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Temperature measurement —

Part 2: Expansion thermometers —

Section 2.1 Guide to selection and use of liquid-in-glass thermometers

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Foreword

This revision of this Section of BS 1041 has been prepared under the direction of the Laboratory Apparatus Standards Committee. It supersedes the 1969 edition of BS 1041-2.1, which is withdrawn. Previous editions (published in 1943 and 1969) classified and reviewed liquid-in-glass thermometers under four main groups, broadly defined by their applications in meteorology, industry and the laboratory. In this revision, however, those classifications are discontinued since their meaning or relevance is considered obscure or out-dated and, in some cases, too specialized for a document intended to give guidance of a general nature. Paradoxically, the current diffusion of standardization and increasing demand for traceability[1)] in measurement call for a degree of specialization weighted towards the use and maintenance of generally high quality thermometers, conveniently designated as "working standards". Accordingly, this revision is intended to provide an essentially practical guide to the selection and use of thermometers wherever standardization, calibration and traceability are of concern and interest.

Revisions of BS 1041-3 to BS 1041-5 and BS 1041-7 are in preparation.

For the purposes of this Section of BS 1041, the terminology and conventions of ISO 386 "*Liquid-in-glass laboratory thermometers — Principles of design, construction and use*"[2)] have been adopted.

Throughout this Section of BS 1041, the symbol "°C" is used to denote actual temperature, and the words "degree(s) Celsius" to denote temperature intervals.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 18, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1)] Traceability is an accepted term and is, for the purposes of this Section of BS 1041, defined as the ability of a measurement result to be related to the current International Practical Temperature Scale through an unbroken chain of comparisons.

[2)] Published by the International Organization for Standardization (ISO).

1 Scope

This Section of BS 1041 gives guidance on the selection and use of:

a) hermetically-sealed glass thermometers in which a thick-walled capillary stem is fused to a reservoir or bulb containing a thermometric liquid and the temperature scale is engraved or permanently marked on the stem;

NOTE Thermometers of this type are commonly known as "solid-stem thermometers".

b) enclosed-scale liquid-in-glass thermometers, in which a comparatively thin-walled capillary together with a separate strip bearing the scale is enclosed in a hermetically-sealed glass sheath.

Collectively, they span a temperature range from – 200 °C to 1 050 °C and are in some cases capable of measurement uncertainties of ± 0.005 degrees Celsius (see **5.2**).

Generally, but not without exception, they fall within the scope of the following British Standards:

BS 593	BS 692	BS 791
BS 1365	BS 1704	BS 1900
BS 5074	BS 2000-0:Addendum 1	

NOTE 1 In this Section of BS 1041, temperatures below 0 °C are indicated with a minus sign; temperatures above 0 °C have no sign.

NOTE 2 The titles of the publications referred to in this Section of BS 1041 are listed on the inside back cover.

2 Principle of temperature measurement by liquid expansion

The apparent differential expansion of a liquid, in glass, provides a conveniently measurable parameter (length) to indicate a temperature along the scale associated with a capillary stem. This expansivity, defined in terms of the apparent cubic thermal expansion coefficient of the thermometric liquid concerned k (in $°C^{-1}$), is given by the following equation:

$$k = \frac{1}{V}\frac{dV}{dt}$$

where

V is the liquid volume;

$\frac{dV}{dt}$ is the rate of change of volume with temperature.

Therefore, the scale length, L, equivalent to a temperature interval t for a given capillary and liquid volume is given by the equation:

$$L = \frac{Vtk}{a}$$

where

a is the cross-sectional area of the capillary.

If k and a are constant, then L is, to first order accuracy, linearly dependent on temperature.

Tapering or non-uniformity in the bore and errors in marking and dividing in the graduation process lead to inherent errors in the reading of a thermometer and hence to the need for calibration of the complete instrument.

Other potentially serious sources of error arise from both short-term and long-term glass instabilities, the characteristic behaviour of the liquid filling, conditions of immersion, pressure and anomalous effects, parallax and poor maintenance. All of these aspects of liquid-in-glass thermometry are normal and are discussed in this guide.

3 Materials

3.1 Glasses

3.1.1 *General*. Thermometric glasses are fused mixtures of inorganic oxides, in which the major constituent is silica, but whose characteristic properties can be altered significantly by the addition of other constituents in various concentrations. Of the important physical and chemical properties, the following are those of overriding importance in the development of the three major approved glass types (see **3.1.2** to **3.1.4**) which are used in the manufacture of thermometers:

a) the softening point which limits the working temperature range;

b) resistance to devitrification;

c) the ability to be clearly etched or engraved and to be welded to an opaque enamel backing;

d) freedom from physical imperfections;

e) thermal stability.

3.1.2 *Normal glass*. Of the three glasses, so-called normal glass is most common. It is a soda-lime glass, also containing zinc oxide and alumina and used extensively to make both bulb and stem for continuous use from – 200 °C up to 350 °C, and for short-term use from – 200 °C up to 400 °C.

NOTE The term "normal" arises from an early practice of glass technologists, namely that of setting out the limits of composition of durable commercial glasses by molecular formulae. The existence of a compound whose molecular ratio of silica-lime-soda was 6 : 1 : 1 was investigated, and samples were found to be comparatively most resistant to corrosion. This nominal composition came to be known as "normal".

3.1.3 *Borosilicate glass*. Borosilicate glasses contain soda, boric oxide and alumina; they offer considerably improved thermal stability over normal glass, and an extended working range from – 200 °C up to 450 °C and 500 °C for long- and short-term exposures, respectively. Where high stability and precision are of primary interest, borosilicate thermometers are used to advantage in place of normal glass thermometers. Both the bulb and stem are made from the same glass since it does not fuse satisfactorily with alternative thermometric glasses.

3.1.4 *Combustion glass*. Combustion glass is borosilicate glass containing higher proportions of boric oxide and alumina than in normal borosilicate glass (see **3.1.3**). Thermometers made throughout from this glass can be used up to 600 °C.

3.1.5 *Approval*. The thermometric glasses in **3.1.2** to **3.1.4** have been the subject of approval tests by national standardizing laboratories and they are registered and recognized internationally by a scheme of coloured lines running the length of the bulb glass or by an engraved inscription (see Table 1). Sometimes the coloured lines may be very fine and difficult to detect; if the thermometer is held vertically with the bulb resting on a white surface, the line is usually made visible against the reflected white background. Combustion-type glasses do not satisfactorily fuse to the coloured enamel glasses used for identification purposes and are therefore recognized instead by a coded inscription engraved on the thermometer stem.

It should be emphasized that only approved glasses appropriate to the required range of temperature are suitable for thermometer manufacture and usage.

3.1.6 *Lead glass*. In the temperature range from – 200 °C up to 300 °C an alternative glass containing lead, which imparts a characteristic brilliance and clarity to the stem, may be used in conjunction with a normal glass bulb.

Table 1 — Thermometric glasses approved by the National Physical Laboratory

Glass	Identification stripe(s) or approved abbreviation	Normal maximum working temperature
		°C
Normal glass, made by Whitefriars Glass Ltd.	Single blue stripe	350
Normal glass, Dial, made by Plowden and Thompson Ltd.	Double blue stripe	350
Normal glass, Schott-N16, made by Jenaer Glaswerk Schott and Genossen, Mainz	Single red stripe	350
Normal glass, 7560, made by Corning Glass Co.	CN	350
Corning borosilicate glass, made by Corning Glass Co.	CB	450
Thermometric glass, Schott-2954, made by Jenaer Glaswerk Schott and Genossen, Mainz	Single black stripe	460
Borosilicate glass, made by Whitefriars Glass Ltd.	Single white stripe	460
Corning glass, 1720, made by Corning Glass Co.	C1720	600
Schott-Supremax R8409, made by Jenaer Glaswerk Schott and Genossen, Mainz	SPX 8409	600

NOTE 1 The maximum temperatures given in the last column of the table are a guide to normal practice. The performance of a thermometer depends greatly on the stabilizing heat treatment which it has been given during manufacture, and a well-made thermometer of normal glass may be quite satisfactory for many purposes at temperatures as high as 400 °C. On the other hand, for the best accuracy, the use of one of the borosilicate glasses may be preferred for temperatures lower than 350 °C. In general, the lower the maximum temperature of use when compared with the approved temperature of the glass, the better will be the "stability of zero" of the thermometer (see **6.8**).

