

THE NATIONAL PHYSICAL LABORATORY
AND ITS RELATION TO ENGINEERING.

A LECTURE

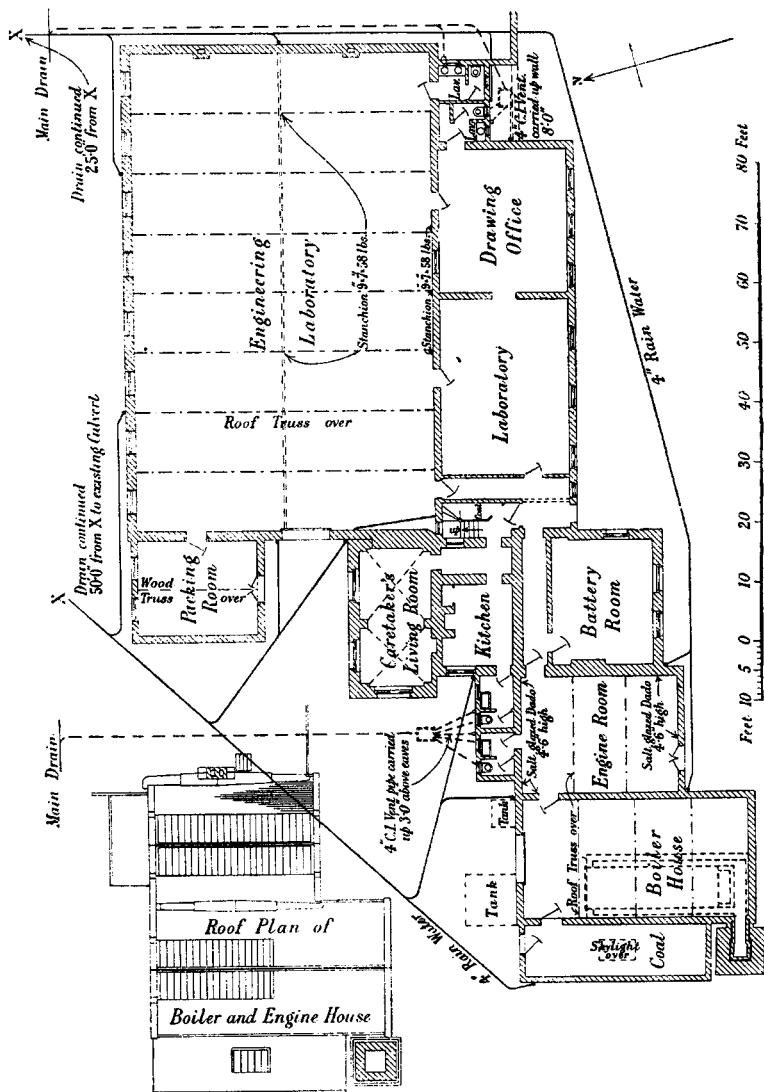
BY DR. R. T. GLAZEBROOK, M.A., F.R.S.,
DIRECTOR OF THE NATIONAL PHYSICAL LABORATORY, TEDDINGTON,

AT A MEETING OF THE GRADUATES ON
MONDAY, 9TH FEBRUARY 1903.

WILLIAM H. MAW, ESQ., *President*, IN THE CHAIR.

When I received your very gratifying invitation to lecture here to-night to the Association of Graduates of the Institution my first impulse was, as you know, to decline. Not that I failed to appreciate the offer and the opportunity, but I thought I could do more justice to my subject and bring before you results more worthy of the occasion, if, at a later date, I might be allowed to describe some of the researches which are now in progress at the Laboratory. The President reassured me by a most kind letter, in which he told me that I could do a service to the engineering profession by pointing out the directions in which the Laboratory might do work which would be practically and commercially useful to engineers. He invited me in particular to draw attention to the possibility of placing in our hands short enquiries on definite points to which an answer is required rapidly, as well as to those more long and costly

FIG. 2.—Plan of Engineering Building.



investigations which we hope to carry out. I was glad to be able to accept that invitation, and I trust that what I have to say to-night may really help members of your profession, and may lead them to give us their support by sending us work to do and consulting us on points on which it appears that we may help them.

Let me commence by a brief description of some of our buildings. The Laboratory is at Bushy House, Teddington, Fig. 1, Plate 2, and for many purposes the old house is admirably suited. The engineering building, however, is almost entirely new, being specially designed for the work we had to do. The engineering laboratory itself, of which Fig. 2 (page 58), and Figs. 3 and 4, Plate 2, give views, is a building 80 feet by 50 feet. It is divided longitudinally into two bays, each of which is lighted from the north by a weaving-shed roof. A shaft runs along one bay, and in it are placed the machine tools comprising four lathes, a universal grinder, a shaping machine, drilling machine, etc. The shafting is driven by a Mather and Platt motor. The second bay is for experimental work; in it are the testing and part of the pressure-gauge testing apparatus, Fig. 4, Plate 2. A boiler which can be worked at a pressure of 400 lbs. per square inch has also been installed; the apparatus given by Messrs. Willans and Robinson for testing gauges and steam indicators under steam will shortly be fitted, as well as a very complete alternate-current outfit presented by Messrs. Siemens. A traversing crane runs along this second bay, and has already proved of great assistance in setting up the machinery and apparatus, and at one end is the testing machine, Fig. 3, Plate 2.

The wind-pressure apparatus, about which I shall have more to say later, is also set up in this bay. In sheds near the engineering building are a small forge and a smelting-shop.

The engine-room contains a 75-kw. condensing turbine by Messrs. Parsons. There is also an 18-H.P. Crossley gas-engine, driving a dynamo by Messrs. T. Parker of Wolverhampton. The same firm supplied a very convenient booster set for charging the storage batteries. In the boiler-house is a 100-H.P. boiler, which also serves for the heating both of the engineering laboratory and of Bushy House.

Though most of the work specially interesting to engineers will be conducted in the engineering laboratory, several of the rooms in Bushy House are fitted for experiments which have a direct bearing on engineering practice. Fig. 6, Plate 3, shows the metallurgical room, in which it is hoped to carry on the work begun at the Mint by the distinguished Honorary Member of your Institution, the late Sir William Roberts-Austen, whose labours as Chairman of the Alloys Research Committee have helped so greatly to elucidate some of the changes which go on in metals.

In the centre is the Roberts-Austen pyrometer as fitted at the Mint. The apparatus was the gift of a staunch friend, Mr. George Bailby. To the right are the coke furnaces. The room was the old kitchen, and the chimney and fireplace have been thus utilized; on the extreme left are the gas furnaces.

Fig. 7, Plate 3, shows the Thermometric Laboratory. This is arranged for the accurate measurement of temperature, specially of high temperatures. Here are placed the various baths and ovens by the aid of which steady temperatures up to $1,200^{\circ}$ C. can be produced and measured. For temperatures up to 200° C. an oil bath is employed; from 200° C. to 500° C. a bath consisting of mixed nitrates of soda and potash is most convenient; above 500° C. electric ovens afford by far the best means of obtaining a high temperature. Much of the apparatus in this room was the gift of Sir Andrew Noble.

Fig. 5, Plate 2, shows the basement room in which the measuring machine, dividing engine and standards of length are housed. These comprise a set of standard gauges, a Whitworth measuring machine, a special machine for measuring screws, also by Whitworth, a Pratt and Whitney measuring machine, and a dividing engine by the Geneva Society for the construction of Physical Instruments. Let me turn now from this enumeration of our rooms and apparatus to describe some part of our work; but before doing so, I should like again to express my obligation to Mr. E. G. Rivers, the Chief Engineer of the Office of Works, and to the other Officials of the Office for the skill and care they showed in carrying out the work of erecting the Laboratory.

The Work of the Laboratory.—This I propose to treat of under three heads:—

(1) Routine Test Work.

(2) Original Investigations undertaken at the initiation of the Committee.

(3) Enquiries and Experiments made at the request of Engineers or others, and for which fees are received.

