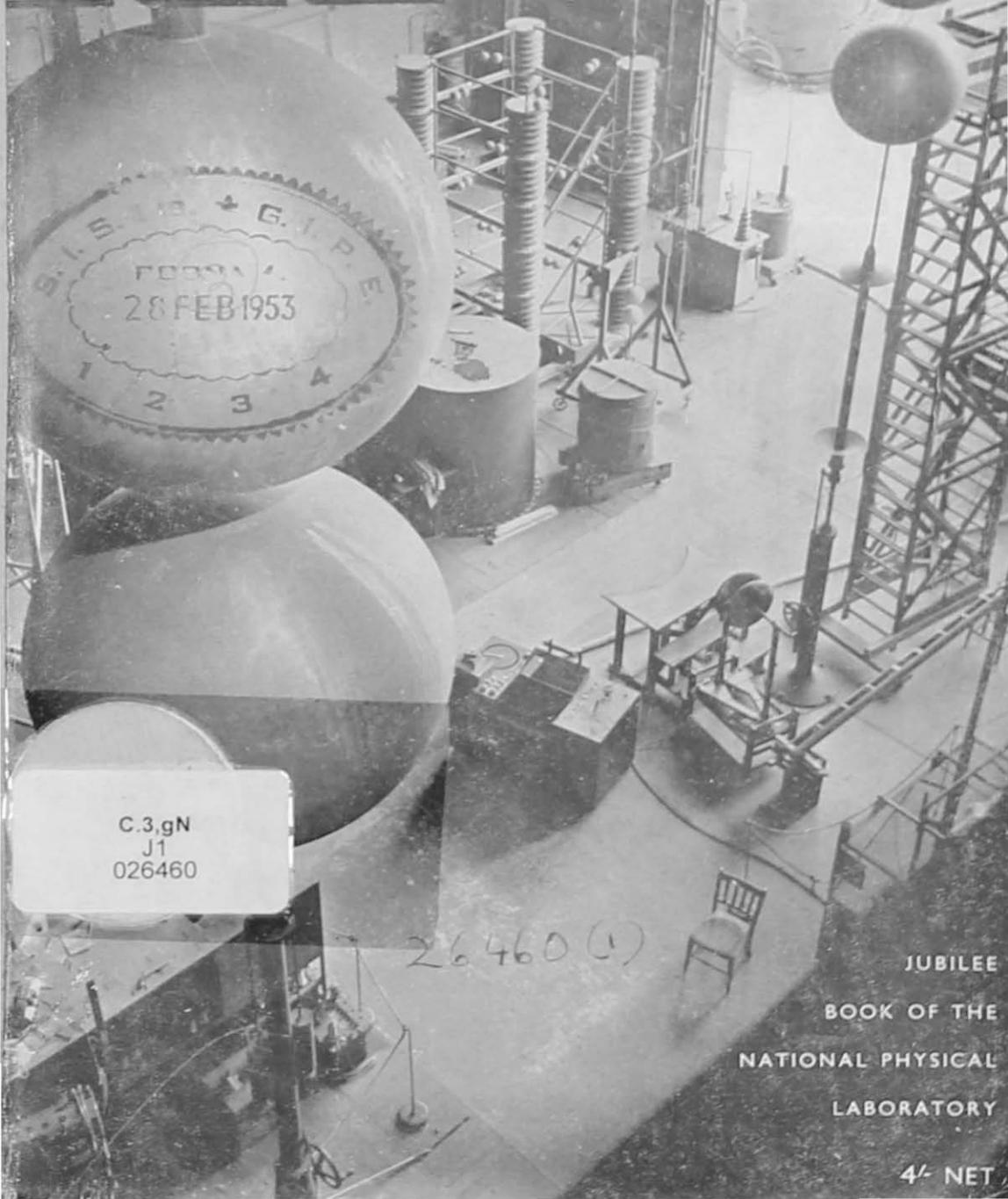


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BOOK OF THE  
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Jubilee Book of the National Physical Laboratory

Prepared for the Department of Scientific and Industrial  
Research by the Central Office of Information



JUBILEE BOOK OF THE  
NATIONAL  
PHYSICAL LABORATORY

*BY*  
*JOHN LANGDON-DAVIES*

*LONDON*  
HIS MAJESTY'S STATIONERY OFFICE

1951

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## What is the N.P.L.?

Of the millions who each year enjoy the lilacs of Kew; the chestnuts of Bushy, the deer of Richmond, and the historic ghosts of Hampton Court, few are likely to know that in the immediate vicinity is an institution which affects their daily lives.

The National Physical Laboratory, Teddington, has for fifty years carried out research, investigation, measurement, over a field which extends from the accurate ascertainment of the velocity of light to the testing of taximeters and thermometers.

Every yard that is measured or pound that is weighed in the Commonwealth depends for its strict definition on the National Physical Laboratory, and without the N.P.L. the degree of accuracy required to-day in most industrial processes would be unattainable.

The National Physical Laboratory lays down how electric current is to be measured and concerns itself with the improved measurement of all electro-magnetic constants; it makes possible the comparison, and therefore the fitting together, of one machine part with another; it sees that screws and screw parts are interchangeable. It saves the Merchant Navy many tens of thousands a year in fuel by correcting the designs of ships before they are built; it watched over the birth of aviation, and is now working on problems arising from the piercing of the sonic barrier. Its contribution to radar helped to save us from invasion. It has done much to win the modern battle against the force of gravity by years of systematic research into alloys of aluminium and other light metals. And this is but one example of its concern with metals and material of all sorts, a concern which is not limited to a study of metals in themselves but includes metals in use, and the measurement of their fatigue and 'creep'.

Whatever requires accurate measurement in this modern world of scientific industry and mass production owes something to the work carried on at Teddington.

*The Sixth Decimal Place*

The nature of this fundamental work at the N.P.L. is very well illustrated in an epigram coined by Sir Oliver Lodge, one of the far-sighted men responsible for its birth. There was only one thing, Sir Oliver said, that a scientist should regard as more important than the fifth place of decimals, and that is the sixth place. The N.P.L. is an institution which concentrates on the millionth part of a unit of measurement.

Now, to the average man, the millionth part of an inch is not, at first sight, a matter of much practical importance. Yet it is very easy to show, by an example, that this concentration on the millionth part is no mere obsession with accuracy for accuracy's sake; it is an essential service to industry and to the needs of our daily life.

0. 001

It is by no means rare for the diameter of a steel shaft to be required accurate to a thousandth of an inch. In war or peace, our lives may be endangered by an error even as small as this. The weapon that does not fire, the safety device that does not function, the engine part that jams or fails to engage, are only a few of the failures which can be traced to a fractional inaccuracy in some machine tool. How are we to guarantee that the shaft will be sufficiently accurate? By measuring it with an accurate tool.

This tool may be a pair of horseshoe gauges, an appliance easily visualized from its name and familiar enough to tens of thousands of workers in munitions and other engineering factories during the war.

The difference in size between the two gauges will be the size of the allowable error in the object they are going to measure, that is, in this case, 0. 001 inch. If the bar to be measured is of correct diameter within the permissible margin of error, the larger gauge will be able to pass over the bar and the smaller will not be able to do so—hence such gauges are often called 'go, no-go gauges'. Since the bar is larger than the smaller gauge and smaller than the larger gauge, it is within 0. 001 inch of the perfect diameter.

0. 000 1

Now these gauges will of course not be absolutely accurate, and the gauge-maker will have to be allowed a maximum error which should be not more than a tenth of the allowable error of the bar, that is, in

## WHAT IS THE N.P.L.?

the region of 0.0001 inch, one more decimal point than the allowable error in the bar to be tested.

The gauge-maker in his turn will have to possess a measuring tool to test his gauges. It will be one or more slip gauges. These consist of small rectangular blocks of metal, each having a given thickness or length. They are remarkable objects—so smooth and flat that they can be 'wring' together. If the polished ends of two blocks are slid together with a wringing motion like that used to wring out a damp cloth, they stick together, thanks to their perfect smoothness, solely as a result of the attraction of their molecules, and considerable force is needed to pull them apart.

By 'wringing' together gauges of different sizes, it is possible to build up from the standard set of 81 blocks a most precise measuring tool which will meet the gauge-maker's requirements up to lengths of 10 inches.

0.00001

To be fair to the horseshoe gauge-maker, the combination of slip gauges which he must accept as his standard must be accurate to one more place of decimals, that is, to 0.00001 inch. As the combination is made up of several separate slip gauges, these individual pieces of metal should each be more accurate still, say to a few millionths of an inch—a degree of accuracy which is in fact guaranteed by their makers.

0.000001

But what is the final proof that this accuracy has been achieved? This is where the N.P.L. comes in. The ultimate measuring tools for measuring all other measuring tools are kept at Teddington, and of course these linear standards for which the Laboratory is responsible must be yet more accurate; that is, accurate to 0.000001 inch, or one millionth of an inch.

An enormous amount of work and planning is required to make sure of that millionth, and, as we now see, it is not done solely for the love of pure measurement. It is done because not only does the entire fabric of theoretical and experimental science rest on agreed standard measures of length, mass, and time, but because, in a scientific age, industry itself can only be firmly based on the accurate maintenance of these measures. The N.P.L. has to busy itself with a millionth part of an inch because industry must be supplied with slip gauges which, used

as practical substandards, will satisfy the exacting demands for accurate measurement essential to modern engineering practice.

*Metrology: the Science of Measurement*

The science of measurement, or metrology, is the basis of the work of the National Physical Laboratory. Primary standards have to be maintained, and research conducted into the best way of applying these to practical measuring problems throughout science and industry.

The other three activities of the N.P.L. are the natural consequences of this basic activity. It is convenient to describe them as long-term research, short-term investigation, and routine testing of a large range of instruments and apparatus. We shall see that these three categories are somewhat artificial and, particularly, that the second and third cannot be carried out without a continuous programme of long-term research.

Indeed, the National Physical Laboratory could never have been of practical use to industry had it not been planned in an atmosphere permeated with a spirit of pure scientific research.

We shall illustrate this essential feature in the history of the Laboratory by a brief description of a group of researches into widely different problems which depend upon certain scientific ideas called, generically, Fluid Flow.

*Fluid Flow*

A ship moving through water imparts to the water a motion the nature of which depends on the speed and the shape of the ship. As it is of no value to anyone to make the water move, but only to make ships move, it is important to study the ways of making this movement of water as little wasteful as possible. That is an example of the problem of fluid flow, and it is studied in large tanks in which models of projected ships are propelled. Years of research have accumulated masses of data about the interplay between a moving ship and water, and the best way of designing a ship so that the least possible part of its energy is wasted on the water.

When it became necessary to study the interplay between a moving aeroplane and air, it was found that the problem was best approached as another example of fluid flow. What the tank did in the case of ship propulsion the wind tunnel was able to do in the case of aviation.

## WHAT IS THE N.P.L.?

Historically, work at the National Physical Laboratory on wind pressure against buildings preceded both ship and aeroplane work. As we shall see, the vital research work in aerodynamics really stemmed out of a scientific curiosity as to what the exact wind pressure against the Forth Bridge really was, and how far the official guess was accurate.

We are now approaching an age of supersonic speeds, and it is important to know what effects such speeds will have on aircraft and projectiles. We find, therefore, that the Aerodynamics and Engineering Divisions have had to study fluid flow in their own supersonic wind tunnels.

A fundamental study of fluid flow proves to be the best approach to many other problems. Thus, when air flows against a bridge, the structural strength required to withstand the stresses set up by winds can be closely estimated beforehand. A model of the bridge, with air flowing past it in a wind tunnel, helps towards this in precisely the same way as a model of an aeroplane tested in a wind tunnel helps to solve the problems connected with flight. To be certain that the projected Severn Bridge will be built in the best way, a model of it in a wind tunnel is being studied at the present time according to the principles of fluid flow.

### *Materials*

The National Physical Laboratory deals with materials. Accurate measurement is useless without a full knowledge of the properties of what is being measured. The simplest example is the metal rod used as the standard of length. Everybody knows that a normal rod will expand with heat and contract with cold. Unless the rod's exact composition is known, and unless the physical properties of the materials of which it is made have been measured, it cannot usefully be regarded as a means of measuring other things.

This is, however, only one of many reasons why the Laboratory concerns itself with inventing ways of accurately measuring the physical constants of the materials, chiefly metals, out of which industry makes its tools, machines, and products. When the N.P.L. began its work, little accurate information existed about such physical properties as the expansion with heat, the elasticity, the resistance to stresses of even such a basically important material as mild steel. Nor did anyone know why a given alloy had its special physical properties and what their

relationship was to the chemical mixture of which it was composed. To-day, all this is accurately studied. Thousands of alloys have had their characteristics measured, but a vast amount of work remains to be done. The systematic study of materials is therefore a continuing part of the Laboratory's programme.

Moreover, although metals were the first materials to be systematically studied by the Laboratory, many other kinds of material have since been added to the programme. These include building materials of every sort whose characteristics determine the success with which we can insulate our houses against heat and cold and noise. While the use of such materials ultimately became the primary responsibility of the Building Research Station, the determination of their properties was, and to some extent still is, the concern of the N.P.L. Another example is offered by the materials used for road construction. Here again the Laboratory was chiefly interested in measuring their physical properties; the application of the results to problems of road construction became the function of the Road Research Laboratory. It should be pointed out, however, that some industrial concerns to-day carry out their own investigations into the properties of new materials used for building or road construction.

### *Instruments*

There is a need for an ever wider range of measuring and other instruments. The N.P.L. has had to devise hundreds of new varieties of meter. Apart from simple tools for measuring lengths and weights, most measuring tools have been very recent inventions. To most of us the thermometer is so familiar an instrument that we take it for granted; indeed the clinical thermometer is one of the oldest of measuring instruments. Yet it was not until 1866 that anybody had his temperature taken with reasonable ease and accuracy.

The National Physical Laboratory has had to design instruments for measurement in a very wide field of theoretical and applied science during the last fifty years. We speak of the voltage of our electricity supply and take it for granted that it is a measurable quantity; we seldom wonder who measured a volt in the first place and with what instrument. We can tune in to a particular radio wave-length at will by turning a dial, but who measured wave-lengths in the first place, and how? How does any one know what  $1,000^{\circ}\text{C}$  is? These are only

## WHAT IS THE N.P.L.?

a few of the primary measurements which are the responsibility of the N.P.L.

### *Electro-magnetic Waves*

Nor do these heavy tasks exhaust the activities of the various laboratories. We shall find them covering almost the whole field of electromagnetic waves—light, radio, infra-red, ultra-violet, radar, and so on. Many optical instruments, including the human eye, are the subjects of investigation; not only sight but sound also comes into the programme with the study of the acoustical properties of buildings; not only the standard volt but also the million volt spark which simulates the effect of lightning on the national grid.

In all this network of research, there is one guiding principle. It was enunciated by King George V when, as Prince of Wales, he opened the National Physical Laboratory on March 19th, 1902 : ' The object ', he said, ' of the scheme is, I understand, to bring scientific knowledge to bear practically upon our everyday industrial and commercial life, to break down the barrier between theory and practice, to effect a union between science and commerce '.

The art of measurement is the cornerstone of the nation's material existence. What our generation has learned to call industrial potential, with its stern twin brother, war potential, depends upon accuracy and uniformity of standards to a decimal place which may seem far too precise to a layman. The story of the N.P.L. is the gradual unfolding of this truth and of its application to practical everyday life.

# How it all Began

### *The German Example*

Nineteenth-century Britain took for granted that the leadership of the world in commerce and industry was, and would remain, securely in her hands. Her wealth, it was felt, lay not merely in coal and iron and the benefits of an early start in the international struggle for raw materials and markets; but equally in the rich tradition of craftsmanship possessed by her engineers and skilled artisans. In those days, success in industry depended not so much on the possession of patents, protected by law, as on individuals who jealously guarded the secrets of their craft—secrets learned not only from their own experience but often from their fathers’.

Craftsmanship lingers to this day; there are important glass manufactories where the most efficient pyrometer is still the judgment of the furnace-man as to exactly what degree of heat is implied by ‘cherry red’. But such methods have for the most part had to give way to the less romantic reading of instruments.

The English manufacturer was, on the whole, slow to read the writing on the wall; though it became easily legible to those who were watching the new Germany that began to take form after the Franco-Prussian War. To them German industry was entering upon a period of remarkable expansion, clearly based on a realization of the paramount importance of scientific research.

The union of German science with German industry took visible form in the ‘80’s when, at Charlottenburg, the *Physikalisch-Technische Reichsanstalt* was founded, with Hermann von Helmholtz as its first director and the industrialist, Werner von Siemens, as one of its main supporters.

By the end of the century, the effects of this union on international rivalries was clear to those who had eyes to see. Germany was rapidly moving towards industrial supremacy in Europe. If England was losing her supremacy in manufactures and in commerce, it was because of the



Sir Joseph Petavel



Sir Richard Glazebrook



Sir Lawrence Bragg

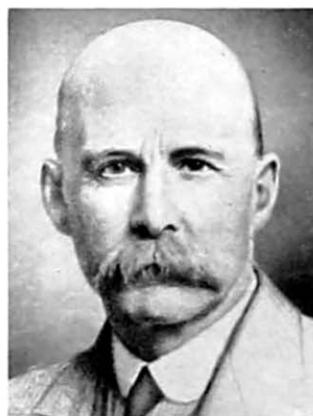


Sir Charles Darwin



Dr. E. C. Bullard

SOME  
LEADING PERSONALITIES  
OF THE  
NATIONAL PHYSICAL  
LABORATORY



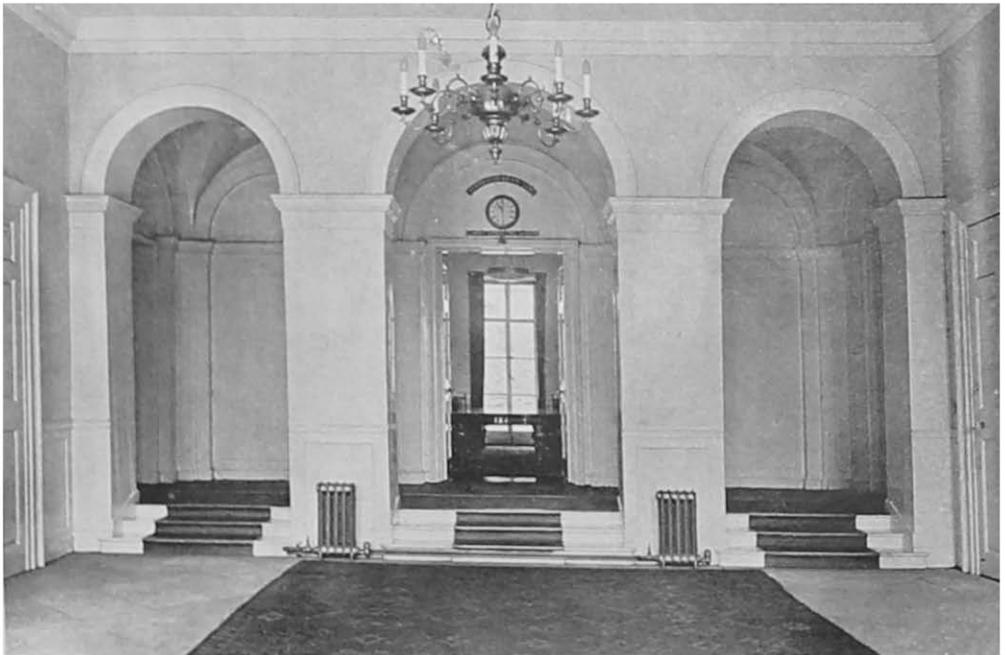
Sir Thomas Stanton



Sir Frank Smith



*Above* : An early view of Bushy House, the old Royal Residence which, fifty years ago, Queen Victoria gave as the first building for the National Physical Laboratory. *Below* : The entrance hall of Bushy House showing one dial of the standard clock, and the main conference room beyond. The house is both a laboratory and the residence of the Director





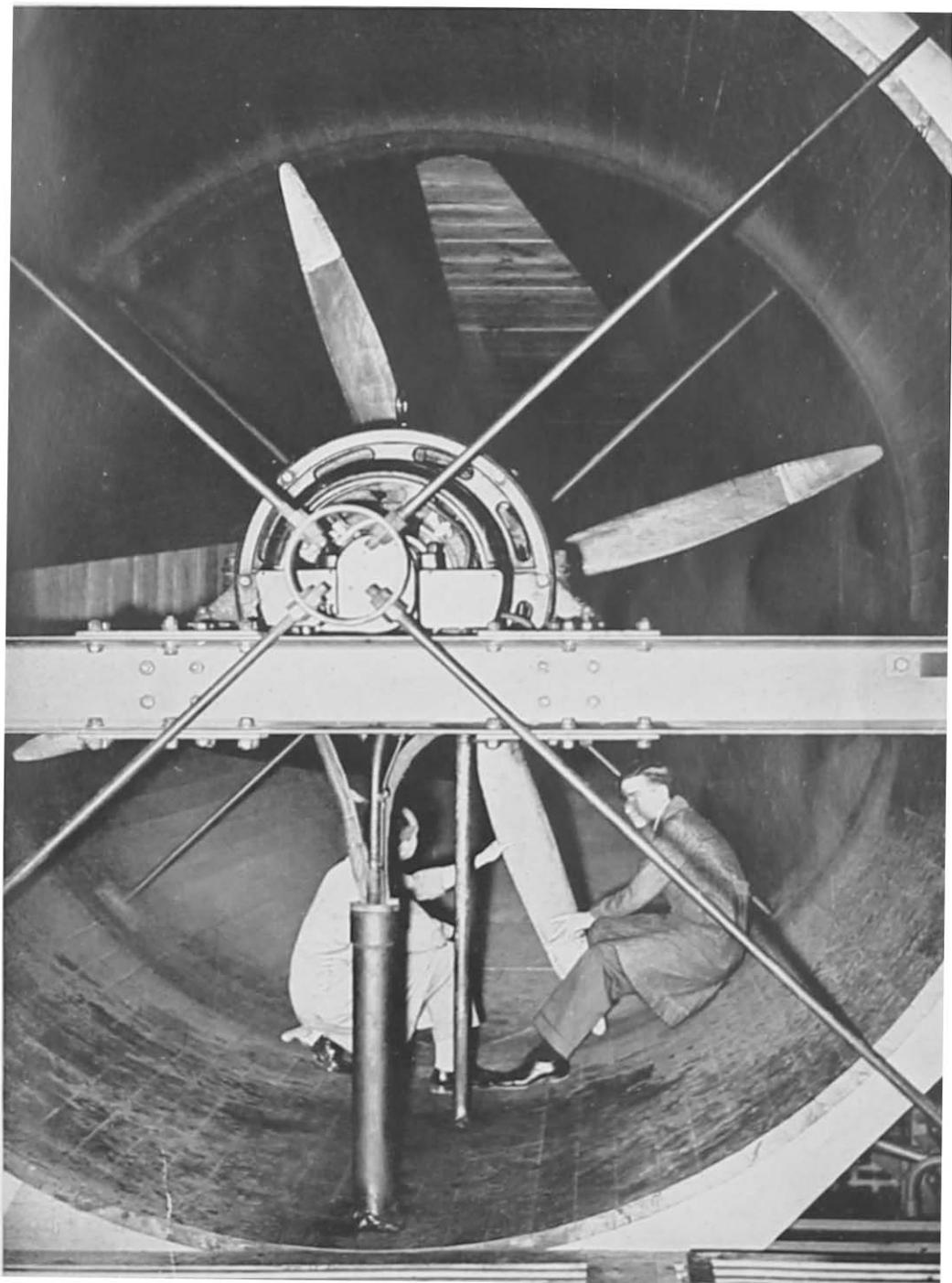
*Above* : The main Physics Laboratory built in 1931

*Below* : The octagonal building which houses the whirling arm (*see Plate VII*)

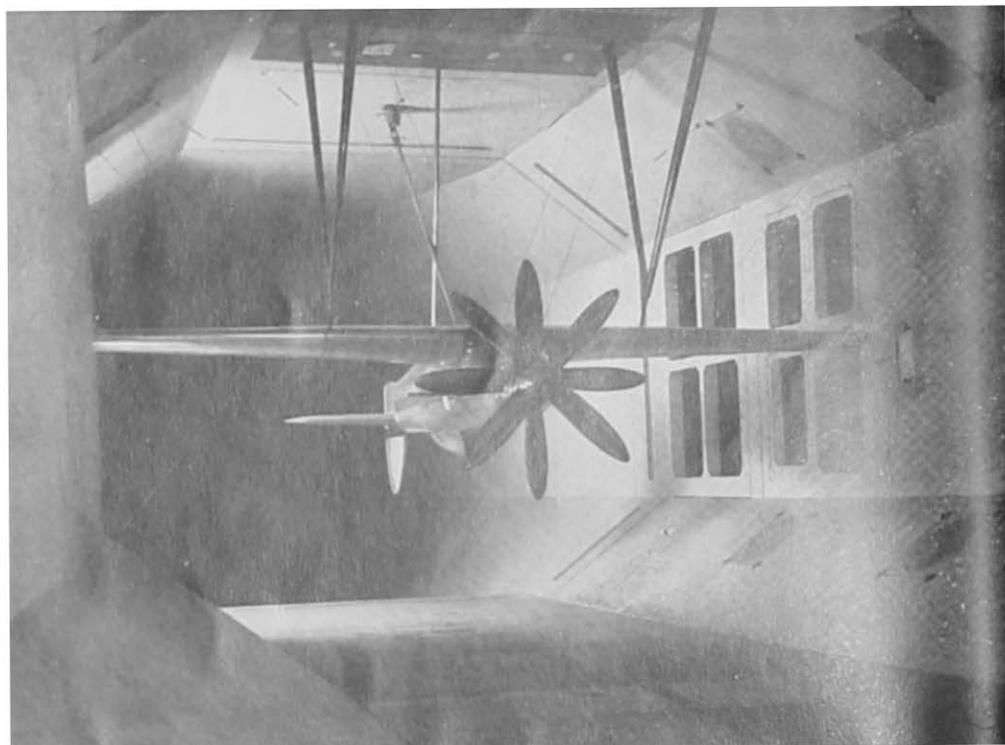




Three heavy duty compressors can produce a pressure of 25 atmospheres in one hour in the compressed air tunnel, providing model testing conditions equivalent to those of full-scale flight



View taken from the rear, looking into the test chamber, of one of the driving fans in the duplex wind tunnel. The working section of this wind tunnel is 14 ft wide by 7 ft high



Model contra-rotating propellers on a typical fighter aeroplane (mounted in an inverted position for test purposes). Each of the two propellers has four blades and is 2 ft 6 in in diameter. The working section of the tunnel is 9 ft wide  $\times$  7 ft high. The maximum wind speed exceeds 150 miles per hour

Adjusting the attachment of a model on the whirling arm, which is 60 ft in diameter and rotates at 100 ft per second



*Plate VII*



The 50-ft model of the proposed suspension bridge over the River Severn is tested in a specially constructed wind tunnel to investigate the effects of various winds on the structure. The devices to be seen on the left of the bridge are arresters for controlling the oscillations of the model

## HOW IT ALL BEGAN

English failure to utilize to the fullest extent the lessons of science; while Germany, once the country of dreamers and theorists, had now become intensely practical. Science there no longer sought court and cloister, but was in open alliance with commerce and industry—such was the way in which shrewd observers summed up the situation.

The fruits of this union were not long in ripening; the German dye industry and the Jena glass industry achieved virtually world monopolies. They did so by methods with which British science and industry were not at that time organized to compete. 'The truly serious side of the matter', wrote Professor Armstrong, 'is not the prospective loss of the entire indigo industry, so much as the fact that an achievement such as that of the Badische Company seems past praying for here'.

### *Sir Oliver Lodge Intervenes*

Counter-action began to be taken by a few far-sighted men, and particularly by leaders of the Royal Society and of the British Association for the Advancement of Science.

Thus, in 1891, Sir Oliver Lodge, F.R.S., as president of the Mathematical and Physical Section of the British Association, devoted his presidential address to a strong plea for the inauguration of a 'Physical Observatory precisely comparable to the Greenwich Observatory and aiming at the very highest quantitative work in all departments of physical science . . . accuracy should be the one great end.

'The Laboratory will also be the natural custodian of our standards, in a state fit for use and for comparison with copies sent to be certified. Else perhaps some day our standard ohm may be buried in a brick wall at Westminster, and no one living may be able to recall precisely where it is'.

Sir Oliver Lodge spoke of the French Conservatoire des Arts et Métiers, and of the new German establishment, and asked whether it was not time that England, which in physical science might in some sort claim a leading place, should be thinking of starting a similar movement.

The Government appeared to ignore Sir Oliver Lodge's plea until, in 1895, Sir Douglas Galton, K.C.B., F.R.S., took up the matter once more. This time action followed. A powerful committee was set up to consider the establishment of a National Physical Laboratory for the more accurate determination of physical constants and for other

quantitative research. The following year this committee, reporting in favour of the establishment of such a laboratory, recommended that the Royal Society should be made responsible for planning and controlling it, and that a paid Director should have immediate executive and initiative power.

*Lord Rayleigh's Committee*

In 1897, a deputation headed by Lord Lister, F.R.S. was favourably received by the Prime Minister, Lord Salisbury; a committee under Lord Rayleigh was established.

In the course of its labours, this committee visited the Reichsanstalt and other German institutions and considered the existing English bodies whose work would have to be correlated with the proposed laboratory, notably the Board of Trade Standards Department and the Electrical Standardization Laboratory.

The committee was able to show how inadequate were the resources of existing English institutions. The chemical analysis of materials employed in constructing standards could not be carried out; the physical data used were known in many cases to need correction, but there were no legal obligations or financial resources to pursue the needed investigations. The Standards Office was dependent on French or German institutions for many verifications.

Electrical standards were in a particularly unsatisfactory condition. The Board of Trade had legal power to make new denominations of standards for the measurement of electricity, temperature, pressure, and gravities, but no facilities existed for the physical investigations preliminary to any such practical work. Many measuring instruments needed by industry could not, for lack of standards, be tested by any legal authority.

Perhaps the most significant item of evidence put before the committee was that users of British steel were in the habit of specifying that before the steel could be accepted it must be tested and stamped at the Reichsanstalt.

The committee made four formal recommendations :

- (i) that a public institution should be founded for standardizing and verifying instruments, for testing materials, and for the determination of physical constants;
- (ii) that the institution should be established by extending the Kew

## HOW IT ALL BEGAN

Observatory in the Old Deer Park, Richmond, and that the scheme should include the improvement of the existing buildings and the erection of new buildings at some distance from the present Observatory;

- (iii) that the Royal Society should be invited to control the proposed institution, and to nominate a Governing Body on which commercial interests should be represented, the choice of the members of such Body not being confined to Fellows of the Society;
- (iv) that the Permanent Secretary of the Board of Trade should be an *ex officio* member of the Governing Body; and that that Body should be consulted by the Standards Office and the Electrical Standardizing Department of the Board of Trade upon difficult questions arising from time to time, or as to proposed modifications or developments.

### *The Government Takes Action*

The report was sent by the Secretary of the Treasury to the Royal Society, with a covering letter dated October 7th, 1898. This letter stated that the Government would adopt the four points, asked the Royal Society if it was prepared to co-operate, and stated that, while the income would consist in part of fees for testing, the Government would ask Parliament for £4,000 a year for five years as well as £12,000 for the erection of suitable buildings.

It is instructive to compare these figures with the German and American figures for establishing similar institutions. The Reichsanstalt buildings and equipment cost £195,000, and the annual expenditure at the start was £15,000; the American Bureau of Standards, which was inaugurated soon after the National Physical Laboratory, was allotted £115,000 for buildings and an annual grant of £19,000.