NOTE 2 The list of manufacturers included in this table is complete at the time of publication, but may not remain exhaustive. Reference should be made to the National Physical Laboratory.

3.1.7 *Silica*[3]. Thermometers made from fused silica offer the highest stability for use from – 200 °C up to 600 °C. Additionally, fused silica thermometers can be used up to 1 050 °C and are more resistant to mechanical and thermal shocks than other thermometric glasses (see also **3.2.4**).

3.2 Liquid fillings

3.2.1 *Mercury*. Mercury continues to be the most popular filling fluid because:

a) it is easily obtained in a pure form;

b) it remains liquid between its freezing point, – 38.84 °C, and its boiling point, 356.66 °C;

c) its surface tension is high (not giving rise to drainage problems);

d) it is readily detectable in glass;

e) its thermal expansion coefficient is very uniform.

Although it boils at approximately 356 °C under 100 kPa[4] pressure, its useful range can be extended to 600 °C by sealing the thermometer at a high pressure of gas, usually nitrogen, to suppress evaporation. At 600 °C, the internal gas pressure is 2 MPa.

3.2.2 *Mercury-thallium*. Mercury alloyed with 8.7 % thallium, by mass, forms a eutectic retaining essentially the same characteristics as mercury, notably stability, while extending the useful working range to – 55 °C from – 38.84 °C.

3.2.3 *Organic liquids*. Some organic liquids enable the thermometer range to be extended downwards. Pure ethanol and toluene have freezing points of – 112 °C and – 95 °C, respectively, while technical grade pentane can be used down to as low as – 200 °C.

Such liquids, having thermal expansion coefficients some six or seven times that of mercury, offer considerable improvement in terms of sensitivity, but some major disadvantages lead to the construction of thermometers having much larger capillary bores and bulbs than mercury-filled thermometers. The expansivity is less regular, being greater at some temperatures than at others. Furthermore, the organic liquids have a low surface tension making them unsuitable for accurate thermometry because they wet the walls of the capillary which cannot, therefore, be as fine as for mercury thermometers. They are also highly volatile even at room temperature; as a result, partial distillation of the liquid and separation of the liquid column can also occur quite readily. It follows that extra care and maintenance in the use of organic liquid thermometers is required (see **8.3.4**).

3.2.4 *Gallium*. This element is used as the filling liquid in high temperature silica thermometers. In spite of its freezing point being at 29.78 °C, it readily supercools and remains liquid within the common range of ambient temperatures. Its great advantage in thermometry derives from its boiling point which, being above 2 000 °C, permits its use up to 1 050 °C without the need for a high-pressure gas filling in the capillary tube. Indeed, the limitation to its use is imposed by recrystallization of the silica glass at temperatures exceeding 1 050 °C. In comparison with other thermometric liquids, its expansivity is much smaller so that gallium-filled thermometers are less sensitive. However, the corrections that have to be applied when the thermometer is used under partial immersion conditions are several times smaller than those required for mercury-filled thermometers.

3.3 Gas filling

Gas filling, to suppress vaporization of mercury (see **3.2.1**), is necessary for all thermometers to be used at temperatures above 150 °C, except those filled with gallium. An inert gas, usually dry pure nitrogen, is used and the thermometer stem is inscribed with a suitable identification of the filling gas.

[3] Commonly known as "quartz".

[4] 100 kPa is approximately 1 at.

3.4 Evacuated thermometers

Evacuated thermometers are now less common but function perfectly well at temperatures below 100 °C, except that, when stored or rested horizontally, vibration or physical shocks may cause the mercury column to fragment. In such thermometers, used at temperatures as low as 70 °C, the mercury shows some propensity to distillation and this effect should be guarded against.

4 Construction and marking

4.1 Shape

In general form, thermometers are straight, with a cylindrically shaped bulb or reservoir whose external diameter is, for reasons of safe handling, smaller than that of the stem.

4.2 Bulb

A cylindrically shaped bulb is most commonly used because, for a given volume, it provides a larger surface area than a spherical bulb and this improves the speed of response. For the same reason, the bulb has a thin wall, typically 0.35 mm to 0.45 mm thick, but consequently is both fragile and flexible. If pressure were to be applied to the bulb, the bulb volume would be reduced which would cause the liquid column to rise.

NOTE Because of the fragility and vulnerability of the bulb, liquid-in-glass thermometers should always be handled carefully and pressure should not be applied to the bulb.

Spherical bulbs are generally confined to meteorological measurements of temperature, where a relatively slow time response is desirable.

4.3 Bulb funnel

Inside the bulb of a well-made thermometer, the taper joining the bulb to the much smaller diameter capillary should be smooth and free from any sharp angles or shoulders which are likely to entrap small volumes of the gas filling from the capillary and give rise to faulty measurements.

4.4 Stem

The thermometer stem is usually round in section and carries in it and on it all other physical and inscriptive features appropriate to its functions. It is nominally uniform in section although a number of instruments are made which carry a ground glass joint or a swelling to fit apparatus under special conditions of use. Stems with a roughly triangular cross section were originally developed to prevent thermometers rolling off smooth surfaces but the advantage of a lens-front that magnifies the meniscus and facilitates its detection was quickly noticed and is incorporated as a desirable feature in some designs.

In general, treatment of the stem and its various features has little direct influence on performance and, in the normal course of events, it is only the stability of the bulb which can give rise to both foreseeable and unforeseen changes (see **6.8.2**, **6.8.3** and **4.10**).

4.5 Top finish

Handling or suspension of thermometers when deeply immersed and/or at high temperatures is made easier by the provision of a ring or button finish to the top of the stem. Rings are obviously more fragile. There is no choice of type of finish on thermometers used above 450 °C, as forming a ring or button requires re-heating and softening of the glass after it has been sealed to contain a capillary gas at high pressure. Softening the glass could lead to a gas blow-out.

4.6 Enamel backing

Thermometers for use from – 200 °C up to 500 °C are provided with an opaque white or yellow enamel strip against which the capillary and mercury are more easily detected and viewed. This enamel backing is a softish clear glass made opaque and coloured by the addition of a colouring agent of metallic (commonly stannic) oxides. It is laid and fused into the glass as a strip during the initial production of glass canes from the original measured portion (“gob”) of molten glass. Its absence from high temperature thermometers is due to the failure of enamel to fuse satisfactorily with high temperature combustion glasses. Instead, an effectively opaque backing is achieved by sand-blasting or etching the surface of the stem.

4.7 Scales

Usually a stem displays one or two scales. The main scale spans the intended range of use and the auxiliary scale, which consists of only 10 or so scale lines, is centred most usually at 0 °C, sometimes at 100 °C, and acts as a fiducial or reference point so that gradual changes in calibration may be detected and accounted (see **6.8.3** and **6.9**).

4.8 Scale lines

Individual scale lines are marked on the stem by acid etching engraving techniques, or ionic staining or silk screen processes. The resultant line thicknesses may be as small as 0.05 mm or as large as 0.2 mm. In all cases, they should be uniform throughout the scale length and the spacing between the centres of consecutive lines should be at least five times the line thickness so that interpolation, with simple optical aids if necessary, is comfortably and reasonably achieved. These sorts of constraints lead to a smallest scale division of 0.7 mm to 0.8 mm being a common optimum, although they may range in some cases from about 0.2 mm to 2 mm. Various preferred combinations of short, medium, and long lines have evolved according to whether the smallest scale division is 1 degree Celsius, 2 degrees Celsius or 5 degrees Celsius or their respective decimal multiples or sub-multiples. Thick lines, a congestion of lines, unevenly spaced and poorly defined lines lead individually, or collectively, to inferior resolution and ambiguities.

4.9 Capillary

The capillary bore is usually round or elliptical in cross section. In the latter case, the ratio of minor to major axes (about 1 : 3) offers both a wider, more visible diameter to the user and a reduction in the quantity and cost of mercury for a given sensitivity. Bore sizes may be as large as 0.4 mm but can be as small as 0.02 mm in relatively short range, high resolution, high accuracy thermometers for which a resolution of 0.001 degrees Celsius is routinely possible, with accuracies of ± 0.002 degrees Celsius and ± 0.005 degrees Celsius for differential and absolute measurements of temperature, respectively. Some extra care in use is necessary to overcome effects due to irregular movement of the mercury in the capillary (see **7.4**).

