Temperature Measurement for Natural, Waste and Potable Waters and other items of interest in the Water and Sewage Disposal Industry 1986

Methods for the Examination of Waters and Associated Materials

This document contains 42 pages

Her Majesty's Stationery Office

Standing order Service

Placing a standing order with HMSO BOOKS enables a customer to receive other titles in this series automatically as published.

This saves the time, trouble and expense of placing individual orders and avoids the problem of knowing when to do so.

For details please write to HMSO BOOKS (PC 13A/1), Publications Centre, PO Box 276, London SW8 5DT and quoting reference

X22.04.22

The standing order service also enables customers to receive automatically as published all material of their choice which additionally saves extensive catalogue research. The scope and selectivity of the service has been extended by new techniques, and there are more than 3,500 classifications to choose from. A special leaflet describing the service in detail may be obtained on request.

Contents

This booklet is part of a series intended to provide both recommended methods for the determination of water quality, and in addition, short reviews of the more important analytical techniques of interest to the water and sewage industries.

In the past, the Department of the Environment and its predecessors, in collaboration with various learned societies, have issued volumes of methods for the analysis of water and sewage culminating in "Analysis of Raw, Potable and Waste Waters". These volumes inevitably took some years to prepare, so that they were often partially out of date before they appeared in print. The present series will be published as series of booklets on single or related topics; thus allowing for the replacement or addition of methods as quickly as possible without need of waiting for the next edition. The rate of publication will also be related to the urgency of requirement for that particular method, tentative methods and notes being issued when necessary.

The aim is to provide as complete and up to date a collection of methods and reviews as is practicable, which will, as far as possible, take into account the analytical facilities available in different parts of the Kingdom, and the quality criteria of interest to those responsible for the various aspects of the water cycle. Because both needs and equipment vary widely, where necessary, a selection of methods may be recommended for a single determinand. It will be the responsibility of the users — the senior technical staff to decide which of these methods to use for the determination in hand. Whilst the attention of the user is drawn to any special known hazards which may occur with the use of any particular method, responsibility for proper supervision and the provision of safe working conditions must remain with the user.

The preparation of this series and its continuous revision is the responsibility of the Standing Committee of Analysts (to review Standard Methods for Quality Control of the Water Cycle). The Standing Committee of Analysts is a committee of the Department of the Environment set up in 1972. Currently it has 9 Working Groups, each responsible for one section or aspect of water cycle quality analysis. They are as follows:

1.0 General principles of sampling and accuracy of results
2.0 Microbiological Examination
3.0 Empirical and physical methods
4.0 Metals and metalloids
5.0 General nonmetallic substances
6.0 Organic impurities
7.0 Biological monitoring
8.0 Sewage treatment and toxicity tests
9.0 Radiochemical methods

The actual methods and reviews are produced by smaller panels of experts in the appropriate field, under the overall supervision of the appropriate working group and the main committee.

The names of those associated with this method are listed inside the back cover. Publication of new or revised methods will be notified to the technical press, whilst a list of Methods in Print is given in the current HMSO Sectional Publication List No 5.

Whilst an effort is made to prevent errors from occurring in the published text, a few errors have been found in booklets in this series. Correction notes and minor additions to published booklets not warranting a new booklet in this series will be issued periodically as the need arises. Should an error be found affecting the operation of a method, the true sense not being obvious, or an error in the printed text be discovered prior to sale, a separate correction note will be issued for inclusion in that booklet.

L R PITTWELL
Secretary

1 July 1986

The analytical procedures given in this booklet should only be carried out by competent trained persons, with adequate supervision when necessary.

Local Safety Regulations must be observed.

Laboratory procedures should be carried out only in properly equipped laboratories.

Field Operations should be conducted with due regard to possible local hazards, and portable safety equipment should be carried.

Care should be taken against creating hazards for one's self, one's colleagues, those outside the laboratory or work place, or subsequently for maintenance or waste disposal workers. Where the Committee have considered that a special unusual hazard exists, attention has been drawn to this in the text so that additional care might be taken beyond that which should be exercised at all times when carrying out analytical procedures. Reagents of adequate purity must be used, along with properly maintained apparatus and equipment of correct specifications. Specifications for reagents, apparatus and equipment are given in manufacturers' catalogues and various published standards. If contamination is suspected, reagent purity should be checked before use. Lone working, whether in the laboratory or field, should be discouraged.

The best safeguard is a thorough consideration of hazards and the consequent safety precautions and remedies well in advance. Without intending to give a complete checklist, points that experience has shown are often forgotten include: laboratory tidiness, stray radiation leaks (including ultra violet), use of correct protective clothing and goggles, removal of toxic fumes and waste, containment in the event of breakage, access to taps, escape routes and the accessibility of the correct and properly maintained first-aid, fire-fighting, and rescue equipment. Hazardous reagents and solutions should always be stored in plain sight and below face level. Attention should also be given to potential vapour and fire risks. If in doubt, it is safer to assume that a hazard exists until proved otherwise.

There are numerous handbooks on first aid and laboratory safety. Among such publications are: "Guide to Safe Practices in Chemical Laboratories" and "Hazards in the Chemical Laboratory", issued by the Royal Society of Chemistry, London; "Safety in Biological Laboratories" (Editors Hartree and Booth), Biochemical Society Special Publication No 5, The Biochemical Society, London, which includes biological hazards; and "The Prevention of Laboratory Acquired Infection" Public Health Laboratory Service Monograph 6, HMSO, London.

It cannot be too strongly emphasised that prompt first aid, decontamination, or administration of the correct antidote can save life; but that incorrect treatment can make matters worse. It is suggested that both supervisors and operators be familiar with emergency procedures before starting even a slightly hazardous operation, and that doctors consulted after any accident involving chemical contamination, ingestion, or inhalation, be made familiar with the chemical nature of the injury, as some chemical injuries require specialist treatment not normally encountered by most doctors. Similar warning should be given if a biological or radio-chemical injury is suspected. If an ambulance is called or a hospital notified of an incoming patient, give information on the type of injury, especially if poisoning is suspected, as the patient may be taken directly to a specialized hospital.

Introduction

The degree of accuracy and precision required when measuring temperature varies with the application. This booklet gives the information in sample terms which will enable users to make water and related temperature measurements up to a high degree of accuracy.

Temperature is perhaps the most "everyday" physical measurement connected with the examination of waters. It is an important quantity in its own right affecting the ability to sustain life. It determines the properties of water such as the ability to dissolve gases or salts. It also has considerable bearing on other methods used to examine water such as conductivity and pH measurements which require the accurate determination of temperature to be meaningful.

Temperature is relatively easy to measure precisely. Accurate temperature measurements (even those of apparently limited accuracy) are surprisingly difficult and/or expensive to make.

Accuracy

is defined as the qualitative assessment of the freedom from error of a measured value compared to a recognised accepted standard or ideal value.

Precision

is the degree of discrimination to which a result is stated.

Resolution

is that change in input signal which gives the smallest distinguishable output.

Repeatability

is the degree to which a measurement may be repeated (sometimes referred to as self-repeatability).

Reproducibility

is a measure of the ability of different operators to obtain the same reading.

Scope

This review outlines the measurement of temperature, the systems used, the methods for its determination and the limitations on temperature measurement. It is concerned with temperature measurement of natural, potable and waste waters. Furnace temperature measurement, optical pyrometry and similar fields are beyond the scope of this monograph and are only dealt with briefly. If the reader requires information on furnace temperature measurement techniques for such process as sludge incineration systems then specialist texts should be consulted. Low subambient temperature measurements are also unlikely to be encountered in the water industry.

Theory

Temperature is a concept with which everyone is familiar from a very early age. The human body is senstive to temperature and our lives are lived showing a considerable regard for it.

A scientific definition of temperature is not as simple a matter as might at first be thought. That which is intuitively obvious is difficult to define precisely.

Temperature is the physical conditions of an object which defines potential heat transfer to or from that object to another. Thus two objects of differing temperatures placed in intimate contact with one another will undergo a transference of heat until they attain the same temperature (assuming no other heat transfer process are occurring).

The affect arises from the kinetic energy of the molecules being shared during collisions which eventually result in the molecular population within the heat transfer system having statistically the same mean kinetic energy.

Most physical properties of materials vary with temperature, the most familiar of which is probably volume. It is these physical changes that we rely on to measure temperature.

From a historical theoretical viewpoint temperature (ie the heat content related to potential thermal flow) can be related to the properties of a so called ideal gas. This ideal gas behaviour is given by the equations derived by R Boyle, J L Gay-Lussac, J A C Charles and E Marotte which can be summarized in the form:–

$$\frac{P^1 V^1}{T^1} = \frac{P^2 V^2}{T^1}$$

where P is the absolute pressure, V the volume and T the absolute temperature the subscripts 1 and 2 referring to two states of the same mass of gas.

It follows that an ideal gas will consequently expand by the same volume for each degree temperature rise or correspondingly contract by the same volume for each degree fall. Therefore if the temperature is decreased sufficiently there will be a temperature at which the gas has zero volume. This temperature can be obtained by extrapolation from the behaviour of real gases and is referred to as absolute zero. Any real gas would have a finite volume at absolute zero, however, all known gases cease to exist in the gaseous state before absolute zero is reached. Absolute zero also used to be considered as the temperature at which all molecular motion ceased, but this view is not now held. The predicted value for absolute zero is −273.15 C and the scale of temperature which takes this point as 0 and uses the Celsius degree is called the Kelvin Scale.

Temperature measurement evolved along two paths, the first using practical arbitrary considerations to give practical temperature scales and the other the thermodynamic approach, incorporating the concept of absolute zero, which made use of gas thermometry and gave the thermodynamic temperature scale.

Temperature Scales

Absolute zero would be a satisfying point to use to define the origin of a scale of temperature. However, this temperature is unattainable in practice and temperatures which can easily be achieved in the laboratory are taken as the basis for the temperature scales in common use. These temperatures were originally freezing point and boiling point of pure water at standard pressure (1 atm or 101325 Pascal), and were called the lower fixed point and the upper fixed point respectively; the difference in temperature between them was known as the fundamental interval.

In order to measure temperature in a practical way, physical (and sometimes chemical) properties of matter which will change with temperature are used. The most familiar is the volume of liquid which expands as the temperature rises. Some liquids do not expand at all uniformly and some contract with increasing temperature and are unsuitable as thermometric liquids. To use such a property it is necessary to measure the property at fixed temperature points. These points are then defined as corresponding to a certain number of "degrees" depending on the scale. The change in the property is then deemed to be linear between the two fixed points and thus the property of that material which would correspond to a certain number of degrees can be measured and the temperature ON THAT SCALE can be measured. Temperatures outside the fixed points are measured by the linear extrapolation of that property as long as this is practical.