It is only fair to say, however, that once the N.P.L. had proved its value successive governments did what they could to help its expansion. As so often with British institutions, there has been a sharing of financial aid between government and private munificence.

The fact that the British Government was able to offer only meagre assistance at the start had a critical effect on the evolution of the N.P.L., for it meant that it had to earn its keep. This caused a perpetual conflict between the need to allocate time, personnel, and apparatus to routine testing, and the desire for as much emphasis as possible on

more fundamental types of research and investigation. Naturally the conflict has had to be resolved in terms of the temperaments of those responsible for the planning of programmes from time to time.

While few scientists would dispute that a close inter-relation between pure and applied research is valuable to both, it cannot be denied that the apportionment of very limited funds, staff, and equipment between the two is bound to present a difficult problem. Thirty years after the formation of the N.P.L. one of the greatest scientists of the century, Lord Rutherford, F.R.S., stated the fundamental difficulty with candour and force. Speaking as Chairman of the Board of the Laboratory and with the added authority of a President of the Royal Society, he said :

‘ In the present conditions of work at the Laboratory there is inevitably a competition between the work which is called for from outside and the prosecution of pure research . . . the advancement of knowledge to which Sir Joseph Thomson specially referred . . . I know that the Director and the Chairman and members of the Executive Committee have done their very best, within the funds allowed, to see that a proper balance is maintained between those two departments of work in the Laboratory; but I would like to stress again that there is always a danger that the continuous and ever-increasing pressure of work which the Laboratory is called upon to undertake, and ought to undertake, will tend to push the purely scientific investigations into the background, and I hope that when that time arrives the Laboratory will take an active part in putting before the necessary authorities the need for assistance in some way to ensure that the balance is not disturbed. I have spoken again and again to a converted audience, but it seems to me that it is the life blood of the National Physical Laboratory to have going on in the various departments work that is not directly concerned with industrial applications. I recognize of course that work of this kind is at present going on, and much of it is very interesting. No one can open and read papers in either engineering or metallurgy without seeing that below all this work for special industrial purposes there is a definite trend to gain further fundamental knowledge in various directions. I hope that policy will be continued in the future, and it will be the duty of the Royal Society, through its various bodies, to see that there is a harmonious balance retained between these two classes of work, because the time will come when the pressure of the

'demand for work for industrial development will crowd out the possibility of doing research of a more fundamental nature'.

Fortunately, as we shall see, by treating 'the work which is called for from outside' as a starting point for pure research, and by limiting as far as possible the encroachment of mere routine testing, those responsible for the Laboratory have minimized the dangers and kept the advancement of knowledge—if not 'for its own sake' at least as the essential background to the successful solution of specific industrial problems—as the main objective.

The necessity of collecting fees for testing was responsible for most of the early opposition to the N.P.L. in Parliament and elsewhere. To a generation which has become accustomed to the State taking part in social and industrial functions, the fear expressed at the time that private enterprise might suffer from the establishment of the N.P.L. may seem excessive. But weighty arguments had to be adduced by its early supporters to convince industry that what it stood to gain from the establishment of the Laboratory vastly outweighed any loss through possible competition with private analysts and industrial testing concerns.

#### *The First Executive Committee*

After various negotiations between the Council of the Royal Society and the Treasury, the Council met on May 4th, 1899, and appointed the first Executive Committee of the N.P.L.

If the money available to launch the new institution was meagre, the wealth of intellectual ability put at its service from the beginning was very great. The first committee included Lord Lister, O.M., F.R.S., Lord Rayleigh, F.R.S., Sir Arthur Rucker, F.R.S., Sir John Wolfe Barry, K.C.B., F.R.S., Mr. A. Siemens, Sir William Roberts-Austin, K.C.B., F.R.S., Sir George Beilby, F.R.S., Sir Oliver Lodge, F.R.S., Sir Andrew Noble, Bt., F.R.S., Sir Arthur Schuster, F.R.S., Sir J. J. Thomson, O.M., F.R.S., and Sir Edward Thorpe, C.B., F.R.S. It would have been hard to assemble a more distinguished group of scientists at any time in our history.

On the committee many of these served *ex officio*, and it was laid down that the President, Treasurer, and a Secretary of the Royal Society, the Permanent Secretary of the Board of Trade, and representatives of Kew Observatory and certain Technical Societies, should always be members. The Technical Societies thus represented from the start were the Institution of Civil Engineers, the Institution of

## NATIONAL PHYSICAL LABORATORY

Mechanical Engineers, the Institution of Electrical Engineers, the Iron and Steel Institute, the Society of Chemical Industry, and the Institution of Naval Architects.

The Executive Committee appointed Mr. (later Sir Richard) Glazebrook, F.R.S., Director as from January 1st, 1900. It set up various sub-committees to discuss programmes of future work, and waited patiently to hear where the laboratory was to be.

### *Bushy House*

Until the last minute it had been the Government's intention to establish the Laboratory in Richmond Deer Park where the Kew Observatory already stood, and since it was always intended that the Observatory should be an integral part of the National Physical Laboratory there was much to be said for this. The change was due partly to public opposition and partly to the fact that a large building existed which, it was felt, could be adapted economically to the new and very different purpose.

Bushy House was originally the residence of a sinecure official known as the Ranger of Bushy Park, who had duties of some small consequence whenever the Court was at Hampton Court Palace. It was granted in 1710 by Queen Anne to the First Lord Halifax, and in 1771 it was occupied by Lord North. On his death the Duke of Clarence, afterwards William IV, became Ranger of Bushy Park, and in 1837 his widow, Queen Adelaide, received the sinecure. Next it was made over to the exiled French Royal Family, and the Duc de Nemours resided there at intervals until 1896.

Glazebrook saw this house as a substantial, although small, scientific laboratory of merit. At least the floor of the main block was steady, and capable of supporting a good deal of apparatus.

It was of course not as big as the Reichsanstalt, but then, as Glazebrook said, size was not everything. He was willing, he declared, to begin in a small way so long as he could do the work thoroughly, 'but there is danger of starvation'.

After many delays and uncertainties, on March 19th, 1902, the future George V and Queen Mary, then Prince and Princess of Wales, formally opened Bushy House. They took tea with the Director and Mrs. Glazebrook in the room which had once been the drawing room of the Duke of Clarence.

## HOW IT ALL BEGAN

### *Sir Richard Glazebrook*

Sir Richard Glazebrook, K.C.B., K.C.V.O., F.R.S., was born in Liverpool in 1854. He was educated at Dulwich and Trinity College, Cambridge, and studied under Clerk Maxwell, and later under Lord Rayleigh, at the Cavendish Laboratory. His work on the determination of the fundamental electrical units gained him his F.R.S. in 1882.

In 1883 he became Secretary of the British Association Committee on Electrical Standards, a position he still occupied when, in 1913, the work of the Committee was absorbed into that of the National Physical Laboratory.

The work that he did on this committee, especially that concerned with the redetermination under Lord Rayleigh of the absolute unit of electrical resistance, the ohm, was of great importance to the later researches of the N.P.L. Glazebrook's results were obtained by the Lorentz method, and the designing of apparatus for repeating the determination by the use of this method was one of the first tasks undertaken at Bushy House.

In 1891 Glazebrook became Assistant Director of the Cavendish Laboratory, Cambridge, and in 1895 Senior Bursar of Trinity. These posts gave him experience of organization and finance which was to stand him in good stead at Teddington; he was already known to be a good scientist; he now showed that he was a good business man.

The multiplicity of tasks which he took on—for in spite of these arduous positions he never gave up his active research, and he still played his part in the university as lecturer and examiner—seem to have proved a strain, for those who knew him well noted with astonishment that at this time he was known to remain in bed until midday on a Sunday morning.

In 1898 he became Principal of University College, Liverpool, but since the idea of the National Physical Laboratory was already in the air, he did so on condition that he might accept the directorship of the new institution if it were offered to him. It was abundantly clear that no man in England had a better combination of scientific and administrative qualities than Glazebrook, and no one was surprised when, in the following year, he was chosen to be the first director. From then, until he retired twenty years later at the age limit, his life and that of the National Physical Laboratory were one.

Glazebrook's directorship was unique in that his great success made

it difficult for his successors to enjoy comparable opportunities. In 1902 the staff numbered twenty-six, and for many years the director was able to have close personal contact with everyone and to know all that was going on. When he retired the staff numbered over five hundred, and the work had expanded beyond the possibility of intimate personal surveillance by any one man.

In spite of the enormous task of directing the National Physical Laboratory throughout its formative years, Glazebrook was able to continue his own lines of research in electrical science and, even more important, to become Chairman of the Advisory Committee for Aeronautics from its inception in 1909 until 1933. Thus he was largely responsible for guiding the early course of flying in this country and had the pleasure of seeing the first completely stable aeroplane, the B.E.2C, flown by de Havilland at Farnborough in 1912, in the presence of his committee.

#### *Kew Observatory*

Glazebrook had very clear ideas as to the subjects of research that the N.P.L. should choose, but there was one factor which dominated the inception and the early programmes. This was the existence of Kew Observatory, to which the Laboratory was in some sort destined to be a successor. The difficulties and delays involved in adapting Bushy House as a laboratory and in buying and installing apparatus meant that for its earlier months the N.P.L. was virtually the Kew Observatory with the addition of unmaterialized hopes, some charitable gifts of apparatus, and a handful of men anxious for the equipment without which their work was at a standstill.

The Kew Observatory's duty of carrying out magnetic, seismological, and meteorological observations remained part of the concern of the N.P.L. until 1910, when it was transferred to the Meteorological Office.

Even more important, probably, was the Observatory's task of verifying instruments, and rating watches and chronometers. This work still remains an essential part of the N.P.L. programme, and the source of a part of its income.

#### *Making a Start*

Apart from carrying on the work of Kew Observatory, a miscellaneous programme was begun. In 1899, sub-committees had been set

## HOW IT ALL BEGAN

up by the Council of the Royal Society to draw up suggestions for work in mechanics and engineering, electricity, optics, metallurgical chemistry, meteorology, terrestrial magnetism, and thermometry. As we have seen, meteorology and terrestrial magnetism soon ceased to be the concern of the Laboratory, but the other subjects became the nucleus of its later divisions.

The specific items of research with which work was begun were tackled in a somewhat haphazard manner. Glazebrook's first report reflects this unavoidable disorder and indicates, too, the financial difficulties. Thus, work was being done at Kew by Dr. J. A. Harker on the comparison of platinum and mercury thermometers over the scale  $0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ . So that this could be continued, a private benefactor, Sir Andrew Noble, F.R.S., the ballistic expert, undertook to pay for it until the N.P.L. was in a position to finance it.

The Director was authorized to visit Berlin and Paris to select apparatus, but having selected  $\pounds 1,000$  worth, he found that he had no money available to buy it. Sir Andrew Noble came forward and paid for it out of his own pocket.

The Director of Naval Contracts was one of the first men in a public position to inquire about the National Physical Laboratory accepting responsibility for a specific item of work, namely the testing of gun-sights and gunsight telescopes.

The Electrical Standards Committee of the British Association lent to the Laboratory the apparatus hitherto used by the Director at Cambridge, and responsibility was accepted for issuing certificates of resistance coils.

Owing to the electrification of tramways in the Richmond district, the magnetic observations at Kew were likely to be affected, and the Director of the N.P.L. was instructed to investigate alternative sites for this work which should be at least ten miles from a railway. He was helped by the fact that on the scale of the Bradshaw railway map the diameter of a two-shilling piece was twenty miles. He proceeded to discover all places where it was possible to lay the coin on the map without cutting a railway line, and spent the summer of 1901 visiting them. Finally, Eskdalemuir, Dumfriesshire, was selected.

The Drapers' Company, as a memorial to Professor Viriamu Jones, Principal of what is now known as University College, Cardiff, presented the N.P.L. with funds for the construction of a Lorentz apparatus

## NATIONAL PHYSICAL LABORATORY

for the accurate determining of electrical resistance. This further preserved the continuity with Glazebrook's Cambridge work and paved the way for one of the Laboratory's most important branches of research; and the fact that the Director became a member of the general committee of the new Engineering Standards Committee (later to become the British Standards Institution) had equally lasting results.

Meanwhile, the Laboratory undertook the preparation of the Indian tide tables. At the same time the London, Brighton and South Coast Railway became the father of the Laboratory's chemical analysis section by submitting some steel rails for analysis.

Even more important was the provision of apparatus for cutting and polishing metal sections and for their photo-micrographical examination. This meant that the Alloys Research Committee's interests would have a vital influence on the Laboratory's evolution from the earliest years.

These apparently unrelated items included in the N.P.L.'s first Report, or referred to at a later date by Sir Richard Glazebrook, are of great interest to those who know how the Laboratory has developed. Each of them contains the germ of a major branch of its research. They emphasize, too, the enormous scope for useful work which presented itself to the infant institution. Those responsible must have felt as if they were dipping buckets into an endless ocean.

There was one outstanding piece of work which could not be started in spite of the general recognition of its importance: in 1901 a committee of the Institution of Naval Architects approached the N.P.L. to know if it would favourably consider the establishment at the Laboratory of a tank for testing ship models. The Laboratory agreed, provided that funds for building and equipping the tank were forthcoming. However, it was only possible to do this seven years later when a private benefactor, Sir Alfred Yarrow, provided the necessary sum. Thus, for seven years, one of the most valuable of all national researches was held up, and a mercantile nation with a carrying trade on the seven seas could not invoke scientific aid.

A glance at the early days of the N.P.L. will inspire great admiration for the small handful of enthusiasts who overcame the inertia of their time and forced upon the community, with very little to help them beyond their own vision, an essential organ of modern material civilization.

## HOW IT ALL BEGAN

### *Some Leading Figures*

Haphazard as the early programme may seem at first sight, the later development of the Laboratory proved that an organizing mind of the first quality had been busy from the beginning.

Glazebrook gathered round him many devoted workers, a task in which he was assisted by the meagreness of the salaries which could be afforded under the Treasury grant, since only extreme enthusiasts could possibly be attracted by them. The *Electrician* commented that the remuneration was not extravagant, 'but no doubt the duties will be equally light'. It is recorded that in early days, when the Laboratory worked somewhat on college lines, the Director was often to be seen wandering through Bushy House at midnight suggesting that it was perhaps nearly bed-time.

Naturally the choice of staff was greatly influenced by previous personal contacts and several of the earliest members had worked with the Director at Cambridge. Not the least valuable of the appointments based on personal acquaintance was that of Mr. F. H. Murfitt. The Cambridge men had struck up an acquaintance on their journeys to and from their university with the railway guard; Murfitt was the guard's son. As laboratory instrument-maker and later, under the more dignified title of Chief Artificer, he served the N.P.L. until 1929.

While the Director himself acted as Superintendent of the Physics Division, the Engineering Division was under Dr. (later Sir Thomas) Stanton, F.R.S., who worked his way through a hard and practical training in mill and engineering shop, and had come under the influence of Osborne Reynolds at Owens College, Manchester.

Largely through Reynolds, Stanton was from the start interested in the use of models for the solution of problems of fluid flow; his other chief interest was the problem of fatigue in metals. Throughout the fifty years of the N.P.L. these two main subjects of research have been among the most fruitful.

As early as 1902, we find Stanton and his colleagues devising a machine for the rapid investigation of the effect of stress on metals. The machine was designed to give 100 to 200 variations of stress per minute and was the first of a long line of machines designed to simulate the experience of metals under working conditions. At the same time, Stanton reports the beginning of work on wind pressure. This, he says, begins with the assumption that the wind pressure on actual structures

## NATIONAL PHYSICAL LABORATORY

can be calculated from experiments on models, with the same degree of accuracy as in the calculation of the actual resistances of ships from experiments on models in a tank. It was this assumption which was to lead to most of the wind tunnel work on aerodynamics which established British aeroplane design in the leading position that it has ever since held.

Stanton continued to direct the work of the Engineering Division until his retirement in December, 1930. He survived his retirement only a very few months.

Other early appointments to the staff were those of Mr. F. E. (now Sir Frank) Smith, F.R.S., who continued the work on electrical units and standards done by Lord Rayleigh and Glazebrook at Cambridge, and Dr. J. A. Harker, who continued his Kew work on the temperature scale and the development of instruments for measuring high temperatures.

### *Growth of the National Physical Laboratory up to 1918*

Bushy House may have been a useful cradle for the N.P.L., but new buildings were needed very soon. The first, opened in 1906, was the Electrotechnics Building where Mr. C. C. (later Sir Clifford) Pater-son, F.R.S., began many years of work on photometric standards and equipment for general electrical tests. This building was largely equipped through the generosity of Sir John Brunner, the engineer, who contributed £5,000.

An early example of co-operation with industry followed the setting up in 1903 of the Engineering Standards Committee by the various engineering bodies. By becoming a member of several committees, Glazebrook established a link between the N.P.L. and the industrial world which greatly helped the Laboratory to fulfil its main purpose. The first research undertaken for the committee by the N.P.L. was into the effect of heat on insulating materials.

In the same way, Glazebrook early found that a difficult and important part of his task as Director was to collect money whenever and wherever possible. This involved publicizing the work of the young organization on all occasions. Thus, in 1904, when the British Association met at Cambridge, he delivered an account of work done and hopes entertained which was very valuable in familiarizing the scientifically minded general public with the national importance of the Laboratory.

In 1905, a memorial presented to the Chancellor of the Exchequer by one hundred and fifty members of the House of Commons, including Joseph Chamberlain, Sir Richard Jebb, Sir Michael Foster and Sir John Brunner, asked for a capital grant of £30,000 and an increased annual grant of £10,000 for the Laboratory. The Treasury were not enthusiastic and only a slight increase could be obtained, sufficient for a Metrology Building and some extra facilities for Engineering research.

In 1909 a most important development began with the setting-up of an Advisory Committee for Aeronautics by Lord Haldane. This will be discussed later, but mention should be made here of the appointment of Mr. Leonard Bairstow, F.R.S., later Professor of Aeronautics at the Imperial College of Science and Technology, as assistant for aerodynamic work.

Two years after the gift of the Yarrow Ship Tank in 1908, Dr. G. S. Baker was appointed Superintendent of the Ship Division.

The years 1910-13 showed a great increase in the Laboratory's work and equipment. The Metallurgy Building, the cost of which was defrayed by Sir Julius Wernher, the South African financier, a new Optics Building, and new Administrative Buildings date from this period. In 1913, the National Physical Laboratory became custodian of the British National Radium Standard after its examination and certification by Madame Curie and Lord Rutherford.

The year 1913 also saw the first serious official recognition of Wireless Telegraphy. A committee was appointed to advise the Government, and Glazebrook, with Dr. E. H. Rayner, later Superintendent of the Electricity Division, the Secretary, were both members.

War broke out at a moment when whole new branches of science were thus being introduced to the N.P.L. War is a most fertile factor in the advancement of science and technology, and the value of the Laboratory was proved by the two world catastrophes of our time.

With the founding of the Ministry of Munitions, the Laboratory was called upon for important advisory and administrative tasks. Its Director became scientific adviser on physical questions to the Ministry, and many members of the staff served on committees or gave help with the development of special instruments. Apart from its work in aerodynamics, the most important war work was probably that done on gauges which, more than any other one factor, made mass production possible.

When the First World War ended, the National Physical Laboratory had grown to occupy a national position altogether greater than in earlier years, and one effect of this was the transference of financial control to the recently formed Department of Scientific and Industrial Research. The Royal Society, however, continued its close relationship with the scientific administration of the Laboratory.

*Sir Joseph Petavel*

A few months later, the Director retired and was succeeded by Sir Joseph Petavel, K.B.E., F.R.S., who had already been a member of the General Board from 1911 to 1916. The new Director was well equipped for the post. He was a scientist of great attainments in physics and engineering who had had valuable administrative experience at universities. During the war he had been closely associated with the aeronautical work of the N.P.L.

A significant effect of the growth of the Laboratory was that Petavel soon found that his administrative duties would occupy his whole time and energies. Unlike Glazebrook, he had to sacrifice his own scientific research to the task of directing others. This did not mean that committee work kept him from knowing what was going on in the laboratories; indeed, it has been said that he could at any moment lecture *ex tempore* on the exact position to which the work of quite junior members of the staff had advanced. In his tours round the divisions his invariable companion was a thick black book in which he made notes on his interviews and on other matters of more personal interest to the members of his staff. One section of the book was alleged to be devoted to records of those who were not punctual in arriving at their work.

The aftermath of war meant for the N.P.L. that whole branches of science had to be added to its programme—X-rays, radioactivity, wireless, new advances in illumination and electricity in general, building acoustics, and noise. These involved the building of new equipment and laboratories, and Petavel was tireless in supervising their planning and construction. Moreover, the N.P.L. had special duties towards the new Research Associations founded under the Department of Scientific and Industrial Research and was drawing closer to an industry more and more aware of its dependence on science. Industrial research associations now looked naturally to Teddington for co-operation, and the

## HOW IT ALL BEGAN

proportion of time spent on committees by the senior members of the staff grew rapidly, if not alarmingly.

In 1922, on the suggestion of Rutherford, a Research Committee of the Laboratory was formed. As can be imagined from the source which inspired it, this committee did everything it could to preserve the opportunities for long-term fundamental research at a time when the enthusiasm which the Laboratory inspired among external industrial and public bodies might well have led to an overwhelming influx of short-term problems.

Petavel formulated a programme of pure research in most of the divisions. The programme included high-vacuum work, the relation between thermal and electrical conductivities, acoustical research, radiology, the wave-length of light as a primary length standard, the vibration clock with an oscillating crystal providing a unit of time, a new determination of the acceleration due to gravity, commonly known as 'g', absolute standards of light, X-ray examination of metals.

The casual visitor will find every spring a pleasing souvenir of its second Director. He caused hundreds of thousands of daffodils to be planted throughout the grounds, and by his Will left nearly all his possessions to the Royal Society, expressing the wish that the upkeep of these gardens should be a charge against his estate.

With the death of Sir Joseph Petavel in 1936 this purely historical survey of the National Physical Laboratory can be brought to an end. During the next two years there were several changes in Directorship. Sir Frank Smith, K.C.B., G.B.E., F.R.S., combined the post with that of Secretary of the Department of Scientific and Industrial Research until Dr. W. L. (later Sir Lawrence) Bragg, F.R.S., was appointed and took up his duties in November, 1937. He left the Laboratory in September, 1938, on appointment to the Directorship of the Cavendish Laboratory.

Sir Frank Smith again took over until the appointment of Dr. (now Sir Charles) Darwin, K.B.E., F.R.S. Sir Charles was Director of the Laboratory from December, 1938, until August, 1949, and it fell to him to guide the Laboratory through a second world war, during which science, and therefore the N.P.L. itself, became of paramount importance to the nation's survival.

Sir Charles Darwin, like Petavel, found that his administrative duties put all personal research out of the question. But his particular interests

left their mark. The Mathematics Division, with its interest in calculating methods and mathematical statistics, was largely his creation. However, history destined him for the specific task of co-ordinating the N.P.L. for war purposes, and the scores of committees on which he sat were concerned with almost every scientific facet of the national effort.

Sir Charles has been succeeded by Dr. E. C. Bullard, F.R.S., who took up his duties at the Laboratory on January 1st, 1950, exactly fifty years after Glazebrook had assumed office as the first Director of the N.P.L.

## CHAPTER III

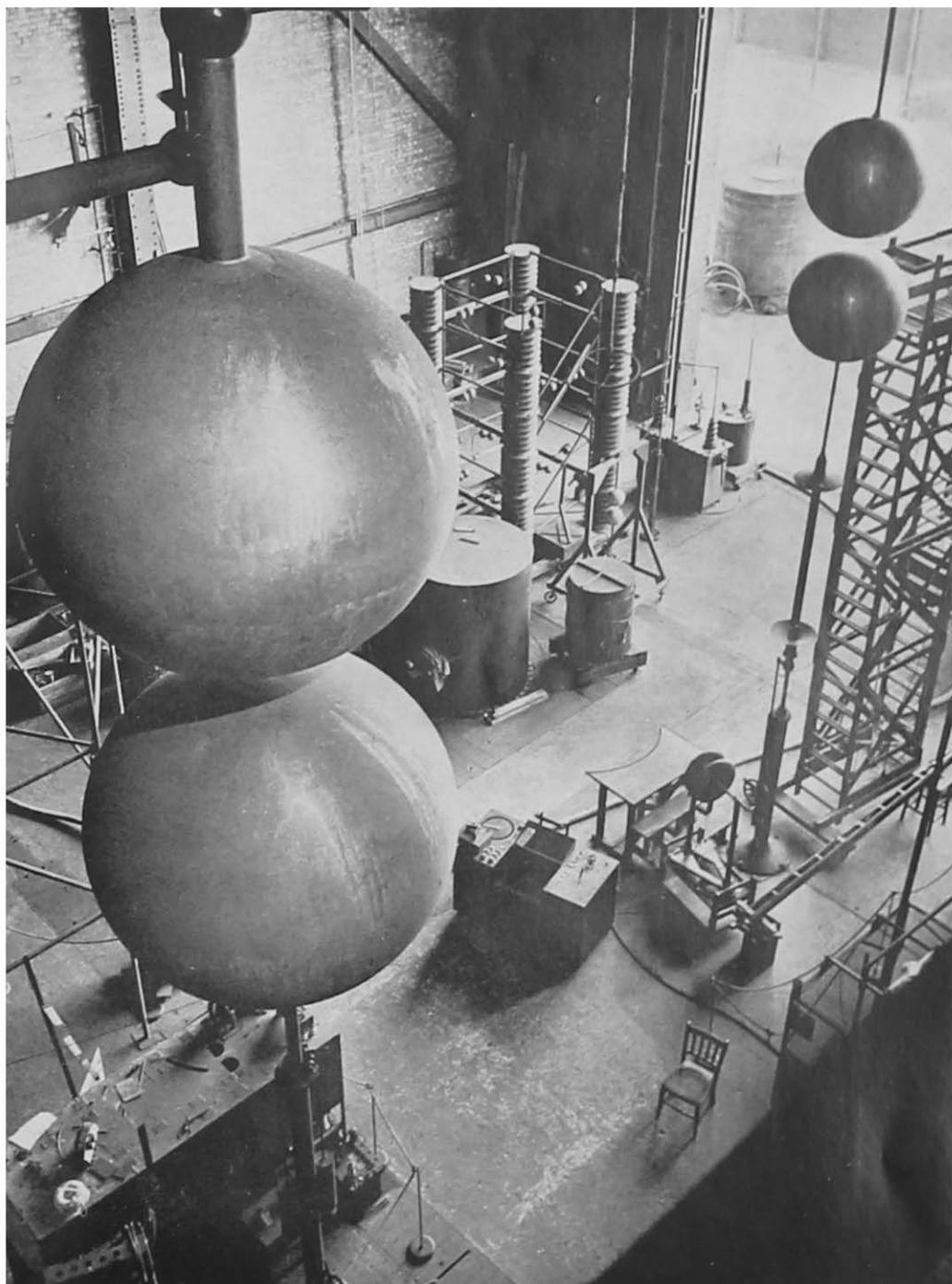
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### Organization

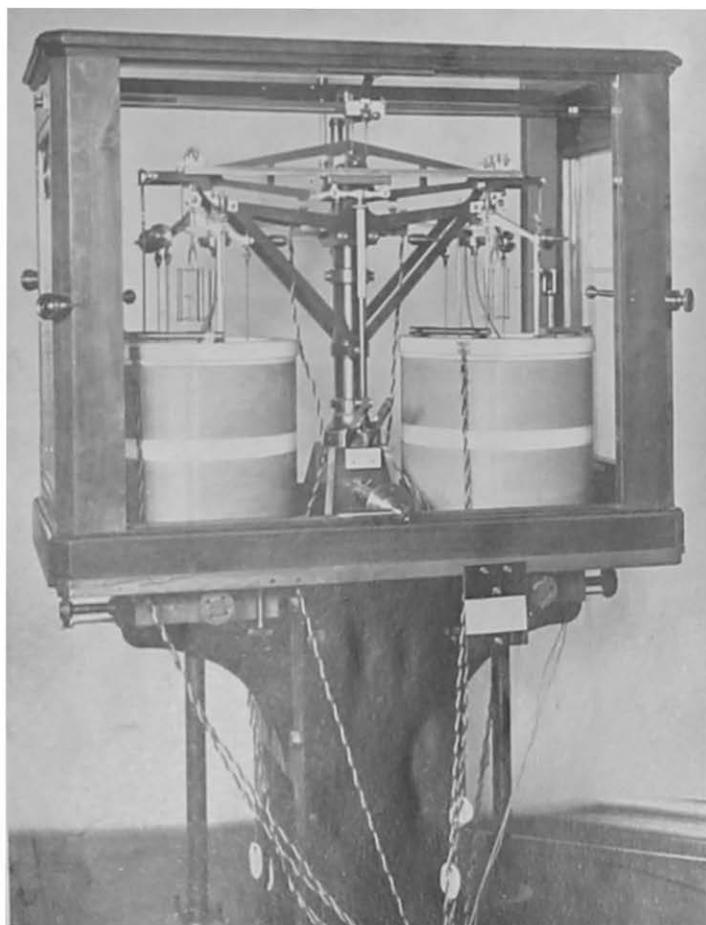
The Department of Scientific and Industrial Research is now financially responsible for the National Physical Laboratory, while the Royal Society remains responsible for its scientific work. The President and Council of the Royal Society appoint a General Board consisting of the officers of the Society, the Chairman of the Executive Committee, and forty-eight ordinary members, of whom eighteen are appointed from nominations made by the following bodies—each being represented by two members: British Standards Institution, Institute of Metals, Institution of Civil Engineers, Institution of Electrical Engineers, Institution of Mechanical Engineers, Institution of Naval Architects, Iron and Steel Institute, Royal Aeronautical Society, Society of Chemical Industry.

The Executive Committee consists of the President, Treasurer, and one Secretary of the Royal Society, a Chairman, and twelve ordinary members appointed by the Council of the Royal Society from the ordinary members of the General Board, one half being selected from the members nominated by the bodies named above.

