is a distinguished member, was formed, and Professor Roberts-Austen was requested, adequate assistance being provided, to undertake the work. He readily accepted the task, and I venture to think that already very encouraging success has been met with. It would obviously be improper for me to explain here the means by which the work is being carried out. A report will very shortly be presented to the Institution of Mechanical Engineers. It will contain the fullest information, and I will therefore only state that Osmond's experiments have been repeated, the rate of cooling of specimens has been registered by the most ingenious automatic methods, and curves produced from which it is possible for even an inexperienced eye to detect the two points to which I have drawn your attention. The mode of procedure requires but very small samples, and a few minutes suffice to obtain a record; so that I am sanguine that before very long a method will be arrived at by which it will be possible to determine the quality and conditions of masses of steel, from the mere shavings turned off, far more accurately and rapidly than by means of any test which we are able at present to apply; and this power is of vital importance now that we propose to build up guns of immense masses of steel, the quality of which, though it may be determinable by present methods at the ends, cannot be ascertained without great loss in other parts of their length. The investigations prove, at any rate, that steel is being treated, or ill-treated, now at temperatures which lie between two critical points, separated from each other by only some 300° Fahr. It has to be treated in masses of ever-increasing magnitude, and the temperatures at which the hardening and annealing are performed can only be judged of by the eye—an extremely unsatisfactory method, considering how much the appearance of a heat is modified by the intensity of the light around. I cannot divest myself of the feeling that the apparently capricious behavior of steel is due not only to the internal stresses engendered by oil-hardening, but also to the circumstance that the chemical condition of the steel and its molecular structure are greatly influenced by comparatively slight errors of judgment, or by carelessness in the adjustment of the temperatures at which the operations are performed.

The circumstance that within the last two or three years three important firms have undertaken the manufacture of heavy guns from steel of their own producing, and have introduced powerful forging presses, renders it possible to modify our specifications in the sense that more attention shall be paid to the nature of the steel employed, and to the mode of working it, than heretofore. It is in contemplation to provide that open-hearth steel only shall be used; that the ingots shall be treated in a special manner when hollow forgings are to be produced; that a certain minimum amount of work shall be put into the steel, and that annealing from a red heat, or about 900 deg. F., shall always be the last operation, even if the mechanical properties aimed at can be attained without hardening in oil or water. It is remarkable that foreign nations appear to attach much more importance to determining the elastic limits than is done in her Majesty's service. The French and American specifications prescribe both the elastic limit and the ultimate strength. The Russian specification defines the elastic limit only, though the ultimate elongation per cent. is prescribed. I believe that the Germans follow the same rules, though I have been unable to obtain any direct information on this point. In her Majesty's service a limit of permanent extension under a load of 21 tons per square inch is prescribed, and a note is to be taken of any yielding under a less load; but the term "elastic limit" is carefully excluded, on the ground that no such limit can, in fact, be defined. All foreign nations seem to prescribe hardening in oil, though no mention is made of any particular temperatures, and in all cases the first and the last operation must be annealing, after which only the test pieces are taken. At the Abouchoff Steel Works, the hardening

and annealing is practically one operation, the object to be treated being immersed in the oil only for a short period, the duration of which is a matter of judgment, and depends upon the dimensions of the steel. It is then rapidly withdrawn and returned to the heating furnace, where it is allowed to cool slowly. It is impossible, within the limits of a paper suited to these meetings, to enter into all the details of the question I have ventured to bring before you. My object is to draw attention to the recent advances in the theory of steel, and to suggest how the knowledge, even now, in our possession must gradually affect our practical work. I trust that the discussion, which will, no doubt, arise, will give to the world the knowledge and experience which is so peculiarly the power of the members of the Iron and Steel Institute. A discussion followed.