The first head need not take us long. Arrangements are complete for tests of length gauges of all kinds. The gauge room in a large shop is a very important part of the establishment, but it is not possible for every firm to maintain a set of standard gauges and the apparatus necessary to compare the shop gauges with these from time to time. This work we can do; I hope in a satisfactory manner and at a reasonable rate. The important Engineering Standards Committee is engaged in a great work at present in standardizing engineering practice. We hope to assist in that work by affording facilities to all to maintain the standards. What I have said as to length gauges applies even more to screw gauges, only here the need for standardization is more marked, because less has been done; with regard to the ordinary cylindrical gauges and length gauges, it must be remembered that the Board of Trade is the authorised guardian of the standards, and that gauges of the standard patterns are tested with great care and exactness in the Standards Department; but with regard to screw gauges this is not the case, while by the action of the War Office we are being placed in a very favourable position. With a view of securing uniformity of pitch in the leading screws of lathes in the various Government workshops, a lathe of special design, with a very accurate screw, is now being constructed by Messrs. Sir W. G. Armstrong, Whitworth and Co. This is to be placed at the Laboratory in a specially constructed chamber, and it will be our duty to issue both to Government Departments and to the public certified copies of this standard screw.

Mr. Donaldson referred to the machine at the last Meeting of the Institution.* Engineers will, I am confident, be interested when they read his Paper on the subject.

* Proceedings 1903, page 26.

A knowledge of the coefficient of expansion of the material he is using is often necessary to the engineer. A comparator of the Geneva Society enables us to measure this, at any rate in the case of materials which can be obtained in the form of rods and for moderate temperatures, while apparatus which will allow us to extend the measurements to a dull red heat is under construction.

Reference has already been made to the testing and standardization of pressure-gauges; for this the Laboratory is singularly well equipped. A mercury column nearly 50 feet in height has been erected in Bushy house; alongside this is a steel scale divided into millimètres, pounds per square inch, kilogrammes per square centimètre, and feet of water. Arrangements are made for applying pressure to the lower end of the column and the gauges in connection with it, from a bottle of compressed air. Thus pressures up to nearly 300 lbs. to the square inch can be read directly on the column, alongside of which a lift is fitted so that any point of the scale may be readily observed. In this case the gauges are read when cold; if it be desired to read them under steam, a direct weight-testing apparatus, given by Messrs. Willans and Robinson, will be employed. This same apparatus serves for testing indicators; steam can be supplied to this up to a pressure of 400 lbs.

For higher pressures a differential direct weight-testing apparatus, designed and constructed in the Laboratory, and described in *Engineering* (9 January, 1903), has been used very successfully. With this apparatus, pressures up to about 8 tons to the square inch are measured to an accuracy of about 0.01 ton. For comparing gauges among themselves, a set of pressure-pumps, supplied by Messrs. Schäffer and Budenberg, who also erected the mercury column, are employed.

In the Thermometric Laboratory high temperature measurements of real importance to engineers are being conducted. I propose to give one striking illustration of these later in the evening. Dr. Harker has very skilfully utilized the appliances put at his disposal, mainly by the generosity of Sir Andrew Noble. Our ultimate standard of reference up to temperatures of say 900° C. to 1,000° C. is the nitrogen thermometer. With this our secondary standards, the

platinum thermometer and the platinum, platinum-rhodium or platinum, platinum-iridium thermo-couples, are being compared. These can be used up to perhaps $1,200^{\circ}$ C. or $1,300^{\circ}$ C.; a method of measuring still higher temperatures is still to be found, and for this some photometric method of measuring the radiation from a black body appears the most promising. To this we hope to go on; meanwhile we are prepared to standardise to a very high order of accuracy instruments for measuring temperature up to $1,300^{\circ}$ C. The importance of the micro-photograph in the study of steel and its alloys is now generally recognised, and accordingly, urged by the advice of the late Sir William Roberts-Austen, a very complete outfit for photo-microscopic research has been installed. In setting this up we have been greatly assisted by Mr. Stead, who presented us with our polishing apparatus and helped Dr. Carpenter, the Assistant in charge, in getting to work. This has already led to some results, which I think will prove of interest on some of the alloys investigated by Professor Barrett and on some special magnet steels described by Mr. Ashworth; but I am speaking of it now as part of the regular testing outfit. We are prepared to examine sections of rails, girders, &c.

It must not be assumed that in this very hasty list I have completely enumerated all the tests we can undertake; there is one omission which will strike any engineer, I have said nothing as to the ordinary tests of material. It has been our object, at any rate in the first place, to fill up gaps; there are many places where the engineer can have access to a testing machine, and indeed such investigations are usually of necessity carried on at the steel works.

Still, it is felt, I know, by many prominent engineers, that we ought to have at the National Physical Laboratory a standard testing machine for ultimate reference in cases of dispute, and to carry out such tests as cannot conveniently be made on ordinary machines. Such a machine costs money and our funds are limited. However, if some generous benefactor will ask Messrs. Buckton and Co. to repeat for us the splendid 300-ton machine they are now making for the Conservatoire des Arts et Metiers in Paris, your President-Elect, Mr. Wicksteed, will, I know, be pleased, and the gift will be cordially welcomed

We already possess a small testing machine of his for our research work.

We have only been working nine months, it is true, and probably in that time ought not to expect much, still the number of engineering tests we have been asked to carry out has been few. Englishmen are conservative; the high-class maker does not want the tests, he knows his products are good; his cheap and nasty rival does not want the tests, they will expose his weaknesses. One firm of deservedly high reputation wrote to me, some short time back, "It would never do for us to admit that our goods stood in need of a certificate." Pardon me if I state plainly my opinion that, in many cases at any rate, the high-class maker is wrong. A certificate such as we can give can only help him and expose his inferiors; there was a discussion of great interest at the Institution of Electrical Engineers a short time since on photometry and the standardization of lamps.* One speaker, of considerable experience in the trade, stated that the want of a certificate in England enables continental manufacturers to dump down on our markets the goods they could not sell at home. Does the same criticism apply to other things besides lamps?

But now I will turn to more interesting matters, to some of the researches in progress. The lines of the first research were mapped out by a Committee of Engineers under the chairmanship of Sir A. Noble, and containing such men as Mr. Froude, Mr. Mansergh, Mr. Maw, Mr. Ferranti, Mr. Parsons, Sir William Preece, Captain Sankey, Sir John Thornycroft, Sir William White, Sir J. Wolfe Barry and Mr. Yarrow. This Committee placed first amongst its recommendations the continuance of the work of the Alloys Research Committee of the Institution of Mechanical Engineers, and indeed it was in great measure with this object in view that the outfit to which I have already referred was acquired. With this was connected very closely the question of the molecular changes in metals due to fatigue, motion, and the like; while the investigation of the pressure of wind on surfaces of various areas was mentioned as an important piece of research.

* Proceedings, Institution of Electrical Engineers, 11th Dec. 1902, page 119.

The Alloys Research was placed first by two other committees, that for Electricity and that for Chemistry. The Electricity Committee referred specially to the connection between the magnetic quality and the physical, chemical, and electrical properties of iron and its alloys, with a view specially to the determinations of the conditions for low hysteresis and non-ageing properties.

Accordingly it is to these two subjects—Alloys Research and Wind Pressure—that our energies are being primarily directed. But the alloys of iron are many, and it was not quite easy to select a starting point. Various enquiries, however, have tended to make us turn our attention to nickel-steel. Mr. Yarrow wrote with regard to some facts he had observed. Captain Longridge again was anxious for some information bearing on the motor industry. Nickel-steel is obviously a most interesting and a most important substance. Most of our knowledge with regard to it is due, I think, to Mr. Hadfield, whose Papers, read before the Institution of Civil Engineers, are a mine of wealth; and to the researches of a special committee of the Berlin Society for the Promotion of Industry, under the presidency of Dr. Wedding. Reference should also be made to a Paper entitled "Nickel-Steel; a Synopsis of Experiment and Opinion," by Mr. David H. Browne, of Cleveland, Ohio, and to Mr. Browne's remarks on the discussion on Mr. Hadfield's Paper and to M. Osmond's remarks on Mr. Hadfield's series of alloys.

