Research, Development and the Maintenance of Standards in Heat at the National Standards Laboratory*

A. F. A. Harper

Introduction

In this address I shall attempt to review for you the work of that part of the National Standards Laboratory with which I have been associated since 1939. In doing so I hope to give you by illustration some understanding of the functions and activities of a standards laboratory so that you will be able the better to appreciate just what it does and how and why it does it. I hope too that in the wide variety of topics I shall be touching upon, each one of you will find something of particular interest.

A further reason for selecting this topic is that the National Standards Laboratory is about to "come of age" and this seems a good time and opportunity to review from whence we have come and to contemplate whither we may be going.

I wish to stress at the very outset that most of what I will be describing has been done by my co-workers: in many cases I have been little more than an interested onlooker. I am indebted to the various members of the Heat Section, both past and present, for their contribution to its record. I also wish to pay sincere tribute to my erstwhile Chief, Dr. G. H. Briggs, a member of this Society, for his guidance and direction in connection with the work I shall be describing.

The National Standards Laboratory

The decision to establish the National Standards Laboratory was made in 1937 in implementation of a recommendation made by a Committee, the Secondary Industries Testing and Research Committee, which had been charged with the task of advising how the Council for Scientific and Industrial Research (as it was then called) could best assist the development of secondary industries (Commonwealth of Australia, 1937). It was not surprising that such a recommendation should have been made, for similar standards laboratories exist in almost all industrially developed countries. They have taken very different forms however; in some cases an organization which is little more than a national testing and calibrating laboratory has been established while in others this aspect has been very much subservient to the activities of the laboratory in scientific research, often of a fundamental nature.

In a country such as Australia, with a relatively small population, isolated and not yet mature industrially, a national standards laboratory has, I believe, a wider function to perform than the equivalent laboratories of say Great Britain, U.S.A. or Canada. As a corollary to this we must expect that with the further development of Australia the functions of the laboratory should change.

Aspects of our activities in these initial years which illustrates this lack of development have been the need to take our standards right to the ultimate user—e.g. by the calibration of equipment actually in use in industry—whereas in more industrialized countries only sub-standards would need to be supplied; by the pressure to solve ad hoc industrial problems which would be the province of Research Associations in Great Britain; and by the need to provide assistance in fields such as medicine, biology, veterinary science and agriculture in which physical assistance is not yet readily available.

The functions a standards laboratory needs to fulfil in this country, at least for the present, seem to be as follows:

(i) It must maintain the national standards for the measurement of physical quantities of importance to industry, commerce and science. These quantities embrace much more than the "weights and measures" of early legislation—length, volume and so on. They include, for instance, temperature, viscosity and humidity, to which I will be referring later. In fact, a standards laboratory will usually be called upon to give guidance as to what national standards of measurement are required by the country. This is an important function if trade and commerce are to be protected and yet not hampered. In Australia this is in process of being worked out now. An Act, the Weights and Measures (National Standards) Act (Commonwealth of

* Presidential Address delivered before the Royal Society of New South Wales, April 6, 1960.
Australia, 1948), has been passed to provide for national standards of measurement in place of the few and not always consistent State standards previously in use. Regulations are being prepared to cover the various physical quantities for which it seems it would be beneficial to have Commonwealth units and standards of measurement. When promulgated these will become the sole legal units and standards for use in transactions involving those physical quantities.

(ii) A standards laboratory must also concern itself with the development of improved standards and improved methods of measurement in terms of them. A standard can seldom be left static—as greater accuracies become available the value of still greater accuracies become apparent. This calls for a type of scientific work to which not many are suited. To increase the accuracy of a measurement by an order of magnitude usually requires also an increase of the complexity of the equipment by an order of magnitude. Special staff, accumulated over the years, are the backbone of a standards laboratory, for members are needed who have the patience for meticulous work and yet a flair for seeing worthwhile departures from long established ways of doing things.

(iii) Calibrations must be made, in terms of the standards maintained: no standard is of any use until it is disseminated to those requiring to use it. A standards laboratory should go further than this and should help to foster calibration services which will be more directly accessible to industry. These will be provided in testing laboratories and in the industrial concerns themselves. Fortunately, in Australia a Government sponsored body has been established for just this purpose: the National Association of Testing Authorities, and the National Standards Laboratory is doing a good deal to further the objects of this Association by the service of its members on N.A.T.A. Committees, by calibrating equipment, by providing technical assistance and advice in the establishment of testing laboratories and by training personnel for work in them.

(iv) In a somewhat similar way a standards laboratory has to be able to assist Committees at the Standards Association of Australia with specialized knowledge relevant to existing or projected specifications and must be prepared to represent Australia on committees of the corresponding international body, the International Standardisation Organization.

To fulfil the foregoing functions it is necessary to maintain an active organization of high scientific standing. If this is not done the laboratory will soon become moribund for the very nature of its work can, or the wrong staff, exert a strong stultifying influence. Yet I hope to show that even in fields where all development might be thought to have ceased a generation ago an original approach can break through, in an exciting way, into new territory.