Foreign material in the form of glass chips, moisture or dirty mercury may appear in the bore of a thermometer and constitute a serious potential source of error, more especially if it is movable. This may or may not be capable of being remedied (see **8.2**) and can lead to the complete rejection of the instrument.

4.10 Contraction chamber

In those thermometers in which the filling liquid would otherwise withdraw into the bulb at room temperatures, or in which an auxiliary scale is required, an enlargement of the bore, i.e. contraction chamber, is provided. As with any enlargement, the chamber should be smoothly tapered where it joins the capillary. Apart from the bulb, this enlargement, which may contain a substantial volume of filling liquid compared with the bore, can also lead to semi-permanent changes in the thermometer's calibration (resulting from semi-permanent changes in the glass itself and hence in the volume of the chamber) (see **6.8.1** and **6.8.2**).

4.11 Expansion volume

An expansion or safety volume is provided at the top of the capillary and serves to prevent the generation of excessive capillary gas pressures which would otherwise threaten to stretch and deform the bulb and, in the extreme, break it. For these reasons it should not be regarded as a reservoir for expanded liquid; clearly, if the filling liquid enters the expansion chamber then the thermometer has been heated above the nominal maximum temperature for which it was designed, annealed and calibrated. On the other hand, there are quite legitimate, desirable reasons for making use of the expansion chamber in order to correct certain temporary defects (see **8.3.3**). An expansion volume can be "pear-shaped", with the hemisphere at the top of the thermometer, or it can be a sufficiently long extension of the capillary; some thermometer specifications include a preferred volume expressed in degrees Celsius.

4.12 Dimensions

Correct design ensures that any one of the features described in **4.1** to **4.11** may exist or function without detriment to another. Thermometer specifications, therefore, describe the size, and precise location of individual features and, importantly, the desirable separation between them. For example, any enlargement of the bore cannot be allowed to interfere with bore uniformity in the scale range and, as an adequacy of immersion has to be provided for, a minimum separation of 5 mm between the enlargement of the bore and the scale line is required although individual clearances vary considerably according to the type of thermometer. Dimensionally, thermometers are expected to comply with the requirements of the thermometer specification within stated tolerances. Thin and (relatively) thick scale lines can be acceptable even if tolerances of 40 % and 15 %, respectively, are allowed (see **4.8**).

5 Thermometer selection

5.1 Necessary considerations

Three factors dominate the selection of thermometers:

a) the required temperature range of operation;

b) the desired accuracy;

c) the working depth of immersion and, hence, permissible length of the thermometer.

For optimum performance over an extensive temperature range, a number of thermometers, each spanning successive parts of the range, can provide a better measurement uncertainty than a single thermometer covering the whole range.

5.2 Accuracy

In general, measurement uncertainty varies both with temperature and with the length of the scale range. The best measurement uncertainty, ± 0.005 degrees Celsius, is available between – 10 °C and 50 °C with thermometers having scale ranges of 6 degrees Celsius and 10 degrees Celsius (see BS 791 and BS 1900). The following tolerances indicate the best measurement uncertainties obtainable for BS 1900 thermometers covering the temperature ranges indicated, using total immersion conditions (see **5.6.2**):

a) ± 0.20 degrees Celsius for – 80 °C to 30 °C;

b) ± 0.05 degrees Celsius for – 40 °C to 2 °C;

c) ± 0.01 degrees Celsius for 0 °C to 100 °C;

d) ± 0.05 degrees Celsius for 100 °C to 200 °C;

e) ± 0.10 degrees Celsius for 200 °C to 300 °C;

f) ± 0.20 degrees Celsius for 200 °C to 450 °C;

g) ± 1.00 degrees Celsius for 95 °C to 500 °C.

Under conditions of partial immersion, the uncertainties given increase approximately by a factor of two.

5.3 Accuracy limits

The widest limits of measurement uncertainty for compliance with the National Physical Laboratory (NPL) calibration requirements are given in Table 2 and Table 3 for various temperature ranges and scale divisions. When the scale range of a thermometer falls within more than one of the test range limits, the most restrictive range is held to apply.

NOTE Although Table 2 and Table 3 originated from the NPL, they are of general applicability, in particular to approved laboratories of the British Calibration Service (see Appendix A).

5.4 Working depth

Thermometers may be used at complete, total or partial immersion (see **7.2**). The commonly available high precision total immersion thermometers require a maximum working depth, depending on the maximum temperature of use, of between 400 mm and 590 mm, according to individual thermometer specifications. Partial immersion thermometers are specified variously for working depths of 75 mm, 80 mm or 100 mm.

5.5 Maximum error

The temperature indicated by an uncalibrated British Standard specification thermometer should fall, excluding any correction, within the tolerance given in the specification under the heading "maximum error".

5.6 British Standard thermometers

5.6.1 *General*. The dimensions, ranges, performance, and correct usage of several types of thermometers are described fully by British Standards (see **5.6.2** to **5.6.8**).

5.6.2 *Secondary reference thermometers*. BS 1900 specifies a comprehensive series of very high quality secondary reference (SR) thermometers most suitable for calibrating other thermometers, in the range – 80 °C to 500 °C. They offer the best level of measurement uncertainty routinely attainable with thermometers, e.g. ± 0.005 degrees Celsius between – 10 °C and 50 °C (see **5.2**). Overall lengths are between 395 mm and 590 mm and they are made only for total immersion.

Table 2 — NPL measurement uncertainties of total immersion thermometers

Thermometer divided in to [in degree(s) Celsius]	Uncertainties of thermometers (in degrees Celsius)								
	Test range entirely contained within the limits[a]								
	– 80 °C to 50 ° C	– 40 °C to 100 ° C	– 25 °C to 100 ° C	– 10 °C to 50 °C	– 10 °C to 100 °C	– 10 °C to 200 °C	– 10 °C to 300 °C	– 10 °C to 450 °C	– 10 °C to 500 ° C
0.01	—	—	—	± 0.005	± 0.01	—	—	—	—
0.02	—	—	± 0.02	± 0.01	± 0.02	—	—	—	—
0.05	—	—	± 0.05	± 0.02	± 0.02	± 0.05	—	—	—
0.1	—	± 0.1	± 0.1	± 0.02	± 0.02	± 0.05	—	—	—
0.2	± 0.2	± 0.1	± 0.1	± 0.05	± 0.05	± 0.05	± 0.1	± 0.2	—
0.5	± 0.5	± 0.2	± 0.2	± 0.05	± 0.05	± 0.1	± 0.2	± 0.2	± 1.0
1.0	± 0.5	± 0.2	± 0.2	± 0.1	± 0.1	± 0.2	± 0.2	± 0.5	± 1.0
2.0	± 1.0	± 0.5	± 0.5	± 0.2	± 0.2	± 0.5	± 0.5	± 1.0	± 1.0

[a] When the scale range of a thermometer falls within more than one of the test range limits, the most restrictive range is held to apply.

Table 3 — NPL measurement uncertainties of partial immersion thermometers

Thermometer divided in to [in degree(s) Celsius]	Uncertainties of thermometers (in degrees Celsius)								
	Test range entirely contained within the limits[a]								
	– 80 °C to 50 ° C	– 40 °C to 100 ° C	– 25 °C to 100 ° C	– 10 °C to 50 °C	– 10 °C to 100 °C	– 10 °C to 200 °C	– 10 °C to 300 °C	– 10 °C to 450 °C	– 10 °C to 500 ° C
0.01	—	—	—	± 0.005	± 0.01	—	—	—	—
0.02	—	—	± 0.02	± 0.01	± 0.02	—	—	—	—
0.05	—	—	± 0.05	± 0.05	± 0.05	± 0.05	—	—	—
0.1	—	± 0.1	± 0.1	± 0.05	± 0.05	± 0.1	—	—	—
0.2	± 0.2	± 0.1	± 0.1	± 0.05	± 0.05	± 0.1	± 0.2	± 0.5	—
0.5	± 0.5	± 0.5	± 0.5	± 0.1	± 0.1	± 0.1	± 0.2	± 0.5	± 1.0
1.0	± 0.5	± 0.5	± 0.5	± 0.1	± 0.1	± 0.2	± 0.2	± 0.5	± 1.0
2.0	± 1.0	± 1.0	± 0.5	± 0.2	± 0.2	± 0.5	± 0.5	± 1.0	± 1.0 ± 2.0 at 500 °C

[a] When the scale range of a thermometer falls within more than one of the test range limits, the most restrictive range is held to apply.