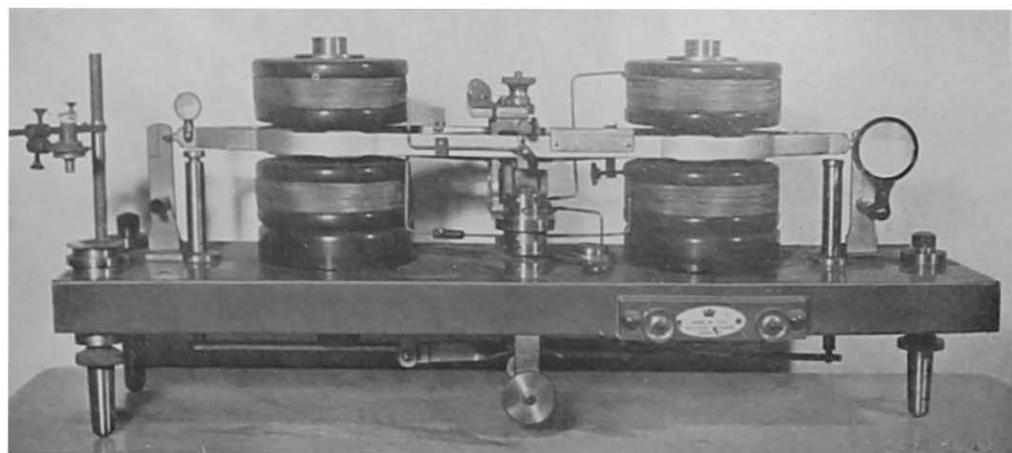
In addition, the Committee of the Privy Council appoints, after consultation with the Executive Committee, representatives of such

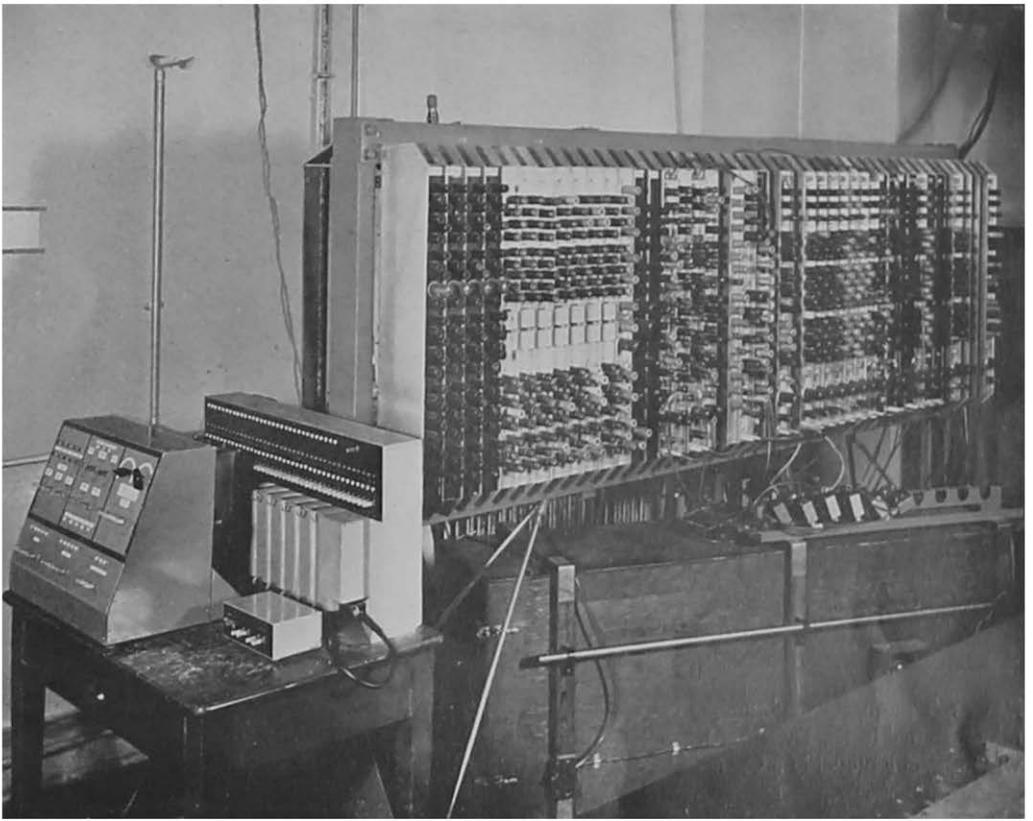


The High Voltage Laboratory where voltages up to 1,000,000 are maintained and surge voltages as large as 2,000,000 are produced for special work such as breakdown tests on transformers



*Left:* The precision balance used for the determination of the unit of electric current—the ampère. *Below:* A Kelvin balance used in the past for the measurement of electric currents

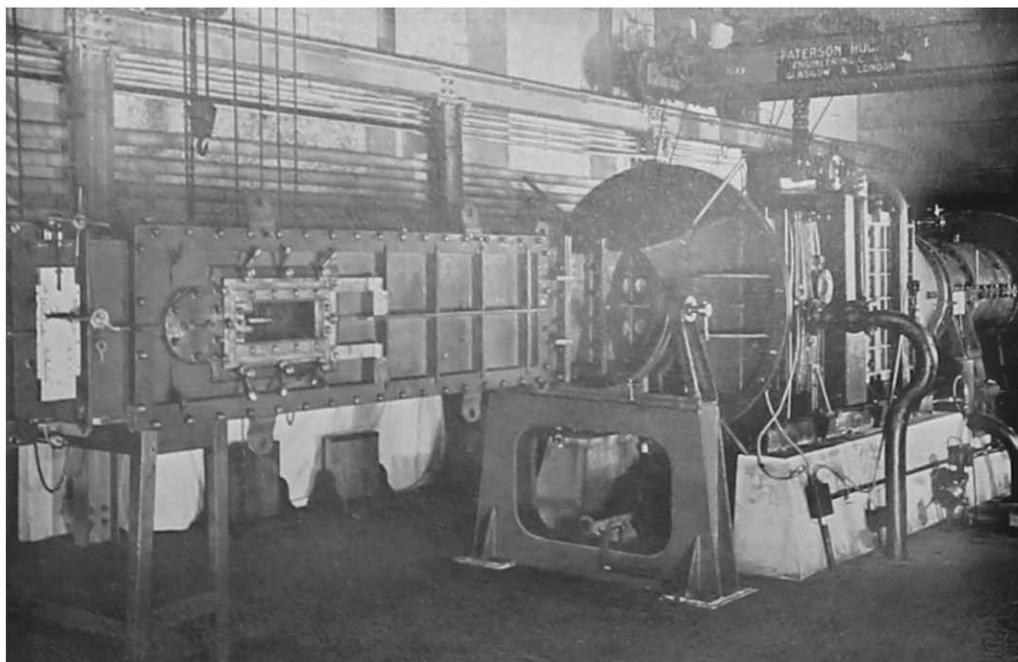


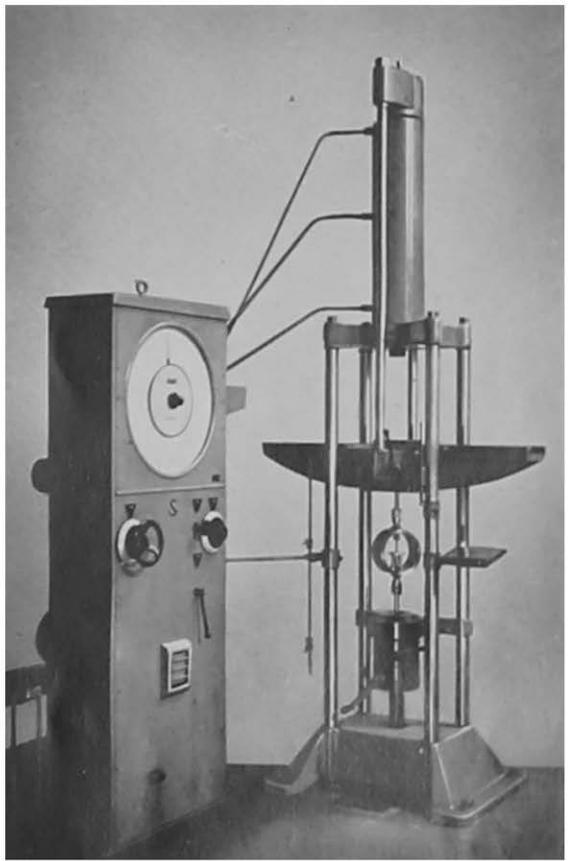


The pilot model of the automatic computing engine known as A.C.E. This machine, which uses a numerical system known as the binary system, will in its final form work at a speed of 1,000,000 digits per second and be one of the most powerful computing equipments in the world



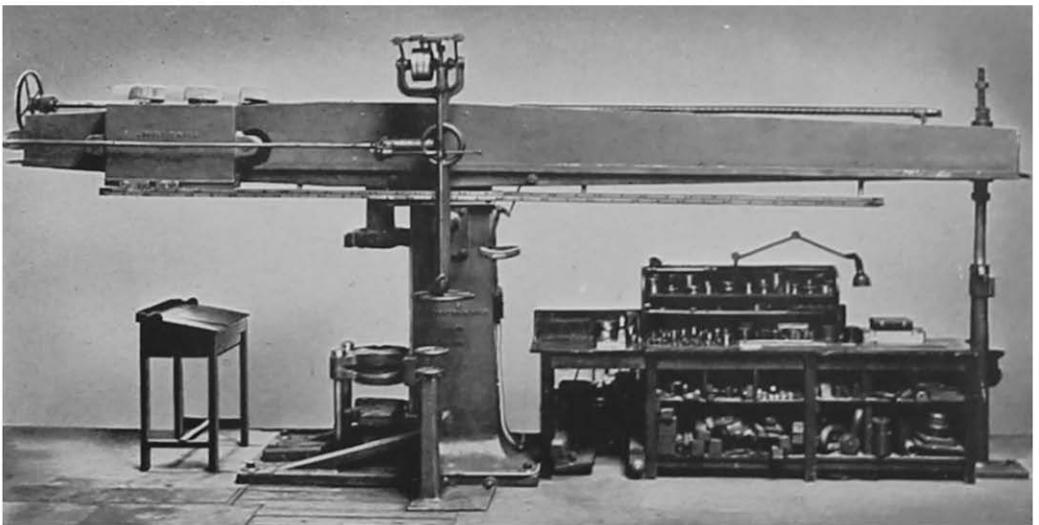
*Above* : The quarter-scale model used to investigate the behaviour of the novel system of ventilation now installed in the Debating Chamber of the new House of Commons. *Below* : In this supersonic wind tunnel a model of a German V2 was tested before the rocket attack was launched against London

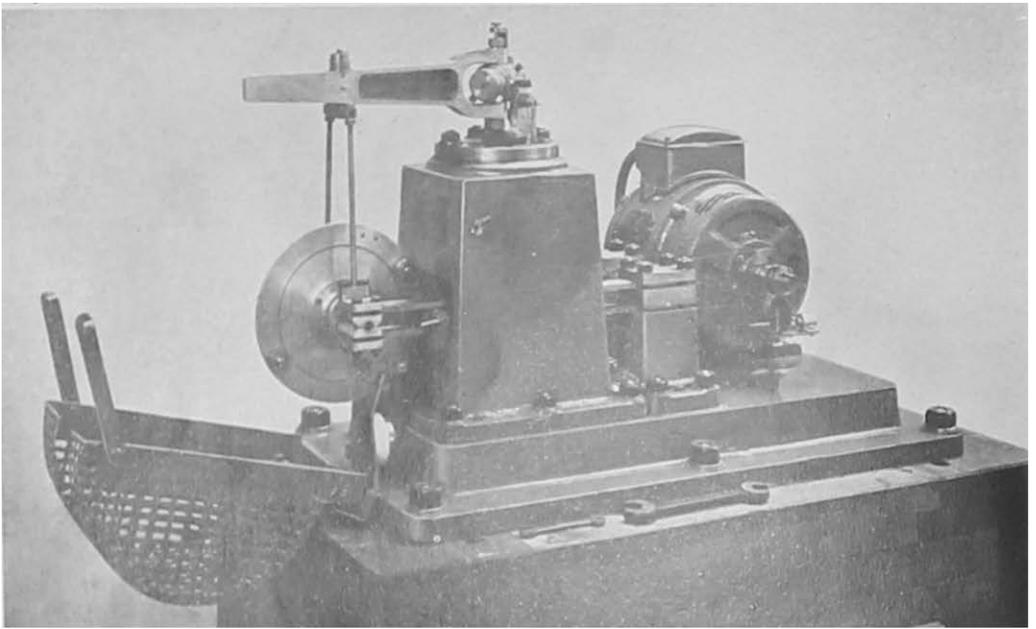




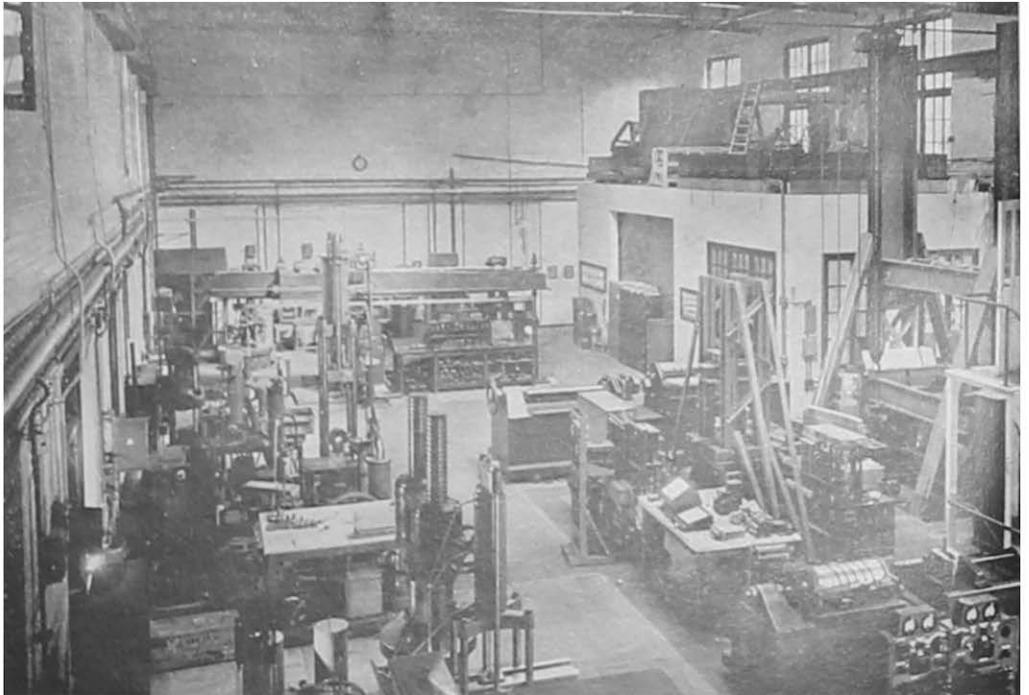
*Right:* A 30-ton testing machine for mechanical tests on engineering materials being re-calibrated by means of an N.P.L. proving ring

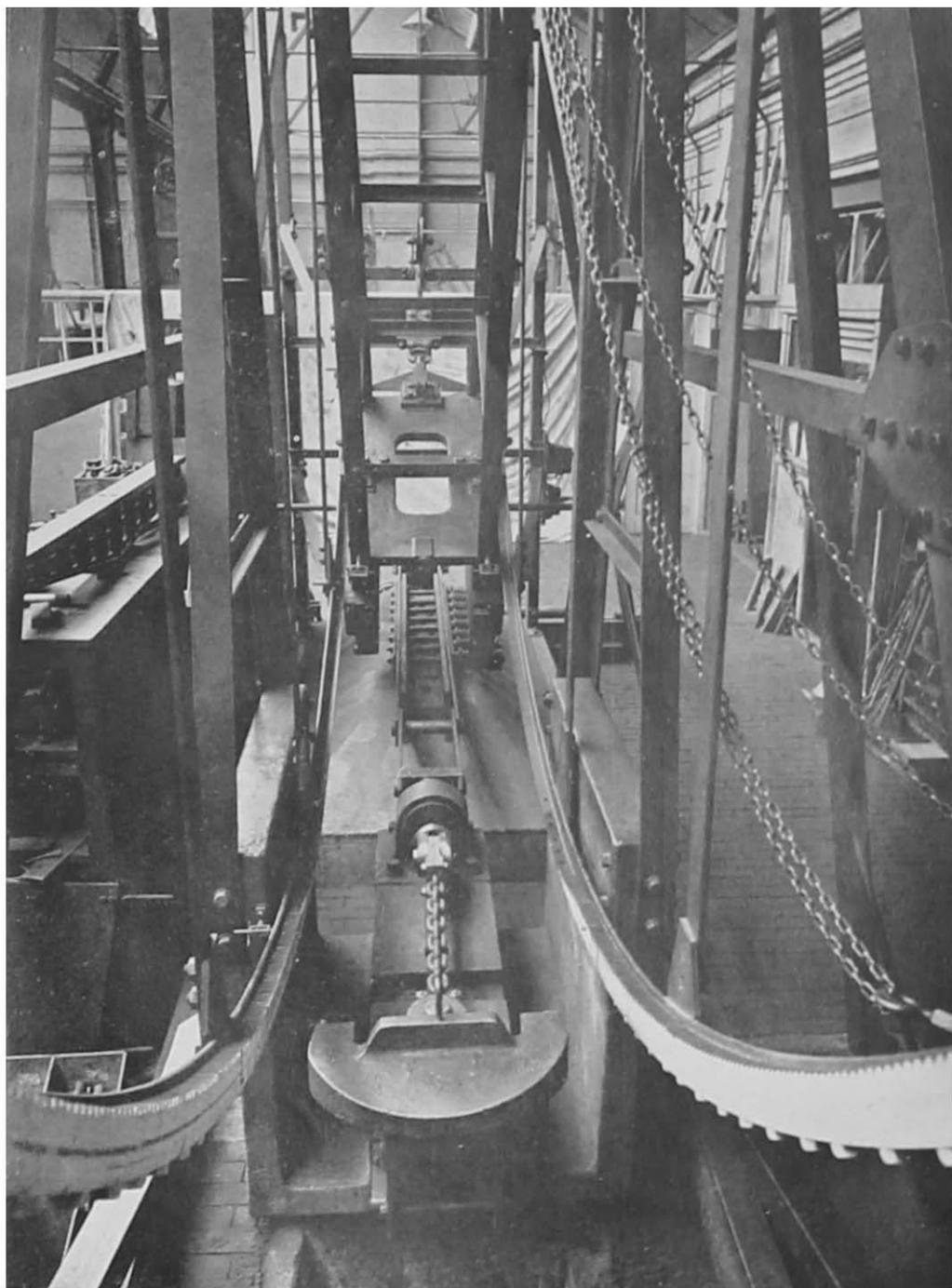
*Below:* A 100-ton single-lever testing machine for various mechanical tests



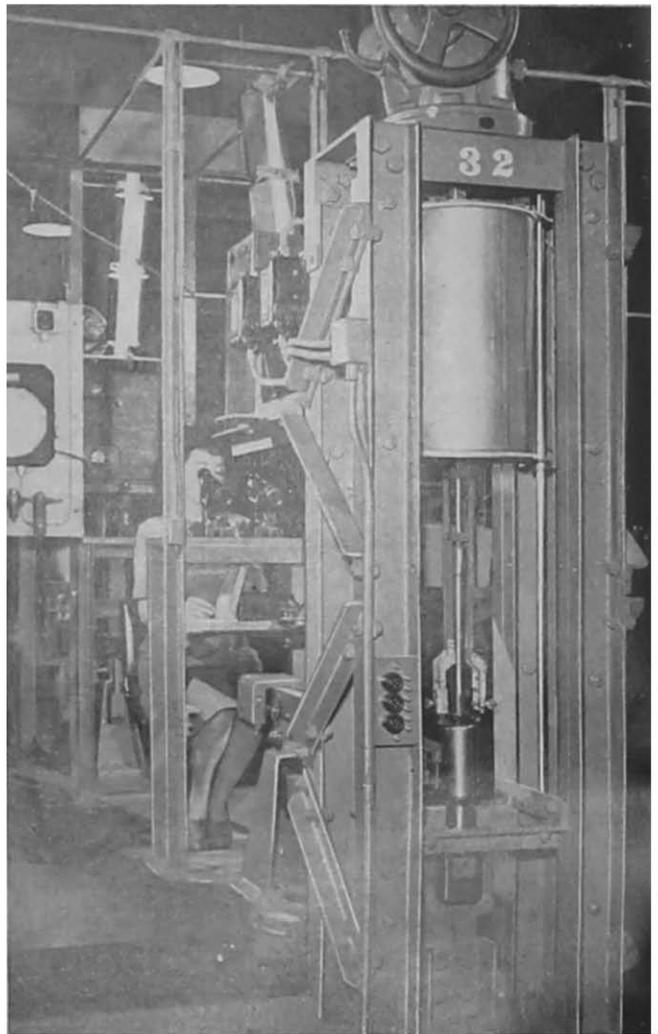
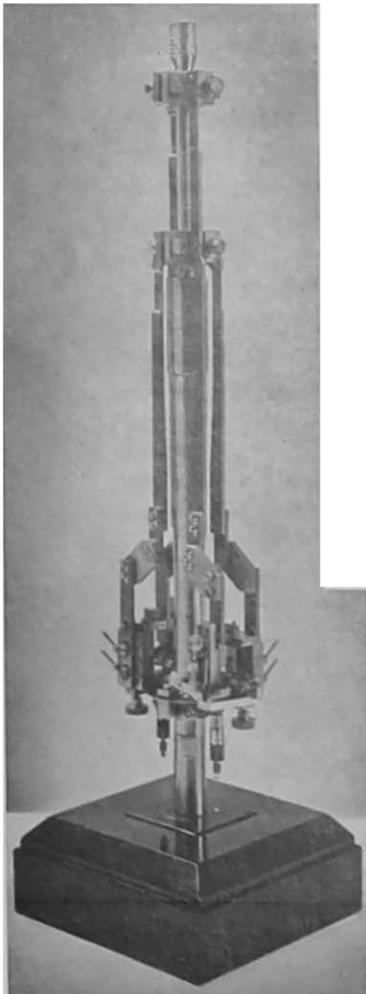


*Above* : Combined torsion and bending fatigue testing machine designed in the early 1930's  
*Below* : The main Engineering Laboratory for mechanical tests





A length of lifting chain ready for successive blows to destruction in the 20 ft ton impact testing machine. Large numbers of railway couplings have been tested in this machine for various authorities



*Above* : The Creep Laboratory. At high temperatures materials tend to distort or 'creep'. A creep testing machine showing the test piece before the electric furnace is lowered and switched on. *Left* : The Mirror type extensometer for high temperature tests on metals. This device is shown on the creep testing machine above

## ORGANIZATION

Government Departments as it may deem necessary to act as assessors to the Executive Committee.

The Executive Committee meets eleven times a year, one meeting being held at the Laboratory. A Superintendent normally attends each meeting to discuss with the committee the present work and future programme of his division. Thus the whole committee gets a comprehensive picture of the work of the Laboratory.

Since 1945 a scheme has been in operation whereby certain members of the Executive Committee accept responsibility for inspecting the work of particular divisions. Each such member invites the assistance of a few leading scientists from universities, industry and Government Departments, who visit the division with him and then submit a report on their findings to the Executive Committee. The membership of these panels varies from visit to visit, and in this way the work of each division is brought under the scrutiny of a wide variety of outside scientists.

In addition to the divisional panels, there is a Ship-Research Subcommittee of the Executive Committee, having on it university and industrial scientists responsible for advising the Executive Committee on the work of the Ship Division. Most of the work of the Aerodynamics Division is carried out in accordance with the programme of the Aeronautical Research Council of the Ministry of Supply; much of the work of the Engineering Division and part of that of the Metrology Division is incorporated in the programme of the Mechanical Engineering Research Board of the Department of Scientific and Industrial Research; and the work of the Radio Division conforms to the programme adopted by the Radio Research Board of the Department.

The work of the Laboratory is organized by subjects into ten scientific divisions. These are Aerodynamics, Electricity (including electro-technics and high voltage), Engineering, Light (including optics and photometry), Mathematics, Metallurgy, Metrology, Physics (covering mainly heat and temperature, acoustics, and radiology), Radio, and Ship.

In addition to the Administration, there is a Test House, and also an Electronics Section which is concerned with the development of a large-scale computing machine and the application of electronic techniques to industrial processes.

The Test House—a recent innovation—enables the Laboratory to

## NATIONAL PHYSICAL LABORATORY

continue to carry out certain routine tests without interfering with the other work of the scientific divisions. These divisions remain, however, responsible for the test methods employed and for their improvement. This experiment should benefit both the research and the test work of the Laboratory. It will, it is hoped, lead not only to less interruption of research, but also to a more flexible organization better able to deal with fluctuations in the demand for various types of tests.

As special needs arise, teams of workers are set up, drawn from the various divisions of the Laboratory. Thus, in the Electronics Section, the team concerned with the development of the Automatic Computing Engine is drawn from the staffs of the Radio, Engineering, Mathematics, Ship, Aerodynamics and Electricity Divisions. The diagram on pages 40 and 41 shows how the various divisions of today have grown out of the original Physics and Engineering Divisions.

Since 1919, when the Laboratory became part of the newly formed D.S.I.R., all capital expenditure has been borne by the Government. The gross annual expenditure on the Department's vote has risen from £204,507 in 1920 to £751,984 in 1950; this is not the whole cost, for the expenditure on such items as printing, telephones, electricity (a very large item), and maintenance of buildings, is shown on the votes of other Ministries, and it has risen in proportion. It may be of interest to note that the income from industry and other sources for testing and research over the same period rose from £45,848 to £236,850.

### *International Connections*

In the process of maintaining our standards, the National Physical Laboratory consults with representatives of other nations on all matters connected with the unification of standards. It provides representatives on many international committees and institutions, such as advisory bodies to the International Committee of Weights and Measures, the International Standards Association, the International Consultative Committee on Radio Communication, and the International Commission on Illumination.

### *Connections with Government and Industry*

The international bodies with which the Laboratory is connected make a fairly long list, but it would be quite impossible to give any list of the engineering, industrial, and government bodies on which it

## MAINTENANCE OF STANDARDS

is represented. Its main activities of this nature are with the British Standards Institution, and here alone the Laboratory has representatives on two hundred and nine committees, sub-committees, and panels.

Besides these, National Physical Laboratory representatives are members of committees of many of the Research Associations, and it is regarded as a continuing function of the Laboratory to assist all government committees on scientific questions within its province.

Senior members of the staff also act in a personal capacity on many committees and on the councils of many learned societies.

In particular, the Director may carry a very heavy committee load. For instance, Sir Charles Darwin was a member of at least sixty committees, including some not immediately connected with the Laboratory or its work.

## CHAPTER IV

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### The Maintenance of Standards

The matters with which physical science is concerned are capable of clear definition only in so far as they can be measured, and all measurements are concerned with one or more of three fundamental quantities—length, mass, and time.

In everyday life we are satisfied to take the word of the milestone that we have walked a mile, or of the grocer's scales that we have bought a pound of biscuits. It does not often occur to us to ask how we can be certain that milestones or scales are correct. Of time we are somewhat more critical, since we habitually reset our watch by Big Ben and assume that Big Ben in its turn is somehow controlled by mechanisms at Greenwich Observatory. In short, with time we see in our own experience the process of checking one measuring instrument by another known to be more accurate, and further checking of the second by a third instrument known to be more accurate still. We do

not often have occasion for a similar process in matters of length and weight.

Now, length, mass, and time are quantities which can only be measured on the assumption that there exists an ultimate criterion which shall be universally accepted as the standard.

### *The Linear Standards*

In the case of length, these standards—there are two of them—are bars of metal kept at prescribed places, against which all other measures of length must be compared either directly or indirectly. These pieces of metal are the Imperial Standard Yard and the International Prototype Metre. The Imperial Standard Yard is deposited in London with the Board of Trade; the International Prototype Metre is in the keeping of the Bureau International des Poids et Mesures at Sèvres, near Paris. Ultimately every milestone and kilometric sign derives its meaning from one or the other. If they were lost, we should live in eternal uncertainty about the last millionth, at least, of an inch or centimetre, were it not for a development to be described later.

What is the Imperial Standard Yard? It is defined by Act of Parliament passed in 1878. It is a solid bar, thirty-eight inches long and one inch square, of a specified metal; near to each end is sunk a cylindrical hole half an inch in diameter and in depth (the distance between the centres of the two holes being thirty-six inches). At the bottom of each hole is inserted, in a smaller hole, a gold plug or pin, one-tenth of an inch in diameter.

Upon its surface are cut three fine lines at intervals of about the one hundredth part of an inch at right angles to the bar, and two lines at nearly the same interval parallel with it. The yard is the distance between the middle transversal line at one end and the middle transversal line at the other end, at their respective mid points, when the temperature of the bar is 62°F.

Copies of this standard yard, known as parliamentary copies, are kept at the Royal Mint, the Royal Society, the Royal Observatory and the Board of Trade. One copy is immured near the staircase leading to the committee rooms of the House of Commons.

In the same way, the metre is the distance at a temperature of 0°C between two fine lines traced on a platinum-iridium bar deposited with the Bureau at Sèvres.

## MAINTENANCE OF STANDARDS

### *The Decennial Comparisons*

An important part of the National Physical Laboratory's duties is to assist in the statutory comparison, every ten years, of the Imperial Standard Yard and its parliamentary copies. It will surprise the layman to learn that two members of the staff worked the equivalent of six months during 1922 to complete this task.

The comparisons involve the use of a good deal of apparatus, all of which has to be carefully tested and calibrated for this special purpose. The readings, naturally, are not taken with the naked eye but through micrometer-microscopes. These microscopes must have fine adjustments of a very great degree of accuracy, and the error of their screws, such as it is, must be known. Six microscopes had to be examined for the 1922 comparison and the accuracy of their screws estimated; the most satisfactory pair was then chosen for the final task.

In order to calibrate the screws of the two selected instruments, it was necessary to verify the accuracy of a particular  $1/200$  inch division on the Laboratory yard-metre nickel bar known as Ni 184, a particularly important standard since it is used for inter-comparing the yard and the metre. Elaborate observations were carried out on a particular  $1/200$  inch division of this bar, and in this way its degree of accuracy was sufficiently ascertained for the purpose of calibrating the screws of the microscopes with which the vital readings had to be made. Every other item of the equipment had to be subjected to an equally rigorous scrutiny.

The opportunity afforded by the decennial comparisons of the Imperial Standard Yard and its parliamentary copies enabled a further piece of research to be carried to a conclusion. For years, work on re-determining the ratio of yard to metre had been going on, and on this occasion the yard-metre nickel standard, Ni 184, could be included in the intercomparison of the Imperial Standard and its five official copies.

The final result gave the value 1 metre = 39. 370 147 inches, whereas the accepted legal value is 1 metre = 39. 370 113 inches, a difference of less than one part in a million. The main yard interval on the nickel standard was found to be 35. 998 661 inches long, instead of precisely 36 inches which, ideally, it should be.

Ten years later, in 1932, when the next comparisons fell due, all the work took place at the Laboratory. On this occasion there was

a very special reason for desiring the last degree of accuracy. Work had been going on for some time towards defining the standards of length in terms of light waves. The nickel standard was now found to be 35. 998 669 inches long, that is, 0. 000 008 inch longer than in 1922, a change which falls within the limits of observational error.

When 1942 came, an Order in Council postponed the decennial comparisons which finally took place in 1947, when strong evidence was found that the Imperial Standard Yard and its original copies had gradually shortened during the past fifty-two years by nearly two parts in a million.

### *The Difficulties of Extreme Accuracy*

It had long appeared to many people that the method of measuring length by reference to an arbitrarily chosen material object such as the standard yard and metre was somewhat artificial. Moreover, the number of variable elements involved in such a measure—not only thermal expansion but often unexpected and unsuspected structural transformations—set a limit to the degree of accuracy and of stability that could be relied upon.

Thus, when the bar Ni 184 was sent to Sèvres in 1923 for comparisons with the standard metre, it was found that the French and British measurements of the bar differed by a minute but quite definite amount. No satisfactory explanation was found. It was thought that perhaps there was a slight difference in the way the apparatus was lighted at Sèvres and at Teddington or that there was a slight natural asymmetry in the observer which made him adjust the microscopes at each end in a slightly different way. At Sèvres this personal equation was got over by having half the measurements taken with the observer on the opposite side of the apparatus so that any such error would cancel out; but this could not then be done at Teddington because the observer could not approach the microscopes in a comfortable position from both sides, and therefore further discrepancies would be introduced as a result of bodily discomfort.

From time to time the various standard copies in the possession of the Laboratory are compared one with another and almost always slight changes of length are found to have taken place. Thus, when the bars called—with reference to their chemical make-up—Nickel 184, 43 per cent Nickel Steel 139, Invar 27, and Invar 182, were compared with

Nickel 16 and with one another, the two Invar bars were found to have grown slightly. This growth had nothing to do with temperature changes, because Invar is a special nickel-steel alloy having an extremely low coefficient of thermal expansion; it was due to a well-known secular change in the structure of the alloy.

