

CONFIRMED
DECEMBER 2007

Temperature measurement —

Part 2: Expansion thermometers —

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

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Laboratory Apparatus Standards Committee (LBC/-) to Technical Committee LBC/4 upon which the following bodies were represented:

- British Laboratory Ware Association
- British Lampblown Scientific Glassware Manufacturers' Association Ltd.
- British Medical Association
- Department of Health and Social Security
- Department of Trade and Industry (National Physical Laboratory)
- Institute of Petroleum
- Ministry of Defence

This British Standard, having been prepared under the direction of the Laboratory Apparatus Standards Committee, was published under the authority of the Board of BSI and comes into effect on 31 July 1985

© BSI 01-2000

BS 1041 first published January 1943
First published as BS 1041-2.1 January 1969
First revision July 1985

The following BSI references relate to the work on this standard:
Committee reference LBC/4
Draft for comment 84/52217 DC

ISBN 0 580 14500 X

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
1 Scope	1
2 Principle of temperature measurement by liquid expansion	1
3 Materials	1
4 Construction and marking	4
5 Thermometer selection	6
6 Calibration	8
7 Conditions of use	10
8 Maintenance	14
9 Working standard liquid-in-glass thermometers	16
Appendix A Calibration services	18
Appendix B The International Practical Temperature Scale of 1968 (ITS-68)	18
Appendix C Procedure for ice point measurements	18
Figure 1 — Emergent liquid column correction for partial immersion measurements	12
Figure 2 — Error in reading a thermometer due to parallax	14
Table 1 — Thermometric glasses approved by the National Physical Laboratory	2
Table 2 — NPL measurement uncertainties of total immersion thermometers	7
Table 3 — NPL measurement uncertainties of partial immersion thermometers	7
Table 4 — Values of k , the apparent cubic thermal expansion coefficient of thermometric liquids in glass	12
Publications referred to	Inside back cover

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 It supersedes the 1969 edition of BS 1041-2.1, which is withdrawn.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 traceability¹⁾ 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 $-200\text{ }^{\circ}\text{C}$ to $1\,050\text{ }^{\circ}\text{C}$ 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 $0\text{ }^{\circ}\text{C}$ are indicated with a minus sign; temperatures above $0\text{ }^{\circ}\text{C}$ 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 $^{\circ}\text{C}^{-1}$), 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 $-200\text{ }^{\circ}\text{C}$ up to $350\text{ }^{\circ}\text{C}$, and for short-term use from $-200\text{ }^{\circ}\text{C}$ up to $400\text{ }^{\circ}\text{C}$.

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
		$^{\circ}\text{C}$
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 Silica³⁾. Thermometers made from fused silica offer the highest stability for use from $-200\text{ }^{\circ}\text{C}$ up to $600\text{ }^{\circ}\text{C}$. Additionally, fused silica thermometers can be used up to $1\,050\text{ }^{\circ}\text{C}$ 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, $-38.84\text{ }^{\circ}\text{C}$, and its boiling point, $356.66\text{ }^{\circ}\text{C}$;
- 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 $356\text{ }^{\circ}\text{C}$ under 100 kPa ⁴⁾ pressure, its useful range can be extended to $600\text{ }^{\circ}\text{C}$ by sealing the thermometer at a high pressure of gas, usually nitrogen, to suppress evaporation. At $600\text{ }^{\circ}\text{C}$, 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 $-55\text{ }^{\circ}\text{C}$ from $-38.84\text{ }^{\circ}\text{C}$.

3.2.3 Organic liquids. Some organic liquids enable the thermometer range to be extended downwards. Pure ethanol and toluene have freezing points of $-112\text{ }^{\circ}\text{C}$ and $-95\text{ }^{\circ}\text{C}$, respectively, while technical grade pentane can be used down to as low as $-200\text{ }^{\circ}\text{C}$.

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 $29.78\text{ }^{\circ}\text{C}$, 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 $2\,000\text{ }^{\circ}\text{C}$, permits its use up to $1\,050\text{ }^{\circ}\text{C}$ 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 $1\,050\text{ }^{\circ}\text{C}$. 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 $150\text{ }^{\circ}\text{C}$, 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).