Still there remains much to be done. Mr. Hadfield's results were all obtained with low carbon alloys; he realised that carbon exerted a strong disturbing influence, and wished to render this as small as possible. It is not probable, I take it, that much of the nickel-steel of commerce contains only the 0.17 to 0.19 per cent. found in his specimens with but one exception. In the German researches the percentage of carbon present has been varied, and still there is no doubt of its extreme importance. Mr. Hadfield discovered a remarkable alloy, having about 12 per cent. of nickel and 0.18 of carbon and 0.9 of manganese. This has a tensile strength of over 90 tons to the square inch, an elastic limit of 55 tons, but a low ductility. Professor Arnold has shown that, by

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reducing the carbon to 0.1 per cent. and the manganese to 0.15, the ductility is greatly increased without seriously altering the breaking stress or the elastic limit. Experiments are, however, still wanting to show how a gradual increase in the carbon modifies the results; it is known again from Professor Arnold's work that, when nickel steel containing a high carbon is rolled at a low temperature, nearly the whole of the carbon is separated as graphite. Under what conditions exactly does this take place, and what is the state of the carbon previously? Again, what is the relation of the nickel to the iron and the carbon it contains when the carbon is low.

The researches of M. Osmond and others have revealed to us the various temperatures at which changes take place in the relation of the iron and the carbon as a mass of steel is cooled down, and the curves due to M. Osmond given in Mr. Hadfield's Paper show that these recalcence points remain on the whole, altered in position it is true to some extent, but still generally recognisable in Mr. Hadfield's series. It will be noted that the points Ar_3 , Ar_2 , have almost disappeared from the 15 per cent. nickel alloy; a curve for the 12 per cent. alloy is not given. What, if any, is the connection between this and the properties of the alloy? Will the microscope tell us anything further of its structure? I gather that the sections of low-carbon nickel-steels are usually very homogeneous.

Mr. Ashton, however, communicated, in the discussion of Mr. Hadfield's Paper, some interesting facts, and M. Osmond has shown us that, at any rate for the larger percentages of nickel, by proper etching or other suitable treatment, something may be developed. Let me quote some sentences from Mr. Hadfield's Paper* :—"As already pointed out it is probable that the special advantage of the use of nickel is due not so much to the properties it confers on iron in carbonless or nearly carbonless iron alloys, but to its modifying influence upon iron in the presence of carbon when it probably forms a special carbide of nickel. In the latter case, it is

* Proceedings, The Institution of Civil Engineers, 1898-99, vol. cxxxviii, page 22.

hardly probable that high percentages of nickel will be required for ordinary uses to which steel is now applied. This theoretical opinion can only be accurately determined by the preparation of say ten specimens to each of the author's nickel percentages, the carbon varying say by tenths. This would mean the preparation of about 140 different specimen alloys. As each of these specimens would require about 500 to 600 separate tests of various kinds, it will be seen that the work will require close application to complete it even in a lifetime."

On the other hand, M. Osmond, in the correspondence which followed Mr. Hadfield's Paper, showed strong grounds for thinking that the direct effect of the nickel was very great in itself. Now without starting on a programme so ambitious as the one just outlined, we can take up some part of the work; we can prepare, for example, a series of alloys with a medium percentage of carbon, say about 0.45 per cent., and another with a high amount of carbon, say 0.9 per cent., varying, as Mr. Hadfield did, the amount of nickel, and then examine by means of tests such as his the properties of the alloys, the state of the carbon and its relation to the nickel. Though probably we shall not by this means find the exact point at which any critical change takes place, we may find limits within which it happens, and thus be able to narrow to its most important part the wider research.

And now I wish to point out the advantages the laboratory has for a research of the kind; it has its disadvantages too, I am aware, and for some of our work we shall have to go outside. We hope to prepare some, if not all the alloys, ourselves. We have a small smelting-house with an oil blast-furnace capable of melting 40 to 50 lbs. of steel. For rolling and working the specimens in large masses we shall have to trespass on our friends. I have a promise from Sir J. Thornycroft that he will help. For the various elastic and mechanical tests we shall have no difficulty. We can also trace the cooling curves and examine the sections under the microscope. Our chemical laboratory will enable us to analyse the specimens exactly and carefully. And, by the aid of the electric ovens of the thermometric laboratory, the effect of various forms of annealing and

of exposure for stated intervals to definite high temperatures can be satisfactorily studied.

Mr. Hadfield's work gains added interest from the electrical measurements of Professor Fleming and the magnetic work of Professor Barrett; such measurements we can make readily and rapidly. The advantages of all working together under the same roof are immense. Speaking of the Berlin research Mr. Hadfield writes:—"The whole research and the complete manner in which it was carried out are but another proof of the great desirability of this country establishing a similar National Physical Laboratory to the Reichsanstalt in Berlin, where the above experiments were carried out." It seems fitting that we should attempt, at an early stage of our life, to perform a complementary series of experiments.

There is yet another point connected with the nickel-steels to which we hope to give special attention. The question of elastic fatigue in metals is one of great interest, and there is a general belief that nickel-steel, with its high elastic limit, stands repeated stress more easily and for longer periods than ordinary steel of similar tensile strength. Little is known as to how this comes about, or what the changes are which finally lead to fracture. A recent Paper by Mr. Smith, of the Owens College, has advanced our knowledge, and Professor Ewing has somewhat forestalled us by applying the microscope to the problem. We are building a machine by which stresses of known amount and of frequencies up to 1,200 or 1,500 per minute can be applied to our specimens, and hope to incorporate tests on this machine with our other results.

Before leaving this part of my subject, I should mention two other related questions which are engaging our attention. In his evidence before the Treasury Committee, to whose report the establishment of the laboratory is due, Mr. Hadfield gave the first place to a determination of the exact melting point of a series of iron, iron-carbon alloys commencing, say, with pure iron, then steel with 0.1 per cent. carbon, the latter element gradually increasing until white iron containing $3\frac{1}{2}$ to 4 per cent. of carbon is arrived at. For this work we think we have the means required and may extend it to some other high-melting-point alloys of iron.

Finally let me refer, though it is possibly of more interest to the electrician than to the engineer, to work on the important silicon and aluminium iron alloys investigated by Professor Barrett; we have already made some observations for him, and hope to be permitted to continue them.

Such is our programme of work on Alloys of Iron. I trust you will recognise in it an honest attempt to carry out the wishes of those appointed to direct our first researches. Such a programme demands funds, and we are deeply indebted to the three societies, the Institution of Civil Engineers, the Iron and Steel Institute and the Society of Chemical Industry, which by their generous confidence have made the work possible. I trust I am not abusing an opportunity kindly given, if I suggest that when the work of the Alloys Research Committee of this Institution has been closed by the issue of its final report, the Institution of Mechanical Engineers may also join the other three, and by its assistance claim some direct share in our results. The raw material for the research we owe mainly to the generosity of Mr. Hadfield's firm.

To turn now to the second large Research. The wind-pressure experiments are the outcome of those of Sir Benjamin Baker made at the time of the building of the Forth Bridge, and described to the British Association at Montreal in 1884. Sir Benjamin set himself to examine two points:—

(1) What is the maximum average pressure which a continuous surface of large area may be expected to have to withstand?

(2) In the case of complex structure such as a bridge composed of lattice girders, tubes, &c., what is the area on which the wind is effective and how far is the back surface of a girder or of the bridge shielded by the front?

A Committee of the Board of Trade, appointed shortly after the Tay Bridge disaster, advised the adoption of certain rules—I am quoting from Sir B. Baker—"Shortly stated these were (1) That a maximum pressure of 56 lbs. per square foot should be provided for. (2) That the effective surface upon which the wind takes effect should be assumed to be from once to twice the front surface according to the opening in the lattice girders. (3) That a factor

of safety of four for the ironwork and of two for the whole bridge, overturning as a mass when gravity alone comes in, should be adopted. Sir Benjamin Baker's Paper contains results, from which it appears that the limiting presses of 56 lbs. is rarely, if ever, reached, and that when this does happen the great pressure is limited to a small area, the centre of a gust of great local intensity.