Moreover a further difficulty arises directly measurement becomes as refined as present standards require: the coefficient of expansion due to heat has to be measured with increasing accuracy, and this implies the use of an exceedingly accurate thermometer. Now it is known that with a mercury thermometer it is not possible to obtain the temperature of a standard bar to an accuracy within  $0.01^{\circ}\text{C}$ , so that the limit of accuracy in measuring length tends to become the limit of accuracy in measuring temperature.

#### *Wave-length as Linear Standard*

The ideal standard, it was felt, would be some naturally invariable distance, and it seemed that this standard could be found by choosing light of a suitable wave-length and of spectrometric characteristics.

Mr. J. E. Sears, Superintendent of the Metrology Division, in his capacity of Deputy-Warden of the Standards, was concerned in initiating informal talks with representatives of Great Britain, America and Russia on the International Committee of Weights and Measures, and in bringing the matter before the committee formally in 1923.

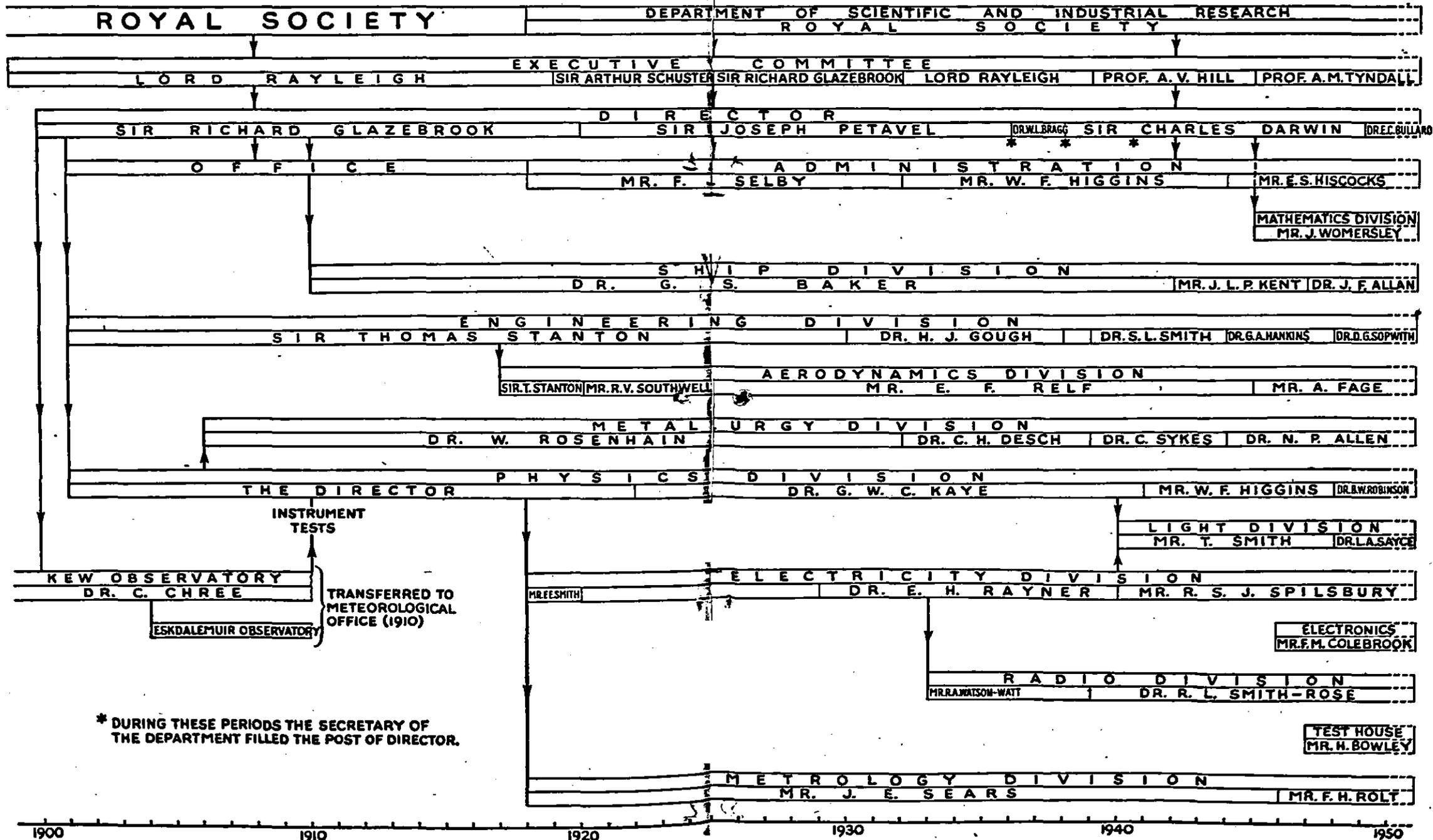
By the end of that year general agreement on the ultimate use of light waves as standards of length had been reached, and the Board of Trade asked the Laboratory to begin research.

The first task was to develop a technique for measuring short gauges by the use of light waves of a known length and also a systematic search for suitable monochromatic light. The control of the temperature of the gauge posed one special problem; another problem was the ascertainment of the absolute magnitude of the film of oil used to produce 'wringing' adhesion between the gauges and the optical plates forming part of the apparatus.

In 1925 a new form of cadmium lamp was found to give reasonably satisfactory monochromatic radiation. In 1926, four-inch block gauges were measured by the new technique, using light from the inert gases krypton and xenon. The difference between the results obtained by the

# THE NATIONAL PHYSICAL LABORATORY 1900-1950

This chart illustrates the development of the N.P.L. and names the Chairmen of the Executive Committee, the Directors and the Superintendents of the Divisions.



use of light and by mechanical methods was found to be less than one part in a million.

In 1927 the Seventh General Conference of Weights and Measures accepted measurements in wave-lengths as equivalent to measurements in terms of the international metre, on the provisional basis of one metre = 1 553 164 13 wave-lengths of the red line of cadmium in dry air at 15°C under a pressure of 760 mm of mercury.

The wave-length of the red line of cadmium was chosen because it was the accepted fundamental standard of wave-length of light; but it was not long before it was found to have serious disadvantages. The Report for 1931 indicates dissatisfaction with the cadmium lamp, and at first it was thought that the lamp rather than the chosen radiation was at fault.

Once again, in 1932, we read that although it is not definitely established that the cadmium lamp provides the ideal radiation for the purpose of an ultimate reference standard, 'it would appear that no radiation other than the red line of cadmium has been found which has met with general approval'. This was not surprising, for the ideal radiation did not exist in nature and was finally to be created by man as a result of the pursuit of a very different objective. Seven years later, the discovery of uranium fission was to set in motion the long series of researches which led on the one hand to the atomic bomb, and on the other to the discovery of the ideal radiation. For it is now considered that the ideal standard for linear measurement by wave-length may exist in the radiation of an artificial isotope of mercury which is a fission product of the atomic pile.

However, much valuable work was done using cadmium, and finally, in 1933—ten years after the beginning of the research—all was ready for the complete determination of the yard and metre. The result gave a value for the metre of 39. 370 138 inches, being different from the previous measurement by the older method by less than 1 part in 4 millions.

In 1948 the American National Bureau of Standards presented the Laboratory with a discharge lamp containing a form of mercury (the isotope of mass 198) obtained when gold is subjected to radiation in an atomic pile. With this it was found possible to measure standards sixteen inches long with an accuracy of a millionth of an inch. Thus the alchemist's dream of transmuting base metals into gold has, in

reverse, produced the equally satisfactory result, from the point of view of the metrologist, of transmuting gold into the ideal measure of length.

### *Other Linear Standards*

The N.P.L.'s copies of the standard yard and standard metre are not the only linear standards which have to be kept, carefully measured, compared and copied.

There are two main types of linear standard; the first, to which these copies belong, is the line standard, measured from two engraved lines on the surface of a bar. Clearly this could not be used for certain important purposes. For example, a 'go, no-go' gauge could not be used with a line standard but only with a standard of the equally important second type—the end standard. As its name implies, an end standard is measured from end to end of a bar which has parallel and flat ends.

The most important type of end gauge is the set of slip gauges. There are also standards of cylindrical and spherical form, such as precision steel rollers and balls, which are used for special purposes.

### *Comparators*

Standards would be useless without the special measuring apparatus called a comparator, used to compare one standard of the same type with another. One example of this is the one-metre comparator consisting of an inner and an outer tank. In the inner tank are two girders which can be adjusted in all or any of three directions mutually at right angles. So that heat cannot be transmitted into or out of the inner tank, it is filled with distilled water circulated by a small stirrer, and water is also circulated in the outer tank.

The standard bars are measured while immersed in the inner tank so as to preclude alterations of temperature, and the measurements are taken through slots in the cover; with the help of the adjustable girders their positions are varied eight times. All these precautions ensure an accuracy of one part in five millions.

Besides the comparators, the maintenance and duplication of standards require a dividing engine with which the total length can be subdivided with great accuracy.

## NATIONAL PHYSICAL LABORATORY

### *Secondary Standards*

From the primary linear standards, both line and end, a large range of secondary standards has to be constructed.

Very important among these are the standard tapes used for testing the accuracy of surveying tapes. These include four of 24 metres, three of 100 feet, and three of 50 metres, all made of invar alloy.

The first stage in constructing these is to standardize a four-metre bar by reference to the metre standard, with which it is compared with the help of a special four-metre comparator. The four-metre bar is then used for standardizing the bench marks of a 50-metre base. This base was observed to elongate by one centimetre, or one part in five thousand, in the course of forty-five years. This change of length (secular change) can be measured by means of sag wires so attached that a change in length of base causes a change of sag in the wires which can be easily read through micrometers. These sag wires have themselves been subject to secular changes in length, but have steadied down to a change rate of not more than 0.3 parts in a million per annum.

With the help of this 50-metre comparator, surveying tapes have been made for use as controls in geodetic surveys all over the world. Means have even been found to reduce the secular growth tendency of invar tapes so as to achieve a still higher degree of accuracy. The surveying of the 30th meridian in South Africa was one of the practical tasks which inspired this supreme refinement of accuracy.

### *Standards of Mass*

Just as there is an Imperial Standard Yard, a definite material object kept at the Board of Trade, so there is an Imperial Standard Pound kept in the form of a platinum cylinder 'nearly 1.35 inch in height and 1.15 inch in diameter, with a groove or channel round it, whose middle is about 0.34 inches below the top of the cylinder, for insertion of the points of the ivory fork by which it is to be lifted; the edges are carefully rounded off, and such standard pound is marked P.S.1844 1 lb'. There are parliamentary copies of this and also a chain of subsidiary standards, so that it is true to say that the pound weight used in the local market place, which is checked against an inspector's standard, is indirectly dependent upon the work of the N.P.L., and on the decennial comparisons of the Imperial Standard Pound and its parliamentary copies.

## MAINTENANCE OF STANDARDS

The National Physical Laboratory possesses its own collection of working standards of mass and exceedingly delicate balances. One of the older balances was used by Professor Poynting in his classical experiments on the determination of the gravitational constant, 'G', or, more popularly, 'for weighing the earth'.

### *Electrical Standards*

Length measurements of high precision are required, not merely for their own sake but for the precise establishment of many other standards. An obvious example is the measurement of standard areas, but even electrical standards depend as much on accurate linear metrology as on electrical determinations.

Thus the standard ohm was, until recently, internationally defined as the resistance, under certain conditions, of a measured length of a column of mercury and, in order to arrive at an accurate value, the length of the mercury resistance tubes had to be most carefully measured.

Today the N.P.L. is the custodian, on behalf of the Ministry of Transport, of the three British legal electrical standards representing the ampere, the volt, and the ohm. These standards were originally expressed in terms of the 'international' units defined by an International Conference on Electrical Units and Standards which met in 1908.

These 'international' units were defined by material standards, but the International authority agreed to displace them as soon as possible by a system of absolute units expressed in terms of units of length, mass and time. The changeover to the new units took place on January 1st, 1948, and a corresponding adjustment was made in the legal standards.

In preparation for this change (originally intended to take place in 1940), a great deal of work had to be done. There had to be a comparison between the carefully determined material standards and the new absolute standards.

The original definition of the international ohm is 'the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14. 452 1 grammes in mass, of a constant cross-sectional area and of a length of 106. 300 centimetres'.

The original definition of the international ampere is the unvarying electric current which, when passed through a solution of nitrate of

silver in water, deposits silver at the rate of 0.00111800 of a gramme per second.

A determination of the absolute ohm was made by the N.P.L. in 1912-1913, and again in 1935, and a re-determination of the absolute ampere was carried out in 1910 and again in 1936. Everything was therefore ready for making the comparatively minor adjustments for the changeover from one system to another.

### *Frequency Standards*

The N.P.L. is responsible for the maintenance of standards of length and mass, but standards of time are primarily the concern of the astronomers at Greenwich and Hurstmonceux.

But in recent years physics has discovered even better time-keepers than the earth, the sun, and the stars. The oscillating quartz crystal is a more accurate clock than the revolving earth. The 'vibration' clock is the name applied to a method of measuring time by the use of crystals. When quartz crystals vibrate, small electrical effects are produced, which can be magnified by a valve amplifier. The oscillating crystal can be made to behave like a tuned grid circuit common in wireless, and the oscillations can be indefinitely maintained. By choosing a crystal of the right size and electrically 'gearing' its high-frequency oscillations, it is possible to count and automatically record the oscillations of another electrical circuit oscillating at any chosen frequency.

The Dye quartz-ring oscillator (named after Dr. D. W. Dye, a former member of the N.P.L. staff) consists of a ring cut from a crystal of quartz and freely suspended so that it can vibrate at its fundamental frequency of 20 kilocycles per second. The ring is suspended in a vacuum and under constant thermal conditions. It has now been replaced by the Essen ring, which gives an equal performance under less exacting conditions of operation.

The constancy of frequency, as determined by comparison with astronomical time signals, is of the order of two parts in a hundred million over a period of several months. If two such oscillators are compared for a short period, such as one hour, the relative consistency is of the order of a few parts in one hundred thousand million.

### *Does the Ether Exist?*

The comparison of the frequencies of two piezo-electric quartz oscillators of nearly equal frequency gives a sensitivity of a few parts in

## MAINTENANCE OF STANDARDS

one hundred thousand million. This unequalled sensitivity has suggested the possibility of experiments to ascertain whether any effect of the earth's motion through space might be detected.

According to the FitzGerald-Lorentz theory, a body moving through space is subject to a contraction of length in the direction of its motion relative to the ether. Naturally this contraction would be so small as to make it very difficult to construct an experiment to measure it. Attempts had been made in the earlier and well-known Michelson-Morley experiment on ether drift to find the difference in the apparent velocity of light along a path first in the direction of the earth's motion and then across it, and it was the negative result of this experiment which led FitzGerald and Lorentz to formulate their theory.

The frequency of oscillation of a quartz bar depends on its length; if this varies according to its position in space, the frequency will vary also. Since the frequency can be measured to such a remarkable degree of accuracy, the variation should be detectable. Two quartz oscillators of bar form were made for this purpose. When comparisons of the two oscillators at different orientations were made, no change could be observed which would give a result of even one per cent of the effect which would correspond to the FitzGerald-Lorentz contraction calculated from the earth's orbital motion.

This result is a negative experimental corroboration of the general theory of relativity which indicates that in no circumstances should any difference due to the earth's motion in space be detectable.

It is a pardonable though irrelevant digression to note that the paragraph (in the Report of 1936) immediately following that which describes this relativity experiment reads: 'Turning to other general activities of the Department, 11,833 taximeters and 10,062 gear boxes were submitted to routine tests on behalf of the Commissioner of Police of the Metropolis'.

There could be no more striking example of the interplay between research and routine activity which is at once the chief problem, as well as perhaps the chief advantage, of the N.P.L.

### *Acceleration due to Gravity*

It is a curious fact that work was not begun until 1928 on evaluating a constant which is essential to the correct determination of many other physical quantities, namely the acceleration due to gravity. A precise

## NATIONAL PHYSICAL LABORATORY

value of 'g' is essential, for example, for the determination of 'absolute' electrical units and for defining the temperature scale. Yet, until that year, the assumed value of 'g' at the N.P.L. was based on an indirect connection with the last independent determination made in Europe, at Potsdam, in 1906.

The measurements were completed in 1936 using a new pendulum, and the computations were carried to a conclusion by the following year, when 'g' at Teddington was found to be 981. 183 cm/sec<sup>2</sup> (32. 191 1 ft/sec<sup>2</sup>) with a probable error of two parts in a million.

It would require much space to describe all the standards and secondary standards for which the N.P.L. is responsible. Throughout its history it has had representatives on international committees engaged in the preparation of standards, new and old, in every branch of metrology, and has been responsible for the British share in the work.

Almost anything of a physical nature that can be measured comes into the N.P.L.'s orbit, and anything that needs to be measured requires a standard with which it can be compared. Such a standard is often defined, designed and made at the Laboratory.

## CHAPTER V

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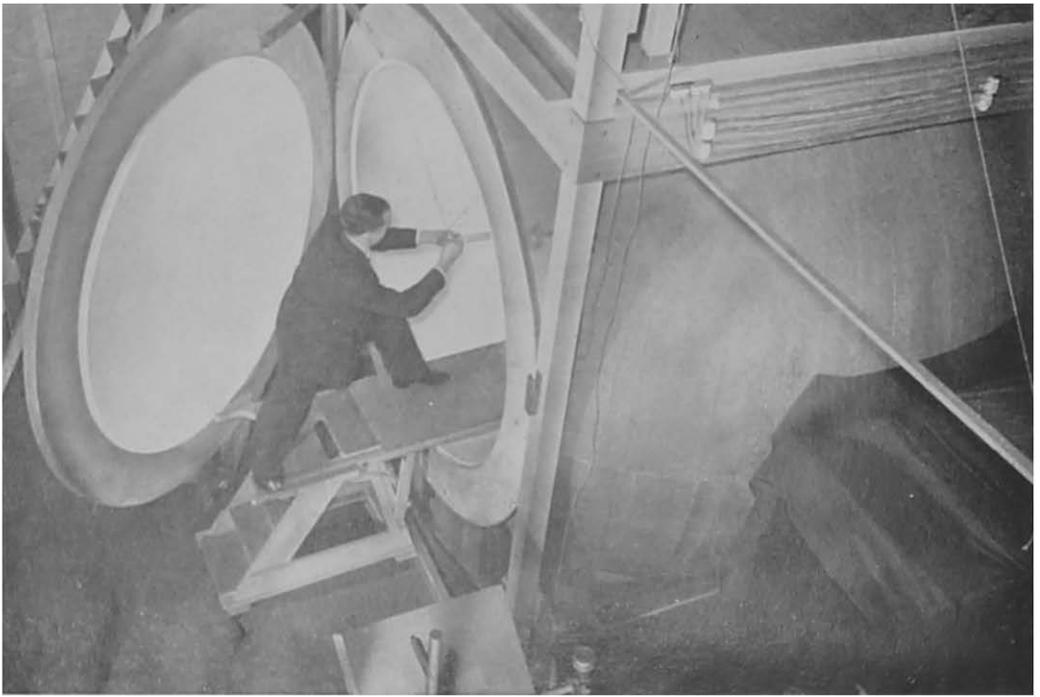
### Research

The selection of a subject for long-term research may be due to any one of a number of reasons. In some instances the research covers a wide field which at the beginning of the Laboratory's history obviously needed a systematic treatment. An example of this is the nature of alloying in metallurgy.

Other long-term research began with a specific problem hitherto not subjected to scientific analysis, out of which the need for a new type of fundamental investigation was seen to grow. Thus the problems of

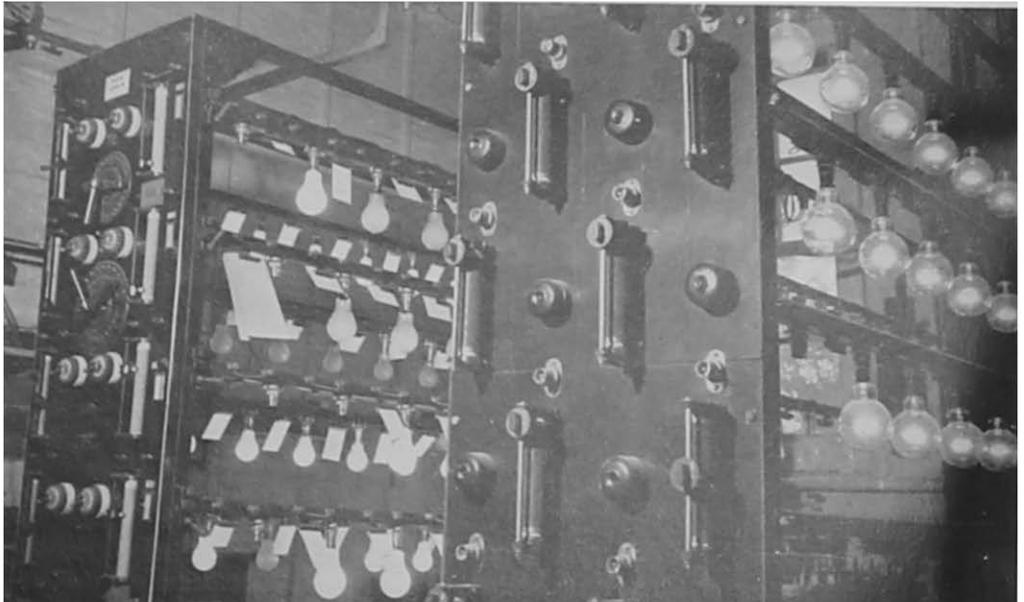


View of the observing portion of the ' Universal ' lens testing interferometer with an aerial camera lens under examination to obtain, in the laboratory, an estimate of the performance of the lens



*Above* : Preparing to compare the luminosity of a lamp with that of the Laboratory's standard lamp

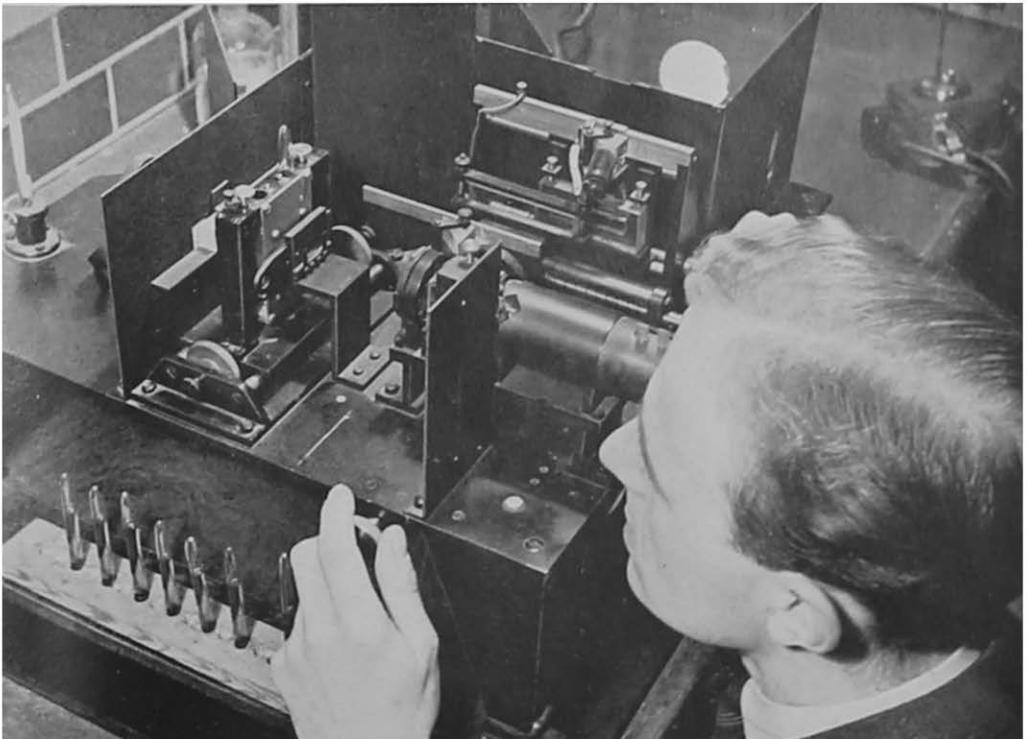
*Below* : Life tests on manufacturers' sample lamps are made under precise voltage control

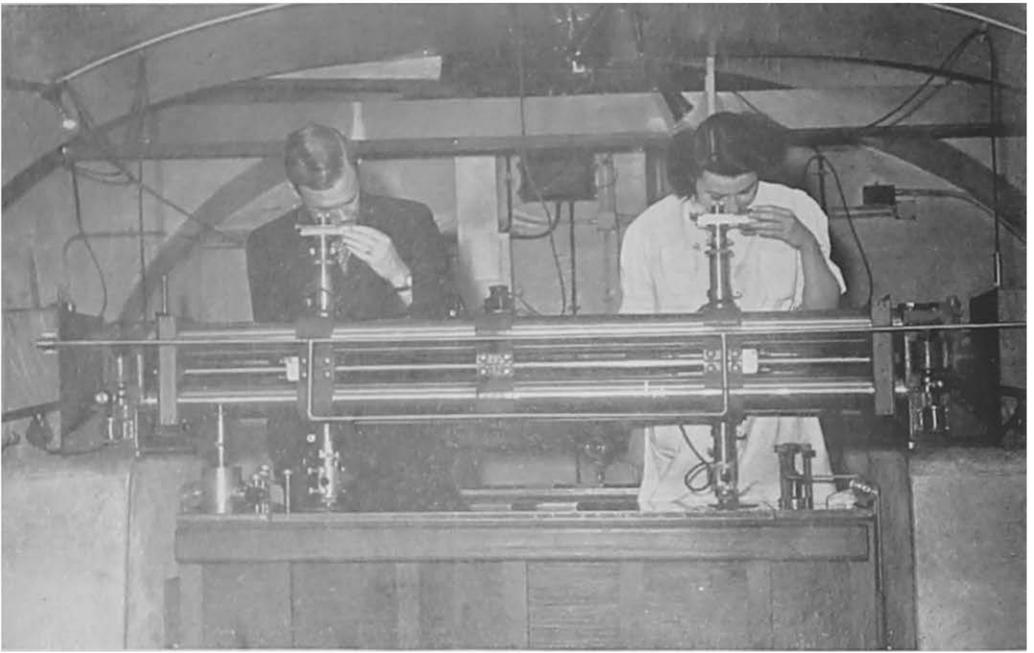


*Right* : A skilled technician gives the final finish to a lens for apparatus used by the Optics Section

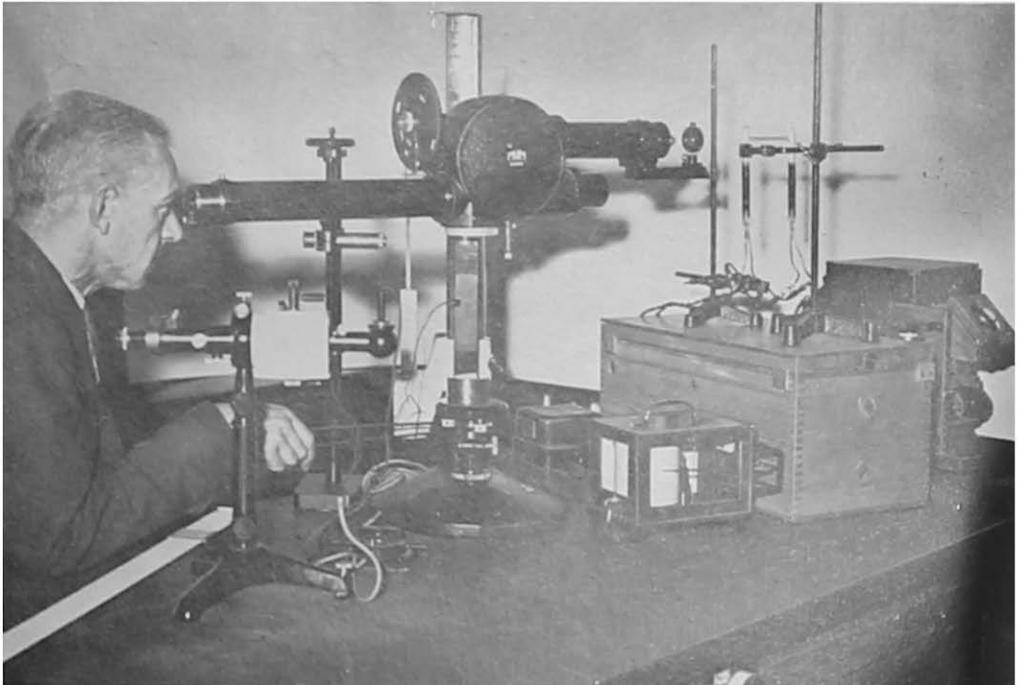


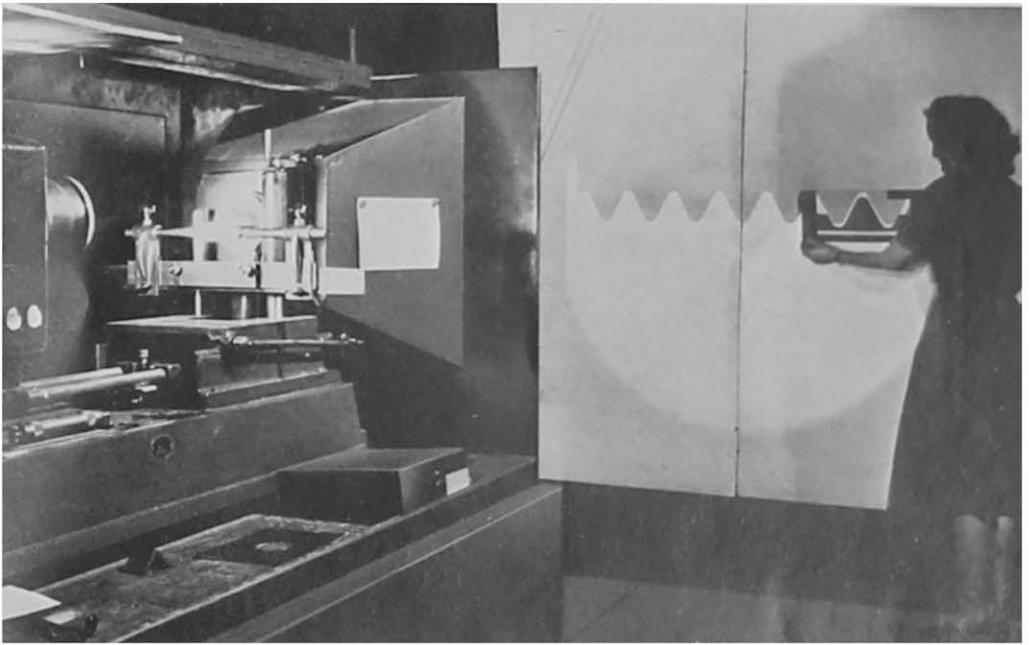
*Below* : Information of value to medical research on blood disorders is obtained at the N.P.I. by measuring the colour value of blood specimens