To have a virile laboratory of high standing calls for the continued recruitment of good staff, for a flow of personnel through the laboratory should be expected and indeed encouraged because in this way the specialized knowledge of the laboratory can be more widely disseminated. Experience has shown elsewhere and here that to recruit staff of the requisite calibre it is necessary to provide them with research opportunities and that the position is further improved if the laboratory can gain recognition not solely as a standards laboratory but also as a physical research centre. To this end an active research school should be maintained, not necessarily in a field closely associated with the standards activity. In the Heat Section of the Laboratory this has been done in the fields of low temperature and solid state physics.

The Heat Section

The Heat Section—which as will soon become apparent by no means restricts its activities to “heat”—is roughly half of the Division of Physics, which in its turn is one of the three Divisions of C.S.I.R.O. which comprise the National Standards Laboratory. The others are the Divisions of Metrology and Electro-technology.

The Section’s major fields of activity are concerned with temperature, humidity, viscosity, low temperature physics and solid state physics. Other activities include aspects of medical physics and the study of the thermal properties of materials.

Because many of its fields of work are of direct concern to industry this Section has always endeavoured to maintain a close liaison with industrial personnel. Nearly 200 technicians, drawn from every State in the Commonwealth, have passed through its training courses and many thousands of problems have been dealt with either by advice or investigation. This close contact with industry was established very early in the history of the Laboratory because of the exigencies of the War. Lack of alternative facilities made it necessary for us to undertake the calibration of furnaces and
Temperature measuring equipment used for defence work. It was soon realized that it was to the advantage of the Laboratory staff as well as of industry for us to undertake this work as it provided valuable insight into problems of practical thermometry and pyrometry. Accordingly this facility has been maintained to a limited extent, although every encouragement has been given to industry to become self-sufficient in these matters. Inevitably this class of work should ultimately pass entirely to laboratories such as those registered with the National Association of Testing Authorities, but, as this happens, I expect as a parallel development that there will be a greater awareness of the potentialities of the Laboratory for the solution of more recondite problems.

**Temperature**

The statutory functions of the Section in connection with temperature measurement involve the establishment and maintenance of what is known as the International Temperature Scale (I.T.S.) (Comite International des Poids et Mesures, 1948). This is a scale of temperature adopted by international agreement in 1927 (Septieme Conference General des Poids et Mesures, 1930) to provide a uniform means for measuring temperatures throughout the world, which would conform with the thermo-dynamic scale of temperature as nearly as was practicable at the time. Such a scale is clearly an empirical one but it is only rarely, as in the measurement of the thermo-dynamic constants of chemicals, that differences from the thermo-dynamic scale are significant. From the nature of the scale the lines of its further development are not difficult to foresee; one can expect attempts to improve its internal consistency, to extend its range and to improve its conformity with the thermo-dynamic scale. All three of these aspects have been and are still being actively pursued throughout the world. Two of them are currently receiving attention here.

The Scale is defined by allocating temperatures to several so-called “fixed points”, such as the melting point of ice, the boiling points of oxygen and sulphur and the melting points of silver and gold, and by prescribing means of interpolation (and extrapolation) between these temperatures, e.g. by the use of platinum resistance thermometers in which the physical characteristics of the platinum and the interpolation formula to be used are laid down.

The accuracies of reproducibility of the initial scale were of the order of 0·01 deg. C at —190°C, the lower limit of the Scale, 0·001 at 0°C, 0·01 at 400°C, 0·1 at 1,000°C and 2 deg. C at 2,000°C. Inevitably these have proved inadequate. This may seem somewhat surprising for they are quite high accuracies, but it must be borne in mind that it is rarely convenient to make practical measurements of temperature directly in terms of equipment of the type used to realize the I.T.S. so that one or more intercomparisons are usually involved, each with its consequent lowering of accuracy. In certain measurements the accuracies quoted are directly significant; thus in the sale of chemicals purity is often the criterion for the price and is judged by melting point. We were consulted on just such a case not long ago where a few thousandths of a degree meant many thousands of pounds.

Some improvements have resulted from subsequent minor changes in the definition of the Scale: thus the platinum used for platinum resistance thermometers must now be of greater purity than was originally required. The Scale has been terminated at —183°C because below this it rapidly departs from the thermo-dynamic scale, and the approximate Wien law of radiation used for high temperature measurements has been replaced with the exact Planck law.

Greatest precision, in the numerical sense, is usually required in the vicinity of room temperature and this has received a fillip from the replacement of the ice point with the triple point of water (0·010°C). It is not at all difficult to realize with this latter point a temperature which is constant and reproducible from cell to cell to 0·0001 deg. C.

The position is not as satisfactory at the boiling point of water, the second of the fundamental points used to define the thermo-dynamic scale. This has the weakness of all boiling points, that they are markedly sensitive to pressure—a change of 1 mm. of mercury in the pressure changes the boiling point of water by 0·04 deg. C. The position is aggravated by the difference in density between the vapour and the atmosphere above the vapour so that any variations in the condensation line will result in a change in the pressure at the point in the vapour at which the temperature is being measured. The other major problem is the establishment or measurement of the pressure at which boiling is occurring. Each standards laboratory in which the I.T.S. is realized has to face up to this problem and will meet it in its own particular way. In all cases where high accuracy is desired a controlled atmosphere will be used, usually of hydrogen or helium to
take advantage of the sharp condensation line which results from the high thermal conductivities of these gases. The pressure will be either adjusted to one standard atmosphere or kept near it and measured. Such a system, with which we hope to obtain pressures accurate to 0.001 mm Hg, is now nearing completion in the Heat Section. The mercury of the manometer is contained in a stainless steel system kept at constant temperature. The position of the upper and lower mercury surfaces relative to flat plattens separated by precision end bars is determined by measurements of electrical capacitance. Space above one mercury surface will be continuously evacuated and over the other will be filled with helium. The boiler (hypsometer) to be employed with this is already in use. It has been modelled on one developed at the National Bureau of Standards, U.S.A. (Stimson, 1955), and found to give very satisfactory results.