The preferred temperature scale for scientific and engineering work is the Celsius (formerly centigrade) Scale. This scale takes the boiling and fusion points of water as 100 and 0 degrees respectively. As previously mentioned, the Kelvin Scale takes its origin as absolute zero and the boiling and fusion points of water as 373.15 and 273.15. The Fahrenheit Scale takes the boiling point of water as 212 and its fusion point as 32 degrees. The Rankine Scale like the Kelvin Scale, uses absolute zero as its origin but uses the Fahrenheit degree rather than the Celsius degree. The Reamur Scale takes the boiling point of water as 80 and the lower as zero degrees. Apart from the Celsius scale the Fahrenheit scale is the only other scale that will be commonly encountered. It is preferred in industries where the convenience of having a whole number temperature with smaller increments is found useful, such as brewing, and is in wide use in the United States of America.

In practice, gas behaviour is not ideal and gas thermometry was only possible in well equipped standards laboratories and is difficult to perform. Temperature calibration points which were more easily realized were required. There is also a need for several fixed points (i.e. more than just two) and this has led to the development of the International Practical Temperature Scale of 1968 (Table 2) Ref 1. This is based on the rigorous assessment of fixed points attainable in the laboratory. Of these fixed points only the numerical value assigned to the boiling point of water is common to the International Practical Temperature Scale and the historical Celsius Scale. For example the fixed point near 0°C is now taken as the triple point of water being 0.01°C as this is a more reproducible standard than the freezing point.

Differences in Temperature Scales

The theoretically ideal temperature sensor system would be one that correlated with the temperatures that would be indicated by the behaviour of an ideal gas. Every measureable physical parameter is non linear with respect to the ideal gas temperature scale.

Whenever a temperature is measured it should be noted which physical property has been used to measure it, as the linearity of the physical property which is assumed in

establishing the scale will not necessarily be linear with any other scale based on a different physical property. This means that if the temperature of an object is measured using different physical properties then different values may be recorded and thus for accurate work there is the need to record the sensing system.

Table 1

Difference between	Platinum Resistance and Mercury in Glass Scales
Platinum Resistance C	Mercury in Glass C*
0	0
50	49.75
100	100

*The convenient whole numbers chosen in the table for mercury-in-glass thermometry would of course also have differences from an ideal gas scale at temperatures other than at the fixed points

The International Practical Temperature Scale

The International Practical Temperature Scale is an attempt to produce a practical temperature scale which approximates to the thermodynamic Kelvin Scale as closely as can be realized by current measurement practices. The International Scale also attempts to extend the range and accuracy of measurement outside that of the Fundamental Interval. The Scale has undergone major revisions in 1887, 1927, 1948, 1954, 1960 and 1968. The 1968 Scale is based on the Celsius scale and has the following fixed points all of which are defined at Standard Pressure (1 Atmosphere or 101325 Pascal) except the triple points, e.g. (The triple point of water is that at which all three phases, solid, liquid and gas simultaneously co-exist in equilibrium and corresponds to 273.16 K at a pressure of 6.11 millibar. National standards laboratories still use constant volume thermometry for thermodynamic temperature measurement but elsewhere the International Practical Temperature Scale is now the definitive scale of temperature and for practical purposes completely replaces gas thermometry and any other temperature fixed points.

A platinum resistance thermometer can now measure temperature with greater precision and reliability than a constant volume gas thermometer but it cannot measure temperature thermodynamically.

Table 2 International Practical Temperature Scale of 1968-Fixed Points (ref 1)

Equilibrium state of fixed point	Assigned value of International Practice Temperature
	C
Equilibrium between the solid, liquid and vapour phases of equilibrium hydrogen (triple point of equilibrium hydrogen)	−259.34
Equilibrium between the liquid and vapour phases of equilibrium hydrogen at a pressure of 33 330.6 Pa (25/76 standard atmosphere)	−256.108
Equilibrium between the liquid and vapour phases of equilibrium hydrogen (boiling point of equilibrium hydrogen)	−252.87
Equilibrium between the liquid and vapour phases of neon (boiling point of neon)	−246.048
Equilibrium between the solid, liquid and vapour phases of oxygen (triple point of oxygen)	−218.789
Equilibrium between the solid, liquid and vapour phases of argon (triple point of argon)	−189.352
Equilibrium between the liquid and vapour phases of oxygen (condensation point of oxygen)	−182.962
Equilibrium between the solid, liquid and vapour phases of water (triple point of water)	0.01
Equilibrium between the liquid and vapour phases of water (boiling point of water)	100
Equilibrium between the solid and liquid phases of tin (freezing point of tin)	231.9681
Equilibrium between the solid and liquid phases of zinc (freezing point of zinc)	419.58
Equilibrium between the solid and liquid phases of silver (freezing point of silver)	961.93
Equilibrium between the solid and liquid phases of gold (freezing point of gold)	1064.43

Use of Temperature Measurement in the Examination of Waters

Temperature measurement is an essential determinand in the field of water quality. A record of the temperature of water is necessary for the interpretation of biological and chemical processes and legislative requirements. Temperature also enables the meaning of other water quality data to be understood. Examples are dissolved oxygen, conductivity, pH, redox potential, free ammonia, fluoride by ion selective electrode, carbon dioxide, all require a knowledge of temperature to allow a correct interpretation of the values to be made. Temperature is often measured simultaneously with other field measurements.

In the laboratory the liquid-in-glass thermometer is still the most widely used temperature indicator but with the falling cost and the increased robustness of electronic equipment, electrical temperature measurement systems are becoming increasingly used.

Electrical Thermometers readily permit the separation of sensor and indicator making such systems more suitable for temperature measurement of bodies of water, avoiding many of the problems associated with such measurements when using liquid in glass thermometers.

In the continuous monitoring of water temperature, a technique should be used which would be accurate and give a permanent record. Thermocouples, electrical resistance measurement and fluid filled systems (q.v.) are the most commonly used.

A sample taken for laboratory analysis may undergo changes on storage which will affect the subsequent analysis. Failure to store samples at a suitable temperature or to ignore this problem, together with a failure to analyse samples quickly after sampling, will result in false values.

Temperature Compensation

Temperature measurement is also required for many routine operations in the laboratory, e.g. for the accurate control of chemical tests. Temperature measurement can also be incorporated into instrument design to compensate for the temperature effect on the readings taken, in order that they can be meaningfully related to other readings at different temperatures. This system is called Automatic Temperature Compensation (ATC). Such a system is often found on pH meters, dissolved oxygen meters and conductivity meters. It can be a very useful and time saving inclusion on an instrument but it cannot be stressed enough that its precise mode of opreation and the nature of its effect on the final result should be clearly understood.

A good illustration of this is given by conductivity measurement. If we require to compare our reading with those taken at a standard temperature of 25°C then ATC could be used. If we assume that the temperature coefficient of conductivity for the water sample is 2.5% per degree and that conductivity is being measured at 5°C then the final reading will be modified by adding 50% (viz. $(25 - 5) \times 2.5\% = 50\%$) and becomes 150% of absolute. If an error in the temperature coefficient has been made and 5% per degree is used then the reading is modified by 100% and becomes 200% absolute. If that data is required on a future occasion we may not know what temperature the conductivity was measured at nor the value of temperature coefficient used and it may be impossible to unscramble the correct or absolute reading from the data. In an area such as conductivity, ATC should be viewed very guardedly, as a record of conductivity as an absolute figure, together with a separate record of temperature would not have been confused in this way and could meaningfully be compared with other sets of similar data. Similar consideration should be given to pH, dissolved oxygen and other meters and monitors fitted with ATC units. Users should also ensure the exact effect of temperature deviations as linearity cannot be assumed.

Interferences

The concept of interference when applied to temperature seems a little strange. A temperature itself cannot be interfered with; but of course the measuring systems used depend on physical changes which occur with alterations in temperature, yet temperature variation may not be the only means of bringing about these physical changes. Systems which depend on volume changes may be affected by external pressure variations, for example by being lowered down a borehole. Electrical temperature systems may be affected by stray radiofrequency radiation, electromagnetic fields, or by thermal effects in the cables and measurement electronics. Other systems which are mechanical in nature may suffer from backlash and hysteresis and go out of calibration.

A form of hysteresis may occur when any temperature measuring device is exposed to a working temperature for a long period. Physical changes may occur which do not immediately recover on removing the transducer from the environment being measured, rendering the unit out of calibration. This effect is known as Thermal History Error. A similar effect results from the ageing of the glass thermometer that starts after its manufacture and which will cause the device to go out of calibration. Where high accuracy work is required, regard must be taken of Thermal History Error, cross referencing of equipment will help estimate this as will a record of the use of equipment.

If there is a possibility that interference is occuring, then the temperature value obtained should be cross checked against other methods which are known not to respond to the same interference. Users should be aware of the problems associated with sampling errors and care taken to minimize this problem. This is a major factor when sampling from large bodies of water.

Temperature Measurement Systems

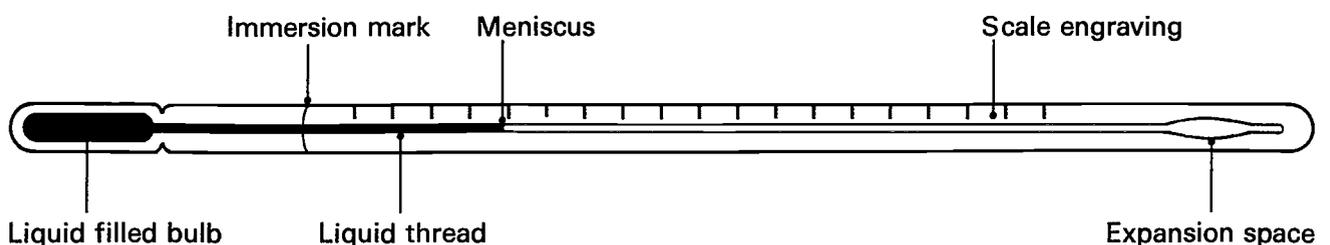**Liquid in Glass Thermometers**

(Ref 3,4,5,6,7,8,9,10,11,12,13,14,15)

This thermometer is still the most widely used means of temperature measurement. A bulb containing the thermometric liquid (which is most commonly either mercury or coloured alcohol although some extended range thermometers use a mercury-thallium alloy) is attached to a long stem of capillary tubing. Changes in temperature cause this liquid to expand or contract which in turn causes the length of the liquid in the capillary tube to change. The capillary tube is normally sealed at its end to prevent liquid loss either by spillage or by evaporation. Most liquid thermometers have the space above the liquid column evacuated. For certain applications gas is deliberately sealed into this space in order to extend the range of the thermometer by raising the boiling point of the thermometric fluid. Once the fixed points have been determined for a particular thermometer, then the scale is equally divided and either engraved directly on to the glass of the capillary tube or the thermometer is fixed to a graduated backing plate.