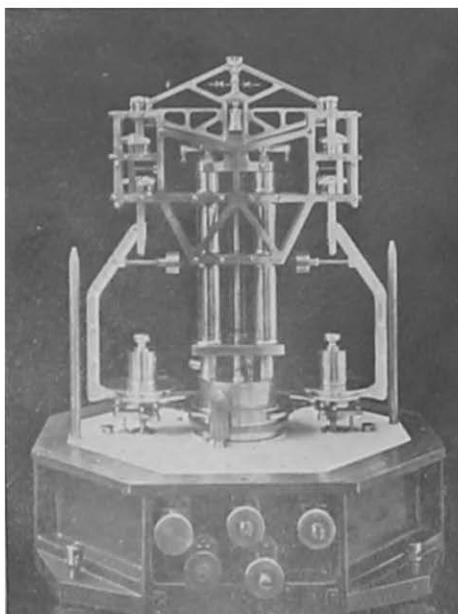
*Above* : The new microscope comparator for yard and metre line-standards. This is the apparatus used in decennial comparisons of copies of the Standard Yard. *Below* : Measuring in terms of light waves an 8 in (20 cm.) length standard. Accuracy of one-millionth of an inch is obtained





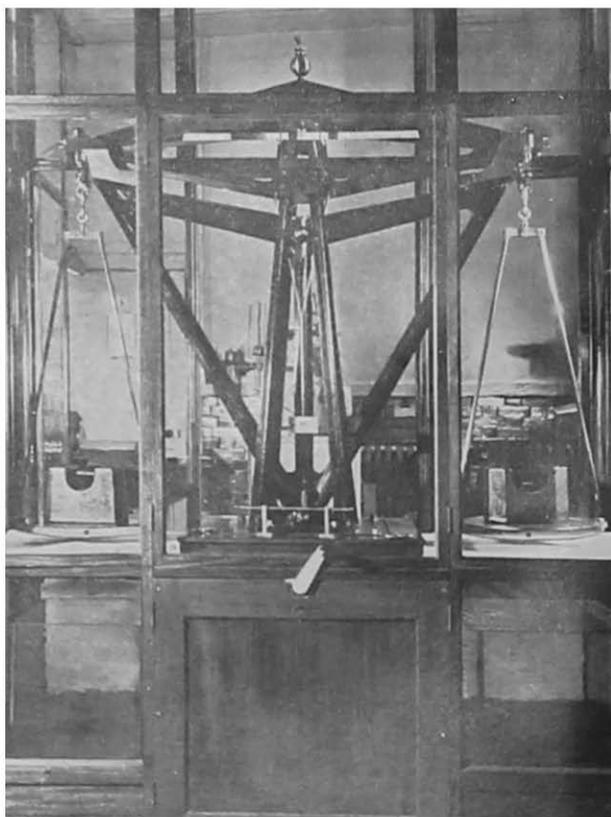
*Above* : In industry it is important that screws should be uniform. In this case, the accuracy of a screw thread is being tested in the Laboratory by projection and comparison with a standard profile. *Below* : This instrument is being used for measuring the circular pitch of gear teeth



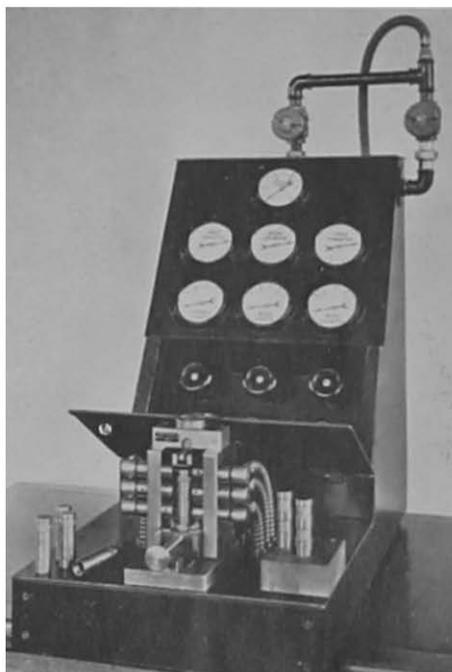


*Left* : Comparisons of the primary standards of mass are made on a precision balance with an accuracy of 1 part in 1,000 millions

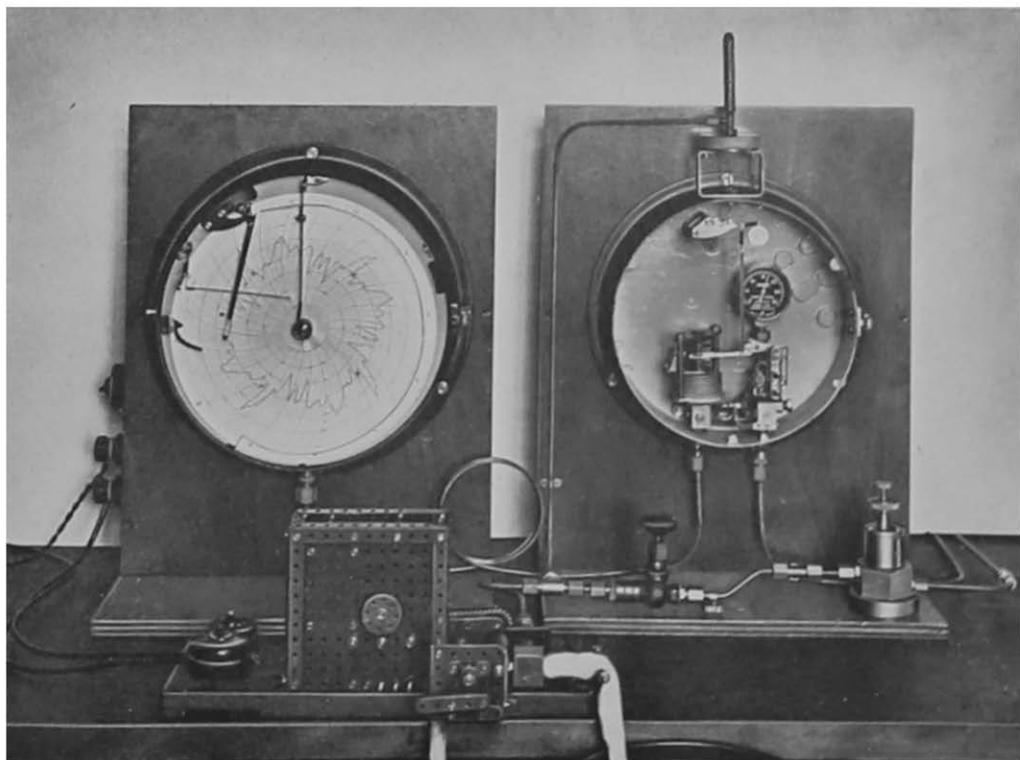
*Right* : This balance, used by the Metrology Division for weighing large masses up to 50 kilogrammes, was used by the late Professor Poynting for his classical experiments on the determination of the Gravitational Constant, popularly known as 'Weighing the Earth'



*Right:* A pneumatic gauge designed in 1944 for the simultaneous measurement of six dimensions of shell case; the readings are displayed on dials

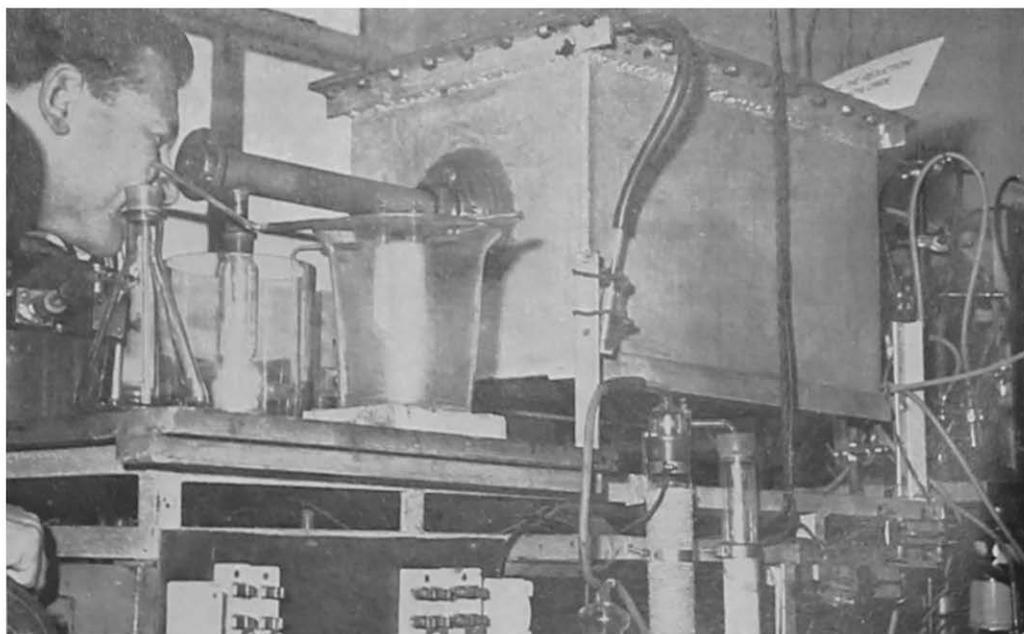


*Below :* A pneumatically operated recording gauge designed in 1948 for continuous measurement in the processing of textiles





*Above :* For metallurgical research at high temperatures the Laboratory makes crucibles from refractory materials. *Below :* Apparatus for the reduction of titanium tetrachloride by hydrogen. The Metallurgy Division is producing and studying the properties of vanadium and titanium



industrial fatigue and street lighting accelerated the investigation of the human eye as an optical instrument.

A third stimulus to long-term research has been provided by new scientific discoveries of practical application—radium, the aeroplane, piezo-electricity. Such discoveries naturally open up new fields requiring years of systematic investigation.

Finally, the invention of new research tools may reopen the investigation of problems on a more fruitful level. Thus the technique of wind tunnel research, perfected for purposes of aircraft construction, provided an entirely new method of approaching problems of bridge design, and, to take another example, artificial isotopes gave a source of light with a wave-length more suitable for use as a primary unit of length.

All these forms of research have one factor in common: they may consume the work of years without the certainty that this work will prove to possess practical value.

#### *What is 'Practical Value'?*

This is, however, very different from saying that such work is never likely to be of value, for although it is not carried out for any specific purpose it invariably contains a latent possibility of usefulness. It is certain that the nation which dispenses with long-term research will be found unprepared sooner or later to take advantage of some new specific scientific opportunity.

It is estimated that about fifty per cent of the N.P.L.'s annual budget goes to long-term fundamental research. This figure is, however, only an approximation, since the various categories of work overlap. Moreover, long-term research may suddenly initiate a 'special investigation' and, conversely, many special investigations provide the stimulus for years of research.

It should also be borne in mind that the Laboratory is the chief centre of the science of measurement, and that therefore almost any new development of applied science or technology will have to turn to the accumulated techniques of measurement existing at the N.P.L. If, tomorrow, an entirely new use for a metal is found, or a new noise menaces our ears, or electrons begin to be used for a new safety device or automatic control or calculating machine, it is almost certain that problems will arise which must be referred to the Laboratory, where,

## NATIONAL PHYSICAL LABORATORY

calling on fifty years' experience, someone will shortly devise a new measuring or testing machine.

It follows that no strict division is possible between long-term research and special investigation. The first is a sturdy limb full of sap on to which the second will be grafted. The N.P.L. can help industry in a new practical problem only in so far as the research of past years has been healthy, thorough and fundamental. This will become quite clear in the following brief descriptions of four types of research.

### FLUID FLOW

It has often been pointed out that the N.P.L.'s research is oriented differently from that of an organization devoted, let us say, to research on building or road-making or pest control. Such organizations arrange their programmes with a given object in mind—the building of houses, the making of roads, the protection of crops. For these purposes any relevant branch of science is used, but only so much of it as is useful for the object in hand.

Now the N.P.L. is just as 'practical' in its final purposes, but it approaches its problems in a different way. It selects a scientific subject such as metal alloys, or acoustics, or the effect of stress on material, and it studies that subject in the confident knowledge that it will lead to valuable practical applications in more than one direction.

An excellent example is the subject of fluid flow. Serious study of fluid flow may be said to have begun with the building of the Ship Division's Tank, and to have been directed to the object of testing ship designs. But if there had been no interest in anything but that one restricted object, a great deal of future development would have been more difficult to organize. For the movement of a ship through water is only one example of a very general type of problem, one facet of a far wider and more important scientific subject.

Lord Rayleigh had shown that there was a similarity between the problems of a solid body passing through air and one passing through water; that, therefore, what could be learned from studying a ship model in a tank might well have useful applications for the study of a solid body moving in air. By concentrating at an early date on this similarity, the Laboratory's engineers under Stanton were laying the

## RESEARCH

foundation for research not only in the immediate field of ship design but in another field which was to prove far more important than they could have guessed.

### *The Ship Tank*

When in 1905 Sir Alfred Yarrow offered to give £20,000 for the building of an experimental tank for investigations on the lines made familiar by the work of William Froude, he said he hoped its use would not be confined to the testing of actual models of ships, but would include long-term research with a view to the improvement of naval architecture and marine propulsion. It was destined, by throwing light on the general subject of fluid flow, to do all this and much more.

The Alfred Yarrow Tank, completed in 1911, is a concrete basin over 550 feet long and 90 feet wide. The depth of water at the centre is 12½ feet.

The model under test is towed by an electrically propelled carriage which spans the tank and runs on rails, carefully levelled, laid along each side. The apparatus for determining the water resistance to the motion of the Ship model or for making other measurements, is installed on the carriage.

### *Making a Wax Model*

When a shipbuilding firm sends the plans of a new ship to the N.P.L., the experts in the Ship Division may begin by modifying them in the light of accumulated experience. A paraffin wax model is then moulded to the approximate form according to the plan, with or without amendments, and is then shaped with a cutting machine to the exact lines of the ship. The wax is easy to work and the shape can be altered to test the effect of modifications of the hull.

The model is floated in the tank, attached to the carriage, and moved at various speeds under different ballast conditions. In each case its water resistance is measured and the horse power required to drive it is worked out. The model may then be altered, re-tested, and any improvement in performance duly registered.

It is quite usual to find an improved efficiency of design of over five per cent, and cases have occurred where a thirty per cent improvement has been made. It was estimated that the saving in fuel due to improvements to 114 vessels tested in the four years 1927-30 alone amounted to £105,000 a year.

*Many Types of Ships*

Except for warships, which are tested by the Admiralty at Haslar, any type of ship may be submitted to the N.P.L. for testing, but cargo vessels of all kinds constitute the majority. The dimensions of the proposed hull and the other characteristics of the ship's design are by no means the only variables that have to be considered in these investigations. The depth of the water, the width of the channel, the roughness of the surface, are all relevant factors which need to be investigated.

Out of the data accumulated from such tests, various types of general research have arisen, and also many generalizations about ship design. Thus the acceptance of the 'cruiser stern' on ordinary mercantile vessels is the direct result of work with models in the N.P.L. tanks. As a result of researches on cargo ship models carried out almost without interruption since 1911, a ten per cent reduction of resistance to motion in the modern well-designed vessel has been gained. By experimenting with the effects of rough water on pitching and other motions; a very substantial improvement in sea-worthiness has been achieved.

Nor is it only the hull design that has been subjected to long-term research; the ship's superstructure has been studied in relation to the effects of wind pressure on the power required to propel the ship and on its steering qualities and general manoeuvrability. Experiments have included the towing of ship models upside down. Much of this work has been checked by observation on ships at sea.

*Ships' Propellers*

Thought began to be given quite early to problems of propeller design, and great improvements in propulsion have been made as a result of self-propelled tests. But out of this there has grown a very different long-term research based on a new way of testing propellers in a novel piece of apparatus.

One of the most serious problems facing the designer of ships' propellers is their tendency to break down through 'cavitation'. Cavitation is the formation, due to the propeller motion, of cavities in the flow over the blade surface. These cavities are formed in regions of low pressure but collapse when carried by the flow to regions of higher pressure. Due to the collapse the intensity of pressure may be so high

that the blade surface may become pitted with holes. Repeated action of this kind may eventually cause serious erosion of the blade surface.

It is of interest to note that Sir Charles Darwin, soon after his retirement from the directorship of the National Physical Laboratory, propounded a theory of the origin of cosmic rays which was evidently suggested by his experience of cavitation problems in the Ship Division. Describing the violence with which cavitation discharges energy against the propeller, he suggested that some such phenomenon might account for the otherwise puzzling energy known to be possessed by cosmic rays. Thus are the researches of one part of science linked with problems in seemingly remote fields.

In 1936 it was decided to make a thorough investigation of the factors causing this erosion in propellers. It was assumed that both the design and speed of revolution were responsible for the destructive cavitation, but no accurate knowledge existed. The Lithgow Propeller Tunnel was installed in order to observe the behaviour of propellers under controlled conditions.

In this tunnel the water is circulated past the rotating propeller, and the static pressure can be controlled so that ship conditions can be simulated. Observations are made through a glass window. Propeller forms of optimum performance can be worked out by studying the effect of change of blade section.

### *Aerodynamics*

Meanwhile, tunnels for observing fluid flow had been in use in quite a different context. In 1909 very important decisions were taken by the Government as to the way in which aerodynamic research should be organized. An Advisory Committee for Aeronautics was set up to make a 'scientific study of the problems of flight, with a view to their practical solution'. One of its duties was to advise the new Aeronautics Section of the N.P.L. The Committee's chairman was Lord Rayleigh, and the Director of the N.P.L. was a member.

Stanton and Bairstow immediately set to work to construct a programme of research, which included the determination of the resistance of plates and models in the first experimental wind tunnel, experiments on the efficiency of air propellers on a whirling arm, and experiments on the list and drift of a model dirigible at various inclinations to the current in an experimental water channel.

In 1911, experiments showed the existence of hitherto unknown motions around models placed in the water channels. Photographs were taken of the flow of water round model dirigibles in a tank specially constructed for the purpose. The experiments in the water channels showed clearly that ' even for an elongated fish-shaped airship model the relative velocity of flow near the tail is considerably less than in the main stream '. In the same way investigations into the eddying motion in the rear of plane and curved surfaces ' demonstrated the existence of two distinct types of flow for the same surface at different velocities '.

These researches, which seem very elementary today, are of particular interest because they show the intimate association of early aerodynamical research with work done on models of ships in tanks.

The Laboratory concerned itself with the broad scientific aspect of fluid flow, and used dynamical similarity as an aid to research.

The experience of two wars has shown that continuous fundamental experiments with models in wind tunnels, and other apparatus for studying fluid flow, are essential to the maintenance of an adequate standard in aviation.

### *Wind Pressure on Buildings*

Before dealing with the further important advances in aerodynamics associated with the N.P.L. another aspect of its earlier history is worth noting. As we have seen, the experience gained with ship models in the Yarrow Tank assisted in the success of air flow research; another factor of equal importance was the research carried out by Stanton on wind pressure on buildings.

As early as 1902, Stanton wrote: ' The assumption on which the experimental work is based is that the wind pressure on actual structures can be calculated from experiments on models with the same degree of accuracy as is obtained in the calculation of actual resistance of ships from experiments on models, the resistance of which is determined in a hydraulic tank '.

The first experiments were on small flat plates and models placed in a current of air twenty-four inches in diameter and with a velocity varied at will from five to thirty feet per second. These experiments were followed by the building of a fifty-foot tower on which plates and models of structures were exposed to wind pressure, and the resultant stresses measured. By 1906 Stanton was able to show that his original

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assumption was correct, and that when once the wind resistance of a large area of simple form had been determined, the resistance of complicated structures in the wind could be accurately predicted from observations on a small model of the structure in a wind tunnel.

Looking back after forty-four years, it is easy to see that Stanton had laid the foundation for that very considerable part of aerodynamical research which involves the use of wind tunnels and similar contrivances for the study of fluid flow. But that was not the purpose for which he had begun his researches into wind pressure. His real purpose can be found in certain observations made by Sir Benjamin Baker, K.C.M.G., the bridge designer, and later quoted by Glazebrook, about the building of the Forth Bridge.

### *The Forth Bridge*

A bridge must be strong enough to withstand the maximum wind pressure likely to be met by any part of its structure. This factor will influence the cost of the bridge: if it is built to resist greater wind pressure than it will ever encounter, money will be wasted.

When the Forth Bridge was constructed there were certain Board of Trade rules which had to be obeyed. These provided that a maximum pressure of fifty-six pounds per square foot must be provided for; that the effective surface on which the wind acts should be assumed to be one to two times the area of the front surface, according to the extent of the openings of the lattice girders; and that a factor of safety of four for the iron work and two for the whole bridge overturning must be assumed. These rules were not based on experimental evidence. They were guesses.

During the construction of the Forth Bridge, Baker made certain observations from which it appeared that the wind pressure never exceeded 32.5 pounds per square foot, except for one reading which seems to have been faulty. Moreover, other observations showed that the pressure measured by a small gauge is always much greater than that measured on a large one and therefore greater than the wind pressure on the structure as a whole.

There was therefore, in 1901, a *prima facie* case for believing that the Board of Trade rule of fifty-six pounds per square foot was excessive and that the cost of large engineering works was being unnecessarily increased.

As Glazebrook pointed out, this was precisely the sort of problem that the Laboratory should investigate. Here we have the explanation of Stanton's early programme, which was not concerned in discovering answers but in finding the correct questions to put.

By 1909 it was clear that in any gale the pressure very rarely reaches the same intensity at two points forty feet apart at the same instant. By 1911 sufficient data had been obtained to enable a calculation of the wind pressure over an area of several thousand square feet to be made from observations of the average pressure at a few selected points in that area. What was still needed was a study of the effect of the more or less exposed nature of the site on the lateral variation of wind force.

This was begun in the next year on the Tower Bridge. A long series of experiments enabled the wind effects on most forms of bridge construction involving the use of lattice girders to be estimated with fair accuracy. One of the incidental findings was that the original Board of Trade guess of fifty-six pounds per square foot for maximum wind pressure had not been very far out.

By 1946 the Severn Suspension Bridge was a project taking definite shape; the technical advances in methods of research enabled the Aerodynamics Division to report considerable progress with aerodynamical research for the Ministry of Transport on the proposed new bridge.

The work included investigations into structural stability as well as the determination of forces for the essential stressing of the structure. Stability tests in a 4×4 ft wind tunnel were made on rigid models of typical bridge sections, while reduced stiffness models of complete bridges were constructed for tests in a special bridge-testing wind tunnel. A theoretical analysis of the problems was helped by observations made by means of smoke, and by tests in a water tunnel of the flow past bridge sections.

Two years later wind-tunnel tests on a complete model suspension bridge had provided a spectacular demonstration of the important influence of the structural form of the bridge on its stability.

Thus the Severn Bridge, when it is built, will be the first great suspension bridge constructed after a scientific analysis of all the problems involved in its design. Not only will it be safe, but its safety will not be the result of allowing arbitrary margins of safety. It will be built scientifically and therefore economically.

*All Problems are Generalized*

We have seen that a long series of researches was chiefly inspired by ignorance about an important engineering problem.

Although work started in 1901, by 1909 comparatively little progress had been made with the specific problem of wind pressure on bridges. This slow progress was largely due to the method of approach. Stanton and his colleagues did not direct their work towards a specific practical object, such as how to build a bridge economically; they generalized the matter and studied it as a scientific subject, part of the general problem of fluid flow.

They might possibly have found an answer more quickly to the problem of wind pressure on a bridge if they had adopted a different approach, but in that case much would have been lost of even greater importance. For by 1909, when a far more vital problem arose—the designing of a practical experimental method of solving urgent problems of aerodynamics—their work on wind pressure, as part of the scientific subject of fluid flow, had provided them with a fruitful beginning.

Moreover, by approaching the aerodynamical work in a spirit of pure research, Dr. R. A. Frazer, F.R.S., was able much more recently to apply advances made during the rearmament and war periods, and particularly the results of studies of wing flutter, to the problem of the Severn Bridge.

*Fluid Flow and Pipes*

Another fluid flow problem began to occupy the attention of the Engineering Division at an early date: this was the flow of steam or liquid along a pipe. As early as 1908–9, Stanton and his associates had begun to devise apparatus for measuring the speed of air near the wall of the pipe. Their object was, in part at least, the practical one of assisting the makers and users of tubular boilers; but they conducted their work in such a way that it afforded a method of measuring the velocity of fluid flow, not only exceedingly near the interior surface of a pipe against which air was passing, but also exceedingly near the surface of any solid body passing through a fluid.

Thus when, by 1930, the problem of skin friction at the surface of an aeroplane wing had become very important, the data and method of measuring it were already available.

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### *Lubrication and Fluid Flow*

Another practical problem involving the fundamental principles of fluid flow is that of lubrication. Special committees have existed since 1918 to organize research into lubrication, and in this research the Engineering Division has played a leading part. Once more a practical problem has been treated as a special facet of a larger scientific subject. As such, it is related to other problems such as those presented by the transmission of heat from surfaces to fluids (important in studying the problems of cooling motor and aeroplane engines), and the study of friction within fluids and at their boundaries.

These engineering researches connect with the body of work done by the Ship Division and the Aerodynamics Division. Once more we realize that the classification of the N.P.L. into divisions is largely an administrative convenience. Scientific subjects are no respectors of such artificial divisions, and are liable and freely encouraged to enter the corridors and laboratories of each and all.

### *Evolution of Aerodynamical Research*

When it is realised that all these researches were being pursued year after year, inevitably training the minds of many people to see the way through scientifically analogous problems, it is easy to understand how well prepared the National Physical Laboratory became to lead the way in aerodynamical research.

In due course a division of labour between the Royal Aircraft Establishment at Farnborough and the Laboratory at Teddington was established. It can best be described by saying that Farnborough is primarily concerned with getting a specific aeroplane into the air, while the N.P.L. studies fundamental problems of aerodynamics, some of which may not be of immediate practical importance.

Thus the Laboratory is at present greatly concerned with problems concerning speeds at which the phenomena caused by the compressibility of air become important.

The Royal Aircraft Establishment and the Aerodynamics Division of the N.P.L. are closely connected by committees on which their representatives sit together. The influence of Glazebrook and Stanton, who were active from the time the first Advisory Committee for Aeronautics was formed in 1909, largely accounts for the continuing prominence of the N.P.L. in this work.

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Regular meetings are held at which the Laboratory's chief subjects of research are discussed. Every two months there is a meeting attended by the Division's Superintendent, Mr. A. Fage, F.R.S., the Director of Scientific Research (Air) of the Ministry of Supply, the Superintendent of the Aerodynamics Department of the Royal Aircraft Establishment, the heads of the departments in the Ministry of Supply responsible for the design and supply of military and civil aircraft, and the Secretary of the Aeronautical Research Council. This Aerodynamics Executive Committee is a co-ordinating body responsible for maintaining the nation's position in aviation.

Although by its nature the work of the Aerodynamics Division is largely concerned with Government, close touch is kept with private industry. Models are sent for test in the Compressed Air Tunnel (C.A.T.) and other N.P.L. wind tunnels, and exchange of information goes on continuously.

Thus the study of such phenomena as 'flutter', as they will affect the supersonic aeroplanes of the future, is the logical outcome of Stanton's earliest experiments of subjecting a plate a few inches square to the impact of a wind of 30 miles per hour maximum velocity. Many researches into apparently unrelated problems have helped; and success has been due to the clear vision which has kept in sight the unity of the scientific problem in the diversity of practical objectives.

## MATERIALS

When Glazebrook was forecasting the usefulness of the infant Laboratory in 1901, he referred to the condition of metallurgical research in Britain and to the gaps in our knowledge of alloys in general and of carbon-steel in particular.

He spoke of the changes which take place in iron as a result of various treatments, and after asking whether it were not possible to produce, by scientific research, a steel more suited to shipbuilders, railway engineers, and dynamo-makers, than any then available, he discussed carbon. There was no doubt that the changes which could be induced in steel were connected with the effects of the carbon molecules on the iron; was it not possible that by introducing other elements besides carbon other changes—and possibly more useful ones—could be produced?

There was at the time an Alloys Research Committee of the Institution of Mechanical Engineers, but it had done little more than demonstrate the importance of metallurgical research and the need for expanding the laboratory facilities for carrying it out. Its chairman, Sir William White, K.C.B., was the first to see the advantages of initiating such work in the new organization, and in this way began what was to prove a major preoccupation of the N.P.L., the study of the chemical and physical laws which cause one metal to differ from another.

### *Systematic Research on Alloys*

When an industrial firm conducts metallurgical research into alloys it is generally concerned with the limited practical objective of finding the best metal for doing a given job. It is not usually so much concerned with a systematic study of the basic physical laws. But because the N.P.L. and others have carried out a systematic study of this more fundamental problem, the industrial metallurgist need not today rely on guess-work and empirical methods; he has at his disposal a vast body of systematic knowledge from which he can deduce the probable effects of different mixtures of materials.

It is of course true that the general researches of the N.P.L. did lead to the making of many very useful alloys which have been widely used in industry. But the discovery of these alloys was not the primary objective of the researches, although they proved valuable and welcome by-products.

The new metallurgical laboratory began at once to make an extensive determination of the mechanical and other properties of a series of medium and high carbon-nickel-iron alloys.

It set about determining the electrical and magnetic properties of some low carbon-nickel-iron alloys so as to find an explanation of certain unexpected changes in their physical properties; and it began the study of iron-aluminium and iron-silicon alloys which already seemed likely to be important to the electrical industry for constructing transformers.

In these early days the field for research was so wide that great credit is due to the pioneers for their wisdom in selecting problems for special attention. They had to steer a course between purely academic studies and too severely restricted *ad hoc* problems.

In this case, as has so often occurred with the N.P.L.'s investiga-

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tions, there can be no doubt that fundamental research gained from being anchored to practical problems. Although N.P.L. research is seldom as strictly utilitarian as that carried out by most industrial firms, the research workers never forget the practical end, nor is the absence of such an end ever regarded as a positive scientific virtue. The N.P.L. is not a factory, but neither is it an ivory tower. The programme of metallurgical work, although systematic and fundamental, was for ever solving problems which had hitherto puzzled industry or, by solving problems before industry was ever aware of them, pointing the way to advances which would otherwise have seemed impossible.

### *Copper and its Impurities*

An early research began in 1904 into the influence of small amounts of impurities on copper.

There are two ways in which such a problem, vital to industry, may be tackled. A copper object which has been proved unsatisfactory can be examined, and its fault may be traced to the presence of some small percentage of another chemical. Such investigations are constantly being undertaken by the N.P.L., and much useful knowledge is obtained, but that is not the way in which the problem as a whole can best be tackled.

In 1904 a systematic investigation was begun into the effect of adding to pure copper amounts varying from 0.1 to 1.0 per cent of oxygen, sulphur, phosphorus, arsenic, antimony, bismuth, tin, lead, iron, manganese, and nickel. The effects of all these, in varying quantities, on various physical properties of copper were studied; the entire research consumed more than thirty years and was finally published in 1937 in a large volume by the British Non-Ferrous Metals Research Association which had backed the work in its later stages.

Thus the knowledge now exists to enable industry to judge the effect of all sorts of alloying of copper. The short-term investigations are, in consequence, conducted with far greater ease, and fewer difficulties are now likely to arise since manufacturers know beforehand what types of alloy to use and what types of impurity to avoid.

### *Air Warfare and Alloys*

We have seen in the case of fluid flow that war has been one of the great formative factors in the history of the Laboratory. We find this

again in the case of research into materials. The value of systematic research into metals for peace-time industry was, of course, obvious from the start. Indeed, it was acknowledged when, in 1910, Sir Julius Wernher gave £10,000 for a specially designed building for metallurgical research. But it was the coming of air warfare that virtually transformed the work done on light alloys.

By 1921 eleven reports on alloys research had been published by Dr. (later Sir Harold) Carpenter, F.R.S., and Dr. W. Rosenhain, F.R.S., Superintendent of the Metallurgy Division. The last three dealt with a series of alloys of aluminium. The final report, devoted to war-time work largely supported by the Air Ministry, records, among other matters, the invention of the well-known 'Y' alloy, which has since been most important to the aircraft and other industries.