As with many other aspects of the work of the National Standards Laboratory, advantage can be taken in this case of the specialized techniques developed in other parts of the Laboratory. We are utilizing the facilities of the Division of Metrology for the construction and measurement of precision end bars and very accurately lapped flat surfaces, of the Division of Electrotechnology for the very precise comparison of electrical capacitances and of our own Section for accurate temperature control.

Although the completion of the manometer will, it is hoped, increase the accuracy of realizing the steam point to 0.0002 deg. C, this will clearly always be a less satisfactory fixed point than the triple point of water. It would be very convenient if it could be replaced with a satisfactory freezing point. Benzoic acid (freezing point 122° C) has been suggested (Schwab and Wickers, 1915) but has not proved sufficiently reproducible. Organic materials are usually at a disadvantage because of low latent and specific heats and poor thermal conductivity, as was found by us in some investigations on the use of diphenyl ether as a secondary fixed point located conveniently near ambient temperatures at about 28° C. An accuracy of better than 0.01° C proved very difficult to achieve.

The present International Temperature Scale covers the range from 0° to 630° C by the use of platinum resistance thermometers calibrated at 0°, 100° and 444.6° C. These calibration points are not ideally spaced so it is worth contemplating the replacement of the steam point (100° C) with a freezing point at say 150° C. Indium which melts at 156° C is a possible substance. We have commenced work to investigate the suitability of this.

If the steam point is a somewhat unsatisfactory boiling point, the boiling point of sulphur (444.6° C) is even worse, for here, the chemists tell us, we are dealing with a molecule which can adopt many forms: S_2, S_4, S_8 etc. and which will slowly change from one to the other with time in a non-equilibrium thermal environment. Fortunately there is a melting point conveniently close to the sulphur point, namely zinc (419.5° C), and a good deal of work is proceeding in various standardizing laboratories throughout the world on investigating this (Preston-Thomas, 1955). We have found it to give temperatures repeatable to 0.0002° C in agreement with the findings of others and there seems little doubt that the zinc point will replace the sulphur point in a future revision of the I.T.S.

A word of warning is called for in the use of melting points in place of boiling points, however, for while they are insensitive to pressure, they can be very sensitive to impurity, unlike the condensation temperature of a vapour. In our work on zinc and indium (and also on cadmium which we are examining for use as a secondary fixed point) we are finding it necessary to resort to zone melting refining techniques to obtain the purities we desire.

The extrapolation of the I.T.S. from about 450° to 630° C is not particularly satisfactory and the possible use of a higher melting point as a fixed point may repay investigation. The temperature 630° C is indeed the melting point of antimony but this has not proved to be a very satisfactory fixed point, perhaps because of the difficulty of obtaining it in a pure state. An alternative is that if the stability of resistance thermometers at high temperatures could be increased, the upper limit for resistance thermometry could be extended to the melting point of silver (960.8° C) or even gold (1063° C). In the latter case the thermocouple range of the I.T.S. would be eliminated.

At low temperatures the cessation of the Scale at −183° C (the boiling point of oxygen) has not been a serious limitation because of the relative paucity of technological interest at temperatures much below this. However, the increasing use of liquid helium and liquid hydrogen and of pumped liquid nitrogen for scientific purposes is leading to technological applications and is making the extension of the Scale to lower temperatures desirable. Growing interest in rocket propulsion and interplanetary
and interstellar space investigations must inevitably lead to an increased need for reproducible measurements at low temperatures.

The Scale was only cut off at $-183^\circ\text{C}$ because the interpolation formula used with platinum resistance thermometers gives results which diverge rapidly from the thermo-dynamic scale below this temperature. Difficulties have been experienced by a number of workers in obtaining a reproducible scale in terms of the electrical resistance of platinum at these low temperatures; but in some recent work (Lowenthal et al, 1958, 1960) we have been able to show that these difficulties can be overcome by suitably taking account of peculiarities in the resistance-temperature characteristics of platinum and a method has been given for defining a satisfactory scale, reproducible to $0.005^\circ\text{C}$ down to $20^\circ\text{K}$ ($-253^\circ\text{C}$). Below this temperature the vapour pressures of hydrogen and of helium are possible means of defining a scale. Platinum resistance thermometry would not be suitable because of the low resistances involved.

In the upper region of the I.T.S. where temperatures are measured in terms of the emission of radiation by the hot body the position is again interesting. Here the measurements are usually made with what is known as a disappearing filament optical pyrometer. It is operated by the observer determining the current of a lamp filament at which its luminance is exactly the same as that of the body on which the instrument is sighted, so that the filament "disappears" against the background. The measurement is made in more or less monochromatic light. One of the disadvantages of the method is that the filament rarely does disappear completely owing to variations in the luminance of the filament across its width. Work done some years ago in conjunction with the Light Section of the Division of Physics (Giovanelli and Kemp, 1950) showed that this could be overcome by taking advantage of the change in polarization of the light with its angle of emission.