5.6.3 *Laboratory thermometers*. BS 593 specifies three series, A, B and F, of good quality thermometers, as follows.

a) Series A, covering ranges of about 30 degrees Celsius or 40 degrees Celsius within the range – 30 °C to 160 °C. Best measurement uncertainties of ± 0.02 degrees Celsius are possible between – 20 °C and 100 °C with total immersion. Overall lengths are about 400 mm. These thermometers are available as total immersion and 100 mm immersion thermometers.

b) Series B, similar to A but covering ranges of about 60 degrees Celsius between – 20 °C and 260 °C. Best measurement uncertainties of ± 0.05 degrees Celsius are possible between – 20 °C and 160 °C with total immersion.

c) Series F, 100 mm partial immersion only, covering 50 degree Celsius ranges between – 2 °C and 302 °C. Best measurement uncertainty is ± 0.05 degrees Celsius between – 2 °C and 102 °C. This series corresponds to the Institute of Petroleum and American Society for Testing and Materials thermometers.

5.6.4 *Short-range short-stem thermometers*. BS 1365 specifies two main series, A and B, of short-stem thermometers, having overall lengths of 220 mm and 240 mm, respectively, as follows.

a) The A1 series for total immersion, covers 60 degree Celsius ranges between – 10 °C and 360 °C with a best measurement uncertainty of ± 0.05 degrees Celsius between – 10 °C and 105 °C. A similar A2 series is for use at 80 mm immersion.

b) The B1 series covers 10 degree Celsius ranges between – 10 °C and 220 °C with a best measurement uncertainty of ± 0.02 degrees Celsius between – 10 °C and 105 °C. A similar B2 series is for use at 70 mm immersion.

5.6.5 *General purpose thermometers*. BS 1704 (technically related to ISO/DIS 1770) specifies an assortment of general purpose (GP) thermometers, mostly about 300 mm or 350 mm in overall length and available for total immersion or 100 mm partial immersion. Individual scales span about 100 degrees Celsius within the total range – 120 °C to 510 °C. Best measurement uncertainty is ± 0.02 degrees Celsius between 0 °C and 100 °C.

5.6.6 *Short and long solid-stem thermometers for precision use*. BS 5074 specifies two series of thermometers for precision use with total immersion only, and either 250 mm or 375 mm in overall length. Within a total range of – 25 °C to 600 °C a great variety of short-, medium- and long-range thermometers are specified with a best measurement uncertainty of ± 0.02 degrees Celsius between – 5 °C and 105 °C.

5.6.7 *Institute of Petroleum thermometers*. BS 2000-0:Addendum 1 specifies thermometers having specialized application in the petroleum industry. Until publication of the British Standard in 1983, this specification was published only in the Institute of Petroleum handbook. The standard and the handbook detail about 90 instruments of many sizes, various depths of immersion, and working ranges between – 80 °C and 400 °C. In some cases, measurement uncertainties of ± 0.01 degrees Celsius are possible.

5.6.8 *Meteorological thermometers*. BS 692 specifies requirements for maximum, minimum and ordinary (i.e. wet and dry bulb) meteorological thermometers protected by glass sheaths and suitable for mounting in a louvred screen. They are graduated for complete immersion conditions.

6 Calibration

6.1 Traceability

In essence, the calibration of a thermometer relates a subsequent measurement of temperature using that thermometer to one made with a standard thermometer calibrated to the required accuracy. For a calibration to be regarded as traceable directly or indirectly to the International Practical Temperature Scale (IPTS), it has to be carried out in a laboratory approved for the purpose. The calibration certificate provides documentary evidence of traceability and ensures that values of temperature read from the thermometer conform, within the stated uncertainty, to the current International Practical Temperature Scale of 1968 (IPTS-68). Throughout this guide, therefore, the use of a thermometer to measure temperature presumes the use of a calibrated thermometer.

A brief explanation of the basis of IPTS is given in Appendix B.

The result of calibration is a series of arithmetic corrections supplied in an appropriate certificate to enable a user to calculate values of temperature from a thermometer reading. The calibration process does not involve any physical adjustment or change to a thermometer so that it will then indicate temperatures correctly.

6.2 Calibration laboratories

Usually, working standard thermometers are calibrated by comparison with similar reference standards or superior instruments such as platinum resistance thermometers. The process is undertaken by national or approved calibration laboratories (see Appendix A) maintaining specialized apparatus and reference standards calibrated in terms of IPTS-68.

6.3 Calibration points

It is recommended that a thermometer is calibrated at either a minimum of five evenly spaced temperatures or at intervals of 100 smallest scale divisions, covering 80 % of the scale range. When the highest precision is required, calibration checks are made at intervals not greater than 50 smallest scale divisions and include measurements at and between the pointing marks (the marks made by the manufacturer on the thermometer to facilitate the subsequent positioning of the scale).

Appendix C describes a procedure for measurement at the ice point, which is the most widely-used reference point in liquid-in-glass thermometry.

6.4 Special temperatures

If a particular temperature on the thermometer scale is to be of repeated interest or special interest, a calibration check should be made within five smallest scale divisions of that temperature.

6.5 Comparison standards

In calibration, as in subsequent use, a minimum of two reference instruments is strongly advised; they are mutually self-checking, and they may detect the occurrence of exceptional temperature gradients in the calibration environment.

6.6 Re-calibration frequency

Re-calibration is advisable at intervals of not more than 5 years, or as soon as a determination at a reference point indicates that a significant change has taken place. A change of about 0.04 degrees Celsius in 1 year may be due to normal change in the bulb volume (see **6.8.1** and **6.8.2**) and can be allowed for by applying a correction, equal to the detected change, to all other scale corrections.

Regular monitoring at the reference temperature is advisable. It is recommended that new thermometers be checked more frequently during the first 1 year or 2 years after manufacture, when bulb changes are likely to be greatest. It is, therefore, recommended that the secular change in a new thermometer be determined every 1 month to 2 months until the projected value of the annual change is about one-half of the uncertainty of calibration. Thereafter, reference point checks can be made preferably at six-monthly but certainly at yearly intervals.

6.7 Comparison procedure

Measurements should be carried out when the temperature of the environment is rising slowly and regularly, so that movement of the liquid filling, especially mercury, is kept uniform. Additionally, when precisions of ± 0.01 degrees Celsius or better are sought (usually with the thermometers having smallest scale divisions of 0.05 degrees Celsius or less), the stems of the thermometers should be vibrated or tapped while measurements are made (see **7.4**).

In the course of a cycle of comparison measurements, the rate of rise of temperature of the medium should be uniform and the change of temperature from beginning to end of the measurements should not exceed two or three times the calibration uncertainty. In the time taken (for an experienced observer) to assess the reading of an individual thermometer there should be no discernible movement of the meniscus. A preferred procedure is to scan thermometer readings in a sequence of arrays, usually starting with the first reference thermometer, scanning the series of test thermometers, then the second reference thermometer, and repeating the cycle in reverse. Provided that the sequence of measurements is symmetrical and the bath temperature is changing at a uniform rate, the average of the measurements for each thermometer relate to the same mean temperature given by the reference thermometers.

6.8 Stability

6.8.1 *General*. Since the average value of k for mercury in glass (see clause **2**) is 1.6×10^{-4} (1/6 250), the bulb volume is about 6 250 times the capillary volume equivalent to 1 degree Celsius. In those cases where the thermometer's calibration uncertainty is to be ± 0.005 degrees Celsius, the bulb volume is required to be stable to about ± 0.0001 %. With the possible exception of fused silica, no thermometric glass is ideally stable. Two types of instability occur, one long term, the other short term, caused mainly by the properties of the bulb glass (see also **4.10**). Both instabilities, usually termed secular change and depression of zero, respectively, are, however, normal features of thermometer behaviour and are easily and routinely managed.