Readings taken with a mercury in glass thermometer are in reasonable agreement with those of the I.P.T. scales, those taken with an alcohol in glass thermometer also closely agree with those of the I.P.T. scale but are inferior to those of the mercury in glass thermometer. The nature of the liquid in glass thermometer, the differences in materials and dimensions used for manufacture, and the differences in design will produce inconsistences in temperature measurements within thermometers of the same type.

Table 3 Common Thermometric Systems

Instrument type	Range °C
Liquid in glass thermometer	−200 to 600
Mechanical Fluid (gas or liquid) filled system	−270 to 650
Thermocouple	−190 to 2100
Resistance thermometer	−270 to 650
Optical Pyrometer	Greater than 700
Bimetallic thermometer	−135 to 425
Thermosensitive indicators (see Text)	0 to 1400
Scanning Thermography	8 to 100
Quartz thermometer	−80 to 250

A liquid in glass thermometer

Immersion mark   Meniscus   Scale engraving

Liquid filled bulb   Liquid thread   Expansion space

Clinical thermometer

Kink
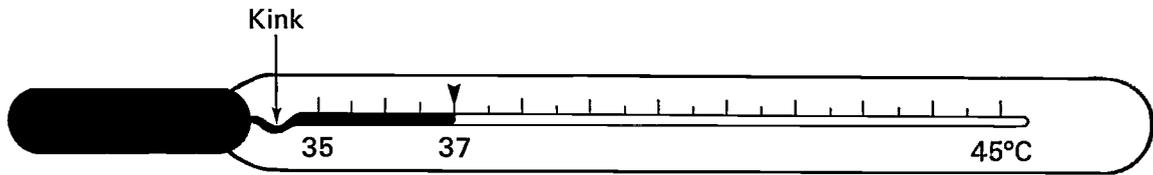
Precautions in using Liquid in Glass Thermometers

Care should be taken to select the correct design for the required task and with regard to factors which may affect performance.

A common mistake is to use different immersion thermometers indiscriminately where one type or another should be chosen for the measurement. The complete immersion thermometer is intended to be completely immersed in the fluid whose temperature is being measured. Typical applications of this type would be the measurement of atmospheric temperature or measuring the temperature of a water bath being completely immersed in it. They are NOT suitable for the routine measurement of temperature of waters in the field due to the difficulty in reading the scale when the device is fully submerged. A partial immersion thermometer is designed to take a reading with only a stated part of its stem immersed in the fluid being measured. The amount of the stem to be immersed will depend on the manufacturers design and intention for that device. The calibrated depth of immersion should be engraved on the stem together with a line to show the user where the correct immersion level is. Typical applications of this type of thermometer would be in the field measurement of water temperature or showing the temperature inside an oven on a stem outside. The total immersion thermometer requires that all the thermoelectric liquid be immersed but that none of the space above it is exposed to the medium being measured. All liquid in glass thermometers should be clearly marked as to whether they are complete, total or partial immersion types and if the latter then the immersion depth should be clearly shown. (Ref. 3,6,9,12,13) **ALL UNMARKED THERMOMETERS SHOULD BE DISCARDED UNLESS THEY ARE CLEARLY FOR A SPECIFIC PURPOSE E.G. INTENDED FOR USE WITH SPECIFIC INSTRUMENTS OR INTENDED FOR USE WITH A GLASSWARE SYSTEM. THESE SHOULD BE KEPT AND MARKED SO THAT UNTRAINED PERSONNEL DO NOT USE THEM FOR ROUTINE WORK BY MISTAKE.**

All thermometers are designed to be read after a specific immersion time in the fluid measured. The time taken to reach the calibrated reading should be known and adhered to. Ideally it should be engraved on the stem of the thermometer.

Liquid-in-Glass thermometers are generally made with a fragile liquid bulb and differences in the pressure at which readings are taken will affect the reading. If high accuracy work is required then any differences between the operating pressure and the calibration pressure (normally one atmosphere) should be noted and compensated for if necessary. This problem will also arise with liquid filled capsule systems (q.v.).

Liquid in Glass Thermometers which undergo prolonged storage or measurements at temperatures other than room temperature will undergo long term changes which will not practically recover. The nature of glass itself will also cause dimensional changes with time necessitating recalibration.

Special Types of Liquid in Glass Thermometers

Thermometers should always be chosen for a specific task rather than because they are available, and users should consult British Standards for specified types of liquid in glass thermometers.

Clinical Thermometer (Ref 4)

The clinical thermometer is a special design of the mercury-in-glass thermometer which enables the reading to be retained to facilitate reading after the thermometer has been removed from the patient. The design incorporates a constricted kink immediately above the bulb. In use the temperature measured is assumed to be above ambient. In measuring the temperature the mercury expands producing a thread in the capillary above the constriction and indicating the temperature. When the thermometer is removed from the patient the temperature of the bulb falls causing the volume of the mercury to diminish. The constriction prevents the thread of mercury in the capillary from being drawn back into the bulb by the decrease in volume of the mercury. The thread indicating the measured temperature remains in the capillary recording the temperature, to be noted at will. After use the mercury thread is rejoined with the mercury in the bulb by shaking the thermometer sharply.

Point Contact Thermometers

Point contact thermometers consist of a mercury in glass thermometer with a movable electrical contact which can be set at the desired point in the capillary by means of a screw in the top cap of the thermometer. When the mercury rises and touches this contact a conducting path between the mercury and the contact is set up. By using a circuit incorporating a sensitive relay the device can be used as an accurate thermostat or to control other devices. Care should be taken to ensure that the contact point is free of moisture and corrosion for correct operation. They used to be a common method of temperature control for devices such as waterbaths. With the development of electronics and advances in electrical temperature measurement this device can be regarded as obsolescent.

Beckmann Thermometer

This was an attempt to produce a thermometer which could be read to a high degree of precision (typically 0.01°C). A detailed description of this special mercury in glass thermometer is beyond the scope of this work, but the problems with the device are its delicate design and the fact that it gives only a relative temperature reading. It therefore needs careful setting up and calibration on each occasion. If high accuracy temperature readings are required, then modern instruments such as the quartz piezo electric thermometer are much more suitable.

Six's Maximum and Minimum Thermometer

(formerly BS 2840 but now withdrawn)

This is a liquid in glass thermometer using both alcohol and mercury. The prime temperature measuring fluid is alcohol which on expanding and contracting moves a slug of mercury. Two dumbell like indicators are incorporated into the capillary one either side of the mercury slug. If the temperature increases, the alcohol is able to pass the indicator on its side of the mercury without moving it but when the mercury slug touches the other marker it is moved by surface tension effects along the tube, being abandoned at that position when the mercury slug recedes. As the slug travels back towards the bulb with decreasing temperature it forces the lower index back as soon as it contacts it. The result is to leave the indexes at positions which indicate the maximum and minimum temperatures attained. Two scales, one for the maximum and one for the minimum are used for this purpose. The indexes are reset using a magnet. These are not high accuracy devices.

Deep Sea Reversing Thermometer

These are mercury in glass thermometers which are of special design similar in operation to clinical thermometers. They are designed for recording temperature at depth in bodies of water. A messenger is sent down the suspending cable which releases the frame holding the thermometer. This has the effect of inverting the thermometer which in turn breaks the continuous mercury thread free of the mercury in the bulb at a kink in the capillary which thus "stores" the measurement, enabling it to be read on recovery. Normally two (or three) thermometers are used, one (or two)

Maximum and minimum liquid in glass thermometers

Maximum thermometer (mercury filled)

Index
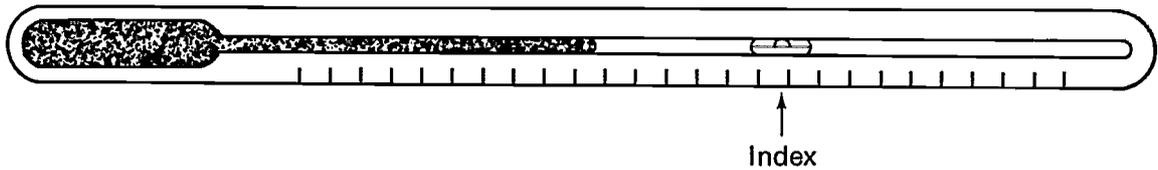
Minimum thermometer (alcohol filled)

Index
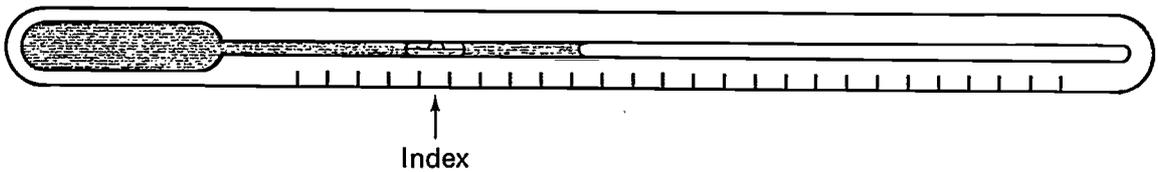
protected and the other unprotected, the latter, as an indication of the pressure the thermometers were subjected to at measurement so that depth may be calculated.

In much oceanographic work measurements of temperature are still made at internationally accepted standard depths using reversing thermometers attached to rotating frames attached to standard water sampling bottles. When the bottles are at the required depths a brass weight (messenger) is released down the suspension cable. When it reaches the bottle it releases a catch which allows the caps on the bottle to close and the thermometer frame to reverse; in addition, it releases a further messenger which then falls to the next bottle. Sampling in this way has the disadvantage that it reveals only the gross temperature features in the water column.