More serious is the fact that the answer is significantly dependent on the colour vision of the observer since it is not usually practicable to make observations in truly monochromatic light. In any case the subjective criterion of whether a filament has disappeared is not a very satisfactory basis for accurate measurement. In some work recently undertaken in the Section to set up with greater accuracy this portion of the I.T.S., errors resulting from this source were so considerable that it was necessary to have each of eight observers take over 90 observations under carefully controlled conditions to obtain an accuracy of setting at the gold point of $+0.25^\circ\text{C}$.

In an endeavour to obviate this source of trouble work is proceeding on the development of an instrument which will eliminate the effect of the human eye on the settings made. It is simple in conception but less simple in execution. It consists of a photoelectric device which scans across the filament and background and by the use of a suitable phase sensitive electronic detector gives a null reading on a sensitive meter when the luminance of the centre of the filament is the same as that of the hot body being observed. Edge effects of the filament are thus eliminated. This instrument has proved itself to be very sensitive; individual settings can be made to $0.05^\circ\text{C}$ (at about $1100^\circ\text{C}$) where for a trained human observer the mean of ten successive readings would have a standard deviation of about $2^\circ\text{C}$. Some difficulties have been experienced in obtaining satisfactory long term stability with the instrument but it is believed these have now been overcome.

The various lines of investigation or development in relation to the I.T.S., referred to above, indicate that this is a field in which there are plentiful opportunities for worthwhile work. Numbers of other investigations have been made or are awaiting attention as opportunity occurs; the responses of resistance thermometers at low temperatures have been studied (Lowenthal and Harper, 1960); we have participated in international intercomparisons of the realization of portions of the I.T.S. and a study has been made of factors affecting the accuracy of optical pyrometry (Mortlock and Harper, 1953).

With the completion of the photoelectric optical pyrometer a whole new range of investigations will be opened up, for the examination of phenomena which affect visual optical pyrometry and yet are on the border line of optical pyrometry and of the triple point of neon ($27^\circ\text{K}$) as a possible calibration point for an extended I.T.S. (Lowenthal et al, 1958).

Other investigations planned include studies of the reproducibility of the melting point of tin ($232^\circ\text{C}$) and cadmium ($321^\circ\text{C}$) to examine their potentialities as secondary fixed points and of the triple point of neon ($27^\circ\text{K}$) as a possible calibration point for an extended I.T.S. (Lowenthal et al, 1958).

The calibration of instruments in terms of the I.T.S. is often effected relative to an intermediate substandard which is not itself an instrument of the type covered by the I.T.S. specifications. Thus liquid-in-glass thermo-
meters, unless they are to be calibrated to the highest possible accuracy, are compared with other liquid-in-glass thermometers which have in their turn been calibrated against I.T.S. resistance thermometers. This, and our natural concern with the types of measuring equipment in practical use and submitted for calibration, means that attention must be given to the limitations of such instruments, to possible ways of improving them and to finding ways of solving unusual problems of temperature measurement or control.

Two of the matters of this type investigated have been the effect of strain on the thermoelectric properties of metals (Mortlock, 1953) and factors affecting the stability of liquid-in-glass thermometers.

Because thermometers are so widely used by all scientists it might be of interest to mention explicitly one of the findings of the latter study. It is well known that with time the volume of the bulb of a thermometer alters, giving rise to what is known as secular change in the thermometer. This is usually allowed for by taking readings from time to time at a fixed temperature such as the ice point and correcting for the observed change. If the thermometer has recently been heated the bulb will not immediately return to its initial volume so a further change will be superimposed on the secular change; they may be of opposite sign. This transient effect will disappear at room temperature in a more or less exponential manner. If the best accuracy is desired from thermometers it is usual, therefore, to measure the ice or other reference point after the thermometer has been left resting for at least a couple of days. This has been our practice for many years. Despite this precaution the measured ice points of some of our best secondary standards were found to behave in a rather irregular manner, even when the thermometers were of such a range that they were never heated above say 30°C. These variations amounted to as much as 0.01°C for thermometers graduated in 0.02°C. Our first reaction was to blame the ice points themselves or stiction of the mercury of the thermometers, but further study showed this was not the cause. The answer became apparent as soon as we tried storing the thermometers at constant temperature (0°C) for 48 hours or so before measuring their ice points. Immediately the ice point corrections became virtually constant, indicating that the previous variations had been due to variations in ambient temperature during the so-called "resting" period.

The further we study the behaviour of liquid-in-glass thermometers the more convinced we become that if their apparent accuracy is to be achieved, they must be used with a very full understanding of their idiosyncrasies and previous thermal history.

The Section is constantly being approached with requests for assistance in the solution of unusual problems of temperature measurement or control. Often special instruments have to be devised or special techniques evolved. Examples are the design of a resistance thermometer for measuring, in the field, the rectal temperatures of cattle; and of another resistance thermometer for measuring the temperatures of estuarine muds in connection with oyster studies. Recently a request was received for measurements of the temperatures of biscuits as they pass at high speed through a 300 ft. baking oven; and a somewhat similar problem of measuring the temperatures of oil drums as they pass, after painting, through a 200 ft. furnace was solved some time ago.