6.8.2 *Long-term stability (secular change)*. The stability of glass depends in a complex way upon its thermal history, with the result that the density and volume slowly change in order to achieve a state of equilibrium consistent with the temperature at which the glass is maintained or stored. In fact, the bulb volume slowly shrinks, irreversibly, with time. This secular change is most apparent in the first year of manufacture, and may amount to a rise equivalent to 0.04 degrees Celsius in the thermometer reading. In each subsequent year, the drift may be 0.01 degrees Celsius but may well be negligible or absent, notably in old thermometers. Clearly there is some advantage in planning a preliminary 1 year or 2 year shelf-life for new thermometers. Secular drift is easily monitored from regular, six-monthly or annual checks at the ice point or alternative fiducial point (see **6.6**).

6.8.3 *Short-term stability (hysteresis or depression of zero).* Thermometric glasses also exhibit a simple hysteresis characteristic. Once heated, glass fails to return quickly to its original size. If thermometers are used to measure successively 0 °C, 100 °C and 0 °C in a very short period, the second ice point reading will be lower than the first by about 0.05 degrees Celsius, i.e. it is depressed, hence the term "depression of zero". The depression per 100 degrees Celsius rise of temperature is generally about 0.05 degrees Celsius and 0.02 degrees Celsius for bulbs of normal and borosilicate glasses, respectively. Recovery from the depressed condition may not be complete for several hours, or even days. The effect imposes some limitations, since once a thermometer is used at a high temperature it cannot be used at a lower temperature until the bulb has been allowed to recover, usually after 24 h. This precaution can be waived if the estimated depression is smaller than the required uncertainty of measurement. In any one day, any number of progressively higher temperatures can be measured safely. Measurements at the ice point, especially when monitoring for secular change, should be undertaken only when the thermometer has rested for about 48 h and so regained a stable reproducible condition. The depression of zero effect can be entirely suppressed if, after use, the thermometer is cooled at a rate of 15 degrees Celsius/h.

The use of mercury-filled thermometers at temperatures below room temperature with intended precisions better than ± 0.010 degrees Celsius should also take account of the depression of zero effect. For example, when a thermometer made from normal glass is taken from room temperature and held at a lower temperature, it typically changes its indication over a period of about 48 h by about 0.005 degrees Celsius for each 10 degree Celsius drop in temperature. Before a calibration, it is recommended that the reference and test instruments should be accorded the same pre-test treatment, i.e. they should ideally be maintained in an ice-water mixture close to 0 °C for a period of 48 h.

6.9 Corrections

Secular change can be monitored conveniently and accounted for within the calibration procedure in which each of a thermometer's corrections is separated into two parts. If the correction at 0 °C is subtracted from each of the other corrections, the resultant series of corrections apply as if the thermometer reads exactly zero at 0 °C. These values can be regarded as semi-permanent. In daily use, the working correction is the semi-permanent value plus the current ice point correction. At such times as the zero correction is re-determined, the new correction is added to the semi-permanent scale corrections.

6.10 Annealing and stabilization

Modern manufacturing methods include annealing and stabilization treatments to minimize secular drift Inadequate annealing of a thermometer might lead, after exposure to temperatures of about 300 °C and above, to permanent contraction of the bulb glass and a rise in the thermometer's indication of about 20 degrees Celsius or more.

7 Conditions of use

7.1 Inclination

Most thermometers are used vertically unless another condition is specified or indicated on the calibration certificate.

7.2 Immersion

7.2.1 *General.* It is imperative that the condition of immersion, usually engraved on the stem, is observed, or a correction made for any departure from that condition.

Three modes of immersion, described in **7.2.2** to **7.2.4**, are recognized.

7.2.2 *Total immersion.* Total immersion requires the bulb and the liquid column to be immersed so that whatever the temperature only about 1 mm of the column protrudes, sufficient to enable the observer to read the thermometer. The highest precisions in measurement are obtained using total immersion. At temperatures above 150 °C, the risk of mercury distillation increases so it is advisable to obtain the total condition only shortly before observations are made. For the rest of the time, the thermometer should be withdrawn a few centimetres to reduce the meniscus temperature.

7.2.3 *Partial immersion.* Partial immersion requires the thermometer to be immersed always to a prescribed depth, as given in the thermometer specification and usually engraved on the stem both as a ring and a numerical inscription. In general, partial immersion thermometers measure temperature with an uncertainty twice that of total immersion thermometers.

In use, a length of exposed liquid, the emergent liquid column (e.l.c.), protrudes above the medium being measured, in a temperature gradient whose mean temperature is variable and different from that of the medium.

A thermometer's indicated temperature can be seriously in error unless account is taken of the e.l.c. temperature and an appropriate correction made. The average e.l.c. temperature can be measured in one of two ways as follows (see Figure 1).

a) The first uses a series of auxiliary thermometers with the bottom of the bulb of the first distanced 10 mm from the point of emergence (i.e. the immersion level), others spaced evenly at intervals not exceeding 100 mm and a last thermometer with its bulb level with the meniscus.

b) When the measured temperature exceeds 100 °C, a more precise method is to use one of a series of specialized calibration thermometers known as "Faden thermometers", whose bulb length is equal, to within about 1 cm, to the e.l.c. length. Faden thermometers may be purchased singly or as a set with bulb lengths ranging variously as required from 50 mm to 300 mm. In use, the bottom of the bulb of a Faden thermometer should be level with the test thermometer's immersion line and in contact with the medium being measured. The Faden method gains, in terms of precision, over the auxiliary method because the Faden bulb is, like the test thermometer, in contact with the medium measured and both mercury columns experience closely similar temperature profiles. A number of Faden thermometers may be used with the bulbs in series spanning an e.l.c. For example, consider a 27 cm long e.l.c. measured by two Faden thermometers of bulb lengths 22 cm and 5 cm. If the longer and shorter thermometers register 45 °C and 23 °C, respectively, then the average e.l.c. temperature, in °C, is:

$\{(5 \times 23) + (22 \times 45)\} / 27$

$= 41$

When the bulb temperature is higher than 100 °C, the Faden method is considered to give more reliable, reproducible results. Both the auxiliary and the Faden thermometer methods yield corrections which may be estimated as accurate to ± 10 % or better.

Under any circumstance where a correction for the e.l.c. temperature is necessary, the correction, C (in degrees Celsius), to the indicated temperature is given by the equation:

$$C = kN(t_1 - t_2)$$

where

k is the apparent cubic thermal expansion coefficient of the liquid in the particular glass from which the stem is made (in $°C^{-1}$);

t_2 is the average e.l.c. temperature (in °C);

t_1 is the apparent temperature of the bulb indicated by the test thermometer (in °C);

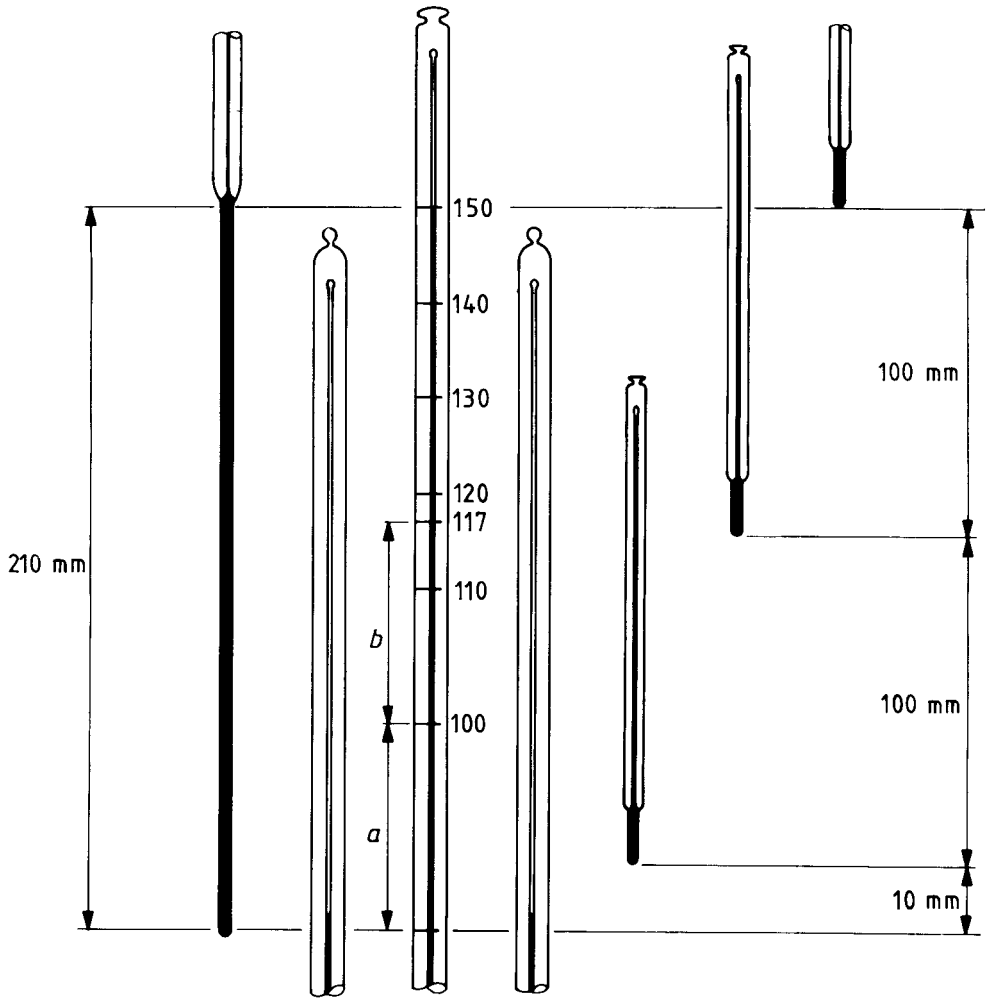
N is the number of degrees Celsius equivalent to the length of the e.l.c., and is the difference between the thermometer indication and the actual or extrapolated scale value corresponding to the specified immersion level.