He conducted experiments for several years at Inchgarvie on the Forth with three pressure gauges. The first of these had a surface of $1\frac{1}{2}$ square foot, and was swivelled about a vertical axis so as always to face the wind. The second was of the same area, but was fixed with its plane north and south so as only to be exposed to easterly or westerly winds. The third was 200 times as large, 300 square feet, and was fixed with its plane also north and south.

TABLE 1.

Revolving Gauge.		Small Fixed Gauge.		Large Fixed Gauge.	
Mean Pressure.		Easterly.	Westerly.	Easterly.	Westerly.
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0 to 5	3.09	3.47	2.92	2.04	1.9
5 to 10	7.58	4.8	7.7	3.54	4.75
10 to 15	12.4	6.27	13.2	4.55	8.26
15 to 20	17.06	7.4	17.9	5.5	12.66
20 to 25	21.0	12.25	22.75	8.6	19
25 to 30	27.0	—	28.5	—	18.25
30 to 35	32.5	—	38.5	—	21.5
Above	65	—	41.0	—	35.25
(One observation only above 32.5)					

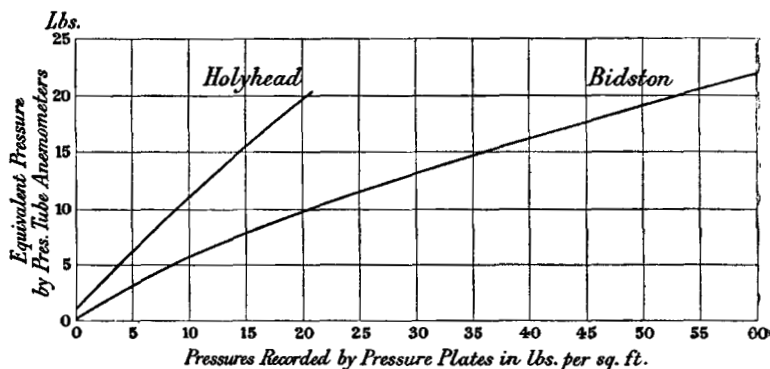
The above Table, taken from Sir B. Baker's Paper, gives the results of two years' observations. The pressures recorded by the revolving gauges are set down in groups 0 to 5, 5 to 10, &c., and the mean of each group taken.

The mean of the corresponding readings at the same time of the small fixed gauge, and of the large gauge for easterly and westerly winds, are set down opposite. It will be observed that throughout the pressures recorded by the small gauge are in excess of those given by the large gauge. Moreover, on only one occasion was a pressure above 32·5 lbs. observed, and this it was shown was due without doubt to a sudden gust causing the needle of the gauge, in consequence of its inertia, to register an amount far in excess of the true pressure.

Sir Benjamin Baker has kindly placed at my disposal the results of further observations lasting up to 1900. The large gauge became unsafe in 1896 and was removed, and according to these, pressures of over 50 lbs. have been registered on three occasions on the top of the piers in November 1893, March 1898, and October 1898, when the gauge broke under a pressure of 60 lbs.

An instructive contribution to the question is contained in a Report on Anemometer Experiments by Mr. R. H. Curtis, printed as an appendix to the Report of the Meteorological Council for the year ending 31 March 1900. Each of the stations at Bidston and Holyhead is fitted with two anemometer gauges. One of these in each case is a Dines pressure-tube, the other is a spring plate. At Bidston the plate is free to oscillate in the usual manner. At Holyhead the plate is constrained. It can only move in the direction in which it is forced by the wind, and the position in which it is found at any moment indicates the maximum pressure to which it has been subject since it was last set. The two stations are about 60 miles apart and have approximately the same aspect. The observations recorded lasted, I believe, about a year. The maximum pressures observed on the two pressure-tube instruments during the period were much the same; that at Holyhead was between 20 lbs. and 21 lbs., while at Bidston it was 22·5 lbs. to the square foot. The plate observations at Holyhead agree closely with those given by the tube; they are uniformly somewhat less, but the difference decreases as the pressure rises. At Bidston, with the oscillating plate, the results are entirely different. At one time when the tube read 22·5 lbs. the plate gave 63 lbs. Records of from 30 lbs. to

FIG. 8.—Comparison of Air-Pressure Records recorded by Plates and Pressure-Tube Anemometers.



50 lbs. per square foot were obtained on other occasions, in all of which the tube readings were below 17 lbs. On one occasion in 1871 the Bidston plate registered the huge pressure of 90 lbs. per square foot. The results are plotted in Fig. 8. In each of the two curves the ordinates give the pressure as read on the tube, the abscissae give the pressures on the plates. The Holyhead curve is nearly straight and inclined at 45° to the horizon, the readings of the two instruments are alike; the fact that the curve does not pass through the origin shows that there is a zero correction to apply to the plate readings. The coincidence of the values obtained from the two instruments proves that either of them is very approximately correct, and that during the period of observation the wind pressure did not exceed some 20 lbs. to the square foot. For Bidston the results are quite different; the plate readings start at low pressures by being nearly twice as great as those given by the tube; while at the maximum pressure recorded the plate pressures are three times as great as those given by the tube. The fact that the latter agree well with those obtained by both tube and constrained plate at Holyhead leads inevitably to the deduction that the plate results at Bidston are enormously too great; the high record is due in great measure to the inertia of the moving plate.

The diagram brings out clearly the uncertainty of the measurements and the importance of further experiments.

Now we do not get great storms at Bushy, and we can hardly hope to determine there the maximum wind pressure, but we may hope to determine (1) how far the average pressure over a large area differs from the maximum pressure at any one point, and (2) what are the screening effects due to the front member of a lattice girder or to the windward side of a bridge. This we are now doing on a Laboratory scale; but before describing our work I should like to call attention to two series of observations published also by Mr. Curtis of the Meteorological Office in the Quarterly Journal of the Royal Meteorological Society for 1882 and 1883.

Mr. Curtis made a large and careful series of observations by exposing perpendicularly to the wind four plates of areas 1 square foot, 2 square feet, $6\frac{1}{2}$ square feet, and 16 square feet: the second plate was round, the others square. A number of holes were bored in each plate, and the holes were connected by turns in pairs to the opposite arms of a water-gauge; the centre hole in each plate was taken as a standard for that plate and the difference in pressure at different points measured. Mr. Curtis was thus able to map out the distribution of pressure on his plates. Then the pressure at the centre of each plate in turn was compared with that at the centre of the round plate. As a result he finds (1) that the pressure at the centres of the various plates was practically the same, and (2) that the mean pressure per unit of area is greater on the large plate than on the small one. This result is apparently in contradiction to that found by Sir Benjamin Baker; it may well arise however from the difference in area of the plates experimented on, 16 square feet and 300 square feet respectively; or, as Mr. Curtis observes, from the fact that he measured the actual pressure on one side of a fixed plate, not the resultant force on the plate due to the difference in pressures on the two sides.

Our knowledge of the pressures on a girder or other engineering structure is due in large measure to Sir Benjamin Baker's experiments on models. A model of the girder was fixed to one end of a horizontal arm, at the other end was a flat plate or disc with its

plane vertical and parallel to that of the girder. The area of the disc was variable.

The arm was supported at its centre by a vertical string, and allowed to swing as a pendulum in a plane perpendicular to the discs. When the resistances to the motion experienced by the disc and the model were the same, the plane of the disc continued at right angles to that of motion; if these two resistances were different the system began to oscillate about the suspension. But by adjusting the area of the disc, a balance can be obtained. Thus a value can be found for an area which experiences the same resultant pressure as that acting on the girder.