**Other Fluid Filled Thermometers (Ref. 7,16,17)**

These devices are similar in concept to a liquid glass thermometer. They consist of a sensing capsule, a connecting tube and some elastic element such as a diaphragm or Bourdon tube which replaces the visually observed liquid meniscus. The system is filled with a suitable thermometric fluid (liquid or gas). The fluid in the sensing capsule will change in temperature and this volume change in the system will cause the elastic element to move, this motion being translated into either a pointer movement or into an electrical signal. As with bimetallic systems (q.v.) sufficient force is generated by this volume change to actuate a pointer, pen or even a controller without the need for an external power source. A clockwork recorder can also be incorporated making a recording thermometer which requires no electrical power. This type of temperature sensor is in widespread production by a large number of manufacturers and is a well tried and developed technique. This means that a wide variety of sensors, ranges and housings are commercially available and that the units are of low costs and high reliability. Modern design of these systems will allow the sensor and indicator to be separated by up to about 120 metres. As the system is not dependent on electrical power the system is suitable for use in hazardous areas.

Thermometers of this type tend to hold their calibration for long periods and the sensing element can be designed so that temperature changes on the detector and

display system are compensated for. Although such systems are susceptible to external pressure changes (e.g. a reading may be affected by 3% for a 1000 p.s.i.g. pressure change), they can be designed so that this effect is minimized. The most commonly used filling fluids are mercury and hydrocarbon liquids. Mercury can be used in the range −40°C to 650°C with the shortest span about 10 to 15°C; organic liquids for the range −90°C to 260°C to be used with the shortest span of about 20 to 25°C.

This type of thermometer is most often encountered as a fixed installation for plant and works monitoring. The sealed nature of the design means that each unit is supplied with a fixed length of connecting tubing. It would be troublesome to shorten this tubing as recalibration would be necessary. This means that these units are not ideal for field deployment, but because of their low cost, high reliability, freedom from power requirements and ready availability, they are often successful in temporary field applications.

Fluid filled mechanical thermometer schematic
(e.g. mercury in steel thermometer)

Scale and pointer

Pointer mechanism

Bourdon element

Tube

Fluid filled bulb
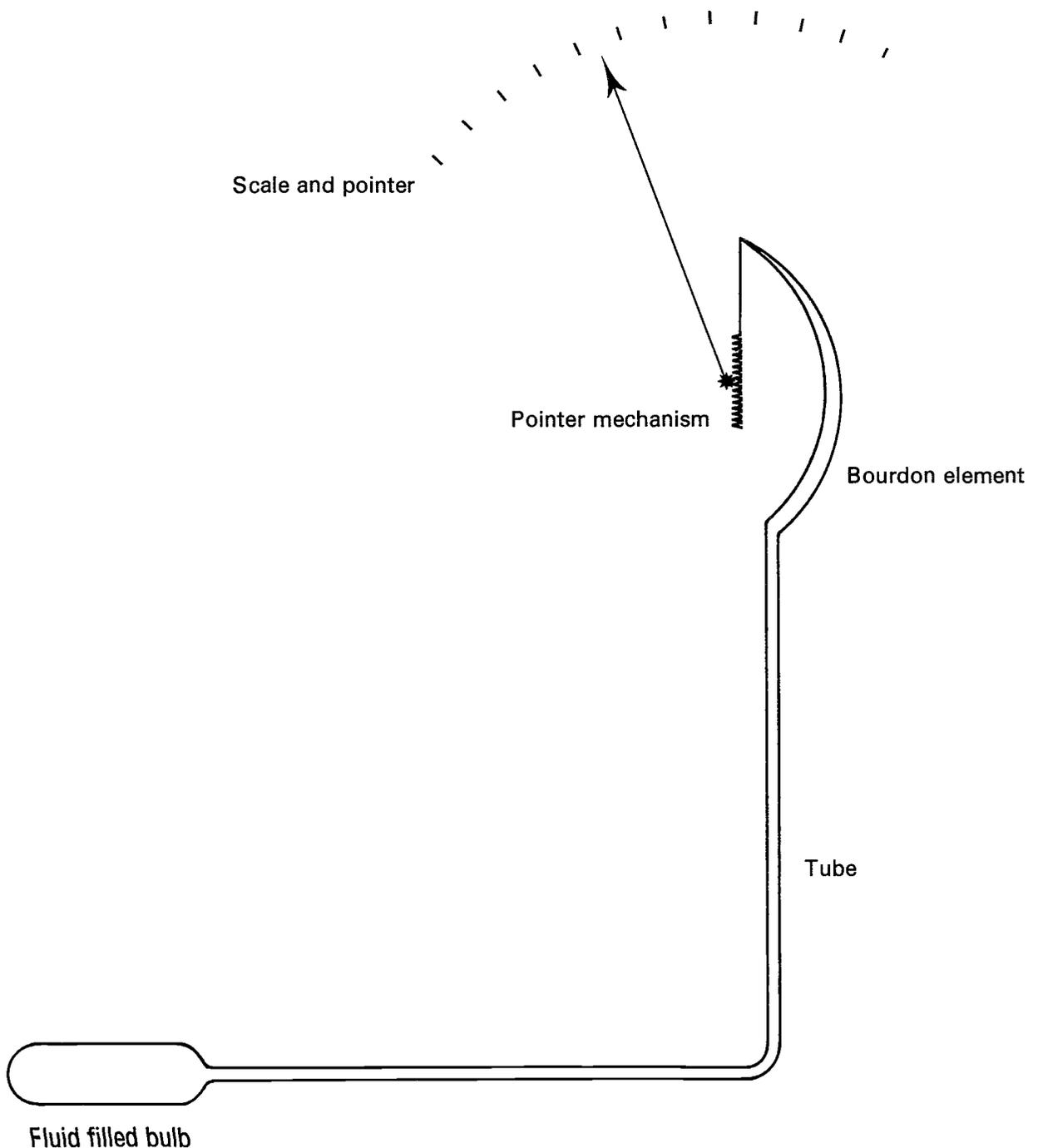
Electrical Thermometers

Electrical thermometers fall into two broad groups, electrical resistance thermometers and thermoelectric thermometers.

Electrical Resistance Thermometers (Ref. 7,18)

These consist of an electrical resistor which has a well defined reproducible temperature coefficient and which follows the characteristics of other temperature measurement techniques. The resistor material is often a metal, platinum, tungsten and nickel are among the commonly encountered varieties, thermometers using this principle are termed resistance thermometers. Doped ceramics form another family of temperature indicating resistances which are commonly known as thermistors. Differences in the electrical resistance of these devices caused by variations in temperature are measured by conventional techniques, scaled and displayed as temperature. Devices of this type are available as sensor and indicator thermometer units or as hybrid electronic modules which will process the signal from electrical resistance elements and give a voltage signal directly corresponding to temperature.

Measurement systems can either be of the two, three, or four wire resistance types. With a two wire system the same wires are used for current sourcing and voltage detection, whereas in a four wire system the current source is supplied via one pair of wires and the voltage is detected by the second pair. The three wire system is a compromise between these two systems. The electrical nature of this means of temperature sensing means that this technique is well suited to automatic temperature compensation systems. Their small physical size and the reliability of the complete system are also advantages in this respect. Electrical resistance measurement is a much more accurate sensing technique in the temperature ranges experienced in the work of the water industry than are the thermocouple or pyrometric sensing techniques described below.

If used in gases then sensor self heating errors can occur. Calibration of sensors will be affected by shock, and recalibration is advised.

In oceanographic work resistance thermometers are used for temperature — depth profiling. During the last 20 years probes have been developed which can be lowered down the water column to a depth of 3000m. These provide a continuous record of temperature and salinity against depth. In modern instruments temperature is measured to $\pm$ 0.002°C by means of a platinum resistance thermometer having a very rapid response. Salinity is evaluated to $\pm$ 0.005‰ from measurements of electrical conductivity, corrections being applied for the effects of temperature and pressure on conductivity. Depth is measured to $\pm$ 3m by means of an electrical strain gauge. Signals from the three probes are telemetered to the ship as frequency shifts and decoded by the computer on board the research vessel.

Commercial platinum resistance thermometers can offer an accuracy of about $\pm$ 0.01°C.

Typical Performance Data on some Commerical Platinum Resistance Thermometer Assemblies Complete with Read Out.

| Range °C	Accuracy °C	Maximum Variation in 1 year °C	Typical Price 1985 per complete unit both scales
−230 to 0	$\pm$ 0.08	0.15	
0 to 204	$\pm$ 0.08	0.15	
−200 to 0	$\pm$ 0.14	0.18	c. £3000
0 to 750	$\pm$ 0.14	0.30	

If a free choice is available resistance thermometers are the preferable method of electrically determining temperatures within the liquid range of water.

Thermistors

Thermistor are ceramic resistors designed to have specific temperature characteristics including a high temperature coefficient of resistance. They are made from fused mixtures of oxides of nickel, manganese, iron, cobalt, copper, magnesium, titanium and other metals. Modern production techniques permit good replication of device characteristics.

The temperature response is exponential and linearization in the detecting circuitry is required. The resistance is measured using conventional bridge techniques. Special manufacturing can produce complex integrated devices which behave as resistors with linear temperature coefficients. The high temperature coefficient or resistance means that less expensive instrumentation is required than for conventional resistance thermometry.