NOTE For example, in Figure 1, if $a = b = 17$, then
$N = 150 - 100 + b$
$N = 67$.

If the resultant correction is large, a second evaluation should be made using the temperature corrected according to the first evaluation. The equation can be applied to a total immersion thermometer being used at partial immersion by changing the sign of the correction. The quantity t_1 can be greater or smaller than t_2 and, in some circumstances, t_1 and t_2 can both be different average e.l.c. temperatures, i.e. one measured and one specified.

Typical values of k which give corrections sufficiently accurate for most purposes are given in Table 4.

7.2.4 *Complete immersion.* Complete immersion requires the entire body of the thermometer to be immersed and, consequently, the internal gas pressure is also affected by the temperature of the medium. If the thermometer is used under total or partial immersion conditions, the internal gas pressure may be lowered sufficiently to cause an additional error in measurement. Such a change cannot be calculated and can only be deduced from comparative measurements made under the complete immersion condition and under total or partial immersion conditions, as appropriate.



NOTE See **7.2.3**.

Figure 1 — Emergent liquid column correction for partial immersion measurements

Table 4 — Values of *k*, the apparent cubic thermal expansion coefficient of thermometric liquids in glass

Temperature	Apparent cubic thermal expansion coefficient, k				
	Borosilicate glass	Other normal glasses			
	Mercury	Pentane	Toluene	Ethanol	Mercury
°C	$°C^{-1}, \times 10^{-4}$	$°C^{-1}, \times 10^{-4}$	$°C^{-1}, \times 10^{-4}$	$°C^{-1}, \times 10^{-4}$	$°C^{-1}, \times 10^{-4}$
– 180	—	9.0	—	—	—
– 120	—	10.0	—	—	—
– 80	—	10.0	9.0	10.4	—
– 40	—	12.0	10.0	10.4	—
0	1.64	14.0	10.0	10.4	1.58
20	—	15.0	11.0	10.4	—
100	1.64	—	—	—	1.58
200	1.67	—	—	—	1.59
300	1.74	—	—	—	1.64
400	1.82	—	—	—	—
500	1.95	—	—	—	—

7.3 Pressure effects

7.3.1 Since the wall of the bulb glass is intentionally thin (to improve speed of response) and therefore flexible, the bulb volume is susceptible to changes in pressure, whether they be external or internal in origin, with the result that thermometer readings may vary with everyday atmospheric pressure changes, with altitude or with a change in angle of use, e.g. from vertical to horizontal (see **7.3.2**). A change in the barometric pressure of 3 kPa[5)] changes a thermometer's reading by about 0.005 degrees Celsius leading to a typical external pressure coefficient of 0.15 degrees Celsius per 100 kPa.

The correction for a particular thermometer can be measured by supporting it in a closed transparent tube maintained at a constant temperature and connected to a variable pressure device, e.g. bellows and manometer. The coefficient can be determined by measuring a series of corrections over a range of pressures. This type of correction should be considered when measurement precisions of ± 0.01 degrees Celsius or better are required, or when high pressure applications are envisaged.

7.3.2 A thermometer used horizontally has a higher reading than the reading when used vertically because the internal pressure, governed mainly by the head of mercury, is reduced. Typically, a change in reading of 0.1 degrees Celsius occurs when the mercury is at the upper end of its scale, and at intermediate scale points the change is proportional to the distance from the centre of the bulb. Practical measurement of the pressure effect correction can be obtained in a restricted temperature range by placing the thermometer bulb at the centre of a liquid-filled spherical flask and observing the meniscus level in both vertical and horizontal positions.

7.4 Column stiction

On heating and expansion of the mercury in a thermometer the meniscus becomes more convex and rises suddenly, or jumps, and becomes flat again. With a rising temperature the meniscus ascends in a series of uneven jumps, each corresponding to between 0.005 degrees Celsius and 0.010 degrees Celsius. In fine bore thermometers, typically those having a smallest scale division of 0.05 degrees Celsius or less and an associated measurement uncertainty of ± 0.01 degrees Celsius or better, the effect constitutes a potentially serious source of error which is overcome by gently tapping the thermometer stem in the course of measurements. Alternatively, electromechanical devices, e.g. electric bell mechanisms, may be suitably adapted. Additionally, and as a general rule, measurements should be made under slowly rising temperature conditions so that the capillary forces remain uniform and the thermometer behaviour is most reproducible.

7.5 Reading of thermometers

In order to achieve the desired resolutions and measurement uncertainties, it is usual to resolve the temperature indication of a thermometer to 1/10 or 1/20 of the smallest scale division. Subdivision of the smallest interval can be estimated by eye with simple optical aids (see **7.7**). The use of a graticule in the eyepiece of an optical aid is of little use because the smallest scale division is rarely the same on different thermometers and varies even on different portions of the same thermometer. The appropriate skill can be acquired with practice.

7.6 Parallax

Unless the liquid meniscus is viewed with the eye normal to the stem, errors due to parallax arise. The magnitude of the error is dependent on the angle between the normal and the incorrect line of sight, and on the separation of the capillary and the graduation lines. For a given wrong line of sight, the error is greater for a thick stemmed thermometer than for a thinner one. Typically, if a 6 mm diameter thermometer, graduated in intervals of 0.2 degrees Celsius, is viewed 4° from the normal, an error of 0.05 degrees Celsius is generated (see Figure 2). Such errors are reduced or eliminated quite easily by means of suitably mounted simple optical aids.

[5)] 100 kPa is approximately 1 at.

7.7 Optical aids

The simplest devices are plano-convex lenses or cylindrical plano-convex lenses, which are held or mounted with the plane surface almost in contact with the thermometer. A sliding clamp or sprung clip allows temporary attachment, and the provision of a fine line or similar indication on the plane face gives some safeguard against parallax errors. Magnification beyond 10 × is not recommended. A cylindrical lens magnifies only the image of the bore and meniscus, and is useful mostly as a locator rather than in estimations by interpolation. Optical aids mounted so as to allow free vertical movement and some horizontal movement are preferred when the meniscus levels of thermometers are not similar and when a row of them are to be compared. Properly mounted binoculars or a monocular telescope provide optically favourable and strain-free viewing conditions. They may be focused at infinity, and mounted in conjunction with an external collimating lens to adjust focus and permit convergence at a convenient working distance, e.g. 450 mm, from the thermometers. The collimating lens may be used as the object glass or mounted externally when, if it is also mounted on a slide, it also permits manual adjustment of depth of focus.