Our own experiments now being conducted by Dr. Stanton combine the principles both of Mr. Curtis and of Sir B. Baker's observations, only in our case the disc or model to be subject to pressure is mounted on one end of a delicately suspended horizontal beam which can turn about a horizontal axis; the plane of the disc is horizontal and the wind vertical. The other end of the beam carries a scale pan, and the resultant force on the disc or model is measured directly by the weights in the pan. These can be determined to the 1-100,000th of a pound. A number of holes in the disc can be placed in communication with one arm of a very delicate water-gauge, which allows a pressure difference due to 1-10,000th of an inch of water to be measured. The other arm of the gauge is connected to a fine tube placed in the incident stream of air, and thus the difference in pressure between a point on either side of the disc and one in the free air is measured, and the distribution of pressure over the disc determined. The diameters of the discs experimented on up to the present vary from 1 inch to 6 inches. These are placed in a current of air 24 inches in diameter, which has a practically uniform velocity across its section. The current is produced by an electrically driven fan, and the velocity can be varied between 5 feet and 30 feet per second. It is assumed, of course, that the wind pressures on structures can be calculated from experiments on models with the same kind of accuracy as is obtained in the calculation of the actual resistance of a ship from an experiment in a tank.

The first step is to determine the distribution of pressure on both sides of a flat plate as well as the resultant force on the plate, in view of the marked differences between the observed resultant force and that calculated from pressure measurements on the windward side alone. Concurrently with this, it is proposed to study the effect of the form and linear dimensions of the plate on the resultant force. Preliminary experiments have already indicated that the average intensity of pressure is very little affected by the form and size of the plates. The case of flat plates placed behind each other will then be taken, as there seems to be little agreement in the results of previous experiments as to the effect of the screening due to the windward plate. Then models of latticed girders of the usual type will be tried, and it is proposed to investigate the effect of wind pressure on solids, beginning with cylinders and rectangular prisms. These results may have some bearing on chimneys. We then hope to go on to the effect of wind pressure on oblique surfaces, first by trying a flat plate, and then approximating to the conditions of a roof by screening one side. Such is our programme; we have not advanced far with it, but we have learnt sufficient to feel fairly confident it will work, and I trust that when we have results to publish, it will be found that they have a real value to engineers. I should add, I think, that that part of the apparatus which has not been made in our own shop has been purchased by funds supplied by the Government Grant Committee of the Royal Society.

And now let me turn to the third section of our work—enquiries or experiments made at the request of engineers or others for which fees are received. It would not be difficult to make a list of enquiries of this kind, on which I think the results of our experiments on comparatively small points might be of service to the profession. I am glad, however, to be able to illustrate my meaning by a short account of two or three investigations which we have already carried out in response to such enquiries. Some few months since Mr. F. B. Behr brought us some specimens of cast steel which the maker had assured him would be found excellent as a tool steel, and which it was said could be produced at a less cost than that ordinarily paid for tool steel. He asked us to test the

steel in any way we thought best, and I am indebted to his kindness for permission to use the results. Table 2 gives the result of the tests.

The specimens consisted of an ingot about 3 inches square in section and two rolled bars, one $\frac{7}{8}$ inch in diameter, the other $\frac{7}{8}$ inch square.

TABLE 2.—*Tensile Tests.*

No. 1.—Specimen turned from the round bar $\frac{7}{8}$ inch diameter in the state in which it was received.

No. 1A.—Specimen turned from the 1 inch \times 1 inch bar forged from the ingot.

No. 2A.—Specimen turned from the 1 inch \times 1 inch bar forged from the ingot.

No. 3A.—Specimen turned from the 1 inch \times 1 inch bar forged from the ingot.

No.	Initial Diameter.	Load in tons.		Stress in tons per sq. inch.		Elongation on total length.	Remarks.
		Yield.	Fracture.	Yield.	Fracture.		
	inch.					per cent.	
1	0.425	6.19	8.93	43.4	62.7	6.5	{ Fracture shows remarkable fine uniform grain.
1A	0.460	—	9.66	—	58.2	5.0	{ Yield load not perceptible.
2A	0.341	—	6.00	—	65.9	5.7	{ Yield load not perceptible.
3A	0.380	—	6.55	—	57.9	4.0	{ Broke at collar of specimen. Yield load not perceptible.

General Remarks.—In all these tests the breaking stress is somewhat higher and the elongation lower than in an average sample of unhardened cast tool-steel. The appearance of the fracture in specimens 1A, 2A, and 3A was markedly different from that in No. 1, the grain being much coarser.

The mechanical tests consisted of—

(1) Tensile tests on specimens turned from the $\frac{7}{8}$ inch bar and from a bar 1 inch by 1 inch forged for us from the ingot by Sir J. Thornycroft.

(2) Tests of hardness on the round bar and also on the bar forged from the ingot.

(3) Cutting tests made on tools forged from the bars supplied and from the forged bar.

And in the first place, as to the treatment of the ingot at the Chiswick works. This was heated to a very bright red heat, and forged all over from 3 inches square to 2 inches square under a steam hammer. The bar was then raised to almost a white heat and drawn down to 1 inch square, when it was allowed to cool slowly in the air.

The breaking stress is somewhat higher and the elongation lower than in an average sample of unhardened tool-steel. It was clear from the fracture that the rolled bar supplied with the ingot had a finer grain than that forged from the ingot.

TABLE 3.—*Tests of Hardness.*

The Tests of Hardness were made by measuring the amount of indentation produced by a hardened steel knife-edge, ground to an angle of 90°.

Material.	Load per inch width of knife-edge.	Indentation.
	tons.	inch.
Normal cast steel	4·43	0·01465
Specimens of steel cut from ingot .	4·43	0·01585
Specimens of steel cut from bar forged from ingot	4·43	0·01405

These results show that, as might have been predicted from the tensile tests the forged bar is harder than normal cast steels and the material of the ingot less so, the variation in either case not being considerable.

In Table 3 (page 77) we have the tests of hardness. These were made by a method due, I believe, to Professor Unwin, by measuring the amount of indentation produced by a hardened steel knife-edge, ground to an angle of 90° and forced into the material.

The first line gives the result for some ordinary tool steel. The results show that the ingot is less hard than this steel, while the forged bar is harder. The variation in either case is not large.

TABLE 4.—*Cutting Tests of Tool Steel.*

Tools Nos. 1 and 2.—Cutters made from a round sample $\frac{3}{8}$ inch diameter, hardened and tempered.

Tool No. 3.—Forged from a square sample 1 inch \times 1 inch, hardened and tempered.

Tool No. 4.—Made from the 1 inch \times 1 inch bar forged down from the ingot, hardened and tempered.

No. of Tool.	Duration of Test.	Mild Steel Bar on which Test was made.			Rate of cutting feet per minute.	Cubic inches of metal removed per min.	Remarks.
		Length.	Initial diameter.	Final diameter.			
	minutes.	ins.	ins.	ins.			
1	18.37	22	1.75	1.47	33.3	0.848	{ Cutting edge in good condition after test. Good supply of lubricant used.
2	10.77	22	1.47	1.28	49.8	0.835	{ Cutting edge blunt. Good supply of lubricant used.
3	40.32	48	2.00	1.70	38.7	1.04	{ Cutting edge blunt. Good supply of lubricant used.
4	18.75	39	1.69	1.49	57.5	1.04	{ Cutting edge in good condition. Good supply of lubricant used.

In Table 4 (page 78) we have the results of the cutting tests. The steel was hardened at a temperature of about 730° C. (1,350° F.), tempered in the usual way in the shop, and tested under ordinary workshop conditions in reducing a bar of mild steel in an 8-inch lathe. No attempt has been made to compare it with the effect of self-hardening high-speed tools working without lubricant.

It will be found, I think, from the figures that the depth of cut was from 0·10 to 0·15 of an inch, that the rate of cut was about

TABLE 5.

Analyses of Ingot and Bar.

	Ingot.	Bar.
	per cent.	per cent.
Carbon	0·896	0·828
Sulphur	0·086	0·075
Silicon	0·253	0·200
Phosphorus	0·141	0·135
Arsenic	0·045	0·043
Manganese	0·313	0·310
Nickel	0·166	0·210
Chromium	trace	trace

Analysis of bar hammered from Ingot.