Often apparently simple enquiries can lead into strange by-ways. One such case was when a request for the loan of a thermocouple resulted in our becoming involved in that fascinating development in medicine known as hypothermia—the lowering of body temperature for medical purposes.

By such a lowering of temperature the metabolism of the body is slowed down so that its need for oxygen is reduced and the blood supply to the brain can be stopped for ten minutes or so without the production of permanent injury whereas at normal temperatures this could only be done for about three minutes. It soon became apparent to us that the physical problems involved in cooling a human patient from the normal temperature of 37°C down to say 30°C, holding him at that temperature perhaps for several hours, and then bringing the patient back to near normal temperature, went far beyond the comparatively simple measurement of his temperature. The heat to be removed is of the order of a million calories. In an interesting collaboration between medical men, engineers and ourselves equipment and techniques were developed which allowed surgery to proceed in parallel with the removal (or provision) of heat so that the patient's temperature would be under control at all times (Cass et al., 1956). This equipment has been used on well over a hundred cases, mainly children suffering from cardiac defects, with very satisfactory results. The simple request for a thermocouple has taken us still further, however,
for it has brought before us other physical problems associated with this type of surgery.

There are many operations for which the ten minutes provided by hypothermia would not be sufficient, and for these either much lower body temperatures must be used or a machine must be provided to maintain the circulation of oxygenated blood while the heart is stopped—a so-called heart-lung machine.

The pump to circulate the blood is comparatively straightforward although it has to meet quite stringent requirements. It is with the oxygenator that the ideal has proved the hardest to attain, as is indicated by the many different models designed. The problem is to expose to oxygen a sufficient number of the blood corpuscles passing through the unit to be able to supply the patient with an adequacy of arterial-type blood. The demands, of course, may be reduced by combining hypothermia with the extra-corporeal circulation, as can easily be done.

Most oxygenators tend to copy the human lung by spreading the blood out on a large surface area. This tends to result in a large unit which requires a good deal of blood to prime it—a serious disadvantage, and particularly so if the techniques are to be applied extensively to newborn children in need of assistance for the first few hours or days of their lives.

In an endeavour to overcome these difficulties we have adopted a new approach to the problem. In most of the large-surface type oxygenators those corpuscles exposed to the oxygen spend much longer so exposed than is required, because the process of oxygenation is almost instantaneous. This tends to increase the size and hence the priming charge unnecessarily. In the device we are working on the blood flows down a screw-like helix as a stream. It is hoped that by adopting a suitable shape for the helix "thread" the internal circulation of the stream will be such as to bring virtually every blood corpuscle to the surface for the brief time required for its oxygenation. The method undoubtedly works but we are unable to say yet whether it will have a high enough efficiency to provide the compact, low priming charge oxygenator desired by our medical collaborators.

The activities of the Section on temperature measurement represent its major effort in standards work and provide its closest industrial connections. Each year over 300 Certificates and Reports are issued on calibrations and tests performed in this field and a great deal of other work which does not give rise to formal reports is undertaken. In parallel with this, improvements in the facilities for the realization of the International Temperature Scale and for measurements in terms of it, and research in the field of temperature measurement and control are constantly in progress.

**Hygrometry**

Humidity, in the meteorological sense, has long been recognized as a quantity of significance for our comfort and wellbeing and of prime importance in agriculture and animal husbandry. Industrially we know that it was a factor in determining the location of spinning and weaving mills before the days of air-conditioning. In none of these cases has a precise knowledge of humidity been of much interest. There are other industries, however, such as the food processing, photographic, tobacco, sugar and printing industries in which tolerances of humidity or its related quantity, moisture content, can become quite critical. Other special cases exist in which more difficult measurements of humidity are required, as in the checking of the moisture content of the breathing oxygen for pilots to ensure there will be no risk of ice blocking the control valve, or in the control of the atmosphere of furnaces used for the surface carburization of steel to harden it. Scientific investigations of innumerable kinds call for a good knowledge of the humidity, often under unusual conditions. In fact, one of the characteristics of work in hygrometry is the wide variety of circumstances under which measurements are required and the correspondingly wide variety of instruments which have been developed. The majority of these are empirical and many have been crude in the extreme. It is not my purpose to review such instruments here, however.

While the work of the Section in hygrometry includes the calibration of a certain number of instruments for use as sub-standards, by far the greater part of the effort is devoted to research and developmental activities. We believe that if improved methods of measuring, recording and controlling humidity can be provided then industry will in time learn to take advantage of the additional accuracy and control thereby made available.

Over the years particular attention has been devoted to four basic types of hygrometer, one or other of which is applicable to almost any humidity measuring problem. The work has in all cases gone a good deal deeper than the mere development of an instrument.
The most commonly used instrument for the measurement of humidity is the wet and dry bulb hygrometer—the "psychrometer". This semi-absolute instrument has the disadvantage that the response of its wet thermometer is dependent on air velocity unless this velocity is greater than about 10 ft. per second. A far more versatile instrument is obtained if the thermometers are replaced with thermocouples (or a differential thermocouple). An investigation of the basic characteristics of such instruments revealed that if fine wires were used for the thermocouples, then the full depression of the temperature of the wet junction relative to that of the dry could be obtained with an air velocity of only 0.5 ft. per second (Wylie, 1949). The instrument obviously lends itself to remote reading.