8 Maintenance

8.1 Routine maintenance

Maintenance of thermometers is as vital as with other sensitive instruments. Even with everyday careful use it is possible for defects or irregularities to arise. Regular, careful examination, and rectification of temporary defects (see **8.3**) is usually easily and quickly done; it requires only a simple hand lens of about 5× magnification, a coolant such as solid carbon dioxide (sublimation point – 78.5 °C) or an ice-salt mixture, a low temperature flame such as that provided by a methylated spirits lamp and ample (desk-top lamp) illumination. The entire length of the bore and any chambers should be examined occasionally, with the aid of the lens, for the presence of defects. The examination should also include any part of the bore which usually contains mercury when the thermometer is not in use.

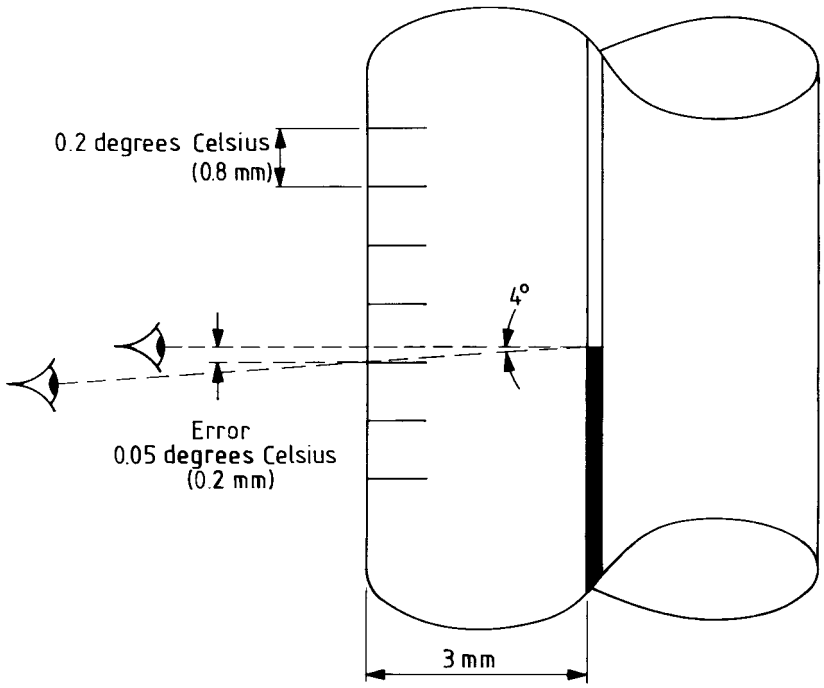


Figure 2 — Error in reading a thermometer due to parallax

8.2 Permanent defects

Certain defects cannot be rectified, and so render a thermometer unreliable in use and potentially hazardous in some circumstances. Such thermometers should be discarded. The following are the most common defects.

a) Glass or other solid fragments in the capillary, if immovable, can give rise to irregular movement of the liquid meniscus, or, if movable, cause errors when covered, by displacement of a corresponding volume of filling liquid.

b) Dirty or damp mercury appears as a black ring around the bore, most commonly observed around the thermometer's storage temperature range and frequently obscured by the mercury column itself, unless the thermometer is cooled well below ambient. Its deleterious effects are to anchor small bubbles of the filling gas and to make the movement of the meniscus irregular.

c) A flaw or split in the stem, and especially the bulb glass, heralds the possibility of breakage in use, with consequent release of mercury and mercury vapour, which is potentially hazardous, especially at higher temperatures. Under a bright light, flaws can be distinguished from scratches by reason of their reflected brilliance, depth, and flashes of colour. At low temperatures, and in apparatus not at risk from mercury or spirit contamination, the chance of breakage may be acceptable.

d) A liquid-filled secondary or false bore presents the observer with two menisci and the possibility of erroneous measurements.

8.3 Temporary defects

8.3.1 *General*. The remedying of some temporary defects calls for the use of heat, so it is essential that the user is aware of the likely and immediate limitations of use arising from the depression of zero effect (see **6.8.3**).

8.3.2 *Entrapped gas*. The most common difficulty results from transportation of thermometers and physical shocks, when bubbles of gas may appear in the bulb, or contraction chamber, or throughout the mercury column, the last giving it a fragmented appearance. The remedy is to cool the bulb taking care, if solid carbon dioxide is used (sublimation point – 78.5 °C), not to freeze the mercury (freezing point – 38.84 °C). If the mercury is inadvertently frozen it should not be re-melted by heating from the bottom of the bulb. On cooling, individual lengths of a fragmented mercury column are slowly drawn down to the contraction chamber or bulb and enter it either as a droplet on the wall or a membrane spanning the chamber. The thermometer is then tapped laterally until the droplet falls into the bulk of mercury beneath it, and successive fragments of the column are treated likewise.

A large bubble of gas can be trapped in the bulb, notably when a poorly made thermometer has squared rather than smoothly tapered "shoulders". The gas can be liberated into the bore if the bulb is first cooled until all of the mercury has contracted into the bulb leaving the bore clear for the gas bubble to rise to the liquid surface. Movement of gas or mercury droplets by vibration is encouraged by gripping the bulb of the thermometer in the palm of the hand and gently striking the heel of the hand on a bench or table top.

Another serious difficulty, usually only visible with the aid of the lens, arises when gas is trapped in the bulb in the form of very small, widely dispersed bubbles. With cooling, the mercury is allowed to recede into the bulb which then includes a large bubble of gas from the capillary bore. This large gas bubble is retained, by maintaining cooling of the bulb, and then used to sweep up the small bubbles by inverting and manoeuvring the thermometer. When all the gas bubbles have collected, the thermometer is returned to its upright position. This, coupled with withdrawal of the cooling, allows the gas to escape into the bore, above a now homogeneous mercury column. If the mercury column cannot be restored to a homogeneous condition by these means, the thermometer may be rotated or swung by hand, bulb downwards, so as to produce a centrifugal force at the base of the bulb.

8.3.3 *Mercury distillate*. Droplets of mercury found in the expansion volume should not be retrieved by heating until they are gathered by the rising mercury column (see **6.8.3**). Instead, the expansion volume is gently heated by waving it slowly through a methylated spirit flame to vaporize the mercury, allowing it to re-condense lower down in the graduated part of the capillary tube where it may be swept up by driving the mercury column to it.

8.3.4 *Spirit distillate*. Organic liquid fillings are highly volatile, and the presence of droplets of condensate in the expansion chamber and capillary is quite usual. Similarly, these liquids have a low surface tension so that the bore is quite usually covered with a thin film of liquid. Both conditions are remedied by moving the thermometer through a flame (see **8.3.3**), working from the expansion volume downwards. If this process is continued, and the bulb is also slightly cooled, it is possible to allow condensation to take place at a temperature close to ambient. With removal of the flame and cooling, the thermometer is left free of any condensate or film in the bore and expansion volume. Alternatively, before use, spirit thermometers can be stored, vertically, with the area around the expansion volume heated above ambient temperature by a low-powered heater or lamp.

In use, wetting of the bore resulting from low surface tension, can cause a drainage problem and erroneously low measurements. This happens most commonly if the rate of cooling is too fast. In general, a cooling rate should be about 1 degree Celsius/min, but may vary for individual thermometers.

9 Working standard liquid-in-glass thermometers

9.1 General

Of the great variety of commercially available instruments, relatively few call for additional or special comments. However, attention is drawn in **9.2** to **9.6** to likely sources of error in such instruments.

9.2 Enclosed scale thermometers

Envelope, insulated or sheathed pattern thermometers are used almost exclusively throughout mainland Europe where the advantages of the design are seen to be:

a) thermal insulation of the filled capillary;

b) chemical insulation of the inscriptive pigment filling;

c) reduction of parallax errors by use of a very small diameter capillary stem;

d) relatively large flat strips to carry the scale and inscriptions.

The most significant source of error arises from the fact that the scale, on a separate strip from the capillary stem, may become detached or shift from its original fixed position. Any movement is detectable provided that the outer sheath is marked with a datum line to correspond with a designated line, usually the lowest, on the scale. In the UK, engraved-on-stem, or solid-stem thermometers are preferred because they are less bulky, measurement of e.l.c. temperatures is more realistic and, in manufacture, fewer processes are necessary.