Carbon = 0·890 per cent.

$\frac{1}{8}$ inch per revolution, and that the weight of steel removed was from 15 lbs. to 20 lbs. per hour. These numbers compare, I think favourably, with the results given in Mr. Donaldson's recent Paper (page 5).

These tests again show that the bar compares favourably with good commercial steels. They were carried out in the

Engineering Laboratory under Dr. Stanton's directions. Specimens of the steel were then analysed in the chemical laboratory by Dr. Carpenter. Table 5 (page 79) shows the results. In order to test if any serious change had taken place in the bar forged from the ingot, an analysis of its carbon was also made. The material was then subjected by Dr. Carpenter to a series of photo-micrographic tests.

The first photo-micrograph, Fig. 9, Plate 3, shows the structure of the original cast ingot magnified 102 diameters. With the exception of the black patches scattered here and there, and which are probably slag, the etched surface is coloured a uniform brown. This structure is characteristic of pearlite, the eutectic mixture of iron and carbide of iron, and is what might have been anticipated from a knowledge of the carbon content of the steel. The next photo-micrograph, Fig. 10, gives, under the same magnification, the structure of the bar hammered from the ingot, and shows very well the effect of hammering in removing slag. Only one patch is to be seen.

The character of the pearlite is shown in the next two photo-micrographs, Figs. 11 and 12, which are magnified 820 diameters. In the case of the ingot, Fig. 11, granular pearlite is found in the interior, lamellar pearlite near the edge. The banded structure seen in Fig. 11 is due to alternate lamellae of iron and carbide of iron. The white streaks are the carbide which is not attacked by the nitric acid used for etching, and which therefore reflect the light back up the tube of the microscope, vertical illumination being used. The dark lines are the iron which has been pitted by the etching fluid, and which reflect the light in another direction. The effect of hammering in rendering the metal more homogeneous is seen in the photo-micrograph of the hammered bar, Fig. 12, where the lamellar and the granular pearlite have penetrated the one into the other. For the sake of comparison, Fig. 13 is reproduced from a photo-micrograph (magnified 850 times) of an unhardened spring steel, given on Plate 20 of the Fifth Report to the Alloys Research Committee.* It contains 0.78 per cent. carbon, and 0.17 per cent.

* Proceedings, 1899.

chromium, and its structure is quite similar to that of the hammered and unhardened bar, except there the pearlite is almost wholly granular.

The change of structure subsequent upon the hardenings of a soft tool-steel is seen in Fig. 14, Plate 4. A small section cut from the hammered bar was quenched at 741° C. in water at 15° C., reheated to straw temper and afterwards cooled in the air. It was then polished, and the structure of the surface developed by rubbing it on parchment with ammonium nitrate solution and calcium sulphate. Under this treatment the surface takes on a variety of colours—yellow, blue and black in parts, and when examined under high magnification, in this case 1,500 diameters, three types of structure are seen:—

- (1) The white areas, which are ferrite, that is, iron.
- (2) The light granular areas which are sorbite, that is, unsegregated or partially segregated pearlite.
- (3) The dark areas which are troostite. As to the nature of this last-named structure, considerable doubt exists at the present time.

Thus a photo-micrograph of the hardened section gives some idea of the condition and distribution of the various constituents of the steel at the temperature of quenching; and, provided the chemical composition of the steel be known, it is possible to judge from the photo-micrograph within certain limits what the quenching temperature actually was.

With a view to examining the effects of hardening, small sections, 2 cm. \times 1 cm. \times $\frac{1}{8}$ cm., were prepared from the forged bar and heated in an electric furnace to 792° C., 741° C., 691° C. and 642° C. respectively. These were polished and examined for cracks. It had been found in tempering the tools that some care was required, and in one case a crack had developed. The specimens quenched after heating in the electric furnace were found to be free from flaws.

Thus finally we were able to conclude as follows:—

Mechanical tests.—The tensile tests show that the steel is of greater strength than average cast-steel, but that there is a corresponding reduction of elongation. The indentation tests confirm these results, and show further that the material of the ingot before working has a

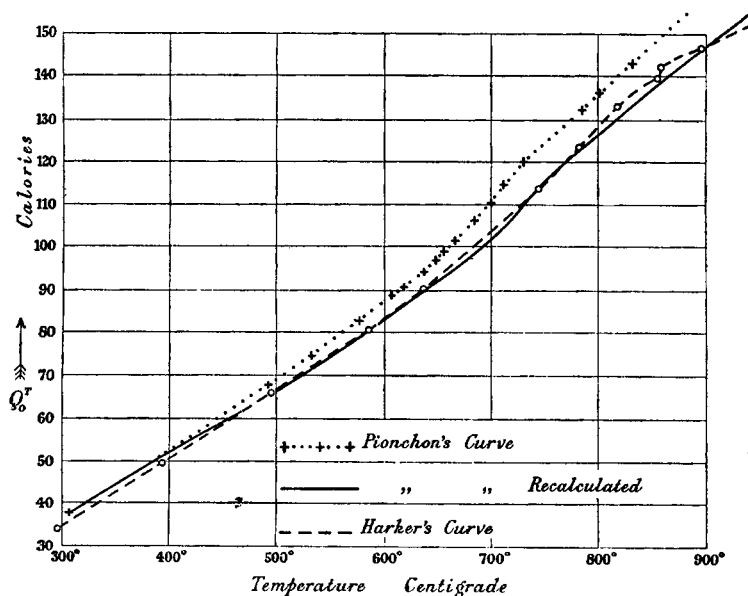
H

degree of hardness very little less than a rolled bar of average cast steel. The cutting tests were satisfactory in every way. The results show that the steel is very suitable for use as a cutting tool, and bears favourable comparison with the best cast-steel used in lathes with a good supply of lubricant. It would seem that care is required in the forging and hardening of the steel to prevent the development of cracks, but with ordinary attention this can be avoided. These particulars seem to me to illustrate very clearly the point I wish to bring home—the commercial use of the Laboratory to the engineering profession. There are few places if any, I take it, except Bushy, where Mr. Behr could have had such a series of tests carried out; the value of the report is obvious and its utility clear. It should be noted that at least four departments of the Laboratory combined to obtain the results, and that all the work of preparation, except the forging of the ingot, was done on the spot.

The next case is a simpler one, but not less interesting. An engineer in practice in South Wales wrote to us with regard to the well-known method of determining the temperature of a furnace by the use of an iron ball and a calorimeter. The method is a bad one, it is obvious. Nowadays the platinum thermometer or the thermo-junction ought to supersede it in all permanent installations; still it has its uses. Our correspondent pointed out that there were considerable discrepancies in the values given for the specific heat of iron at high temperatures, or what comes to the same thing for the total heat emitted by a given mass of iron in cooling from a high temperature; he told us that he had made a number of experiments himself with great care, and always found a lower value than that given by Pionchon, whose work was generally looked upon as a standard, and he asked for assistance. He pointed out, moreover, that the value used by Pionchon for the melting point of silver, determined by Violle was 907°C ., while the temperature is now known to be nearly 50°C . higher, or 962° , and suggested that this might be the cause of some of the difference. I asked Dr. Harker to look into the question. The electric oven gave us a ready method of heating the iron, while its temperature was easily found by the aid of a platinum thermometer, and a number of experiments were

made. An oven was mounted with its axis vertical, and arranged so that it could be brought over the calorimeter and the iron dropped directly into the water. In some experiments, 42 (in others 26) grammes of Mr. Hadfield's Swedish charcoal iron were used, and the usual precautions necessary in calorimeter work taken. The diagram, Fig. 15, gives the results so far as the research has yet gone.