A second instrument which will be familiar to most is the dew point hygrometer. Anyone who has used this instrument will know that the detection of the presence of dew on the surface is usually so difficult that very great care is needed if the temperatures for appearance and disappearance of the dew are to agree to within 0.1°C. Photoelectric detection of the formation of the dew leads to an appreciable increase in the precision of measurement. Such an instrument has been made automatic by causing the photo-current to control the temperature of the condensing surface. This instrument is particularly well suited to recording automatically the humidity of a stream of gas.

Each of the above instruments has the disadvantage that it requires a largeish sample of the gas whose humidity is to be determined and by its operation adds or removes water from the gas studied, i.e., affects the conditions being measured. There are many problems in which a humidity "probe" is required for measuring the conditions at a point without significantly affecting these conditions. Typical of the many such cases on which we have been consulted is that of measuring the humidity in the fleece on a sheep's back. I understand this was required in connection with the following problem: when a female louse on a sheep decides to lay an egg it leaves the sheep's skin, climbs out along the wool fibre and at a certain place turns around, lays the egg and crawls back again. What determines where she will turn around? Temperature or humidity (for there will be a gradient of each)? To meet this type of problem use has been made of a method which while empirical in nature has the advantage that it is quick in response, uses only minute quantities of water, can be incorporated in an electrical circuit and is relatively stable (Cutting et al., 1955). The sensitive element comprises a small disk or rod of aluminium, the surface of which has been anodized to form a thin layer of aluminium oxide over which a moisture permeable gold film is evaporated as an electrode. Measurements are made of the electrical resistance or capacitance of the anodized layer, each of these quantities being a function of the relative humidity of the gas with which the probe is in equilibrium. The response of these probes is to some extent dependent on their previous hygrometric history and to overcome this a special calibrator unit has been developed which contains a number of cells in which known humidities are maintained by means of saturated salt solutions. It is thought this apparatus will find particular application to field work.

The fourth instrument to which I wish to refer is in a class by itself for it represents a new technique in hygrometry which provides facilities not hitherto available (Wylie, 1955a). With it measurements can be made to an order of magnitude better than the best dew point measurements with a time constant of the order of only a second. Unlike the dew point hygrometer and the psychrometer, measurements can be made at sub-zero temperatures without there being any uncertainty as to whether the measurements are relative to the vapour pressure of water or ice. It is interesting that this technique was the outcome of fundamental studies of the condensation process on solid surfaces and yet the idea could have been developed several decades ago. This is a good example of the fact that even in fields which seem to have become static opportunities will exist for worthwhile advances.

This hygrometer, christened the electrolytic condensation hygrometer, is quite simple in conception. The sensitive element is a watersoluble ionic crystal. If this is cooled in the presence of the gas to be examined a temperature will be reached at which the crystal will begin to exhibit "deliquescence", i.e. a film of saturated solution will begin to form on the surface of the crystal. This will occur when the vapour pressure of the water in the gas first exceeds the saturation vapour pressure of the saturated solution. As long as the vapour pressure exceeds this critical value, additional solution will form and the film will thicken; if the vapour pressure becomes less than the critical value the film will evaporate. The presence of such a film may be easily detected electrically by placing electrodes on the crystal; a decrease or increase in the electrical resistance will
correspond respectively to a thickening or thinning of the film. The instrument may be made self-balancing by placing the crystal in a temperature controlled enclosure containing the gas sample and arranging for the temperature of the space to be brought to such a value that there will be a predetermined resistance (i.e. film thickness) between the crystal electrodes. The equilibrium temperature should be independent of this thickness for a wide range of thicknesses and this has been found to be so to better than 0.005°C (Wylie, 1957).

Because the response of the instrument is electrical it is particularly well suited to the automatic recording and control of humidity. It can be adapted to the measurement of a wide range of absolute humidities by selecting appropriate crystal materials. Patents have been taken out on this device (Wylie, 1956, 1959) and it is hoped that it will soon be available as a commercially manufactured instrument.

The electrolytic condensation hygrometer provides more than an instrument for practical hygrometer, however. It also represents a valuable research tool which can be applied to a wide range of investigations. It has already served to show that films of saturated solution of average thickness as little as 8 mg. still have essentially the properties of bulk liquid and it has provided information on the fine structure of the crystal surfaces. It is proposed to apply it to further fundamental studies of the condensation process, accurate measurements of the interaction constant between gas and water molecules and to the determination of the vapour pressures (relative to the vapour pressure of water) of a number of saturated salt solutions. The field of hygrometry, far from being worked out, has proved to be redolent with opportunities for research, development and practical application.

Viscometry

A “standards” function of the Heat Section which bears little relationship to heat is the calibration of viscometers in terms of the absolute units of viscosity, the poise and the stokes, although, it is true, the accurate control of temperature plays an important part in precision viscometry. This field, which is of considerable industrial and economic importance, particularly in the lubricating oil industry, is the subject of a large number of standard specifications and codes of practice designed to effect reproducibility in viscometric measurements (e.g. British Standards Institution, 1957). It is true that high absolute accuracy is seldom important, in fact for many years virtually empirical scales were in almost universal use, but a study of standards specifications will reveal the lengths to which those interested in such measurements will go to obtain high reproducibility.