Schematic of a four wire resistance thermometer
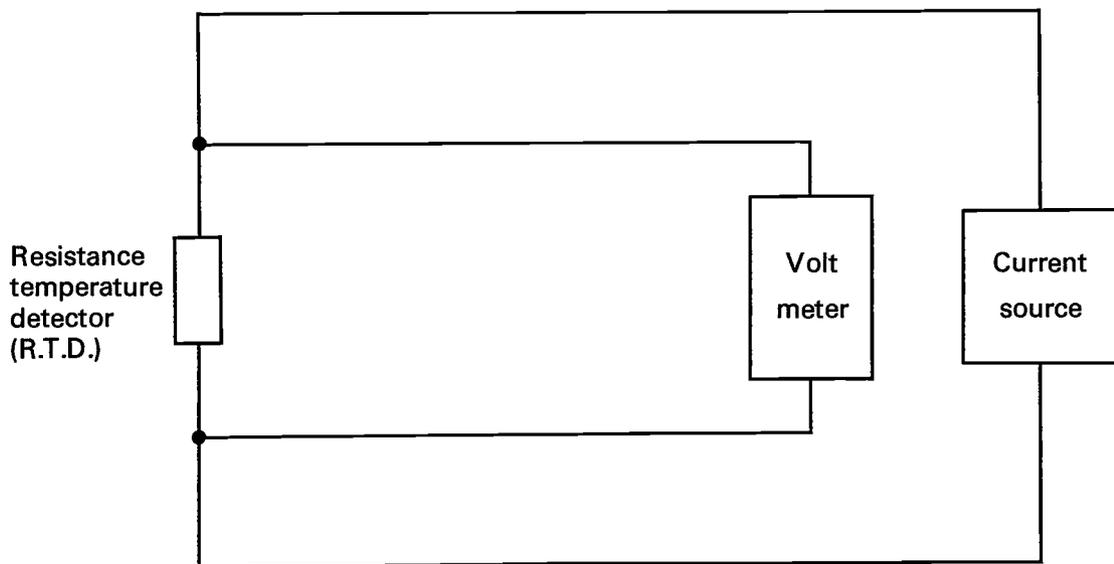
Typical resistance element
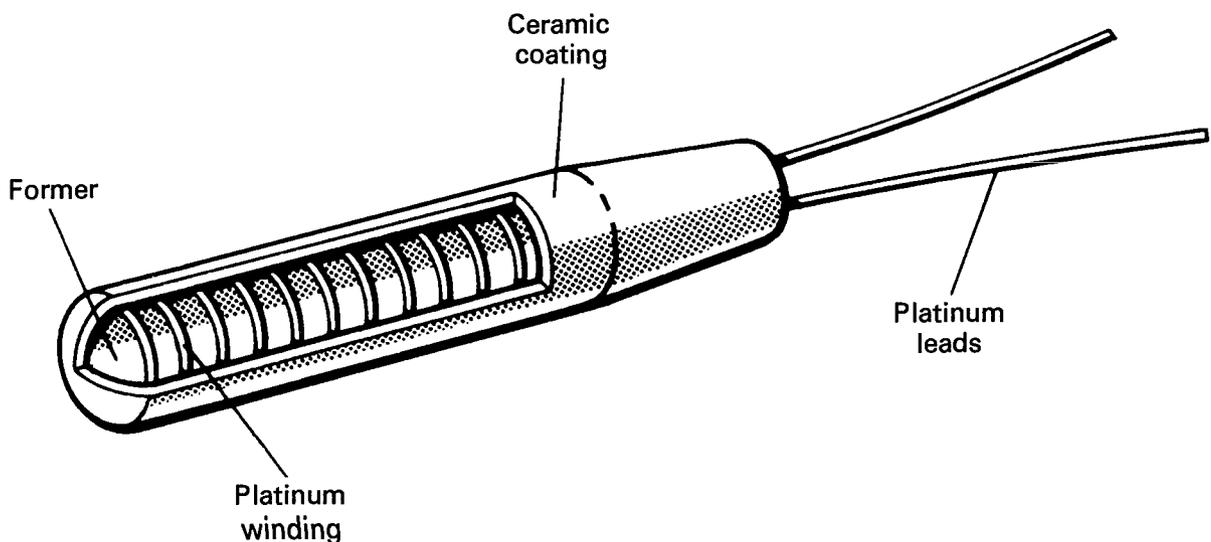
Standard two, three and four wire connections of an R.T.D.

4-wire connections

+I
+V

RTD

−V
−I

3-wire connections

+I
+V

RTD

−V
−I

2-wire connections

+I
+V

RTD

−V
−I
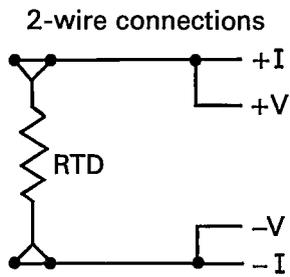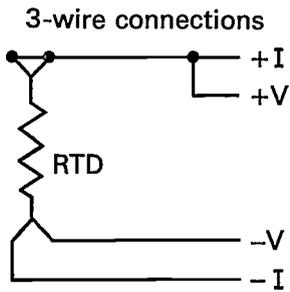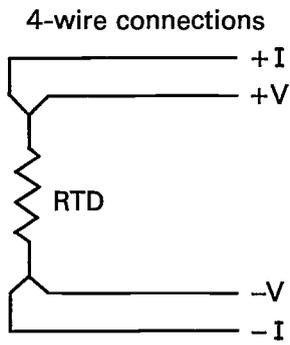
+ and − V arc developed (reading) voltage on application of a known stabilized current + and − S

Thermocouple circuit

A

B

Measuring
junction

Reference
junction

To voltage
measuring
device

Table 4 Table of Common Thermocouples

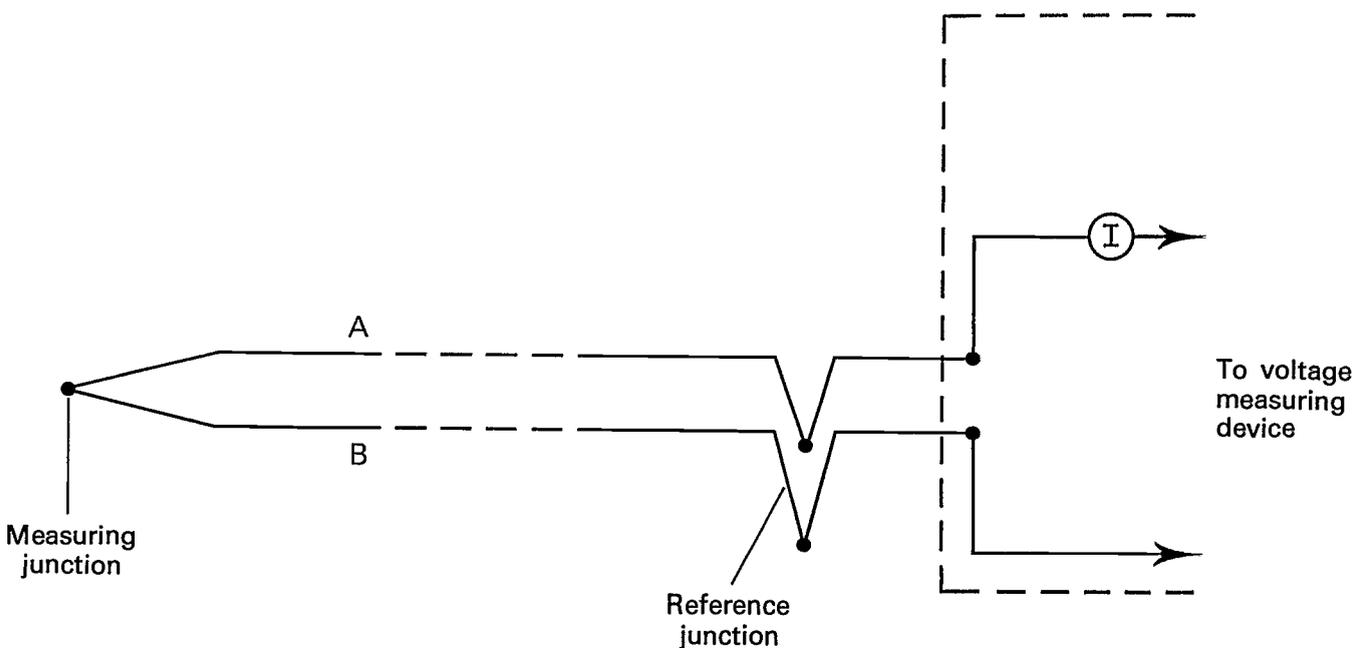| Type Code	Conductors	Temperature Range	Corresponding British Standard
B	Rhodium/Platinum/Rhodium	0 — 1820	BS 4937 : Part 7
E	Chromel/Constantan	−200 — 850	BS 4937 : Part 6
J	Iron/Constantan	0 — 850	BS 4937 : Part 3
K	Chromel/Alumel	−200 — 1100	BS 4937 : Part 4
R	Platinum 13% Rhodium/Platinum	0 — 1700	BS 4937 : Part 2
S	Platinum 10% Rhodium/Platinum	0 — 1800	BS 4937 : Part 1
T	Copper/Constantan	−250 — 400	BS 4937 : Part 5
U	Copper/Cupronic	used for compensating Pt Rh/Pt	
Vx	Copper/Constantan (Low Nickel)	used for compensating Chromel/Alumel	
N	Nickel-Chromium-Silicon/ Nickel-Silicon	−270 — 1300	BS 4937 : Part 8 not yet published

Thermistors are often used for temperature measurement and temperature compensation in instruments (e.g. Dissolved Oxygen Meters).

Thermoelectric Thermometers (Thermocouples)

These detectors are another extremely important class of temperature sensor: the best known type is the thermocouple. This device is based on the Seebeck effect; an electric current flow in a continuous circuit formed by wires of dissimilar metallic composition if the two intermetallic junctions are maintained at different temperatures. Conventionally, one junction is used to perform the measurement with the other (reference) junction maintained in an ice bath at 0°C. As this is often practically difficult, automatic temperature compensation systems for the reference junction are incorporated in the detection electronics. Although a very wide variety of dissimilar metals is theoretically possible, thermocouples are generally standardized combinations of elements and alloys which have well documented characteristics. The common thermocouple junctions are set out in table 4. In general, thermocouples are used to measure temperatures well above the boiling point of water, very often in the furnace type of application. However, because these detectors are so well documented they are often supplied for the measurement of temperatures or as temperature compensation devices in the normal liquid range. Thermocouple junctions are normally sheathed in metal or ceramic tubes and care should be taken in the selection of the thermocouple to ensure that the junction is correctly sited in the probe for the task required. Thermocouples have complex non linear responses and are not favoured for accurate temperature determination.

A common fault when using thermocouples is to extend leads using any cable which comes to hand. Extension wire and connectors should be matched to the thermocouples used and purchased as a thermocouple extension cable for the device used. If wire and connectors are not matched they will form additional thermocouple junctions at each unmatched joint which will contribute to the signal. These extension wires are often not the same materials as comprise the thermocouple junction itself but materials with electrically similar characteristics. As the thermocouple extension wire will consist of two dissimilar metals it is very important to ensure that they are connected to the thermocouple with the correct polarity. (Ref 7 (Part 4))

Semiconductor Sensors

The electrical characteristics of semiconductors are temperature sensitive. This property can be exploited by device design. Semiconductor packages (integrated

circuits) are available to give an output voltage proportional to temperature. They can be designed to have linear or other customized characteristics.

Currently the accuracy of such devices is inferior ($\pm$ 0.1 to 2°C) to resistance thermometers and the packaging follows current semiconductor device practice (e.g. dual in line packages) making them unsuitable for incorporating into the wide variety of probe types available with other techniques.