FIG. 15.—*Specific Heat of Iron.*



The upper curve with the crosses gives Pionchon's results; the lower one with the circles shows the results obtained by Dr. Harker. He is, you will observe, below Pionchon, though not nearly so much below him as our Cardiff correspondent. But now Pionchon's temperature for the melting point of silver, 916° C., is too low by 50°. At lower temperatures, 200°, 300°, we may reasonably suppose his temperatures were accurate. Let us then modify his results by supposing that there was an error in his temperatures negligible in the lower part of the scale and increasing uniformly up to 50° at

900°; we obtain the full line, which agrees very closely with Harker's results. You will observe the break in Harker's curve at about 850°. M. Osmond determined the recalescent point Ar_3 of this iron, when the change from β iron to γ iron is supposed to occur, as 855° C. Dr. Harker's curve bears an independent testimony to a change at about this point, though of course the number of his observations is too small to afford very exact information. The work does not claim to be done in the same elaborate manner as Pionchon's. It was clear that when the hot metal was dropped into the water there was a certain amount of oxidization, and no attempt has been made to correct for this, but the error thus caused, which Pionchon avoided, must be very small, and certainly occurs in the practical application of the method.

Other examples of the work the Laboratory can do might easily be given. I was present here about three weeks ago at a very interesting discussion on the Cutting Angles of Tools introduced in a Paper by Mr. Donaldson, of Woolwich. Mr. Donaldson was the first to state that his results were not final, and it was clear from the discussion that much remained to be done. May I say without impertinence that what struck me most was the paucity of knowledge on a most important matter. I take it that the technical skill of the English workman has been such that it was best to leave the question to him, and allow him to grind his tools as experience led him to do. Is this a question on which we can render help, and on which our help will be of value? If so, perhaps the President would like to support a proposal at our General Board next month that we should take up the question. I am aware that our 8-inch lathe is not heavy enough, but that is a difficulty which can be overcome, and for the rest, with the kind assistance of our friends in providing material, we have all that we require to carry out the work. I cannot promise to measure forces of 10 tons on the point of the tool, as Mr. Wicksteed suggested might be required, but with Mr. Donaldson's help should hope to supplement the numbers given in his Paper.

I have already referred to the work on the aluminium and other iron-alloys used by Professor Barrett. Perhaps without going into the

details of that work, I may show some photo-micrographs obtained; Plate 5 gives a photograph of three sections of the ingot from which the aluminium rod was made. You will notice in the first place the difference in structure in the different parts of the ingot. Figs. 20 and 21 are from the upper part, and show a series of small nodules forming a ring pattern on a ground mass of what appears from Fig. 21 magnified 1,260 times to be granular pearlite. It seems probable that these nodules are the oxide of aluminium. Fig. 22 and Fig. 23 are chiefly pearlite. There are still some nodules visible and a certain amount of ferrite, while in Figs. 24 and 25 from the bottom of the ingot we have chiefly ferrite. In Figs. 16 to 19, Plate 4, we have photos of the section of the rod 1167 H deeply etched to show grains in the high-power photographs. Figs. 16 and 17 are from near the edge. Note the ferrite on the extreme edge. The white patches in relief are probably aluminium. The small nodules of oxide are seen in the magnified photographs.

In Plate 6 we have photographs of the Swedish charcoal iron bar. Fig. 26 is the polished surface. Figs. 27 and 29 are different portions of the same after deep etching, showing a difference in the carbon present. This has to some extent been confirmed by chemical analysis. In Fig. 28 the ferrite grains are clearly seen; the one in the centre is about $\frac{1}{320}$ inch in diameter. Fig. 30 shows a ferrite grain bounded by pearlite.

In conclusion, may I again thank the President for the opportunity he has given me of placing some account of the National Physical Laboratory before the Graduates. I trust that my own zeal for what I believe to be a great and a greatly needed work has not led me to depict our efforts in too favourable colours, but that I may carry the opinion of the Meeting with me, if I express the hope that what we are doing is of real value to engineers, and if I urge on them the contention that the Laboratory is an institution which deserves their cordial support.

The Paper is illustrated by Plates 2 to 6 and 3 Figs. in the letterpress.

The PRESIDENT, in proposing a hearty vote of thanks to Dr. Glazebrook for his interesting Lecture, emphasised the importance of the work which the National Physical Laboratory was capable of carrying out. There were, he remarked, very few engineering works in the country in which anything like an exhaustive enquiry into the physical properties of materials could be successfully carried out, as not only was the equipment wanting, but also the trained staff necessary to use effectively such an equipment. Engineers would therefore be well serving their own interests, if they referred to the National Physical Laboratory many questions which arose for settlement in the course of practical work.

The vote of thanks was carried with acclamation, and a brief discussion then ensued on some points raised by the Lecture.

Dr. GLAZEBROOK, in replying, thanked the Meeting for their kind reception.

Mr. J. S. WARNER, Chairman of the Graduates' Association, proposed a cordial vote of thanks to the President for taking the chair that evening.

The PRESIDENT suitably acknowledged the vote.

Fig. 1. *Bushy House, South.*



Fig. 4. *Engineering Laboratory, Pressure Tests.*

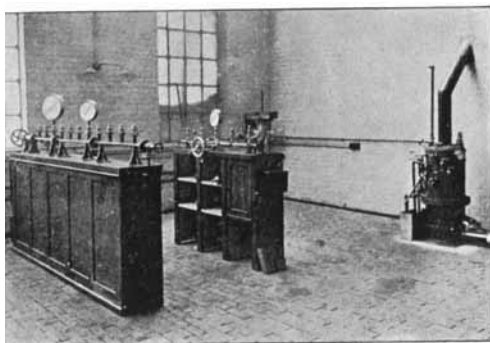


Fig. 3. *Engineering Laboratory, Testing Machine.*

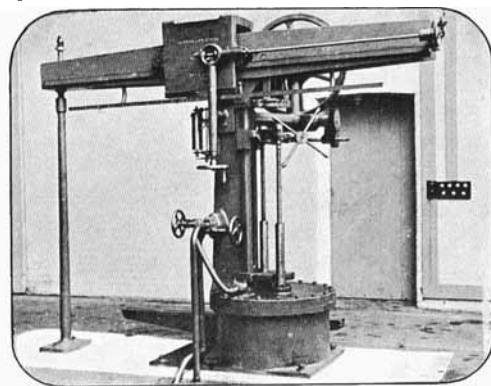


Fig. 5. *Physics Laboratory, Gauge Room.*



Physics Laboratory.

Fig. 6. Metallurgy.

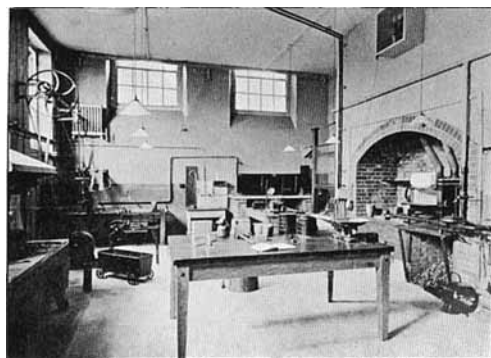


Fig. 7. Thermometry, Outer Room.

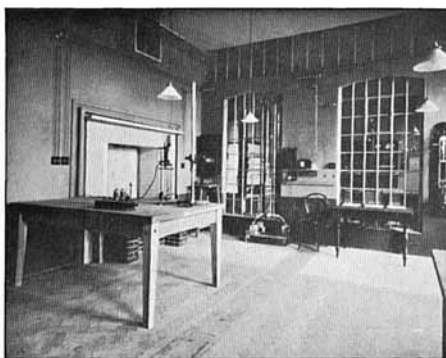


Fig. 9.
Steel Ingot $\times 102$ diams.



Fig. 10.

Hammered Bar $\times 102$ diams.

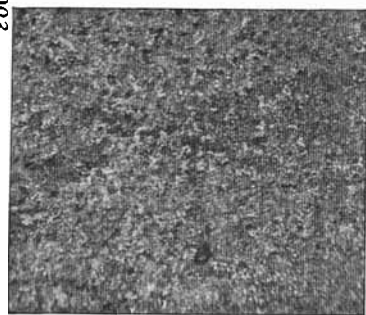


Fig. 11.