It was found that, as with duralumin, 'Y' alloy developed a very greatly increased mechanical strength when subjected to an 'age-hardening' process. This was an empirical discovery of great value, but it was not left at that. A long programme of research into the nature of age-hardening was undertaken, and the process was elucidated in chemical and physical terms. In consequence there came to light new methods of heat-treatment for a whole range of ferrous and non-ferrous materials, and the art of metallurgy benefited not merely by the addition of one more valuable product but by the enunciation of underlying principles permitting fresh advances all along the line.

### *Impurities in Iron*

There is always a danger in scientific research that a sudden emphasis on one type of work, due perhaps to a new social need, may upset the balance of research. This would have happened in the case of alloys research had not the danger been foreseen. In 1901 aluminium alloys were almost an unknown quantity. Owing to the needs of war, the coming of aviation and the enhanced importance of lightness of material in everyday life, a large proportion of available scientific manpower and equipment was concentrated on the study of light alloys and light metals, and by 1922 a great deal more was known of them than of mankind's far older servant, iron, and its alloys.

The N.P.L. was alive to this situation and, after 1922, shifted the emphasis from light alloys to iron. A representative committee was set up which inaugurated research in iron alloys. In so doing it afforded

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an excellent example of a vital kind of research outside the field of private industrial research. One of the main problems was to produce iron of a far purer quality than was to be found in normal circumstances. So long as the metal which was to be alloyed with small percentages of other substances was itself appreciably impure, no sound knowledge of the physical effects of alloying could be obtained.

Here again we have a problem of practical importance suggested in the first instance by people concerned with its value to industry. But again the outlook of the Laboratory had an important effect upon the way it was studied. If the Metallurgy Division of the N.P.L. had been regarded as an isolated compartment concerned with preparing iron and other metals in a high state of purity in order to help industry with alloying problems, an important piece of research would no doubt have been carried through; but much that was of ultimate value would have been lost.

No Division of the Laboratory works as an isolated compartment, and early in this particular piece of research the Physics and Electricity Divisions were called in. The Metallurgy Division was producing appreciable quantities of metals of a degree of purity hitherto unknown, and therefore it was an excellent opportunity to re-determine their physical properties to a greater degree of accuracy.

In most cases it was necessary to melt the iron and other pure metals to reduce them to a form suitable for further study, and it was essential that impurities should not be introduced into the metal during this procedure. The refractory vessels available at the time were not sufficiently resistant to the attack of molten metal, so it became necessary to develop new methods for the manipulation of more resistant materials. The solution of the problem not only solved its immediate purpose but has also provided superior materials to other sections of the Laboratory and to industry.

### *Gas Cylinders*

With the rise of the chemical industry, a new accident hazard arose when compressed and liquefied gases were transported in cylinders from one place to another on railways and along public thoroughfares. At first the design and materials used for the cylinders were chosen largely by guess-work, and although a large margin of safety was allowed by conscientious manufacturers, there were occasional failures.

The question at once arose: to what cause was any given failure to be attributed? And beyond this question was another even more important: how can attention to design and material ensure that further failures will not result?

A Home Office Committee had laid down specifications for cylinders but, by 1916, advances in metallurgy and practical experience had suggested that these rules were out of date. This was the beginning of many years of work at the Laboratory, having as one of its chief results the publication of a series of reports by the Gas Cylinders Committee, D.S.I.R.; these reports remain to this day a guide to cylinder makers. The present Home Office Committee, on which the Laboratory is represented, advises on the application of new techniques, particularly those of welding, to gas cylinder manufacture.

### *The Stresses in Metals*

In the practical world of industry, a material is of little interest apart from the conditions of its use. Metallurgical problems inevitably become engineering problems. After a metal or an alloy has been made it becomes necessary to find out what will happen to it when subjected to the stresses and strains of the workaday world.

In earlier days most of the work was done from the point of view of engineering design; the resistance to stress of a bar of metal was compared with its resistance when it had been shaped into part of a machine. The often astonishing lowering of resistance of a cross-section by such a detail as the boring of an oil-hole through it, or even by a scratch on the surface, was demonstrated, and general rules about design were formulated. In this first stage of the research there was constant interplay between the long-term research programme and short-term investigations into the failure of engineering parts.

The general description of this kind of advisory work belongs to another chapter, but it will be useful to describe one example at this point.

### *Springs Become Tired*

The results of many investigations have now shown that by far the largest number of spring failures are due neither to faulty design nor to faulty material nor to overloading or other misuse, but to the effects of repeated loading or fatigue on the metal. When the spring has

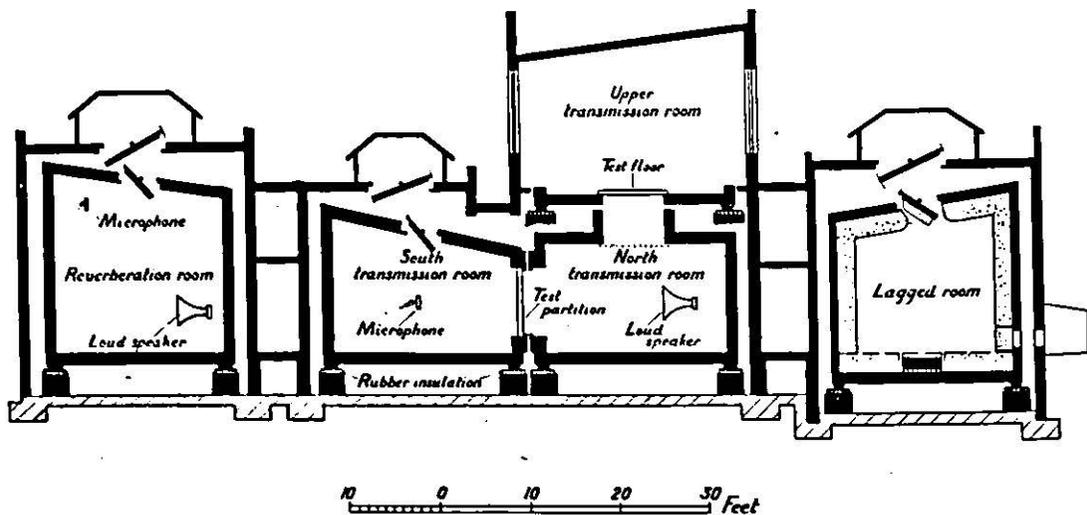


**This special apparatus is used by the Physics Division for the precise determination of X-ray intensities. Problems of protection against radiation are also the concern of this section**



THE ACOUSTICS BUILDING

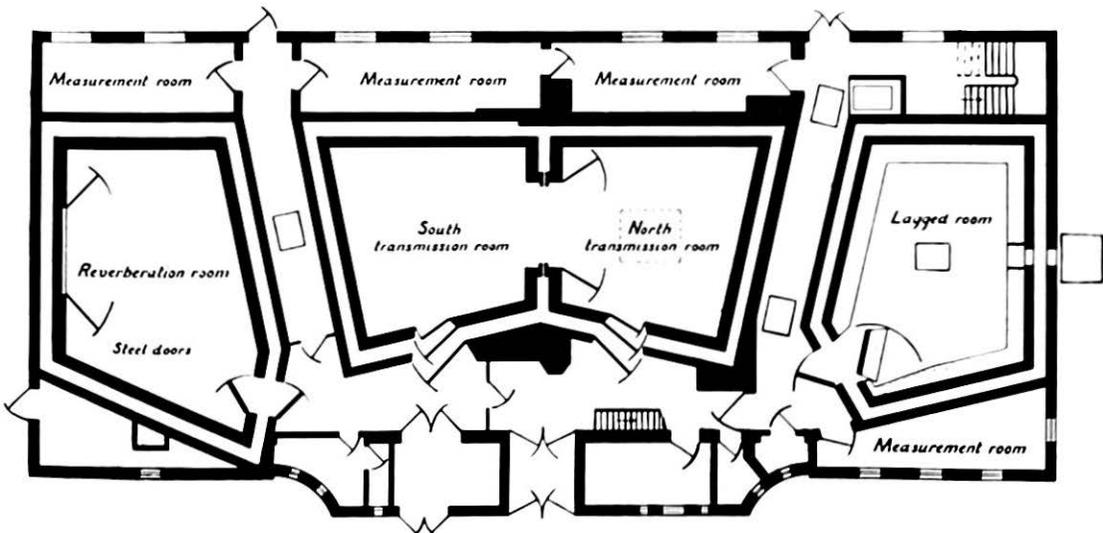
SECTIONAL ELEVATION

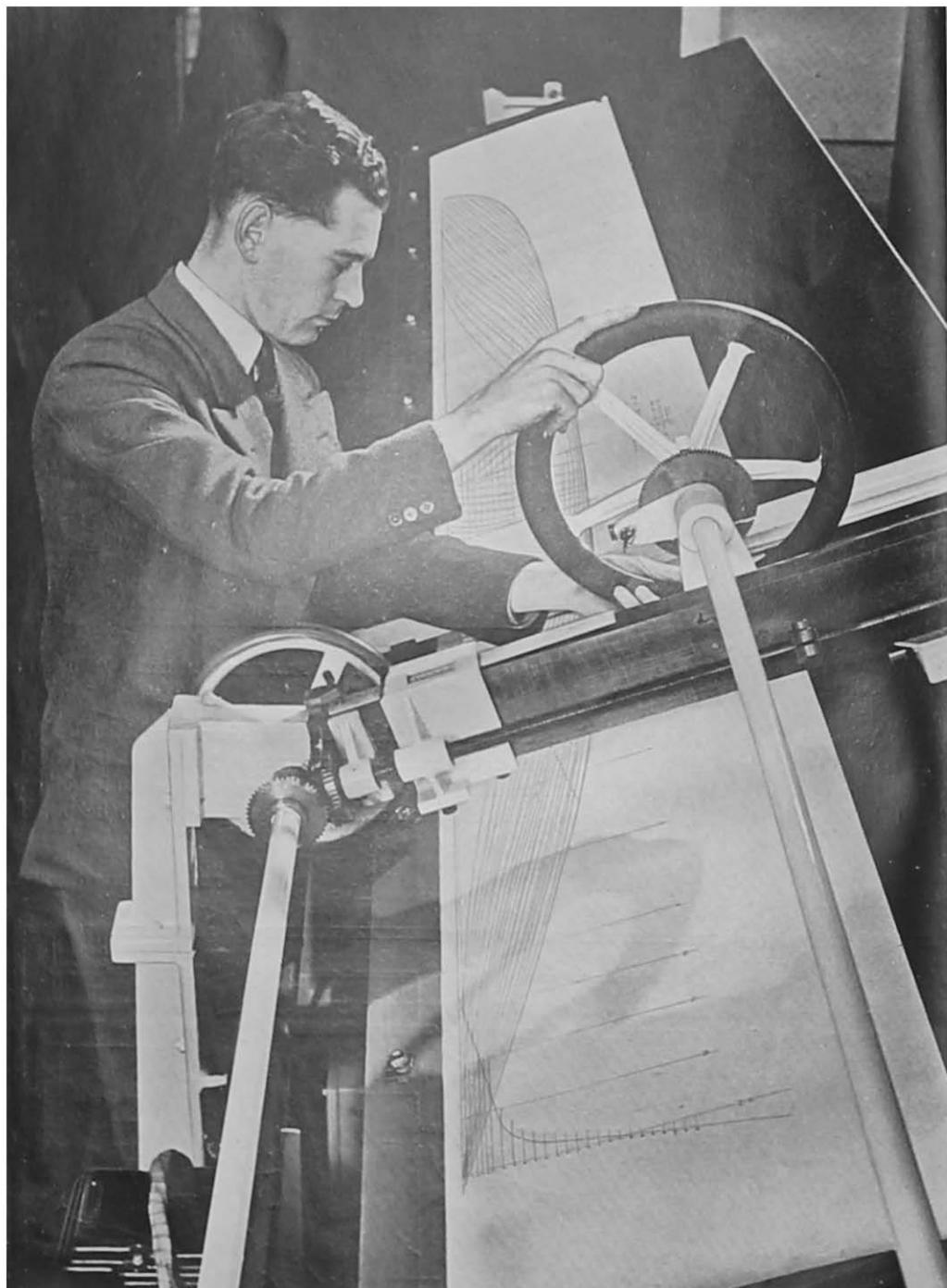




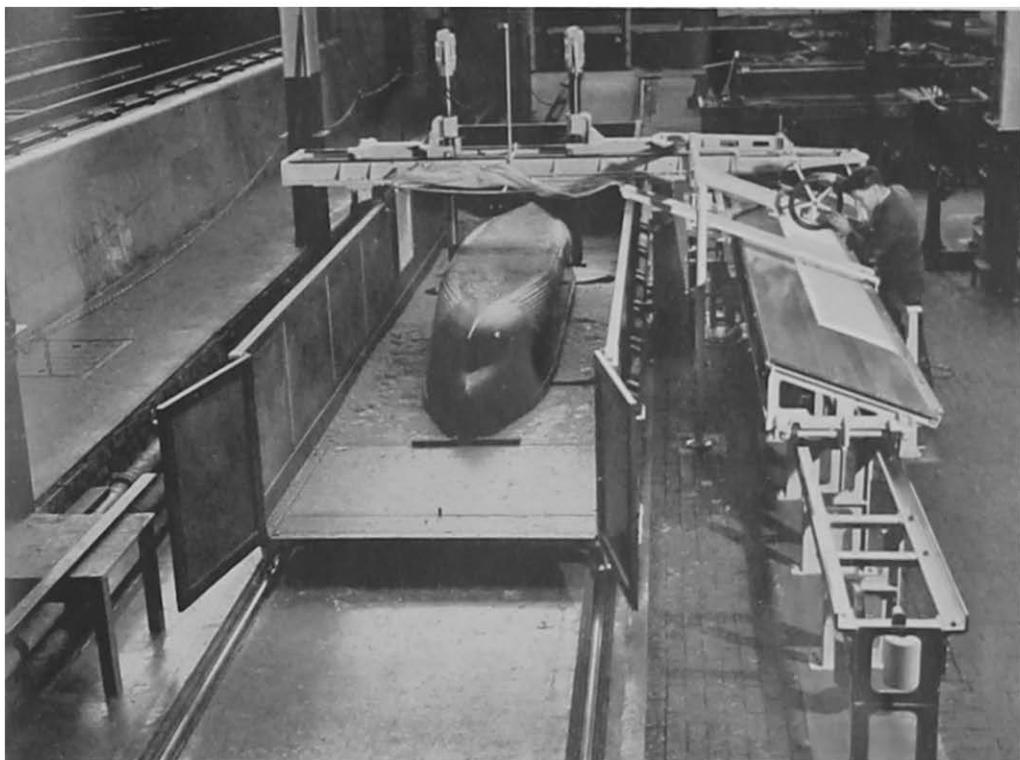
GIRDER PLACED ON RUBBER DAMPER

The Acoustics building is actually a piece of apparatus. The illustrations show the special design, each room being also a separate unit which can be jacked up in order to replace the rubber sound insulation upon which the girders rest. Wall material which is to be tested for sound insulation is built into the space between the two transmission rooms. Floorings can also be tested

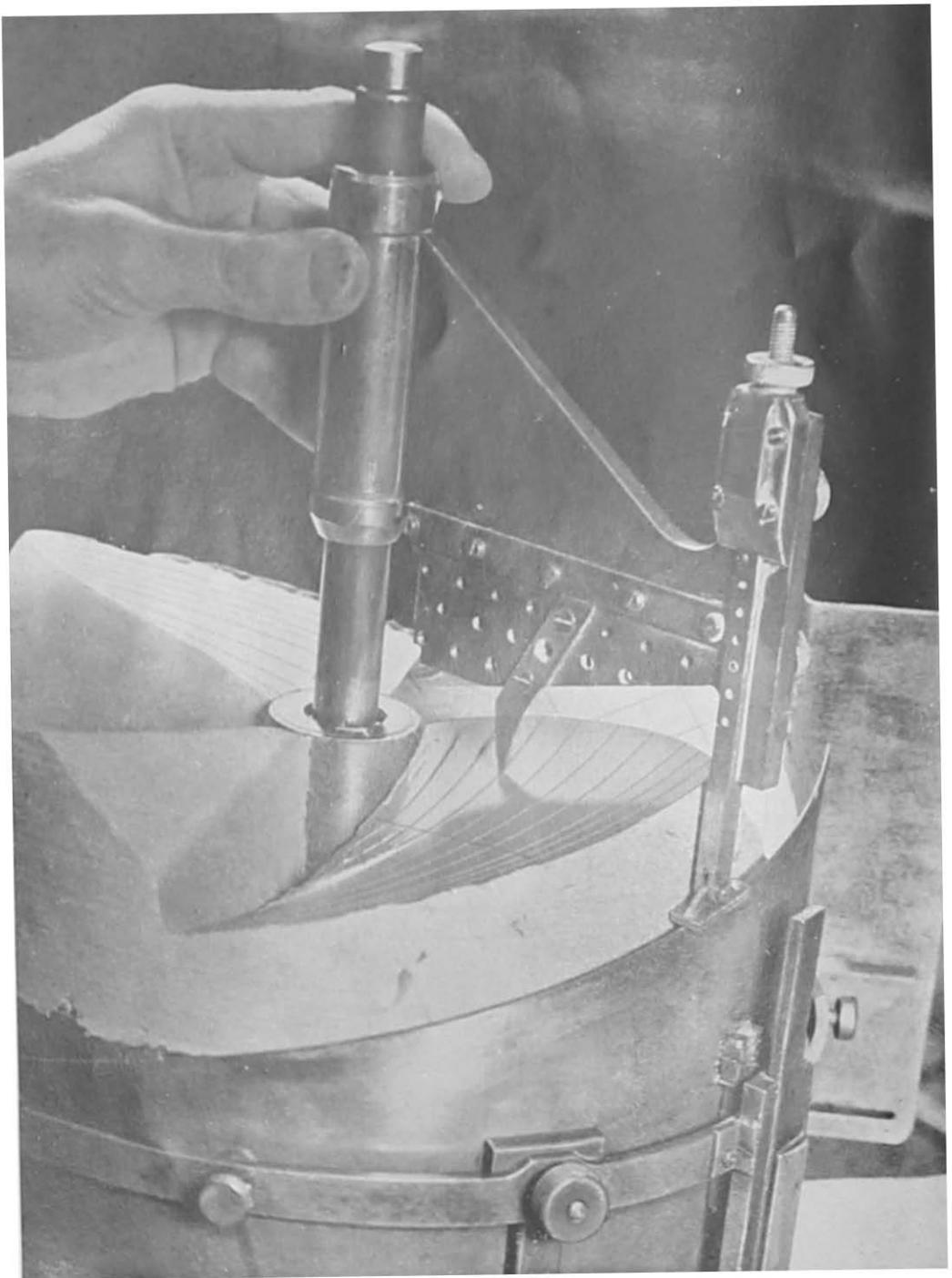




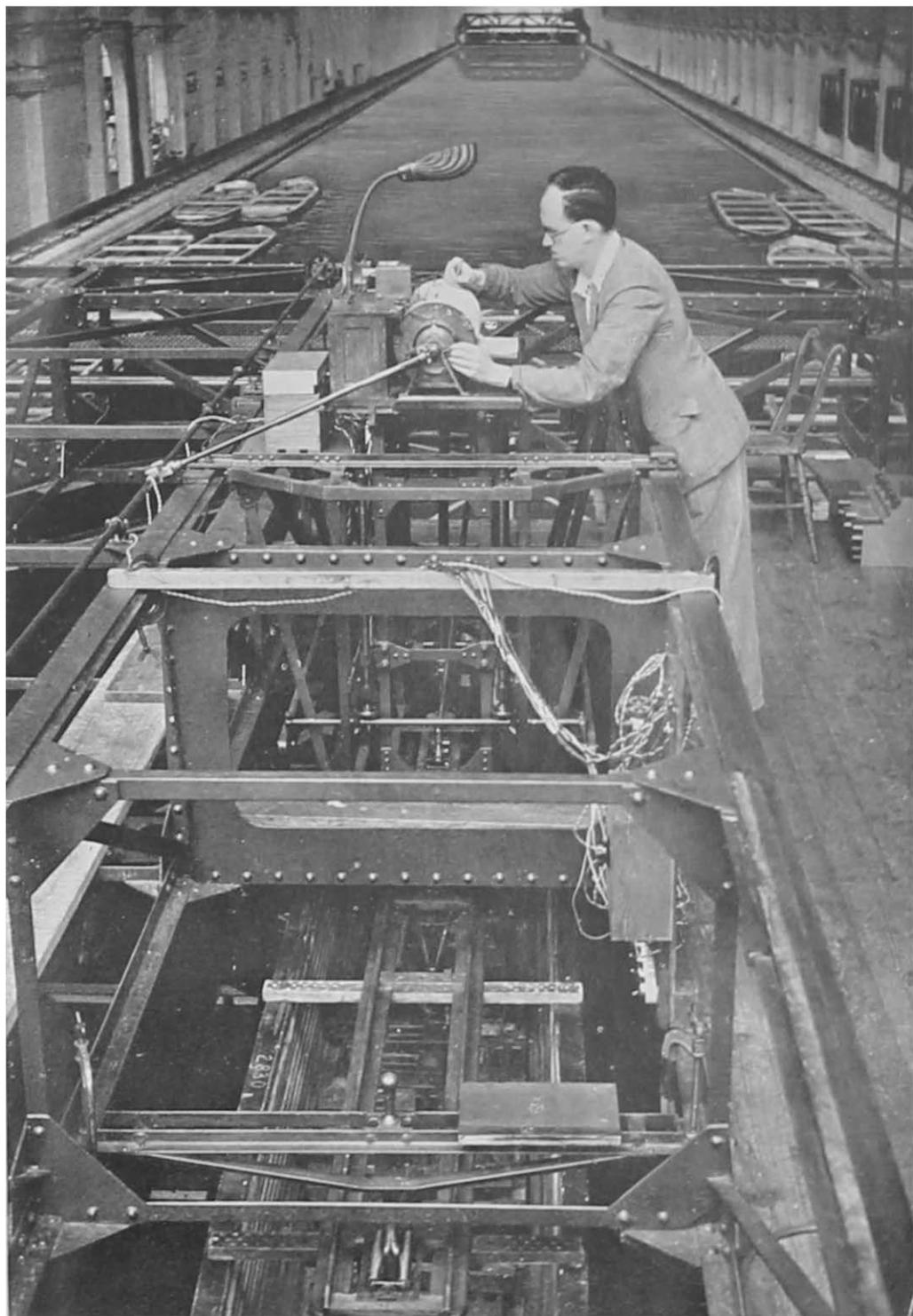
Guiding the cutters to reproduce the ship's lines in the wax model

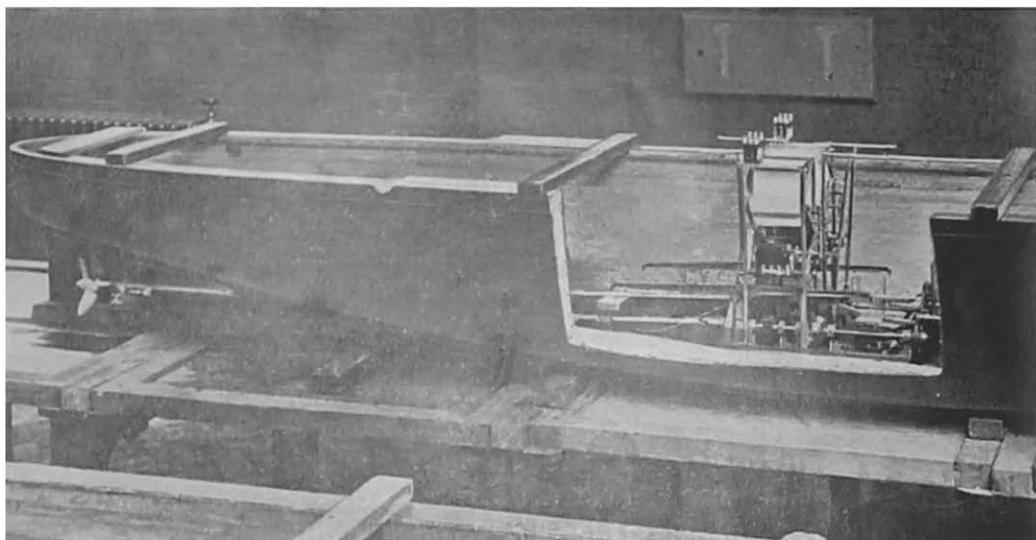


Ship models cast in paraffin wax are shaped in this machine to the ship's lines and the surface is then scraped by hand to the correct form



*Above* : Before making a model propeller a clay mould is shaped to the required form and a plaster cast produced from the mould. *Right* : The electrically propelled carriage tows ship models along, and the apparatus for determining the resistance to the motion of the model is installed on it





*Above* : A twin-propeller ship model cut away to show the recording gear for self-propulsion tests. This gear measures the speed of revolution, torque and thrust of the model propellers, and enables an estimate to be made of the propulsive power required for the ship. *Below* : The twin-screw m.v. *Port Brisbane*, the hull of which was tested in model form by the N.P.L.



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withstood a certain number of cycles, for example road shocks in the case of a car spring, the metal becomes 'tired' and fails.

The interest of the Engineering Division in fatigue was first extended to springs in 1922 when a programme of work, mainly on laminated springs, was begun for the Springs Research Committee. This went on for some years, perhaps the most vital point emerging being the extreme importance of surface conditions. For example, heat treatment of laminated springs as normally carried out was found to result in a loss of carbon from the outer layers of the spring and a consequent loss of fatigue strength of 50 per cent or more. This could be avoided by polishing the surface or by carrying out the heat treatment in a cyanide bath.

During the Second World War similar problems became important in connection with coiled springs for fuse recoil systems, tank suspension, etc. It was found that existing methods of design were unsatisfactory. These were overhauled and the first results embodied in Spring Design Memorandum No. 1, which was very widely used. It was then found that comparatively little was known about the highest stresses which could be used in springs when a limited life would be acceptable, as for instance in a gun, where the number of rounds was limited by other considerations. A large number of tests was then made to establish the allowable stresses.

Now it is quite clear that without the long-term research into fatigue in its relation to engineering design the research into springs would have been handicapped. On the other hand, the results of investigations into spring failures gave added importance to the factor of fatigue in metals. This in itself justified research which might otherwise have seemed useless.

The time came, however, when the study of fatigue in close relationship to engineering design did not seem sufficiently fundamental. Work begun on a practical plane led further back to realms of theory. What were the physical properties inherent in the material itself which caused it to lose, in use, some of its ability to stand up to various stresses?

### *New Tools for Metal Research*

It would have been useless to ask this question had it not been for the invention at Teddington and in university laboratories of new

tools in other branches of science. When metallurgists began their work in the N.P.L. in 1901 the new tool was the metallurgist's microscope through which grosser changes in the structure of carbon steel, when subjected to various treatments, were beginning to be studied. When X-ray instruments had been devised, capable of lightening the darkness within the interior of a metal object, fatigue could be studied in relationship to the lattice of atoms now revealed for the first time. This new scientific tool could be made to trace the distortions of atomic and molecular pattern and of crystal arrangement caused by every sort of stress applied to the specimen under observation.

This development was due to the co-operation between the Physics Division which was responsible for X-ray crystal analysis, and the Engineering Division which was the authority on the mechanical testing of steel. By combining the two in one experiment and carrying out X-ray analysis of structure along with mechanical fatigue stressing, an entirely new technique for fundamental investigations of the strengths of materials was evolved.

It cannot be too strongly emphasized that the usefulness of the N.P.L. largely depends on the fact that scientists are working in close proximity at Teddington upon quite different scientific problems, so that, whenever two techniques or two fields are inter-related, a fruitful co-operation is at once possible.

### *Heat Resistance*

Meanwhile the evolution of industry and engineering in the everyday world was beginning to shift the emphasis towards another research problem. Just as the period up to 1921 was dominated by the desire to find materials that were light in weight, so now the urgent need was for materials capable of withstanding the high temperatures associated firstly with steam power plant and later with the gas turbine engine as used for jet propulsion in aircraft. At these high temperatures normal materials tend to distort continuously even under working stresses. This phenomenon is appropriately known as creep.

This subject was studied with increasing emphasis in the inter-war years, and in 1939 a new high temperature testing laboratory was built in which were carried out the essential tests of nearly every new heat-resisting material used in British aircraft engines during the war.

Since the war these problems have become even more important;

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new tools, such as the electron microscope, have helped in their investigation, and much of the time of two divisions—Engineering and Metallurgy—is at present concentrated on preparing for the demands of the gas turbine age.

The Metallurgy Division is examining the element titanium as systematically as aluminium was examined a generation ago; the Engineering Division is devising new tools for producing and measuring creep under controlled conditions, and the Physics and Metallurgy Divisions are exploring the possibilities of the remarkable new tools, X-rays, electron microscopes, radio-isotopes, Geiger counters, ultrasonic waves, which have by no means yet revealed all their potentialities as aids to scientific investigation.

### *Building Materials*

Metals are not the only type of material which concerns the Laboratory, nor are the Metallurgy and Engineering Divisions the only ones that direct a large proportion of their energies to the study of materials. The Heat Section of the Physics Division is concerned with the thermal properties of building and other materials, particularly the fundamentals and methods of measurement, while the Sound Section is equally concerned with their acoustical properties. The Building Research Station, a sister organization in the Department of Scientific and Industrial Research, now deals with research on all problems of the building industry.

Again we find that the normal N.P.L. approach is maintained. The Heat Section does not set out to find the best insulant for a refrigerator, the best refractory for a furnace, the best plastic for an electrical apparatus. All these objects are likely to be end-products of the basic research, but the basic research itself is a study of the scientific subject, thermal conductivity. This involves an even more fundamental study, namely temperature measurement, which preceded it by many years as a concern of the Physics Division. Temperature measurement requires the purest research of all within the field of heat, that is the establishment of a standard scale of temperature.

Let us see how this series of researches from the pure to the practical interacts. In 1937 the Receiver of the Metropolitan Police District asked the help of the Laboratory over the justifiable complaints of some of the police that the concrete telephone boxes used by them were

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exceedingly uncomfortable, being either too hot or too cold. To deal with this the N.P.L. proceeded to examine the effectiveness of different forms of insulation, as well as the effect of alterations in the mode and distribution of the heating in the telephone boxes.

A glance at the reports of the Heat Section shows that for some years the thermal conductivity of concrete, and for more years still the thermal conductivity of building materials in general, had been studied. Before the earliest mention of building materials the phenomenon of thermal conductivity had been studied as a branch of physical science. For a still longer period the construction of instruments for measuring heat had engaged the attention of the N.P.L. and Dr. Harker, as we have seen, was already in the middle of his work on constructing a temperature scale when the Laboratory was founded.

Many pieces of research going on at Teddington to-day and seeming to be as divorced from immediate industrial application as was, let us say, Dr. Harker's temperature scale, will undoubtedly prove to hold the key to tomorrow's practical problems.

## INSTRUMENTS

As we have seen, the first stage in the solution of many problems to which no immediate answer can be given is almost invariably the invention of an instrument—usually a measuring instrument. It is not surprising therefore that throughout the fifty years of its history a large percentage of the Laboratory's time and effort has been spent on devising them. To-day it possesses a range of accurate instruments unequalled elsewhere in Great Britain.

The visitor to Teddington who is not immune from the human frailty which tends to concentrate on the spectacular and the large will be impressed by such things as the Ship Tank, the Whirling Arm, the Wind Tunnels, the million-volt spark-producing apparatus; but these, admirable as they are, are only the largest of an enormous range of admirable instruments. Others are smaller, but no less valuable and no less ingenious.