Dr. Anderson said the observations that M. Chatelier had made confirmed those of Sir Lowthian Bell as to the volume of steel and cast iron at about the same temperature as the molten liquid being greater than the fluid mass. When the metal was cold the volume was less, no doubt, and when it got heated up to a cherry red heat, apparently it began to float, and after that the volume was decidedly greater than that of the molten mass. Of course, that had an important bearing upon the application of steel which he had drawn attention to. What he had endeavored to show in the paper was confirmed by what Mr. Hadfield remarked, that he found great difficulty in producing a shell of the required quality, that was, that he had a good many failures before he had one success. That was generally the case with steel castings, and with regard to the shell, he thought it exactly arose from that cause, that they were dealing with it at temperatures in which changes took place that depended on various circumstances. The difficulty was to hit off the temperature at which the changes were favorable to the result it was sought to obtain. He believed that the rationale or theory of the difficulty of working steel was that they were obliged to work at temperatures where these various changes took place in the chemical composition of steel, and changes connected with the allotropic form. It was over and over again said, "That bent because the steel was too soft;" but when they asked what softness meant, they were told that soft steel would stretch more than hard steel, whereas the fact was that within the elastic limit there was no difference whatever in the stretching per ton between the softest steel and the hardest. Recently, Captain Younghusband made some experiments with a view of determining that very point on rods 100 inches long. Similar experiments had been made at Enfield with regard to swords, and it was found that perfectly hard steel, as hard as it could be made, would bend. In answer to Mr. Carbutt, he would say that oil-hardening had not been given up; but there was a tendency not to insist upon it if the quality of steel could be obtained by other means. Annealing had in all cases been adopted as a final operation, and was insisted upon. The difficulty was that all nations had adopted it, and it was hard to imagine that they would have done so, and have stuck to a process which had not some virtue in it. He himself had always been greatly against it, thinking that the danger was greater than the advantage. He would, at the same time, say that, to a certain extent, his paper ought not to have been produced. When the president asked him to prepare it, he thought a new specification for steel would have been published and become a service specification; but for some reason it had not yet been adopted into the service, and it was a rule that such things were not to be made public. Therefore his hands were tied, but he had done his best. The tendency was to test the steel in the condition in which it would be tested when put into the gun. In cases where the steelmaker was also the gunmaker he would, of course, have the whole thing under his control, and might produce the steel in any way he liked, provided the last operation was annealing, and it passed the examination after being cut from the steel in the mass. That was a direction in the specification, and he hoped very soon it would be promulgated. He did not quite catch the meaning of Mr. Head's question. Steel that cracked spontaneously usually opened out. At any rate, the parts could not be joined together again. The stress was evident, and made a displacement of parts which prevented their ever being joined together again; but in some recent experiments made at the gun factories by cutting off slices of hoops that had been oil-hardened, it was found that they closed or opened, he forgot which; but after they were annealed to about 900 deg. F. they were neutral, so that if they were cut through they neither closed nor opened. The conclusion, therefore, was that the annealing had removed any mischief, provided there had been no solution of continuity anywhere. He was not able to answer Mr. Weston Smith's question about vibration. As far as he knew, specimens taken from guns which had been in use for some time showed no difference from the samples of steel from which the gun was made. He did not think that the small amount of use that a gun got comparatively was sufficient to make any difference in the physical state of the steel. He was very glad of the opportunity of tendering his thanks personally to M. Chatelier, who had done them the honor of couring among them now, because he really believed that the difficulty which Mr. Snelus had pointed out of finding out whether the great masses of steel now used, 30 feet long, for instance, were the same in bulk as at the two ends would be solved by M. Chatelier's pyrometer. If they took specimens all along the length of a large forging, and found that the curves were all alike, they might be pretty sure that the steel was just the same all through from end to end, and that there was no great difference caused by liquation. It should be remembered that this could be done by means of M. Chatelier's apparatus in a few minutes. If he remembered rightly, Mr. Roberts-Austen told him it took him about twenty minutes to make an experiment, whereas the preparation of microscopical specimens would take a very long time indeed. He was quite sure the president would bear him out when he said he had most profound respect for chemical analysis. It had its proper value. In the government departments they were always governed by the chemical analysis of steel, but what he meant in the paper was that they could not be sure that the analyst would search for everything in the steel, and that they were quite safe in what they were using.