9.3 Adjustable-range thermometers

The Beckmann type is the best known and is intended for measurement of very small but precise temperature differences, the absolute value being less important. The upper end of the scale incorporates an auxiliary reservoir and device, so that by controlled heating of the bulb and manipulations of the thermometer and mercury column, the total volume of mercury in the bulb can be either increased or decreased. Consequently, the value of each scale division is dependent on, and changes according to, the quantity of mercury in the bulb, and the corrections applicable to one range of temperature will differ from those of other ranges. Hence, the corrections to a thermometer vary according to the start-up or "zero setting" temperature of the range, and a thermometer intended for use over a wide range of temperatures should be calibrated successively with an appropriate number of zero settings.

9.4 Maximum thermometers

A constriction in the bore of a thermometer can be used as a valve. On expansion, mercury is forced through, but when the bulb cools the column has insufficient mass or force to pass through the constriction, becomes detached, and so registers the maximum temperature experienced. If the thermometer reading is noted later when the ambient temperature has fallen, a correction should be made for the change in the temperature, and, therefore, the length of the mercury column. To determine the true maximum temperature a correction (in degrees Celsius) is given by the equation:

$$c = k(s + h)(s - t)$$

where

s is the observed maximum temperature (in °C);

t is the ambient temperature at the time of reading the thermometer (in °C);

h is the number of degrees of the scale equal to the length of stem between the constriction and 0 °C, and is positive if the constriction is below 0 °C and negative if above 0 °C;

k is the apparent cubic thermal expansion coefficient (in $°C^{-1}$).

Maximum thermometers designed for vertical use require a particularly small or "stiff" constriction to support the mercury column, by virtue of the surface tension at the constriction. Consequently, resetting may be difficult, and easily achieved only with a centrifuge.

Some maximum thermometers are not required to have a "stiff" constriction supporting a substantial head of mercury, and are used at an angle of 2° to the horizontal to reduce the risk of mercury retreating through the constriction when the thermometer is cooled. Resetting is effected by swinging the thermometer (gripped close to the bulb with the bulb downwards) to produce a centrifugal force at the constriction.

An alternative design does not incorporate a constriction of any kind but a sprung index is pushed up the capillary tube by the rising mercury meniscus to register the maximum temperature. After use, this type is reset by drawing the index down to the receded meniscus by means of a magnet.

9.5 Minimum thermometers

These thermometers are spirit-filled, and appropriate care in their use should be observed (see **3.2.3** and **8.3.4**). A light glass dumb-bell shaped index within the spirit is drawn along by the surface tension of the meniscus to register a minimum temperature. It is too heavy to rise if the spirit subsequently warms. The thermometer is usually mounted at about 2°, and not more than 10°, to the horizontal, bulb downwards, so that the index does not fall back under gravity. It is reset either by inverting the thermometer so that the index falls under gravity or, if the index contains a metal core, by means of a magnet.

9.6 Industrial types

Very many different configurations of thermometers are made to meet the special requirements of manufacturing industry and in many cases they are, of necessity, heavily protected against breakage and/or severe operating conditions.

Whenever a thermometer is contained in or protected by a metal tube or casing it is likely to be influenced by heat loss along the metal, and the bulb may not, in fact, attain the temperature of the medium being measured. Similarly, estimation of corrections for e.l.c. temperatures is made more uncertain since heat conduction along the casing may heat the emergent column more than when the thermometer is used unprotected, and the in-use condition may differ substantially from that used in the manufacture and calibration of the thermometer.

Calibration should be carried out under conditions as similar as possible to those of general use or the thermometer should be compared in the usual condition of use against a suitable standard thermometer.

In some designs, the thermometer stem carries no engravings, and erroneous measurements can arise if it becomes displaced relative to the separate scale (see **9.2**).

Appendix A Calibration services

The examination and calibration of thermometers is undertaken by the National Physical Laboratory and by approved laboratories of the British Calibration Service (BCS). Full details of services and fees can be obtained on application to individual laboratories. A list of BCS approved laboratories can be obtained from British Calibration Service, National Physical Laboratory, Teddington, Middlesex, TW11 0LW, telephone 01-977 3222.

Appendix B The International Practical Temperature Scale of 1968 (IPTS-68)

Historically, the measurement of temperature evolved along two lines determined first by practical, arbitrary considerations, giving rise to the Celsius, Fahrenheit and Reaumur scales and, secondly, by gas thermometry with the notion of an absolute zero temperature, together with the developing science of thermodynamics. In the latter case, the basic physical quantity, theoretical or thermodynamic temperature, could be shown to be independent of the properties of the working fluid in the (gas) thermometer, so providing the key to a scientifically valid temperature scale. But its measurement by constant volume gas thermometry proves to be relatively irreproducible (that is compared to other practical thermometers e.g. platinum resistance thermometers) and, in use, the gas thermometer is difficult and cumbersome. The platinum resistance thermometer can measure temperature with much better precision and reproducibility, but not thermodynamically.

The IPTS-68 is the result of the two lines. A number of reproducible fixed points of temperature have been assigned closely-thermodynamic values of temperature based on primary gas thermometry and, thereafter, highly reproducible, essentially practical thermometers can be calibrated at the fixed points according to prescribed procedures. Interpolation between the points is governed by specified empirical methods. IPTS-68 therefore closely approximates thermodynamic thermometry and is reasonably practical; it is realized usually in national standards laboratories, and is recognized as the local metrological standard.

Between – 260 °C and 630 °C suitable calibrated platinum resistance thermometers are the first line carriers of IPTS-68 and they can be used in a calibration process to transfer the scale to other resistance thermometers or thermocouples and liquid-in-glass thermometers, so they become carriers of IPTS-68, usually with a poorer level of accuracy.

Appendix C Procedure for ice point measurements

The ice point may be realized in a Dewar flask or insulated vessel, ideally one which has provision for easily removing surplus water, e.g. a draincock. It is important to ensure that the ice-water mixture is a melting mixture, and to achieve this condition the ice should be shaved or finely divided so that each particle is in intimate contact with the surrounding water. To achieve this, the ice particles should be no more than a few millimetres in diameter. Both the water and the ice should be pure or prepared from de-ionized water, although in the UK it is likely that normal supplies of domestic cold water would not cause depression of more than a few hundredths of a degree. For the greatest confidence, however, the use of domestic water should be avoided. The water should be air-saturated, but this may not be necessary since the error so incurred is only 0.001 degrees Celsius to 0.002 degrees Celsius. When adequately mixed and consolidated with a clean rod or stick, the surface of the mixture takes on a grey rather than a white appearance and any manual compression of the ice at the surface should just show a corresponding swell of water without any tendency for the ice to float.

Care should be taken when inserting thermometers into the ice, so that the bulb is not subjected to any excess pressures. It is advisable to prepare (with a tube) a hole in the ice of sufficient depth and minimal diameter to receive the thermometer. Once the thermometer has been lowered into the prepared water-filled hole it should be lifted momentarily and replaced to ease any pressure build-up, and tapped gently before it is read so that any sticking of the mercury meniscus is also minimized. In theory, accuracies of about ± 0.001 degrees Celsius may be achieved by this method if the water is well shaken up with air close to 0 °C before-hand, but in practice this and other factors lead to accuracies of ± 0.005 degrees Celsius being more realistic. When the highest precision is required, the thermometer should be maintained at 0 °C for about 10 min.

Publications referred to

BS 593, *Laboratory thermometers.*
BS 692, *Specification for meteorological thermometers.*
BS 791, *Solid-stem calorimeter thermometers.*
BS 1041, *Code for temperature measurement*[6)].
BS 1041-3, *Industrial resistance thermometry.*
BS 1041-4, *Thermocouples.*
BS 1041-5, *Radiation pyrometers.*
BS 1041-7, *Temperature/Time Indicators.*
BS 1365, *Short-range short-stem thermometers.*
BS 1704, *General purpose thermometers.*
BS 1900, *Specification for secondary reference thermometers.*
BS 2000, *Methods of test for petroleum and its products.*
BS 2000-0:Addendum 1, *Standard reagents and thermometers.*
BS 5074, *Short and long solid-stem thermometers for precision use.*
ISO 386, *Liquid-in-glass laboratory thermometers — Principles of design, construction and use*[6)].
The International Practical Temperature Scale of 1968 (IPTS-68), published by HMSO.

[6)] Referred to in the foreword only.

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