Modern practice is to refer all measurements to the viscosity of water at 20°C (1.0038 centistokes), and since any one viscometer can usually only cover a range of about a decade in viscosity this means that a long series of stepping up procedures is necessary if a viscosity of say 100 stokes is to be measured. In any such procedure errors are likely to accumulate, and this is particularly so with viscosity measurements. This is the reason for much of the complexity of standard codes for viscometry. The root of the trouble is that in an ordinary capillary tube viscometer the simple formula, which indicates that the rate of flow of a fluid through the capillary is inversely proportional to the viscosity of the fluid, requires an additional correction known as the kinetic energy correction. This term is hard to determine and yet in the stepping up calibration procedure will tend to introduce systematic errors. These errors can amount to several percent at higher viscosities.

To anyone familiar with the complications arising from the presence of this correction term, it will be as much a surprise as it was to us to discover that by a comparatively simple modification to the design of standard capillary viscometers, it can be made completely negligible (Caw and Wylie, 1958). The modification is to bell the ends of the capillary into a more or less exponential flare. This can be done quite simply by placing the sealed end of the capillary in a suitable linear temperature gradient and then blowing. The change of the viscosity of the glass with temperature causes the hotter portion to blow out to a much greater radius than the cooler.

A viscometer incorporating the long flares at the ends of its capillaries can be used over a much greater range of viscosities than would otherwise be possible and can be calibrated by measurement at a single viscosity. Each of these characteristics helps to make possible the simplification of viscometer specifications.

That this effect should have gone unrecognized for so long is indeed surprising. Perhaps this stems from the fact that in almost all of the early capillary tube viscosity measurements the experimenters were concerned with determining absolute values. The present simplification is
only applicable to measurements made relative to some standard viscosity.

In the stepping up calibration procedure a suitable liquid is measured in one viscometer and then used to calibrate another. The rate of shear in the liquid will be markedly different in the two viscometers, so that the method tacitly assumes that the viscosity of the liquid is independent of its rate of shear, i.e. is a pure "Newtonian" fluid. This assumption is known to be invalid for many liquids but without an instrument in which the flow time is known to be simply related to the viscosity it has been difficult to check this point. The new type of instrument will accordingly be of considerable assistance in the selection of liquids suitable for use as sub-standards or transfer standards.

Because of the high accuracy of the modified viscometers for the measurement of relative viscosities one is being used for a re-determination of the viscosity of water as a function of temperature. A special instrument has been constructed in which the flow time is measured automatically on an electronic counter fed by a constant frequency source. If care is taken to ensure constancy of water temperature a repetition accuracy of 1 in 50,000 can be obtained in the flow time in this way. The best accuracy for visual timing with a stopwatch in this case would be about 1 in 1,000. The ability to compare viscosities to this order of accuracy clearly opens up many other possibilities in a field which has for many years been thought to be without promise for original work. The development has notable scientific as well as industrial applications.

**Low Temperature and Solid State Physics**

I indicated earlier that it would be most undesirable to endeavour to operate a standards laboratory without associating with it the stimulus of active research. In implementing this policy at the conclusion of the War the field of low temperature physics was selected as an appropriate one for active work. This selection was made for several reasons:

(i) It was a field to which our experience and the techniques and facilities developed in our standards work, particularly in thermometry and heat transfer, could be expected to be applicable; per contra low temperature work could well contribute to our knowledge in these subjects.

(ii) It was known that no other facilities for the attainment of low temperature existed within Australia, although no country could consider its physical armoury complete without these facilities.

(iii) It was considered that low temperature technology, for which the name cryogenic engineering has since been coined, was bound to extend to this country and it was thought, therefore, that pilot experience in this field would prove valuable.

(iv) Finally the field of low temperature physics is a most attractive one for research. It is a temperature region in which on the one hand strange phenomena occur, such as the disappearance of all electrical resistance in some metals (super-conductivity) and the apparent disappearance of all viscosity in liquid helium (super-fluidity), while on the other hand many physical processes are greatly simplified because of the reduction in the thermal vibrations of the atoms and molecules. It is a field for the testing of physical theories and for investigations which lead to new ones.

All these expectations have been fulfilled.

Our decision to establish low temperature facilities was made at a fortunate time, for improved techniques for the production of the refrigerant used for most low temperature work (liquid helium) had just been developed (Collins, 1947). By taking advantage of these we were able, from the first, to produce liquid helium in sufficient quantities to supply not only our own experimental needs but to assist others from outside the Laboratory with low temperature experiments.

Our low temperature research has from the outset been concerned with the study of materials in the solid state, a comparatively new branch of physics which extends from pure physics into metallurgy and engineering and has been responsible for such major technological advances as the transistor.

Here I would say that it seems strange that while at least five C.S.I.R.O. Divisions are actively engaged in research on different aspects of solid state physics, it has been almost entirely neglected by our Australian Universities as a field in which to train physicists.