The Ingot $\times 820$ diams.

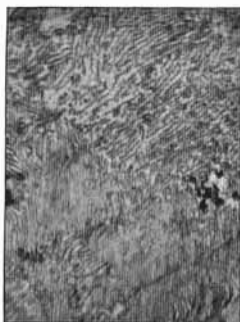


Fig. 12.

Hammered Bar $\times 820$ d.



Fig. 13. Spring Steel, Soft, $\times 850$
diams. (From Proc. 1899.
Fig. 94, Pl. 20.)

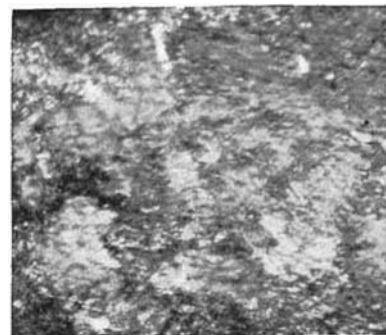
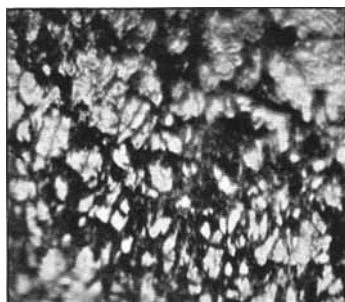
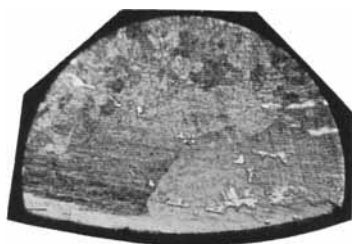


Fig. 14. *Hardened Hammered Steel Bar $\times 1500$ diams.
Quenched at 741° C. and showing Ferrite, Sorbite, and Troostite.*



*Photomicrographs of Transverse Sections of Aluminium Rod 1167 H.
(Etched with 1% Nitric Acid in Alcohol for $3\frac{1}{2}$ minutes.)*

Fig. 16. $\times 60$ diams.



Edge (Ferrite)

Fig. 17. *The same $\times 500$ diams.*

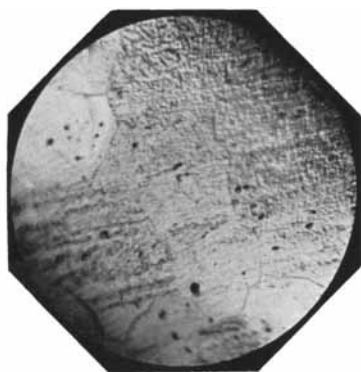
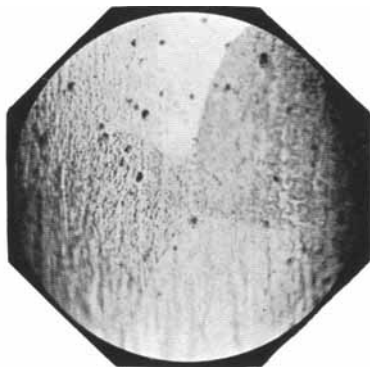


Fig. 18. $\times 60$ diams.

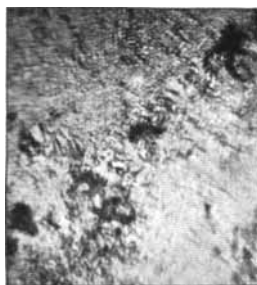
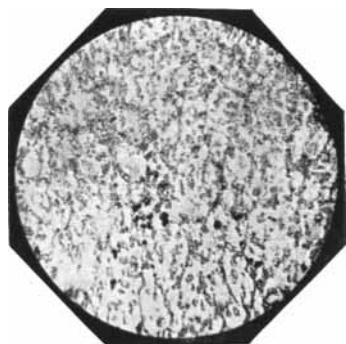


Fig. 19. *The same $\times 500$ diams.*



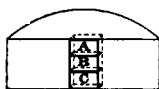
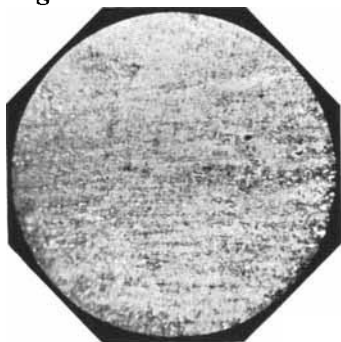
*Photomicrographs of Transverse Sections of Ingot
from which Aluminium Rod 1167 H. was obtained.*

Fig. 20. *Portion A.* $\times 60$ diams. Fig. 21. *The same* $\times 1260$ diams.



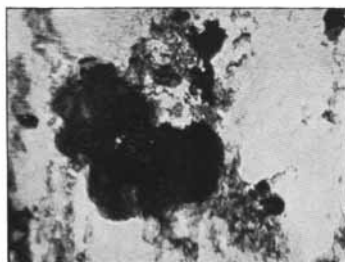
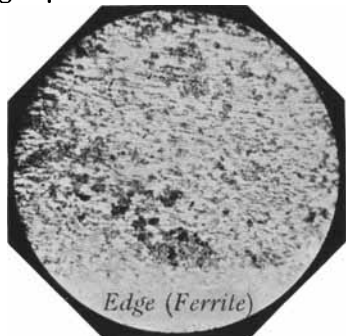
(Etched with 1% Nitric Acid in Alcohol for 50 seconds.)

Fig. 22. *Portion B.* $\times 60$ diams. Fig. 23. *The same* $\times 1260$ diams.



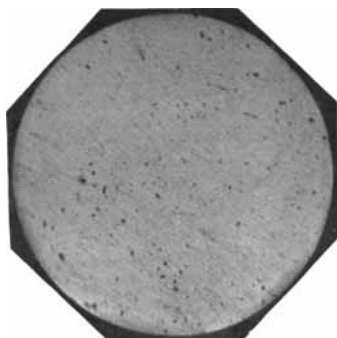
Positions of Portions.

Fig. 24. *Portion C.* $\times 60$ diams. Fig. 25. *The same* $\times 1260$ diams.



Photomicrographs of Transverse Sections of Swedish Charcoal Iron Rod.

Fig. 26. Plain Polished Surface $\times 60$ diams.



Fe. = 99.89.

Si. = 0.07.

P. = 0.004.

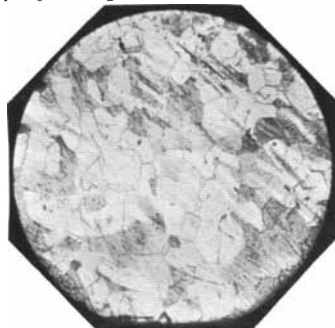
C. = 0.028.

S. = 0.005.

Mn. = Trace.

(Etched with 1% Nitric Acid in Alcohol for 3 minutes.)

Fig. 27. A portion $\times 60$ diams.



Edge

Fig. 28. The same $\times 500$ diams.

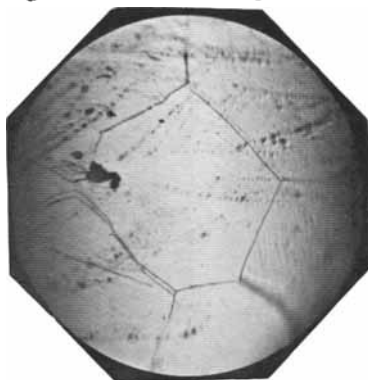
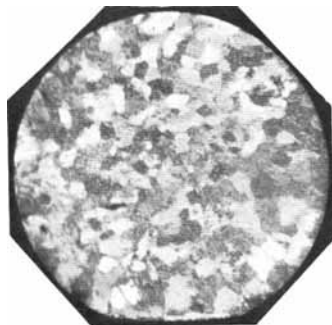


Fig. 29. Another portion $\times 60$ diams.



Edge

Fig. 30. Pearlite and Ferrite $\times 500$ diams.