Devices of this type offer great promise for future sensors.

Bimetallic Thermometers (Ref. 7,20) These depend for their operation on the different expansion rates of metals. If two metals with dissimilar co-efficients of thermal expansion are bonded together, to form a sheet or strip, then a temperature change will cause one side to expand or contract to a greater degree than the other with the result that the strip will bend into a curve. This bending can be measured by some mechanical linkage (or by an electrical potentiometer) and displayed as the motion of a dial or pointer. The bimetallic element is most commonly encountered wound in the form of a spiral. Considerable mechanical force can be developed by this system and indicators or pen systems can be driven directly, hence it can be incorporated in systems which do not require electrical power. This has obvious advantages in remote locations. The mechanical nature of this system of temperature measurement means that the problems caused by backlash and hysteresis prevent the system from achieving high accuracies. One disadvantage of this type of thermometer is that it does not hold its calibration well. This type of thermometer is used in the recording bimetallic thermograph and the bimetallic dial thermometer.

Thermosensitive Materials (Ref. 7) These fall into two main groups, those based on substances which change colour with temperature and those based on substances which melt. The former can be in the form of thermochromic materials applied to surface as a paper label, a paint, or crayon. Pyrometric cones and fuses are examples of the latter.

Thermochromic material, paint or crayon

An example of a thermochromic liquid is an aqueous solution of a transition metal salt such as Nickel (II) Chloride or Cobalt (II) Chloride with Hexamethylene Tetramine. When the surface to which the thermochromic agent is applied exceeds the certain temperature, a colour change will take place in the agent. This may or may not be reversible depending on the thermochromic agent chosen. Thermochromic devices are not expensive and, if a non reversible one is chosen, give an easy means of establishing if a given temperature has been exceeded. They also give good contact with the surface they are placed on and offer an easy means of surface temperature indication. They are not very accurate.

Non reversible thermochromic agents are extremely useful for giving information on thermal histories. They are also available as adhesive labels. An example is to show whether a plant or instrument has been operated at temperatures outside its specification, or if overheating has occurred, e.g. when autoclaving.

Fusible Materials

The pyrometric cone is similarly useful for measuring surface temperatures and consists of a specially formulated cone which is designed to melt at a specific temperature and will therefore give some record of thermal history.

The thermal fuse is a similar device resembling an electrical resistor, normally being part of a closed electrical circuit. If the device is subjected to a certain specified temperature or above, it becomes an open circuit offering protection against and

Fibre optic temperature sensor schematic

Optical fibre

Glass tube

Protective plastic case

Solid silicone polymer

Sensor crystal

Air
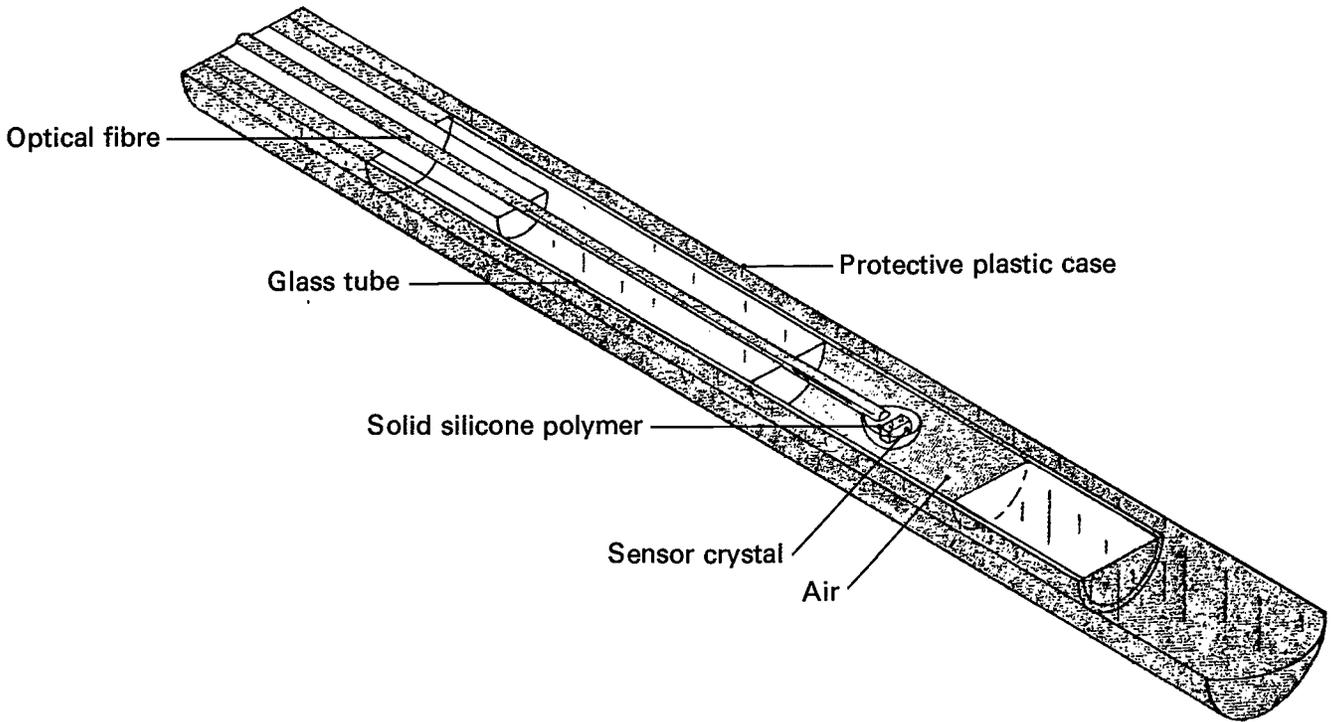
overheating. These can be used to protect instruments or plant. They are usually rated by current and voltage limits and not by temperature.

The above types of device will only find limited application in the water analysis field.

Infra Red Sensors

Temperature can be measured from its infra-red radiation emission using infra-red detectors. Such detectors can sense temperatures remotely and without contact. Calibration is a problem in that they need emissivity calibration from a black body cavity radiator.
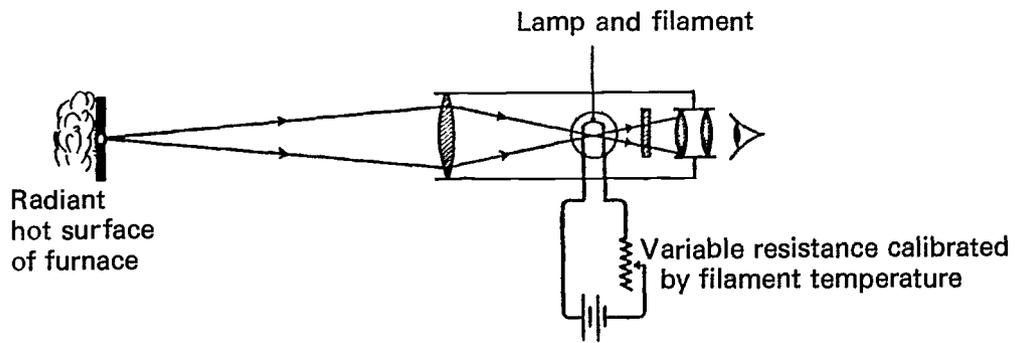
Scanning Thermography and Photographic Representation Techniques

These techniques rely on the detection of heat levels by the use of infra-red sensitive television techniques or by the use of infra-red sensitive photographic emulsion used in conjunction with suitable infra-red optical systems. These systems represent temperatures graphically as an image of the subject usually in false colours where typically blue represents cold and red represents hot, the temperature range being dependent on the required span of the subject. These techniques can be used as manually operated land based systems, aerial surveillance techniques or even as satellite surveillance systems. This makes them very suitable for detection of thermal pollution or the investigation of heat paths in heating or furnace systems. They may also be used for the investigation of flow systems in cases where the relative temperatures of the streams allow the mixing to be detected.
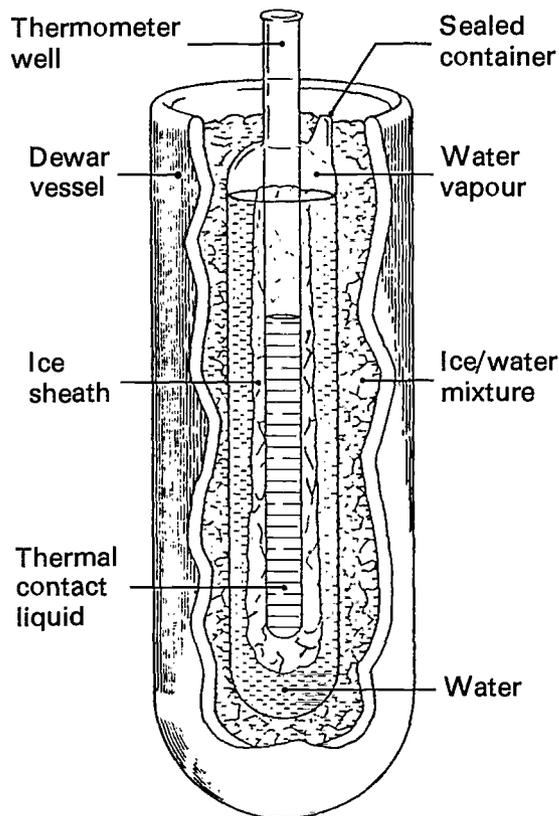
Quartz Thermometers

The quartz thermometer is a relatively modern design of thermometer offering very high accuracy combined with high stability and lack of maintenance. The operating principle is based on a quartz crystal oscillator. A quartz disk, which has been precision cut and gold plated is mounted to form the sensor. This sensor is connected

Optical radiation pyrometer

Lamp and filament

Radiant
hot surface
of furnace

Variable resistance calibrated
by filament temperature

Triple point cell obtainable from
the National Physical Laboratory

Thermometer
well

Sealed
container

Dewar
vessel

Water
vapour

Ice
sheath

Ice/water
mixture

Thermal
contact
liquid

Water

to an oscillator circuit which monitors the reasonant frequency of the quartz disk. This
is typically in the region of 28 MHz. Each Centigrade degree change in temperature
causes a change in the reasonant frequencies of about 1000 Hz. This frequency change
is measured by a precision frequency counter and displayed as temperature. As
probes may differ in their precise characteristics a multipoint calibration is performed
on the probe and then the data is stored on a programmable read only memory device
(PROMO). When the probe and the calibration PROM are plugged into the
thermometer the instruments microprocessor abstracts the data and sets itself
accordingly. Thus probes can be easily changed whilst maintaining the high accuracy
of the instrument. The unit will measure to a precision of 0.0001°C over the range
−80 to 250°C and has an absolute accuracy of 0.04°C over the range −50 to 150°C.
Factory recalibration is not required more than once a year. By using add on external
oscillators and line amplifiers the sensor may be separated from the electronics by up
to 1400 metres.