It should be emphasized that the N.P.L. never makes a new instrument for the sake of making instruments; it devises the tools needed for a purpose which has arisen. Experience shows that the instruments

thus devised for a specific purpose usually prove useful also in quite different fields of scientific research.

### *Noise, a Curse of Civilization*

By the end of the First World War several new factors had become part and parcel of everyday life. Broadcasting began; mechanical devices increasingly took over duties hitherto performed by manual labour; the cheap motor car and the motor cycle, the underground railway, the motor bus and the train, created a mighty volume of traffic; re-housing took the form very often of blocks of flats of light construction; office buildings, too, tended to be larger and of the same light construction; typewriters, telephone bells and other mechanical devices became more numerous. All these new factors gave rise to a practical scientific need, namely the control of noise.

The problems submitted to the Laboratory were specific and limited in range. Thus, in 1920, the bad acoustics of certain Whitehall conference rooms led to a request for help; in 1921 a railway construction company asked for help in estimating the sound-insulating properties of construction materials; in 1924 a forecast of the probable acoustic features of the proposed new Ulster Parliament Buildings was requested; in 1926 the acoustics of the proposed Melbourne Town Hall were assessed, and the general problems of sound insulation in large blocks of flats were investigated.

### *What is Noise ?*

Behind all these problems of noise and its control there was something more fundamental which had to be investigated: when does sound become offensive? It was impossible to rely upon any subjective standard, because such a standard may depend on the whims of individual listeners. How was sound to be measured?

Although the bad Whitehall acoustics and sound insulation in trains were the earliest problems submitted to the new Sound Section, the first work carried out by the Section was to standardize Edelman whistles. These were pipes producing a note of frequency variable at will, which could be calibrated by electrical methods and used as easily portable sources of sound. It should be remembered that this was before the days of the ubiquitous loud-speaker, amplifier and microphone.

In 1923 the problem of measuring the acoustical properties of building materials was investigated, and the first step was, naturally, to make an instrument. This took the form of two adjoining sound-proof chambers with a special opening in their partition wall into which the test material or structure could be built. In one room a noise was to be made; in the other the amount getting through the material under test was to be measured. This involved the invention of noise-making and noise-measuring instruments.

Noise-making instruments first took the form of metal and wooden organ pipes and sirens capable of making a known amount of noise of a known pitch. For the measurement, use was made at first of an existing instrument invented by Lord Rayleigh, but experiments were also begun on new telephonic instruments. This work occupied most of the time of the Section for some years, and during that time the solution of submitted problems was of quite secondary importance. With the object of improving building techniques, the subject of sound measurement was tackled systematically.

In 1924, most of the time and energies of the staff continued to be taken up with testing and perfecting the instruments. The sound-proof chambers had to be improved. It was found possible to concentrate the sound from the sound-producer—now a loud-speaker instead of organ pipes—into a beam centred on the test material, so that outside the beam the sound intensity was less than 4 per cent of that in the beam: Ways of photographing sound waves, either directly or by photographing ripples in a water tank, helped to show what happened when sound was transmitted through the testing apparatus.

#### *Fluid Flow Again*

By 1925 the work being done bore a striking analogy to some of the work summarized in the section on fluid flow. It was found that the acoustics of an auditorium could be studied by making models to scale and using them as 'ripple tanks'. The tank's boundaries correspond to the walls of a longitudinal section of the proposed auditorium; the tank is filled with water, and a ripple-making impulse is applied at the point where the orchestra will sit. The ripples and their reflection from the walls and roof can then be photographed, and it can be shown that their shapes and courses will be the same as those of sound waves in an auditorium of the same shape. For example, by modifying the tank

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boundary which represents the roof, the ripples can be varied, and the best shape of roof for obtaining the required sound effects can be found.

By this time useful advice had been supplied to a number of inquirers, but much more important was the group of instruments and the techniques for using them which had begun to accumulate. One major problem remained to be solved: could there be an instrument for measuring the intensity of sound objectively? Was it necessary to depend solely on some human ear and brain recording that a given sound was louder than another, or that a sound was so loud that it constituted a pernicious noise?

There were various methods possible in theory—for example, the very small force exerted on a delicately suspended plate on which sound falls can be measured; or the twisting action on a thin disc hung by an invisible quartz fibre and set aslant the direction of the sound waves. The latter of these methods—the ‘Rayleigh disc’—was developed over a period of years and is still the ultimate measure of the intensity of a given sound. But very special apparatus and procedure are necessary for its use, so that microphones of specially robust and permanent construction are calibrated from time to time with the Rayleigh disc, and then become themselves the carefully treasured Laboratory standards of sound intensity.

For some years the N.P.L. was still occupied with improving the general and absolute methods of sound measurement and devising new instruments for this purpose; yet all the time the knowledge gained during the course of the work was being used for practical purposes.

Our example shows once more the normal evolution of N.P.L. research: first, a request for advice on a specific problem requiring measurements for which no instrument is available but which is met quickly with the best available knowledge and instruments; second, concentration on devising the necessary instruments, during which much information is obtained; third, as a result of the invention of a battery of new instruments a large amount of new short-term research becomes possible and the practical problems of inquirers can be investigated and answered; fourth, while constant readiness to undertake such practical investigations is maintained, the fundamental research is never lost sight of. Thus every short-term practical research undertaken enriches the capital assets of the Laboratory in the form of knowledge, equipment, techniques and trained staff. None of this would be possible

if there were not a conscious policy of looking for universal principles behind the solution of specific problems.

*From Sound to Noise*

The problem of sound-measurement does not end with the invention of sound-measuring instruments. The force exerted by a given sound does not tell us anything about loudness; for loudness is an attribute of sound given it by the human ear.

In conjunction with the British Standards Institution, a unit of equivalent loudness was set up, the British Standard *phon*. This is a measure of sound as it appears to a human being and involves, therefore, the medium of the human ear. Briefly, people listen to a standard note (or tone) and a noise at the same time, and they estimate the loudness of the noise in comparison with the tone. In this way a 'standard scale of equivalent loudness' is drawn up so that any noise can be translated into terms of sound intensity. Thus the loudness of a motor horn can be measured, and the maximum allowable noise which will not be a nuisance to the neighbours can be stated in an accurate objective way.

The next stage is to dispense with the need for dependence upon the human ear as a measuring instrument. No scientist likes to have to depend for his measurements on the performance of human sense-organs, because he will never get the same results twice. So having used the human ear at the point where its use is inevitable, the N.P.L. acoustic experts proceeded to the next instrument in their series, an artificial ear in the form of a special microphone, amplifier, and rectifier, able to listen to noises anywhere and register them on the standard scale of equivalent loudness. By this means the need to depend upon a neighbour's estimate of the amount of noise emitted by a loud-speaker is obviated. The N.P.L. objective noise meter has been very useful in establishing a generally acceptable standard of what degree of noise constitutes a nuisance.

It has also collaborated with other institutions on problems relating to the national hearing aid, and on the design and examination of audiometers for testing such devices.

*Motor Horns*

Only after devising this succession of instruments can practical problems be reasonably solved. Thus it can be shown that motor horns

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exceeding a loudness of 95–100 phons at a distance of 20 feet cause material annoyance to a normal listener; but that the driver of a moderately noisy vehicle requires an overtaking vehicle to have a horn with a loudness of about 105 phons if he is to be sure of hearing it. Hence a perfect solution is impossible and a compromise recommendation of a maximum loudness of 100 phons has to be decided upon. However unsatisfactory this may be in a particular case, the important result is that subjective estimates are avoided and accurate measurements take their place. Since noise produces more frayed nerves than almost anything else, the social value of this is readily seen.

In this rapid sketch of acoustical instruments, more individual instruments, invented at the N.P.L., have been omitted than described. It will, however, be clear that since the task of the Laboratory is to solve practical problems by devising means of measuring the factors involved, the invention of new instruments is an integral part of the everyday work of every division. Let us look at a few of the most remarkable of these problems.

### *Lighting Problems*

The public are interested in innumerable problems which involve the measurement of light. What is a satisfactory rear-reflector for a bicycle? What are the relative efficiencies of different types of lamps or fittings? How can two colours be satisfactorily matched? How far does an electric lamp simulate daylight? What is the best form of street lighting?

The Light Division of the N.P.L. gives an expert opinion on many such problems and is in a position to do so because research extending over many years has resulted in the invention of essential instruments and measuring techniques. At the same time, almost every short-term problem will require the invention of one or more new instruments for its solution.

It is of fundamental importance to devise apparatus which shall define the standard of light. We talk of lamps of so many candle power; what is the standard unit, the 'candle' itself? It is an internationally agreed measure of light and is reproduced by a series of sub-standard lamps which have to be compared with similar series kept in other laboratories at home and abroad. As we have seen, the whole tendency of metrology is to try to find universal standards which are not based—

as was the standard yard—on an arbitrarily chosen object. Thus the 'candle', as its name implies, was originally the light intensity of a particular candle made according to a particular specification, and was not based on any invariable natural phenomenon.

### *The Standard of Light*

The photometry specialists spent many years devising a less arbitrary way of measuring light, and there is now international agreement that it shall be measured in terms of the brightness of a "black body" at the temperature of the solidification of platinum. This is something which never varies and is independent of human action. The primary light standard can thus be checked at any time without fear of unsuspected inaccuracies being introduced into the materials used for making the source of light.

Having perfected this primary standard, the next step is to measure, by means of it, specially designed lamps which can be used in industrial and other research laboratories as sub-standards. Candle power is not the only light measurement; luminous flux, illumination and brightness, and colour also have to be measured. For all these, standards and sub-standards are prepared for daily use.

### *Illuminant 'C'*

Let us now suppose that the N.P.L. is called upon to devise ways of matching the colours of materials in daylight. What is daylight? It may be satisfactory for ordinary buying to take two pieces of cloth to the door of the shop so as to 'match them in daylight', but everybody knows that daylight varies from hour to hour and, therefore, for more accurate purposes it is necessary to substitute for daylight itself a standard source of light which never varies but has the qualities which we associate with daylight in general. This involves making an instrument to produce Illuminant 'C', which resembles, in its effects on colour and colour matching, the average light from a north sky in England.

Pairs of coloured objects which match under Illuminant 'C' are compared under different kinds of commercial lamps which can be graded as to their efficiency for colour matching purposes.

The solution is found to be not quite satisfactory for commercial purposes, because it takes a long time to carry out the desired match-

ings. The next stage is to devise instruments which will make it possible to work more quickly. This is an example of a constantly recurring problem; the instrument which is suitable for laboratory work may not be suitable for commercial purposes because it is too extravagant of time. The N.P.L. can never be content with devising laboratory instruments; it has to modify and change them to meet the requirements of the world outside. In the present instance this meant the development of a technique in which colour filters promoted ease in use.

### *The Giant Instruments*

Certain instruments stand out in the history of the N.P.L. because of their continuing importance and their costliness. Thus there are the Wind Tunnels of the Aerodynamics Division culminating in the high speed tunnels where aerofoils are being tested for the supersonic speeds of the future, and especially for the comparison of theory and experiment. The Compressed Air Tunnel, or C.A.T., is used for experiments of critical importance in modern aeroplane design.

The Engineering Division built its first wind tunnel forty-five years ago and the 1,500 horse power 11 inch square supersonic wind tunnel, for the production of air speeds up to two and a half times the velocity of sound, was built in 1942. The 12 inch diameter wind tunnel in the Aerodynamics Division was first run at a supersonic speed in 1943. They were the only large wind tunnels of this kind possessed by the Allied Nations until near the end of the war. They were as invaluable then for work in high-speed flight and in ballistics, for example in predicting the probable limiting range of the V2 rocket, as they have been since.

The Electricity Division's High Voltage Laboratory, with its impulse generator capable of generating two million volts, and its transformers able to step up power at 1,000 volts to over a million volts, was originally designed to carry out work for the National Grid and to study such practical problems as the effect of lightning on high tension cables and insulators.

### *Special Instruments*

Far less spectacular than the High Voltage apparatus, but just as useful in its own sphere, is the moisture meter, a portable instrument developed by the Electricity Division for the measurement of moisture in stored grain and for other similar problems.

The Engineering and Metrology Divisions have constructed many prototype instruments and have developed many instruments which have an everyday use. A notable example is the series of electrical resistance strain gauges, by means of which strain is measured in terms of the electrical changes it produces. The device, American in origin, has been developed and improved at Teddington. A recent interesting development is a strain gauge, measuring only  $3 \times 2$  mm overall, including leads, constructed in the Engineering Division for determining the loads imposed on teeth during the mastication of food.

The Radio Division has developed fully automatic instruments for such purposes as sounding the ionosphere with radio waves. By means of these, radio waves are automatically and continuously transmitted into the ionosphere and the variations in reception are recorded. In consequence it is now possible to attempt to forecast some months ahead the likely conditions for communication and broadcasting purposes.

#### *Mathematical Machines*

Much of modern science is mathematical in character, but the results are usually wanted (and can frequently only be obtained) in a numerical form. The Mathematics Division was established in 1945 largely to meet the need for a centre in which numerical mathematics could be developed and applied.

Up to now most of its work has been carried out on standard desk calculators, accounting machines and punched card equipment. It is of more than passing interest that machines developed initially for purely administrative purposes should ultimately prove adaptable for the solution of complex mathematical and statistical problems.

More specialized machines include a Differential Analyser built for Manchester University and now on permanent loan to the Laboratory. A larger and more flexible machine of this type is being developed for the Laboratory, and of even greater importance is the construction of an electronic computer, a prototype model of which is now working, which will solve in a few days problems that would otherwise entail years of human labour.

#### *Temperature Measurement*

These examples, with the Ship Tank itself, the Whirling Arm, and the Engineering Division's dead-weight primary standard of 50 tons

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used for calibrating tension and compression testing machines, are among the most spectacular of the N.P.L.'s remarkable collection of instruments. But there is also a multitude of equally remarkable aids to measurement and testing which have their part in the work of every division.

Take the Temperature Measurement Section of the Physics Division. Wherever, in everyday life or in industry, heat has to be measured, the process involves the use of at least two instruments: the first to take the temperature measurement, the second to test the first instrument. In many cases the first type of instrument was designed at the Laboratory, and in almost all cases the Temperature Measurement Section has had to devise the instrument to test it. Thus all types of thermometers and pyrometers must not only be designed in the first place, but also tested. Temperature comparison baths have to be made for this purpose.

Ability to carry out all this routine work for the community is dependent on a technique developed through many years of fundamental heat-measuring research. Before a thermometer can be tested, a testing instrument must be devised for it. Before this can be done, a temperature scale has to be contrived and the scale has to be carried into regions of great heat such as few people are concerned with in ordinary life. Work in finding fixed points for high temperatures by reference to the melting points of elements and other natural physical phenomena is the background necessary for the solution of everyday practical problems.

The Physics Division adapts, improves and invents all types of thermometers for these purposes—resistance thermometers with accuracies exceeding one thousandth of a degree, thermocouples, and optical pyrometers for controlling the heat of molten steel. Pure research, long-term investigation, short-term investigation and testing are all interwoven, and each is a matter of measurement.

Measurement implies a measuring instrument, and beyond the making of actual instruments there is virtually an independent science which, on the analogy of pure measurement, might be called the science of pure instrument making. The N.P.L., through its collective experience, understands what can and what cannot be done in any given case, and the fundamental principles governing the design of any kind of instrument.

## ELECTRO-MAGNETIC WAVES AND ELECTRONS

Though engineering, metallurgy, heat-physics and optics had been applied practically for many years when the Laboratory was started, the practical applications of electricity were in their infancy; neither electro-magnetic waves outside the visible spectrum, nor moving streams of electrons, were yet thought of as anything but curiosities.

Fixed standards of measurement for the fundamental units of both light and electricity were still needed, and it is noteworthy that when light measurement was considered it was more under stimulus from the gas than from the electric light industry. It was not until 1919 that the Electricity Division became separated from the Physics Division, largely because the Board of Trade Electrical Standards Laboratory was transferred to the N.P.L.

In 1913 several aeriels were put up for the reception of wireless signals. This extension of research on electro-magnetic waves reached its climax in 1933, when the Radio Division was established. Furthermore, the growing practical importance of the physics of light ultimately necessitated a separate Light Division. Last of all, an Electronics Section, concerned mainly with the application of electronics to industrial processes and with the construction of a high-speed calculating machine, completed the expansion of what was once a comparatively restricted field of research. Electrical research began with the devising of standards and with methods of comparing commercial apparatus with them. This work was chiefly concerned with the normal everyday voltages used in lighting systems and small power stations. But the high voltage developments of the future were already being considered, and electrical engineers, realizing their ignorance of the practical problems involved, turned in good time to the Laboratory for help.

*The High Voltage Laboratory*

Although the importance of high voltage research was recognized some time before, such work at the N.P.L. began—and only in a small way—in 1905. The Engineering Standards Committee suggested at that time that the Laboratory should undertake research into the conditions of test to be applied to high voltage machinery.

The specific point was whether the application to a dielectric of a

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voltage insufficient to pierce it weakened its resistance to the pressure it would normally experience.

It was soon recognized that a transformer for 100,000 volts would be needed to make the work really useful, and such an apparatus was presented by the Engineering Standards Committee and set up in 1907 in a separate fire-proof building, necessary because of the ton of oil needed for insulation. The first apparatus proved unsatisfactory, and a second was installed in 1908. Breakdown tests on ebonite, porcelain, and varnishes were at once begun.

Among the early tests was one carried out for the New Zealand Government in 1911. The problem was that rapid temperature changes, due to climatic conditions, on insulators on a circuit operating at 40,000 volts, produced unequal expansion in different parts of the insulator; an artificial rainfall of 12 inches an hour was used in this test.

Before the First World War, tests continued without any marked increase of importance. During that war high voltage work was at a standstill because it was not directly needed for war-time techniques. Its place was, in fact, taken by special short-term investigations into such matters as trench signalling, locating guns by sound, mine and submarine detection, sound-location of aeroplanes and airships, and searchlight carbons.

### *Ever Higher Voltages*

By 1919, however, the problem of high voltage had reached a more advanced stage. Dielectric power losses had been carefully studied up to 12,000 volts, but it had now become imperative to continue the work with voltages of 50,000–100,000. Work on the ionization of air around high voltage conductors had stopped at about 15,000 volts, and it was now necessary to cover much higher voltages. It was estimated that by 1921 commercial voltages had gone up threefold as compared with what was common when the N.P.L. equipment had been installed.

The Electricity Commissioners were using 66,000 volts, and materials for use with this voltage could not be adequately tested on 100,000 volt apparatus. Moreover, in America and elsewhere, there were already voltages of as much as 220,000 in commercial use. The time had come for a specially designed building and equipment for producing, it was then thought, 300,000–500,000 volts.

High voltage research was in no way peculiar in showing signs of having outgrown the programme and equipment at the disposal of the N.P.L. The whole problem of 'general research' was being reconsidered, and in 1922 the special Research Committee, consisting of Sir Joseph Thomson, Sir William Bragg and Sir Ernest Rutherford, with the backing of the Electricity Commissioners, recommended that the new high voltage laboratory should be begun immediately and that it should be designed for work up to a million volts. It was pointed out that a million volt laboratory would not only be of great assistance to the projected developments in national electrical supply systems, but that it would contribute to fundamental research in modern physics.

The building itself began to take shape in 1924, but its equipment took some years longer. Sir Richard Glazebrook and members of the Laboratory staff paid a series of visits to France and the U.S.A. to study high voltage equipment.

The heavy components were put in place during 1927, and a special committee was appointed to consider a programme of research. Meanwhile, high voltage research continued in so far as the existing equipment permitted.

### *The Million Volt Spark*

At last, in 1928, it was possible to embellish the Annual Report with a photograph of the million volt spark obtained from the plant, which it had taken seven years to plan and perfect.

One of the most interesting details of high voltage testing is the question of the electrical resistance of water in the various forms in which it is found in nature. Clearly the effect of rain on transmission lines was an important problem now that plans for the National Grid were well advanced, and the N.P.L. instigated a series of relevant investigations. The local Teddington water supply was found to have a specific resistance of only 3,000 ohms, so that it would not be satisfactory to make artificial rain out of the piped water available. Instead, rain water had to be carefully mixed with distilled water in order to achieve an artificial rain with a specific resistance of 20,000 ohms.

With this a series of tests on vertical insulation systems was carried out, followed by tests on the effect of rain on the sparkover voltage. But for some time the chief occupation of the high voltage laboratory was to test its own apparatus and discover its potentialities.

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### *The Problem of Lightning*

The problem of measuring impulse voltages, such as those caused by lightning, which are able to develop at the rate of ten million volts per second, required a new type of measuring instrument for its solution. As in so many other fields of work, this instrument proved to be the cathode ray oscillograph.

This, with subsidiary apparatus, had to be modified to record events taking place in fractions of a second and not hitherto considered to be within the limits of practical investigation. While this involved a great deal of fundamental research, it was from the beginning linked to tests of a very practical nature investigating the way in which materials stood up to these millionth-of-a-second events.

It was soon found that the oscillograph might not be the only or the best way of analysing these events. The observed oscillations in a transmission line were found to correspond closely with the theoretical results obtained at Manchester University with the differential analyser, starting with the postulates supplied by the N.P.L. This suggested that valuable results in some directions would be obtained more easily by the use of mechanical computers than by experiment.

In pre-war years the amount of testing work increased greatly, chiefly in problems encountered in designing the National Grid. Surge protective devices required serious attention in order to counteract the effects of lightning, and also in order to find automatic means of preventing short circuits from interfering with supply. In the course of this work new gaps in theoretical knowledge were revealed and became the subject of further pure research. Thus it was not known whether the 'resistance to earth' was the same with transient as with steady currents, and this problem involved the Laboratory in fresh research lasting until the outbreak of war.

Today the high voltage laboratory finds ample occupation in testing new insulating materials such as polythene, and in preparing for new developments in electrical engineering.

### *Radio*

The Radio Division will probably prove the shortest lived of all the divisions of the Laboratory. This is simply an indication of the speed with which the science of radio has grown.

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When the division was formed in 1933 it worked in close connection with Prof. (now Sir Edward) Appleton, F.R.S., at King's College, London, and with the Cavendish Laboratory, Cambridge. Its programme was arranged by the Radio Research Board and consisted mainly of research on the propagation of waves, directional wireless, atmospheric, and radio apparatus and materials.

Investigations on the ionosphere were of great importance from the beginning, and much work was done before the recent war cast a blanket of security over most of it. Few people at the time could have known the significance of this sentence in the 1936 Report: ' In July Mr. R. A. Watson-Watt, Superintendent of the Radio Division, left the Laboratory to take charge of an experimental station of the Air Ministry ', thus depriving the National Physical Laboratory of being the physical birthplace of radar.

Radar is an excellent illustration of a truth which has been revealed many times already in this brief history, that major discoveries are seldom the results of a direct approach to a problem, but rather the unsuspected corollaries of more generalized research.

### *Radar*

When the programmes of research were drawn up, radiolocation, or radar as it is now called, was entirely unforeseen. In his report on the work of the Division Dr. R. L. Smith-Rose, who succeeded Mr. (now Sir Robert) Watson-Watt, F.R.S., says that radar was a direct result of the existence of a body of staff skilled in a variety of techniques involving the generation and utilization of pulses, the design of time-measuring systems and of directional aeriels, all of which were initiated for other purposes. The then Parliamentary Secretary to the Ministry of Production summed up the matter thus: ' Radiolocation, by far the most important national asset ever to emerge from the National Physical Laboratory, was a natural but not inevitable synthesis of techniques developed within the Radio Research Board's programme '.

It can therefore be claimed that although—it might even be said because—the fundamental research on radio carried on in the inter-war period was, in general, directly applicable to no particular immediate problem, the team engaged in it accumulated a fund of knowledge and techniques which led to a ready solution of every Service problem as it arose.

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Thus for Service users the N.P.L. was able to improve the accuracy and efficiency of radio direction finding and field-strength measuring technique, for the purpose of locating enemy transmitting stations of various types.

### *Radio and the Weather*

The technique of using free balloons, with radio transmitters attached, for measuring meteorological conditions (balloon-borne radio-sonde equipment) was being developed before the war. Meteorology became a dark secret during the war, since many lives might depend on forecasting the weather correctly and on keeping the forecast from the enemy. Under the influence of war-time needs it has now developed into a new science of radio-meteorology, and later developments have included the long-range radio-sonde equipment designed to transmit meteorological data during a balloon's descent at the end of flights of up to 1,000 miles.

The N.P.L. developed the crossed-coil directional detector of atmospheric for war use by the Air Ministry. With this apparatus, storm centres can be located and tracked far out into the Atlantic, and necessary warning can be given for diverting aeroplanes on airline routes.

An unexpected war-time activity of the Radio Division of the N.P.L. was to assist in establishing the floating balloon barrage for the defence of London. The sequence of events leading to this is, however, obvious in retrospect. The knowledge of balloons was gained from their use, in meteorological researches, for carrying radio recording apparatus; this apparatus was used in meteorology because radio research had shown the importance of a knowledge of the upper air for the transmission and reception of radio signals.

### *Light and the Human Eye*

The development of research into problems of light has undergone many changes since the early days of the N.P.L., when optics and photometry were separate sections of the Physics Division. In 1940 photometry, which had been part of the Electricity Division since 1918, and optics were brought together to form a new Light Division. Photometry may be described as the measurement of light as it affects the human eye. Optics deals with the behaviour of light when it is subjected to the effects of a series of instruments, mostly glass lenses or prisms,

but with the human eye as a necessary member of the series. Photometry measures light. Optics studies its behaviour and is a recognized branch of physics, along with heat, sound, and other subjects.

### *The Eye as an Optical Instrument*

As happened when acoustical problems called for the use of the human ear as a measuring instrument, the physicists studying light had to accept the fact that no optical problem could be fully investigated without a full knowledge of the optical instruments involved. As one of these was the eye they were bound to enter the realm of biology.

When the Department of Scientific and Industrial Research appointed, in 1924, an Illumination Research Committee, this committee's work was at first purely physical in character; biology made no overt appearance. But in 1925 the committee was called upon by the Office of Works to determine the minimum daylight factor which might be considered satisfactory for clerical work.

The method adopted is thus described: 'On an average day, neither bright nor dull, anyone experienced in such work would be competent to judge of the sufficiency or otherwise of the illumination'. Acting on this assumption, members of the committee visited three Government buildings, and points were selected in each room at which the illumination was considered to be the lowest tolerable for reading and writing, and measurements of the corresponding daylight factors were made.

This method of research is likely to seem an example of arbitrary subjectivism or of sound common sense, according to the psychological type to which the reader belongs. We note, too, that the object of the research is connected with the psychological problem of industrial fatigue.

In 1926 street lighting problems were examined, and particularly the effect of glare upon the ability of the human eye to detect small contrasts in the field of view. The report of the investigation remarks that the notions 'just visible', and 'just invisible' are not precise, and that a certain degree of arbitrariness is involved in the results.

During this visual research unexpected anomalies were found; in particular unexplained variations of the threshold of visibility. These could only be understood by greater knowledge of the optical instrument being tested, and it was expected that variations in the size of

the pupil of the eye might be of importance in explaining the variations of the threshold. An arrangement was therefore devised for taking a photograph of the observers' eyes when they were accommodated to any desired background and glare conditions.

The next development of interest was the design of a photometric pupillometer for determining the pupil area in various conditions of illumination. The results of the use of this instrument were anomalous from the point of view of the physicist. They disclosed one of those unexpected pieces of behaviour of which biological mechanisms are full. The results 'could only be explained if the luminous efficiency of a ray terminating on a given retinal image depended on the point in the pupil-opening through which the ray had passed'.

Threshold experiments were carried on with an artificial pupil and, in 1935, with natural pupils to measure their size during recovery from exposure to glare.

#### *Preparing for Black-Out Conditions*

By 1936 visual research had reached considerable proportions, but in 1939 an ominous note entered into the reports: 'Further work has been done under the programme of the Illumination Research Committee on problems of vision; one part of the work has dealt with the recovery of sensitivity of the eye for faint light after a bright light has been removed from the field of view, while another has been concerned with the comparison of the sensitivity to light when either one eye or both eyes together are used'. The practical significance of these studies for men and women about to step out of their well-lighted homes into a blacked-out world is obvious, and the account added that assistance had been given to the Ministry of Home Security in a number of 'black-out' problems.

The post-war years have seen visual research at the Laboratory pursue the evolutionary trend we have noted in other cases. A study which at one time dealt with such short-term matters as the degree of light needed for reading, and the reaction of people to street lighting and glare, has developed into fundamental and widely planned research into the optical characteristics of the human eye.

# Special Investigations and Testing

Long-term research of the kind we have described provides the intellectual capital and the capital assets of equipment, trained personnel and tried techniques from which ample dividends in the form of short-term advisory work are derived. Quick answers based on experience can often be given to problems put to the N.P.L.

### *The National Physical Laboratory and Industry*

When a private firm wishes to take advantage of the services of the Laboratory it will discuss its problem with the appropriate members of the staff. If a quick answer resolves the difficulty and does not involve experimental work, no charge is made. Many troubles, however, require some further investigation. The cost of this work, calculated to cover staff time and overheads, is usually charged to the firms concerned. In cases where the matter to be investigated is considered of general interest to an industry, or to the community, and is related to work already being done by the N.P.L., some or all of the cost may be borne by the Laboratory.

To describe some of this work, let us take, as an example, a commercial concern which approaches the Engineering Division for advice. Let us suppose a firm seeks advice on the suitability of a new material for a piston. Why is the Engineering Division likely to be able to help? The answer is that for fifty years the Laboratory's fundamental research has included a systematic study of all new engineering materials.

### *Testing Machines*

Because the study has been systematic, in addition to standard machines a large number of testing machines has had to be designed, and with them techniques of investigating likely materials.

Teddington today possesses the necessary machines to carry out tests in tension, compression, bending, torsion, hardness, impact, and fatigue on all kinds of materials at air or elevated temperatures. These

basic machines, which can be adapted to test most materials and engineering components, are supplemented by others for testing a limited range of objects. Such objects include measuring instruments such as pressure and vacuum gauges and load-measuring appliances; metal components such as gas cylinders, welded joints, chains, railway couplings, springs, lifting appliances, wire ropes; non-metallic materials such as paper, safety glass, electrical insulating material and plastics, pipe-covers, insulating bricks, joint rings, flooring materials, and many more.

Even if all these instruments cannot meet a special problem the N.P.L. has another asset—its experience in devising instruments in general. The engineering firm which is interested in the piston may not itself be as skilful in devising tests for the piston material as the specialist experts at the N.P.L.

#### *Failures and Accidents*

The Laboratory is often called upon to investigate failures and accidents. If a gas cylinder or a boiler bursts, causing casualties, the Home Office, investigating the cause, may wish to obtain an impartial opinion whether the accident was due to a defect or improper use. In such cases the N.P.L. would be accepted as an impartial witness, thus performing a valuable social duty.

#### *A Typical Year's Work*

During a typical year many special investigations are carried out for the Government and for public bodies; the wide range of these can be seen by noting the special investigations carried out in 1935 by one Division only, the Electricity Division.

During that year the Division was pursuing a varied programme of long-term research and maintenance of standards, and consequently attention was being given to many forms of general research in electro-technics and photometry. Investigations were made into such specialized fields as the A.C. resistance of large conductors, the properties of resistance materials, and the characteristics of photo-electric cells, as well as into absolute standards of inductance, the absolute measurement of resistance, the absolute measurement of current, platinum standards of resistance, standard cells, quartz ring oscillator frequency standards, and many other problems.