The conduction properties of metals and alloys was selected as the first subject for investigation (White, 1953). This has proved to be a fortunate choice for we have found the measurement of conductivities to be a most powerful technique for studying the imperfections which are present in all crystals, a knowledge of the nature and distribution of
which is essential to the understanding of the physical behaviour of solids (Klemens, 1956). Many types of imperfections in the regularity of the crystal lattice can occur and each of these introduces resistance to the flow of heat through the crystal; in a perfect infinite crystal there would be zero thermal resistance. Fortunately each type of imperfection leads to a different dependence of the thermal conductivity on temperature so that by making measurements over a range of low temperatures it is possible to identify the dominant types present. In this way it has been possible to study the imperfections introduced in solids by plastic deformation, quenching, radiation damage and fatigue, and to follow the course of the removal of these imperfections with annealing. The measurements have also been used to deduce the intrinsic conduction of perfect crystals subject only to the residual effects of thermal vibrations, and in this way to check current theories of the solid state and to study the laws of interaction between "conduction" electrons in the solid and the vibration of the crystal lattice.

Additional information about the nature of the mutual reactions between electrons, lattice vibrations, and imperfections in metals and alloys can be obtained from measurements of their thermoelectric forces, and work is proceeding to measure the exceedingly small e.m.f.s. involved.

Further studies of the basic structure of selected solids have been made through the measurement of their heat capacities down to low temperatures (Rayne, 1956) and currently equipment is being set up for the measurement of thermal expansions. In all these cases the measurements can be extended from room temperature down to 1° or 2° K.

Another approach to the study of the solid state is through what is known as paramagnetic resonance. In the presence of a magnetic field atoms which are themselves magnetic will precess and by measuring these precession frequencies by resonance techniques it is possible to deduce the nature of the interatomic forces in the solid. The frequencies are in the microwave region. The technique can also be used for identifying and measuring the concentration of very small amounts of magnetic impurities; with equipment which has been set up for this work the presence of as few as $10^{18}$ magnetic atoms can be detected. The techniques can not only be applied to the detection of such substances as iron, nickel and chromium, but can also reveal the presence of free radicles in chemical compounds. They have been applied to a wide variety of specimens ranging from wool to coal.

Our low temperature facilities play a vital part in this work, too, for although some useful measurements of paramagnetic absorption can be made at room temperatures, the effects are much sharpened by the reduction of thermal vibrations which results from cooling the specimen and can therefore be interpreted more simply and accurately.

A good example of the unpredictable developments which can stem from fundamental research has recently arisen in connection with this field of investigation in the invention of what has been called the "Maser" (Bloembergen, 1956). This device for the amplification of microwaves is hundreds of times more sensitive than any conventional amplifier and consequently can have very important applications to communication engineering. The idea has been enthusiastically received by the radio astronomers, too, for they see in the Maser a valuable ancillary to their radio telescope for the study of extra-galactic microwave radiation.

In conjunction with officers of the C.S.I.R.O. Division of Radiophysics a Maser is at present under construction for use on the large radio telescope being erected at Parkes, N.S.W. A pilot model has already been made to operate successfully. It employs a ruby as the basic material, the red coloration of which is due to the paramagnetic chromium ions. The ruby is cooled with liquid helium and has to be mounted in a magnetic field.

Theoretical studies made in the Section have revealed that in certain cases it should be possible to operate a Maser without requiring any external magnetic field (Bogle and Symmons, 1959). This would be of considerable benefit in many cases and the practicability of such a device is being investigated.

The third major research activity involving the use of our low temperature facilities has been the study of low temperature thermometry. Various aspects of this have already been touched upon. Here, too, as with the other low temperature work, opportunities for interesting research abound.

Conclusion

In reviewing the work of the Section it is apparent that in the course of setting up the facilities which as a Standards Laboratory we are statutorily required to maintain, and in establishing a parallel research programme in the low temperature and solid state fields, numerous
promising lines of investigation have been opened up. It is believed that there will be a good opportunity for developing these lines and others as yet unforeseen, for it would not be expected that the considerable effort which in the past has had to be devoted by the research personnel to purely standards work will need to continue. Nevertheless it would be unsafe to allow any of these standards fields to remain quiescent, for in that direction lies regression.

New fields of work present themselves for consideration; others will arise from time to time. Thus in pyrometry the extension of our work to much higher temperatures must be seriously considered for technology is heading that way already. In viscometry consideration must be given to the complex but technically important field of rheology which deals with the flow properties of such things as pastes and paints.

In whatever direction development takes us, I feel confident the Section will find interesting and profitable work.

References

British Standards Institution, 1957. B.S. 188.


National Standards Laboratory,
University of Sydney Grounds
Sydney

**View This Item Online:** https://www.biodiversitylibrary.org/item/174326
**DOI:** https://doi.org/10.5962/p.360782
**Permalink:** https://www.biodiversitylibrary.org/partpdf/360782

**Holding Institution**
Smithsonian Libraries and Archives

**Sponsored by**
Biodiversity Heritage Library

**Copyright & Reuse**
Copyright Status: In Copyright. Digitized with the permission of the rights holder
Rights Holder: Royal Society of New South Wales
License: http://creativecommons.org/licenses/by-nc-sa/3.0/
Rights: https://www.biodiversitylibrary.org/permissions/

This document was created from content at the Biodiversity Heritage Library, the world's largest open access digital library for biodiversity literature and archives. Visit BHL at https://www.biodiversitylibrary.org.

This file was generated 22 September 2023 at 12:48 UTC