Optical Thermometers These utilize the change in spectrum of a fluorescent compound with temperature. The sensing element is often at the end of an optical fibre. Monochromatic light is transmitted down the fibre and the returned fluorescence light examined and converted to a temperature reading. Long fibre runs are possible (up to 500 m) and the sensing system can avoid the introduction of electrical (or mechanical) systems into sensitive or dangerous areas. The typical temperature range of these fibre optic fluorescence thermometers is typically 0–200°C with 0.1°C resolution and ± 1°C absolute accuracy. Currently they are expensive.

Optical Pyrometers Approximate temperature measurements are sometimes made on the inside of furnaces by matching the colour of a portion of internal brickwork with that of a flowing electrically heated filament, the temperature of which is controlled by varying the current supplied. The filament temperature can be obtained either by a built in resistance thermometer or the instrument may be calibrated directly using the heater current. Frequent checks are necessary with directly calibrated instruments to compensate for filament wear.

Essential Precautions for the Measurement of Reaction Temperatures

Many laboratory processes require the use of heating and cooling to maintain a reaction at a given temperature.

Various devices are used to achieve this including heating blocks, coolers, ovens and incubators. It is imperative to establish that the reaction medium has attained the desired temperature and not simply that the heating or cooling device is at that temperature. Poor thermal transfer, skin effects and other phenomena may prevent the reaction medium attaining the temperature of the unit in which it has been placed.

An example would be using a block heater to maintain a reaction at a fixed known temperature, other than by relying on refluxing. Temperatures for such reactions are often checked by using a contact thermocouple or contact R.T.D., or by using a liquid-in-glass thermometer in a thermometer pocket drilled into, the block. It is erroneous to assume that the samples placed in vessels in the block will attain the temperature of the block. Even if the reaction vessels are an exact fit in the block the temperature of the reaction mixture lags behind that of the block by several degrees Celsius. To establish the temperature of the reaction mixture it must be measured directly or by using a table containing dummy reaction medium. This is critical with tests that do not proceed to finality such as many COD tests.

Practical Consideration on the Measurement of Temperature of Waters

Ideally temperature measurements should be performed in situ rather than by sub-sampling. Care should be taken to minimise sampling errors. The user should be aware of the correct use and specification of his equipment and conform to this in carrying out the measurement. If high accuracy measurements are required (i.e. to better than 1°C) then the method of measurement and its traceability* to known standards should be known and recorded.

The most practical instrument for temperature measurement of waters in the field is the platinum resistance thermometers. It is ergonomically convenient especially for remote readout. It is readily adaptable for recording purposes and need not be affected by pressure. Its performance is well documented and reproducible and high performance systems can enable traceable measurements of 0.01°C to be obtained if the correct calibration procedure is followed.

Mercury in glass thermometers are far from ideal for field measurement. They are liable to breakage with attendant hazards from the mercury (and the glass). They are prone to parallox errors in reading. For field measurements they can rarely be used and read in the manner they were designed to be used (especially true with partial immersion types). They can only be used for superficial measurements of a body of water unless sophisticated types are used. They have the advantage of being low cost devices even calibrated to traceable standards.
(*See p. 32)

Sampling Errors

As important as the accuracy of the measuring device is a knowledge of the sample. Even a small body of water will almost certainly exhibit thermal gradients, layer effects and if moving show lamination of flow with temperature striations. When taking temperature measurements the user must ensure that sufficient data has been obtained to ensure that the reported results are meaningful. The need for averaging a series of results taken at various points is essential in attempting to measure the temperature of a body of water. The methods used in ensuring this should be reported with the measured temperatures. Work carried out by the National Weights and Measures Laboratory seems to indicate that 0.5°C is the best uncertainty to which a body of water could be measured (see Ref. 21).

Calibration
(Ref. 22, 23, 24, 25)

This is a specialist area, adequate facilities for which are not generally available to users. Users within the water industry are advised to use laboratories specializing in temperature calibration. In the United Kingdom laboratories approved by the British Calibration Service should be used and their advice taken regarding accuracy and recalibration.

Practical Temperature Calibration by the User

A user wishing to calibrate his own temperature measurement systems may find that the fixed points of the International Practical Temperature Scale are not easily attainable in a laboratory not equipped for temperature standards measurement. The alternative of using a standards laboratory may not be convenient.

The National Physical Laboratory produces triple point cells to enable the user to check thermometers against temperature fixed points in the temperature range of liquid water. These enable triple point temperatures to be attained to the uncertainties shown in Table 5.

Table 5   Substances used in N.P.L. Triple Point Cells

	t/C	Type 32 cell	Type 16 cell
		±	±
Water	0.010	0.000	0.001
Phenoxybenzene (diphenyl ether)	26.869	0.002	0.005
1,3-Dioxolan-2-one (ethylene carbonate)	36.325	0.002	0.005
Benzoic acid	122.36	0.005	0.01

The design of the cell (see illustration) uses a sealed cylindrical gas cell filled with the pure substance incorporating a well for the thermometer to be calibrated.

Precision calibration fluidized baths and calibration block heaters are available for temperatures up to 1100°C (cryogenic units can extend the lower end of the range to −100°C). The stability of the better units being ± 0.1°C. Such devices would themselves require traceable calibration.

Traceability

In theory it is possible for the user to calibrate temperature measurement systems as the standard temperatures are absolute and theoretically readily attainable. In practice considerable precautions are necessary to ensure that the correct calibration conditions are totally complied with, the attainment of these conditions being beyond the capabilities of the average user. In reality the attainment of these standards for calibration purposes is entrusted to the national standards laboratories. These include the National Physical Laboratory in Teddington which is responsible for maintaining physical standards in the United Kingdom of Great Britain and the National Bureau of Standards in Washington D.C. for standards in the United States of America. In real terms the calibration of a thermometer can be referred back to the standards maintained at these National Standards Laboratories often using the facilities of other standards laboratories whose standards have been directly cross referenced to the standards of the National Standards Laboratories. Equipment in general use may then be calibrated against the units which have been thus standardized. This chain of reference to the national standard measurements is what is referred to by the term Traceability.

Note the NPL Type 32 cell is 32 cm long for use in the highest precision applications. The Type 16 is 16 cm long and intended for less rigorous applications.

References

(1) The International Practical Temperature Scale of 1968 (Amended Edition of 1975), National Physical Laboratory, Her Majesty's Stationery Office.

(2) Methods of practical thermometry in the range 0–3000°C — a survey, from Measurement of high temperature mechanical properties of materials, editors Loveday, Day and Dyson, National Physical Laboratory, 1981, Her Majesty's Stationery Office.

(3) B.S.593:1974 Laboratory Thermometers (Three series of solid stem, mercury-in-glass thermometers).

(4) B.S.691:1979 Clinical Maximum Thermometers (Mercury-in-glass).

(5) B.S.692:1976 Meteorological Thermometers.

(6) B.S.791:1971 Solid-stem Calorimeter Thermometers (for accurate measurement of temperature changes).

(7) B.S.1041: Code of Practice for Temperature Measurement.

(8) B.S.1365:1975 Short Range Short Stem Thermometers.

(9) B.S.1704:1951 General Purpose Solid Stem Thermometers.

(10) B.S.1900:1976 Secondary Reference Thermometers.

(11) BS.2842:1975 Whirling Hygrometers (for determination of Temperature and Humidity).

(12) B.S.5074:1974 Short and Long Solid Stem Thermometers for Precision Use.

(13) B.S.5248:1975 Aspirated Hygrometers.

(14) B.S.5471:1977 Specification for Thermometer for use with Alcohol Hydrometers.

(15) I.S.O. Standard 386 Liquid in Glass Laboratory Thermometers — Principles of Design, Construction and Use.

(16) B.S.5235:1975 Specification for Dial Type Expansion Thermometers.

(17) B.S.3166:1959 Thermographs (Liquid Filled and Vapour Pressure Types).

(18) B.S.1904:1984, I.E.C.751:1983 Specification for Industrial Platinum and Resistance Thermometer Sensors.

(19) B.S.4937 Parts 1–8 & 20 International Thermocouple Reference Tables.

(20) B.S.3231:1960 Specification for Thermographs (bimetallic type).

(21) Withers, M., "Uncertainty of Measurement in Volumetric Calculations", National Weights and Measures Laboratory, London.

(22) The Calibration of Thermometers, C R Barber, SBN 11 480019u, 1970, Her Majesty's Stationery Office.

(23) Thermocouples, Reference Tables and Traceability, February 1975, British Calibration Service, Publication 5551.

(24) General Criteria for Laboratory Approval, Thermal Measurements, October 1968, British Calibration Service, Publication 0602.

(25) Supplementary Criteria for Laboratory Approval, The Measurement of Temperature, June 1971, British Calibration Service, Publication 0611.

List of Useful Addresses

(1) British Standards Institution
2 Park Street
London W1A 2BS

Telephone: 01–629 9000

British Standards are available from Her Majesty's Stationery Office and their agents, and also directly from the British Standards Institution, Sales Office.

(2) National Bureau of Standards
Washington DC 20234
USA

Telephone: 0101 301 927 2467

(3) National Physical Laboratory
Teddington
Middlesex TW11 0LW

Telephone: 01–977 3222

(4) National Weights and Measurements Laboratory
Department of Trade and Industry
26 Chapter Street
London SW1P 4NS

Telephone: 01–211 3000

(5) British Calibration Service
National Physical Laboratory
Teddington
Middlesex TW11 0LW

Telephone: 01–977 3222

The British Calibration Service produces publications relating to calibration and the criteria for standard laboratory approval. They also will provide a list of approved calibration laboratories offering traceable calibration to national standards.

List of Related British Standards

British Standards concerned with temperature measurement with a brief summary of temperature measurement devices covered.

B.S.593:1974 "Laboratory Thermometers"

Revisions:– Confirmed January 1981 Amendment No.1 effective from 31 July 1985.

Devices covered:–

Mercury in glass thermometers of a higher precision than reasonable accuracy (for which see B.S.1704).