All this is the essential basis of the life of the Division, but little

of it is directly applicable to the everyday problems of industry. Indirectly it is essential to the efficient solution of the problems submitted; it is because long-term continuous research is being carried out that any particular problem sent for solution by industry can usually be solved without delay.

During the same year special investigations included a systematic examination, for the British Electrical and Allied Industries Research Association, of the electrical properties of a series of synthetic resins, ebonite, and a special silicon steel sheet. A quartz ring oscillator comparable with the one used in the Laboratory was prepared and tested for the Admiralty Signal School.

The Home Office, the Ministry of Health and the Medical Research Council formed a committee to investigate the possible danger from static electricity in hospital operating theatres during the use of certain anaesthetics; it fell to the N.P.L. to devise methods of experimenting with hospital equipment and to recommend safety measures. Similarly, the Home Office was concerned about the dangers involved in dry cleaning processes where inflammable vapour was produced. Was the electrostatic charge generated by the machinery likely to cause explosion? The N.P.L. investigated the electrical properties of materials used.

The Government of Northern Ireland submitted a problem about an important eel-fishery, where the aim was to guide the eels into that part of a river where traps were installed. This was to be done by building an electrical barrage to electrify the water from which the eels were to be excluded. This led to the hitherto unforeseen introduction of eels to Teddington, where they were experimented with in a wooden tank.

A firm submitted certain marine cables for test. These were sheathed in rubber instead of lead and were to be used on board ship. The requirements of Lloyd's Register of Shipping are the standards to be observed in such cases, and the N.P.L. designed a special electrically-heated oven and a spray-producing apparatus to test whether the requirements were met. With these the cables could be exposed to intermittent heat, and periodically to atmospheres of sea water and Diesel oil spray. The cables were subsequently subjected to electrical and mechanical tests.

As part of the work carried out for the Illumination Research Com-

## SPECIAL INVESTIGATIONS AND TESTING

mittee, a study of the effect of colour on the effectiveness of motor car headlights in fog was carried out by the Photometry Section. This Section also completed in 1935 three years' work on designing a glaremeter.

In most of these examples it is not difficult to distinguish between the fundamental long-term researches of the N.P.L. and their comparatively circumscribed applications to specific problems. On the one side we find fifty years' study of metals under stress; on the other, a "tired" spring: on the one side, a prolonged practice of electrical techniques; on the other, a desire to trap eels. But the distinction between the two types of work is by no means always obvious, and many special investigations involve new fundamental research or at least new fundamental applications.

### *The New House of Commons*

The approach to the problem of the ventilation of the new House of Commons involved an important extension of the principles of fluid flow and the use of models. A brief description of the work done will show how a request for practical and specific advice may lead to a considerable extension of theoretical knowledge.

When the former Debating Chamber of the House (destroyed by bombs in 1941) was designed, those responsible were more impressed with the importance of a Gothic atmosphere than a ventilated one. The Mother of Parliaments had to work in a temperature distribution liable to cause hot heads and cold feet, and from time to time attempts were made to improve the ventilation.

In 1921 the Engineering Division carried out experiments in the Chamber and on models and made some recommendations. When the new Chamber was being designed, the Division was, naturally, asked to advise on the new system and to provide information about air velocities and temperature distribution for different arrangements of inlet and outlet ducts, and the problem was attacked in the light of much experience gained in the use of models. Model ships, aeroplanes, and auditoria had all been found valuable, and had shown the possibilities of the principle of dynamical similarity.

The model used by the Engineering Division was twelve feet cube and represents half the Chamber. It had a glass front to enable the flow patterns traced by smoke generators to be observed. The heat dissipated

by each Member of Parliament was assumed to be 90 watts and was represented in the model by lamps of appropriate size. Experiments with the model gave specific answers to the questions asked by the consulting engineers; these were verified by full scale mock-ups of sections of the proposed Chamber, thus ensuring as far as possible that the new building is well ventilated. In addition, the Physics Division was able to give valuable advice about the acoustical properties of the new Chamber.

The Laboratory is thus able to claim a share in improving the House of Commons. The solution of the problem invites an extension of fluid flow theory and opens a way to useful new lines of fundamental research.

### *Helping Medical Science*

Special investigations can result in new responsibilities if they lead to the setting up of new standards. Thus, during the war, great advances were made in all branches of medicine, and some of the most important ones were in our knowledge of the human blood. This was due partly to blood transfusion requirements and partly to successful advances in the treatment of anaemias, including sub-clinical conditions due often to malnutrition and mineral deficiencies.

It was found that earlier methods of measuring haemoglobin had become unsatisfactory. Methods of measurement in all branches of science become obsolete because of the demand for greater accuracy and greater speed. The Light Division was asked for a survey of the colour properties of human haemoglobin and five of its more common derivatives. Haemoglobin is a constituent of blood which contains iron and transports oxygen. The relation between the colour of each of the compounds and the iron content and oxygen capacity of the haemoglobin was determined. An immediate result is the simplification of tests to determine the haemoglobin content of a blood sample. Any type of haemoglobinometer, visual or photo-electric, can now be calibrated in terms of the British Standards Institution's Haldane scale or, in absolute units, grammes of haemoglobin. Thus a simple bench haemoglobinometer or colorimeter can be made to give readings in accordance with the more elaborate oxygen and iron analyses.

To provide a standard of measurement, the group working together under the Medical Research Council and the National Physical Labora-

tory designed the improved Medical Research Council Haemoglobinometer. As a result haemoglobinometers began to be sent in for calibration and large numbers are expected as soon as certain components cease to be in short supply.

### *Radioactivity and its Dangers*

There is one vital branch of modern applied science in which the N.P.L. has been almost the only organization which could undertake special investigations. This came about because the Laboratory was entrusted with a new standard, the importance of which at the time could not be realized.

In 1912 Britain acquired a National Radium Standard in the form of 21.1 milligrammes of radium chloride. This was bought by a private individual, Dr. G. T. Beilby, F.R.S., and was sent to Madame Curie to be compared with the International Standard deposited with the Bureau International at Sèvres. Sir Ernest (later Lord) Rutherford, F.R.S., arranged that this exceptionally important crumb of matter should be kept at the N.P.L. and this was the beginning of the Radiology Section.

At the time, few could have made even an approximate guess as to what the work of the new Section would be. The first task was naturally one of measurement, to prepare the means for testing radium preparations against the standard.

When the tests had been devised, samples began to be sent in, and in the first full year, April, 1914–March, 1915, the amount of active material present in 68 samples valued at £35,000 was certified.

In the next year samples of radium paint were tested. This required collaboration with the Photometry Section.

It soon became clear that the potent new discovery would exact a heavy price unless the protection of workers from radioactive substances was taken in hand without delay. The Laboratory therefore was asked to find means of measuring the absorption coefficients of the materials used for protective purposes.

In July, 1921 a preliminary report published by the X-ray and Radium Protection Committee suggested precautions, hours of work, holidays, and periodical tests for workers subjected to radioactive substances, as well as standards for protective measures. At the same time practical precautionary work was being carried out, and the N.P.L. was busy with the exhaustive researches which ended in the establish-

ment of an international standard of production and of X-ray dosage. Once more we see how fundamental and applied problems go hand in hand.

*Safeguards for the Atomic Age*

This type of service became even more important to the community with the coming of artificial radioactivity.

The problem has two parts. The more obvious one is the protection of the individual against a dosage above a harmless maximum; the other concerns the maximum dosage which can be permitted in the population as a whole. The prevention of injury to patients and the supervision of the health of all radiation workers are the main features of the Radioactive Substances Act which was passed in 1948. The Laboratory gave valuable advice when it was being drafted, and it is probable, as a result of the Act, that radiation workers will be subjected to continuous radiation monitoring tests and to periodical medical and haematological examination.

It is well established that radiation has certain deleterious genetic effects. It can produce mutations of the germ cells which are almost always harmful. At the same time, these mutations are usually carried on recessive genes, that is, genes which do not produce noticeable effects in the human being unless they have been inherited from both parents. The danger, therefore, of ultimate injury to future generations from a given dosage of radiation is in direct proportion to the number of the total population subjected to that dosage.

The Radiology Section of the N.P.L. is charged with the vital task of giving warning of any approach to such a serious possibility. The radiation assessment is made by means of small photographic films carried on the person during working hours, a method which was originally intended for medical personnel only. Those covered now include not only diagnostic and therapeutic workers in hospitals, together with mass radiographic teams, but industrial X-ray workers, producers and users of radioactive luminous compounds, and all whose work brings them into close association with artificial radioactive products.

All these men and women wear photographic films which are sent to the N.P.L. periodically for examination. The present indication is that the dose received by the total population is about 1 per cent only of that received naturally from cosmic rays, so that the present risk is

negligible both to individuals and to the race. However, in view of the unpredictable expansion of the uses and abuses of atomic energy, the technical experience being gained at the Laboratory is of the utmost importance.

### *Unity of Work at the National Physical Laboratory*

The experience of the Laboratory shows that the categories used to classify its labours—maintenance of standards, long-term research, special investigation, test work—are only valid provided the underlying unity of the scientific subject is never lost sight of. What can best be studied at one time as a subject of long-term research may quite suddenly have to become the subject matter of a special investigation, or even of intellectually unproductive routine testing. The sole arbiter in such cases will be social need. Theoretical or fundamental work of many years may have to be dropped, temporarily at least, because an emergency demands the solution of special problems arising out of it, but, unless that work is resumed at the earliest possible moment the practical efficiency of the Laboratory is liable to suffer.

### *Screw-Threads*

This principle can be well illustrated by the history of screw-threads. It may surprise the layman to learn that the maintenance of standard screw gauges and apparatus for measuring screws is as fundamental a part of the Laboratory's work as the maintenance of standards of length, together with comparators to work with them. For some purposes, of course, close uniformity of screws is not important. But as soon as a precision instrument is required the characteristics of screw-threads become vital and accurate measurement is essential. For industry the most important consideration is that mass production, being dependent on the interchangeability of parts, cannot function successfully unless screw-threads are uniform and accurate.

The Metrology Division, in co-operation with the British Standards Institution, has carried out continuous research on screw-threads ever since the Laboratory was started. During the earlier years the emphasis was laid on discovering the best means of measuring screws. Standard gauges had to be collated, methods of comparing commercially made screws devised, and practical limits of error laid down.

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### *Standardization and War*

This work occupied much time up to the outbreak of the First World War, but that war may be said to have revolutionized the problem. Pure research had to give way to a determined effort to bring engineering practice to a higher degree of accuracy. The testing of screw gauges became of paramount importance; it involved extensive reorganization and increases of staff. By the end of 1915 twelve thousand screw gauges had been tested, and many problems had been disclosed which would require long-term research when that was once more possible. At the time, however, special investigation and routine testing had to come first.

One sentence in the National Physical Laboratory Report reads oddly to-day: 'Even at this early stage', we are told, 'the question of employing women testers was considered, and a number of ladies were interviewed in this connection. It was eventually decided that the introduction of female testers would be likely to lead to objections on the part of some of the gauge-makers, and the scheme was dropped'. It was not long before, in the face of the national emergency, this prejudice was overcome.

A serious situation was revealed by these testings; at the beginning, more than 50 per cent of all screw gauges had to be rejected. Complaints were made that the whole output of munitions was being held up because the Laboratory—a pedantic body—refused to pass gauges which any 'practical engineer' would have accepted.

Fortunately the Laboratory was able to convince the authorities that to accept and issue gauges such as were being submitted to it—some with errors exceeding the total tolerance allowed on the work they were intended to control—would result in confusion and lead to endless disputes with the contractors.

An educational programme had to be carried out before industry was satisfied as to the importance of high accuracy in screw-threads. At the same time the increase of volume—3,000 screw gauges a week by the time of the Armistice—made it imperative to design new and more rapid ways of testing. It is arguable that the work on screw gauges and gauges in general was the greatest contribution made by the N.P.L. to the national effort in the First World War.

With the coming of peace the problem of screw-threads was attacked again on the research level. War experience had shown that commercial

practice was unsatisfactory, and the Engineering Co-ordination Research Board requested the National Physical Laboratory to examine commercial screws, nuts and bolts, with a view to formulating new standards of accuracy.

Relieved from the strain of routine testing, new lines of special investigation were undertaken. Thus the effect of tightening-up on the metal of nuts and bolts was investigated with the co-operation of the Metallurgy Division; the task of convincing industry that, in an age of mass production, gauges were more important than ever was continued by educative publications such as 'Notes on Screw Gauges'.

### *An Obstacle to Allied Co-operation*

Events often move too rapidly for scientific research, especially in its applied and industrial forms. The Second World War broke out before any success had been achieved in tackling the most important of all screw problems—the establishment of an international form of thread.

During two wars co-operation between Britain and the U.S.A. was hampered by the fact that British screws have a Whitworth thread angle of  $55^\circ$ , while American screws have one of  $60^\circ$ . This meant that a vast number of components, both of munitions and of other war apparatus, which might easily have been interchangeable, were not. It is not surprising, perhaps, that this anomaly was not considered important in the early days, seeing that tests showed that the angle of thread in commercial screws often varied by as much as  $5^\circ$  from the standard.

Not until 1945 was much progress made in this matter, but during that year an Anglo-American-Canadian conference on the Unification of Engineering Standards, held in Ottawa, made certain recommendations.

Once more, years of continuous long-term research made it possible for the N.P.L. to carry out a special investigation when that was required. In 1946 two American missions visited Britain to implement a common Anglo-American system of screw-threads. At Ottawa it had been recommended that the three nations should agree on a uniform type with an angle of  $60^\circ$  and a rounded root. It now became necessary for the Laboratory to carry out the investigations necessitated by the

proposed change, and three divisions, Engineering, Mathematics, and Metrology, were involved.

The existing Whitworth form and the proposed new form had to be compared, and it was particularly important to have an estimate of the degree of interchangeability likely to occur during a transition period when both forms might be in use. On the whole, the investigations showed that little loss of fatigue strength would result from certain probable combinations of bolts and nuts of different forms.

With the publication of a specification for the Unified Screw-Thread by the British Standards Institution, this special investigation has reached a successful end; screw-threads will continue, however, to be the subject of continuous long-term research.

### *Routine Testing*

When the National Physical Laboratory was founded with an annual grant of £4,000 from the Treasury, it was clear that an earned income would be required to supplement this sum. Nor was it simply as a means of providing this that one of the stated objects of the Laboratory was the testing of instruments; there was a public service to be performed. The committee responsible for the inception of the N.P.L. considered that a public Laboratory would be of great practical use in testing various forms of measuring instruments which could not previously be tested under any legal authority.

As the scope of the N.P.L. expanded, the types of testing that became possible greatly increased in number; this led to the only policy dispute in the Laboratory's history, when some professional consultants objected to the N.P.L. undertaking tests. In 1907 a committee was set up by the Prime Minister to look into the matter, and it was agreed, as a result, that not only instruments but, under proper restrictions, material too might be tested.

The committee distinguished between contractual and investigatory testing, and stated that any restriction on the latter might hinder the advance of knowledge. It barred the Laboratory from contractual testing but with many important exceptions; for example, where the testing could not be done elsewhere, and where it was for Government Departments or for reference purposes. In any case, the restrictions were not to apply to instruments or to their component parts. A Treasury minute of 1908 approved the committee's findings.

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In 1910 the Kew and Eskdalemuir Observatories, together with their meteorological responsibilities, were transferred to the Meteorological Office; the N.P.L. retained control of the other work which had been carried out at Kew Observatory, including the verification of instruments and the rating of watches and chronometers.

### *Thermometers*

Of the 27,569 instruments dealt with in 1900, 20,476 were clinical thermometers of which only 116 were rejected. For many years the number of these instruments fluctuated around this figure, but a change took place in 1918. The Clinical Thermometer Order, 1918, laid down that all clinical thermometers sold in this country should comply with a certain specification, should be tested at the N.P.L., and should be marked, if accepted, with the Laboratory's monogram. Although this Order is no longer binding, the number of thermometers tested annually remains to-day at the half-million mark, and demands considerable ingenuity in devising apparatus for work on a mass basis.

In 1936 a British Standard Specification for clinical thermometers was issued by the British Standards Institution. This was largely based on N.P.L. practice and adopted a single type as standard. It has a ' lens front ' stem giving a magnified image of the mercury column, and a size of bulb equal to that commonly designated ' half-minute '. To ensure robustness, the stem is required to be not less than a certain diameter. There are other obligatory features, and a maker wishing to use the registered mark ' British Standard ' must submit all thermometers so marked to the Laboratory for testing. Should they pass, they are engraved with the Laboratory monogram.

### *Volumetric Glassware*

In 1917-18 the question of calibrating glass volumetric apparatus was discussed by the N.P.L., the Optical Glassware Department of the Ministry of Munitions, the British Chemical Ware Manufacturers' Association, and the British Laboratory Ware Association, and it was decided that the N.P.L. should undertake the work. Two types of test were arranged: Class A tests for vessels intended to have the highest degree of accuracy, and Class B tests for commercial accuracy.

In 1920 the Laboratory was asked to draw up complete specifications for the glassware used in analysing milk by volumetric methods, and

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for specialized equipment, known as butyrometers, by which, according to the Gerber technique, the percentage of fat in cream and cheese is determined.

In 1921 a Joint Committee for the Standardization of Scientific Glassware was set up as a result of an investigation which showed that much apparatus bought in the open market, including German material, was seriously inaccurate. One of the first acts of this committee was to recommend the use of the litre and millilitre as standard units, instead of the cubic centimetre.

The 1924 Report notes the increasing amount of 'biochemical and medical apparatus submitted for testing'—a certain sign of the coming rapid advance of these biological sciences.

In 1927 the Committee on Dairying of the Imperial Agricultural Conference endorsed the suggestion of the National Physical Laboratory that if greater uniformity was practised throughout the Empire in the official specifications for volumetric glassware used in testing milk and milk products, results of great scientific value would be attained and the task of glassware manufacturers would be made easier. The Empire Marketing Board's Dairy Research Committee drew up memoranda on the subject, and both Eire and the Union of South Africa issued regulations insisting that all glassware used for these purposes should be tested at the N.P.L. This helped to increase the amount of volumetric glassware sent to be tested at the Laboratory by 50 per cent in 1928, while requests for test pamphlets came from 21 different foreign countries.

### *Taximeters*

A useful item of routine testing carried out by the National Physical Laboratory is the testing of taximeters. In 1907, and as a new object in daily life, it was carefully described in the Director's Report: 'These instruments are in part distance meters and in part time meters, and they combine these functions in such a way that, in the motor cab type, if the cab is stationary or travelling at less than six miles an hour, the mechanism immediately actuating the fare wheels is driven by a clock, so that 8d. is shown on the dial for the first ten minutes or part thereof, and 2d. per two and a half minutes, or part, thereafter. If the rate of travelling exceeds six miles an hour, the fare mechanism is actuated by a flexible transmission gear connected to the cab wheel.'

## SPECIAL INVESTIGATIONS AND TESTING

. . . The mechanism is thrown into action by the lowering of a flag, which also indicates that the cab is hired '.

In the first year, 80 per cent of meters failed to pass the test and were refused the N.P.L. seal. Next year a special testing office had to be opened in the Lambeth Road at the corner of China Walk. The amount of test-work was smaller than was anticipated because the horse-cab proprietors would not take up the new fangled machine.

In 1908 the meters had to be redesigned because the Commissioner of Police had reason to believe that the hirers of taxis were insufficiently safeguarded against overcharges. The N.P.L. testing laboratory introduced a vibrating support for the meters under test, since in some types taxi-vibration had the effect of jerking up the fare. In 1911 a discreet mention is made of two members of the Laboratory staff having to give evidence in the Central Criminal Court in a case involving a number of 'damaged taximeters'. In 1913 there was a sudden great reduction in the numbers of meters received, owing to a strike of taximen. In 1920-21 inflation, which sent the fares up, was responsible for a considerable increase of work. In 1928 a further rise in fares necessitated an increase of staff to cope with 6,000 meters in four months. In 1939 a drop is recorded 'owing to the number of taxicabs requisitioned for use with the Auxiliary Fire Service '.

### *Growth of Test Work*

The testing of clinical thermometers is typical of the duties taken over in the early days from Kew Observatory, but they represent a very small part of the modern testing services of the Laboratory.

By 1938, on the eve of another war, these services had grown out of all recognition. Whereas, a generation before, testing was little more than a legacy from Kew, now almost every division was called upon to devote some of its time to this work. It was beginning to be clear that eventually a separate Test House to deal with routine matters would be required.

Test pamphlets describe the types of test the Laboratory is equipped to carry out, and the fee that is charged for each. Thus the Physics Division issued three such pamphlets covering tests in Heat, Radiology, and Acoustics.

Since 1938 there has been an accelerated growth of the testing field, and this has led to a reorganization of the Laboratory's structure. A

Test House now functions as a self-contained unit, but many forms of testing are so closely allied to research that there can never be a complete separation of one from the other.

Compared with many of the more spectacular functions of the N.P.L. routine testing is apt to seem unrewarding. Yet a moment's thought will convince us of the great benefit which the community derives from it. Even such minor everyday securities as being able to sit in a taxi without fear of being cheated, or knowing that a child's temperature is really normal if the thermometer says so, or that the milk has as much cream in it as it should have, are well worth while. The N.P.L. inspires confidence because it has built up a reputation for scrupulous accuracy.

## CHAPTER VII

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### The Future

Bushy House, the old Royal residence, with its gardens, has now become a corner of a fifty-acre estate on which sixteen major and many minor buildings have been constructed. Even more important, perhaps, the N.P.L. has sent out daughter colonies as branches of research, cradled at Teddington, have needed more and more room for expansion.

What of the future? Judging from the first fifty years of its history it will be one function of the Laboratory to nurture branches of applied science which are as yet unborn. We have only to consider some of the applications of science which were virtually untaught fifty years ago, to appreciate how difficult it is to see, let alone plan, ahead; for there is no reason to suppose that the next fifty years will bring less major technical and scientific advances than the first half of the century.

In 1901 there was no reason to suppose that the aeroplane would develop into a dominant factor in everyday life. Though the mysterious Hertzian waves intrigued physicists, the future importance of radio was quite unsuspected. The thermionic valve was not thought of; radium

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was a curiosity only; building was hardly considered as a science, and roads were much as Macadam had left them.

Yet in the last fifty years most of these branches of applied science have grown to maturity at the N.P.L., and some have proved too expansive for the parental roof. Fundamental aerodynamics remains with the N.P.L., but other research stations have taken over the more immediate fields of aviation research.

Radio has grown up and is about to stand on its own feet, although the connection between Teddington and the New Radio Research Laboratory when it is built will remain very close.

Some of the work carried out by the Building Research Station and the Road Research Laboratory on building and roads was begun at the N.P.L. The Hydraulics Research Organization and the Mechanical Engineering Research Organization are two more research organizations of D.S.I.R., some of whose origins may be found in N.P.L. work.

Yet in none of these greatly enlarged scientific enterprises has the function of the N.P.L. ceased. There still remains a large body of work to be done at Teddington in studying the fundamentals on which future advances must be based. It is impossible, for several reasons, to foresee a time when this work will cease.

First, the Laboratory is an invaluable storehouse of equipment, techniques and personnel and these could not be spared without serious loss to the nation's scientific capital. Second, science is a unity in spite of the multiplicity of its facets, so that sooner or later the expert, in any particular field, will find himself at a loss without the aid of colleagues working in fields remote from his own. Third, the Laboratory is a *national* scientific institution to which the Commonwealth and even many foreign countries look for guidance and advice. It must continue to co-operate, as it has always done, in scientific and technical development in the Commonwealth countries. Scientists from Australia, Canada, India, New Zealand, Pakistan and South Africa have received training, and have carried back to their countries techniques developed at Teddington. This will continue.

Nor is it only within the Commonwealth that the Laboratory is an influence. After the last war, especially, it assisted scientists from many countries, particularly those liberated from enemy control or otherwise impoverished scientifically by war's devastation.

## NATIONAL PHYSICAL LABORATORY

There is no doubt that, when the N.P.L. celebrates its centenary, the programme of research it will then be pursuing will be found to be as much changed from that which it is pursuing today as its current programme is changed from that of its earlier years. But a big scientific organization, possessing large and expensive equipment used by specialists, cannot make sudden changes in its direction of advance. Rather, progress is effected by constant adjustment to present and future requirements. The process of adjustment will continue to provide the maximum of scientific information required by Government and industry, now and in the future, though future requirements cannot yet be foreseen in detail. Moreover, the N.P.L. will have a special role to play in the more effective organization of information about scientific research which is a major concern of all scientists.

In a recent Presidential address to the British Association, Sir Henry Tizard, G.C.B., F.R.S., stressed the need for making existing scientific knowledge known more rapidly and effectively to those who are in a position to use it. The N.P.L. has always regarded the spreading of its knowledge as a major concern; in the future this task will clearly take an even more important place.

In this connection it may well interest scientists fifty years hence to look back on the Jubilee Exhibition of the N.P.L.'s work held at the Royal Society's rooms on January 30th, 1950. Pride of place was taken by exhibits representing the Laboratory's most important work—the maintenance of the fundamental standards of mass and length, and of derived standards; particularly interesting were those showing the movement from material to physical standards, as in the cases of the standards of length and light. The method of making precision block gauges and the accurate measurement of angles was demonstrated, as was also progress in the design of engineers' measuring instruments, and such recent developments of measuring methods as the continuous measurement by an air gauge of materials in thread or wire form. Work on fluid flow was represented by exhibits of Stanton's work on compressible flow; models of cargo vessels and illustrations of the laminar and turbulent flow of water around ships' hulls; the development of wind tunnels and wing shapes; work on aircraft stability and control, and on flutter; and examples of investigations in the high-speed laboratory.

Throughout the Exhibition the work of the National Physical

## THE FUTURE

Laboratory in the development of instruments was evident, and exhibits illustrated work on heat-transfer problems; the measurement of temperature; the precise calibration of microphones; and radiation measurement in connection with the protection of radiological workers. Larger equipment showed developments in the technique of the measurement of creep of metals over the past thirty years, and one item of the Laboratory's war work was illustrated by a prototype of bomb disposal apparatus.

Work of general importance, both in industry and the home, was illustrated by exhibits on heat-transfer investigations, including problems relating to refrigerated transport; sound insulation and noise reduction; the development of light alloys and research on colorimetry. Work on high-voltage measurements, devices for frequency measurement, and instruments for the investigation of dielectrics were shown, as well as illustrations of the progress of research in radio-wave propagation and direction-finding, and radio aids to meteorology. Progress in work on the development of an automatic computing engine was illustrated by a simulator, using relays instead of valves.

An exhibit organized by the Test House showed the testing and certification for industry of instruments such as barometers, hydrometers, thermometers, volumetric glassware, taximeters and petrol jets.

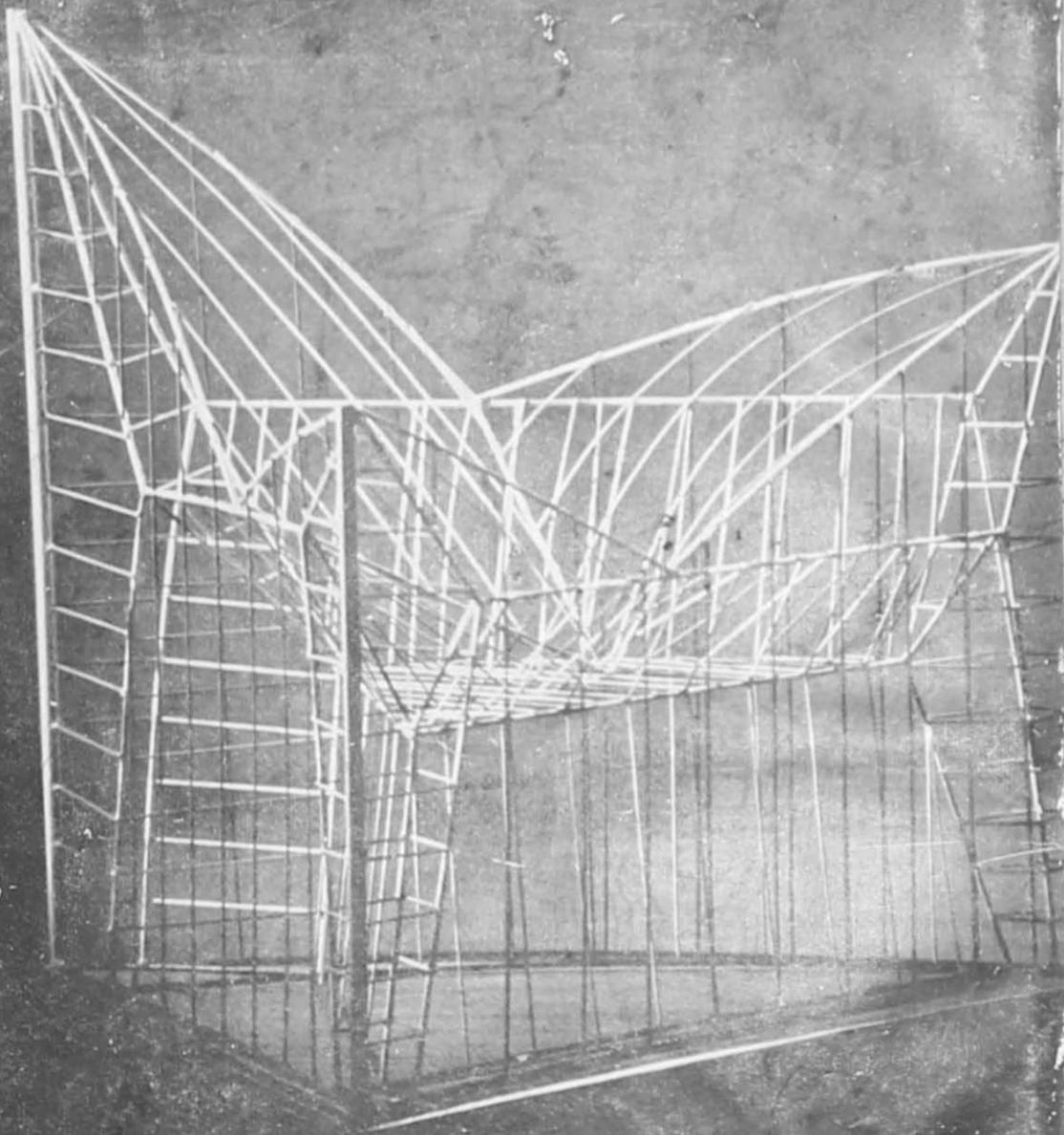
This is how the first fifty years of work was summed up and presented to the general scientific public of 1950. Many of the items will be relevant for a like occasion in A.D. 2000, but there will be spectacular new developments.

One of the clearest indications of the future is provided by the number of vigorous new scientific developments which are still in their infancy. No intelligent forecast about probable future trends in the applications of Science to industry can afford to neglect the fields of applied electronic technique, control mechanisms, and high-speed computation. The N.P.L. is now cultivating these fields among others.

The fact that industry today has accepted the implications of science, and many of the older forms of applied science, is largely the fruit of the N.P.L.'s work in past years. We should, however, remember that much that is now a commonplace of industrial practice seemed as

## NATIONAL PHYSICAL LABORATORY

remote from general usefulness fifty years ago as some of these new researches may seem today. It will require the same persistent attention to the practical side of mathematical and electronic techniques to familiarize industry with their value, as was needed in the past with matters which are now very familiar. And the National Physical Laboratory will continue, in the future as in the past, to be the champion of accuracy in measurement.



Above: A model built to show changes that take place in a series of alloys on heating or cooling

Front cover: The High Voltage Laboratory where surge voltages as high as 2,000,000 are produced