Three series of thermometers are covered by this standard.

(1) Series A. Thermometers about 400mm long, with zeros, covering ranges of about 30°C to 40°C or about 55°F to 75°F, and graduated at each 0.1°C or 0.2°F.

(2) Series B. Thermometers similar to those of Series A, but ith ranges of about 60°C or about 110°F and graduated at each 0.2°C or 0.5°F.

(3) Series F. Thermometers intended for use in the distillation of certain solvents and based on those specified for this purpose by the Institute of Petroleum and the American Society of Testing and Materials. Celsius range thermometers only are specified, the Fahrenheit range previously included having been omitted owing to lack of demand. No extension of the scale beyond the nominal range is specified for these thermometers; they thus remain identical with the corresponding IP and ASTM thermometers.

B.S.691:1979 "Specification for Clinical Maximum Thermometers (mercury in glass)

Devices Covered:–

Mercury in glass clinical maximum thermometers of the solid stem type for the measurement of deep body temperature of human beings.

B.S.692:1976 "Specification for Meteorological Thermometers"

Devices Covered:–

Mercury in glass and spirit in glass thermometers for maximum, minimum and ordinary (wet or dry bulb; meteorological measurements, protected by glass sheaths and suitable for mounting in a louvered screen.

(Note the Six's pattern of combined maximum and minimum thermometer is not covered by this standard.)

B.S.791:1975 "Specification for Solid-Stem Calorimeter Thermometer"

Devices Covered:–

Short range solid stem mercury in glass thermometers for use in bomb calorimetry and for other purposes where an accurate measurement of change of temperature is required. These thermometers are not provided with auxiliary scales at 0°C and are

NOT SUITED TO ABSOLUTE MEASUREMENT OF TEMPERATURE (unless calibrated against other absolute thermometers immediately before use).

B.S.1041:1943 "Temperature Measurement"

Revisions:– Amendment No.1, January 1946

Devices Covered:–   —

Broad review of temperature measurement systems and methods of measurement with some of the attendant problems.

B.S.1041 Section 2.1.1985

Devices Covered:–   —

Solid-stem and enclosed scale thermometers covering the range of −200°C to 1050°C.

B.S.1041 Part 3: 1969

Devices Covered:–   —

Resistance thermometers including principles, application, construction and characteristics and instrumentation and circuits, data logging and processing and linearization.

B.S.1041 Part 4: 1966

Devices covered:–

Thermocouple devices and related instrumentation.

B.S.1041 Part 5: 1972

Devices Covered:–   —

Radiation pyrometers.

B.S.1041 Part 7: 1964

Devices Covered:–

Change of state devices including pyrometric cones and temperature sensitive paints.

B.S.1365:1975 "Specification for Short-Range, Short-Stem Thermometers"

Devices Covered:–

This standard specifies requirements for two series, A and B, of mercury-in-glass thermometers. In each series, thermometers calibrated for total immersion (designated A1 or B1) and thermometers calibrated for partial immersion (designated A2 or B2) are included for each temperature range.

Series A1 comprises seven total immersion thermometers, each with a scale span of approximately 60 Celsius degrees, covering the range −10°C to +360°C.

Series A2 covers the same range for an immersion of 80mm.

Series B1 comprises 25 total immersion thermometers, each with a scale span of approximately 10 Celsius degrees, covering the range −10°C to +220°C.

Series B2 covers the same range for an immersion of 70mm.

B.S.1704:1985, I.S.O.1770:1981 "British Standard Specification for Solid-Stem General Purpose Thermometers"

Devices Covered:–

Two series of inexpensive "commercial quality" liquid in glass thermometers of the solid stem type suitable for general purpose in industry, schools and laboratories where great accuracy of measurement is not required.

a) a series designated A to H, in which nominal ranges and maximum overall lengths are specified but which may not be acceptable for testing by a national verification laboratory;

b) a series designated J to W of greater accuracy than in a) and with specified ranges and a tolerance on overall length, which may be acceptable for testing by a national verification laboratory.

The temperature range covered by each series is from −100°C to +500°C.

The standard is restricted to Celsius thermometers.

B.S.1974:1952 "Chart Ranges for Temperature Recording Instruments"

Devices Covered:–

Preferred charts for fluid filled, thermocouple resistance and radiation pyrometer temperature recording systems.

B.S.1900:1976 "British Standard Specification for Secondary Reference Thermometers"

Devices Covered:–

Liquid in glass solid stem thermometers which can be used as secondary reference (SR) thermometers for calibrating other thermometers in laboratory and industrial use.

Thermometers to this standard can be certified for compliance with this standard by the National Physical Laboratory.

B.S.1904:1984, I.E.C.751:1983 "British Standard Specification for Industrial Platinum & Resistance Thermometer Sensors"

Devices covered:–

Industrial platinum resistance thermometers whose electrical resistance is a function of temperature covering the range −200°C to +850°C with two tolerance classes.

B.S.2765:1969 "Specification for Dimensions of Temperature Detecting Elements and Corresponding Pockets"

Devices Covered:–

The dimensional requirements of thermometer pockets to enable interchange of temperature detecting elements as a part of plant equipment.

B.S.2842:1975 "Specification for Whirling Hygrometer"

Devices Covered:–

Liquid in glass thermometers for use in whirling hygrometers.

B.S.3166:1959 "Thermographs (liquid-filled and vapour pressure types)"

Devices Covered:–

Thermographs of the liquid filled and vapour pressure types suitable for general and marine use in the measurement of temperatures within the range −20°F to 220°F (−30°C to 105°C).

B.S.3231:1960 "Specification for Thermographs (Bimetallic Type)"

Devices Covered:–

Thermographs of the bimetallic type for general and marine use in obtaining a continuous record of air temperatures within the range 0°F to 140°F (−20°C to 60°C).

B.S.3273:1960 "Distant Indicating Thermometers for Ships' Refrigerated Cargo Spaces"

Devices Covered:–

Electrical Resistance and Liquid Expansion thermometers for the above application.

B.S.4937 International Thermocouple Reference Tables

Part 1: 1973 (1981) Platinum — 10% Rhodium/Platinum Type S.

Part 2: 1973 (1981) Platinum — 13% Rhodium/Platinum Type R.

Part 3: 1973 (1981) Iron — Copper/Nickel — Type J.

Part 4: 1973 (1981) Nickel/Chromium — Nickel/Aluminium Type K.

Part 5: 1974 (1981) Copper — Copper/Nickel Type T.

Part 6: 1974 (1981) Nickel/Chromium — Copper/Nickel Type E.

Part 7: 1974 (1981) Platinum/30% Rhodium Platinum/6% Rhodium Type B.

Part 8: (Not yet published) Nickel/Chromium/Silicon — Nickel/Silicon. Type N.

Part 20: 1983 Specifications for Thermocouple Tolerances.

B.S.5074:1974 "Short and Long Solid Stem Thermometers for precision use"

Devices Covered:–

Total Immersion solid stem liquid-in-glass thermometers within the range −55°C to 600°C. Suitable for general use in precision work.

B.S.5235:1975 "Specification for Dial-Type Expansion Thermometers"

Devices Covered:–

General purpose liquid gas or vapour filled dial type expansion thermometers.

B.S.5248:1975 "Specification for Aspirated Hydrometer"

Devices Covered:–

Liquid in glass thermometer for use in electrically or mechanically aspirated wet and dry bulb hygrometer.

B.S.5471:1977 "Specification for Thermometer for use with Alcohol Hydrometers"

Revisions: Amendment Slip No. 1, Effective 30 March 1979

Devices Covered:–

Complete immersion solid stem mercury in glass thermometer specifically for use with alcohol hydrometers complying with B.S.5470. The range covered is −5°C to +40°C with a smallest scale division of 0.5°C.

Address for Correspondence

Every effort has been made to make this review as helpful as possible. If however readers find problems, the committee would be pleased to hear about them. In which event, please write to:–

The Secretary
The Standing Committee of Analysts
The Department of the Environment
43 Marsham Street
LONDON SW1P 3PY
England

Department of the Environment

Standing Committee of Analysts

This review was originally proposed in 1976, but there was exceeding difficulty in preparing a suitable text. However the project was revived in 1985 and has finally been completed, the principal authors now being Dr J Cope and Dr J R P Clarke with some advice from the staff of the National Physical Laboratory, the National Weights and Measures Laboratory, and the British Standards Institutions.

Members of the Committee responsible for these methods:

H T Barnhoorn	1	J S Lealy	1
Dr G I Barrow	4	W M Lewis	1
F B Basketter	1	R Lisle	2
M Beard	3	A Lloyd	2
D G Best	3	P J Long	2
Dr G A Best	2	G H Mansfield	2
R R Birch	2	J C McCullins	1.4
J Borland	4	J Midgley	2
Dr J M Carter	3.4	B L Milford	3
P A Clare	1	P J Morries	4
Dr J P R Clarke	0.2.3	C C Musselwhite	2
Dr G W Clayfield	4	D Myles (deceased)	2
B E P Clement	4	A H Nield	4
Dr V Collins	4	Dr A H Painter	2.4
Dr R L Cooper	4	Dr S J Patterson	4
Dr J Cope	0.2.3	K Petts	2.3
G B Crump	2	L R Pittwell	1.2.4
Dr B T Croll	1.4	Dr J E Portmann	1.4
Dr J V Dadswell	1	L D Purdie	1.4
S J Davies	2	B D Ravenscroft	1.2.4
C Deakin	2	B R Rhodes	4
E de Casseres	2	L A Richards	1
T A Dick	4	Prof J P Riley	1.4
J W R Dutton	4	Prof J M Riley	2
G M C Eastman	3	Dr E A Simpson	3
M C Finniear	1	Mr R Sinar (deceased)	4
G I Goodfellow	1	J Street	2
K Goodhead	4	Dr D Taylor	1
T R Graham	1.4	Dr K C Thompson	1.2
K Guiver	1	D A M Ure	1.4
L Hancock	1	R J Vincent	1
I Harper	4	P J Walker	2
A E Hey	4	B T Whitlam	4
E Hodges	4	Dr D A Williams	1
G J Holland	4	A L Wilson (deceased)	4
M R Hocombe	1	Dr R Wood (LGC)	4
Dr J G Jones	1	Dr R Wood (MAFF)	1
M K Kibblewhite	2		

0. Principal Author
1. Main Committee Member (completion)
2. Working Group 3 Member (completion)
3. Working Group 2 Member (initiation)
4. Main Committee Member (initiation)