

Temperature measurement —

Part 2: Expansion thermometers —

Section 2.2 Guide to selection and use of dial-type expansion thermometers

UDC 536.5.51:67.192.53:531.717.51 – 620.113.004.14

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Industrial-process Measurement and Control Standards Policy Committee (PCL/-) to Technical Committee PCL/1, upon which the following bodies were represented:

British Coal Corporation
 British Gas plc
 British Pressure Gauge Manufacturers' Association
 Department of Energy (Gas and Oil Measurement Branch)
 Department of Trade and Industry (National Weights and Measures Laboratory)
 Energy Industries Council
 Engineering Equipment and Materials Users' Association
 GAMBICA (BEAMA Ltd.)
 Health and Safety Executive
 Institution of Gas Engineers
 Coopted members

This British Standard, having been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 31 January 1990

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First published January 1943
 First revision January 1990

The following BSI references relate to the work on this standard:
 Committee reference PCL/1
 Draft for comment 86/27223 DC

ISBN 0 580 17396 8

Amendments issued since publication

Amd. No.	Date of issue	Comments

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Foreword

This Section of BS 1041 has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee. It is a revision of clauses **34** and **44** to **71** of BS 1041:1943 which was withdrawn as obsolete in March 1985, and it also includes bi-metal strip actuated dial-type thermometers.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 8, 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.

0 Introduction

Dial-type expansion thermometers consist of a metal sensing bulb, which contains a suitable gas, liquid, or bi-metallic coil, connected to an indicating gauge. They may be direct mounting with rigid stem, or distant reading with a length of capillary between bulb and indicator. Thermometers of this type are inherently safe for use in hazardous atmospheres.

BS 5235:1975 specifies requirements for liquid-filled, gas-filled and vapour pressure dial-type expansion thermometers.

The information to be supplied by the purchaser to the manufacturer when ordering dial-type expansion thermometers is given in Appendix A of BS 5235:1975.

1 Scope

This Section of BS 1041 provides guidance on the principles of operation, installation and use of dial-type expansion thermometers. It covers liquid-filled, gas-filled, vapour pressure and bi-metallic types of instrument, as used in the range $-200\text{ }^{\circ}\text{C}$ to $+700\text{ }^{\circ}\text{C}$.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Liquid expansion dial-type thermometers

2.1 General

Liquid expansion dial-type thermometers consist of a metallic bulb connected to a bourdon tube type gauge with the whole system completely filled with liquid. Change of volume of the liquid in the bulb due to change of temperature causes movement of the bourdon tube and the temperature is indicated by a pointer on the dial.

In the liquid expansion dial-type thermometer the gauge or indicator acts essentially as a volume change indicator and not a pressure gauge as in the vapour pressure and gas expansion thermometers.

2.2 Characteristics

Inherent advantages of the liquid expansion dial-type thermometer are as follows.

- a) The scales are evenly divided throughout the range.
- b) a wide variation of range is possible with a single filling liquid.
- c) Ample energy is available for operating the bourdon tube which can therefore be robust and can be arranged to give good pointer control.

d) The filling liquid can be under high pressure. This improves linearity and elevates the boiling temperature to allow measurement of higher temperatures.

e) Accuracy achievable is $\pm 1\%$ of range. (See BS 5235.)

Typical liquid expansion dial-type thermometers are shown in Figure 1(a).

2.3 Filling liquid

Organic based fluids can be used as the filling liquid in liquid expansion dial-type thermometers but in the majority of practical applications mercury in a steel system is used for the following reasons.

- a) The expansion is essentially linear with temperature. This is not true for organic liquids.
- b) Although the coefficient of expansion of mercury is small compared to those of organic liquids and requires mercury-filled systems to have a larger volume bulb for the same sensitivity, mercury will operate readily in smaller bore capillaries (typically 0.15 mm bore) giving a small volume in the capillary. These two characteristics together mean that in capillary type distant reading thermometers, the ratio between the volume of mercury in the bulb and that in the capillary can be kept very large so that the expansion of the small amount of mercury in the capillary is small. This ensures that the expansion due to temperature change of the bulb is two or three orders of magnitude greater than the expansion of mercury in the capillary due to likely ambient temperature changes.
- c) Mercury is liquid over a wide temperature range and this allows instruments to be used in the range $-39\text{ }^{\circ}\text{C}$ to $+650\text{ }^{\circ}\text{C}$. Continuous use above $500\text{ }^{\circ}\text{C}$ is not recommended.

Mercury filling requires the use of steel or stainless steel bulbs, capillaries and bourdon tubes, with welded joints. This construction tends to make mercury-in-steel thermometers more costly than other types of dial thermometers in which copper based materials are used. Organic filling liquids such as xylene and alcohol may be used when capillary length (if any) is small and either the possible contamination from mercury has to be avoided at all costs or a very small bulb is required.

2.4 Sources of error

Errors in use of liquid expansion dial-type thermometers arise mainly from variations in ambient temperature and from the effects of pressure head differences between the bulb and the gauge.

The ambient temperature errors arise from changes in sensitivity, as follows.

- a) The volume of the filling liquid in the capillary and bourdon tube will change with ambient temperature changes and will cause zero shift, therefore the volumes are kept to a minimum.
- b) The modulus of elasticity of the bourdon tube assembly changes with temperature.

These types of error cause the instrument to read high with increase in ambient temperature.

The usual methods adopted to minimize these errors are to use a bi-metallic or a high expansion linkage between the bourdon tube and the quadrant and pinion movement, or a bi-metallic linkage between the bourdon tube and pointer on gearless types. These methods cause a negative zero shift with increase in temperature to offset all of the error from a) and a proportion of the error from b) so as to enable the instrument to give best accuracy in the centre of its scale. These techniques are generally successful, especially on direct mounting types and those using short lengths of capillary. The effects are inherently smaller in mercury-filled systems. (See 2.3.)

In mercury-filled systems more elaborate compensation is necessary for capillary lengths greater than 10 m. The internal volume of the capillary is arranged to increase at the same rate as the change in volume of the filling liquid in the capillary. This is achieved by using a material of very low or zero coefficient of expansion (such as "Invar") either as a wire down the centre of the steel capillary or as cores in larger diameter compensators at intervals along the length of the capillary. The dimensions are arranged so that the volume between the Invar centre and the steel outer of the capillary or compensator is very small. As the liquid in the capillary expands with increasing temperature, the volume in the capillary or compensator increases by a similar amount and no liquid is displaced into the bourdon tube to cause an error in indicated temperature.

Pressure head error on distant reading liquid expansion thermometers arises when the gauge is mounted at a different height than the bulb. This causes a variation in filling pressure between the bulb and the gauge and hence a zero offset.

This possible source of error is treated by the manufacturers as follows.

- a) A relatively high pressure bourdon tube is used so that the pressure change in the system, resulting from the temperature-induced volume change, can be made relatively high (say 50 bar¹⁾ or more). This minimizes the zero offset caused by a given height difference.
- b) A pointer adjuster is provided on many instruments so that the instrument may be set to read a known ambient or other temperature after installation.
- c) If a planned installation gives a difference of height of greater than 5 m the thermometer manufacturer should be informed in order to allow for special calibration to avoid resetting after installation.
- d) Filling the instrument to a high initial pressure improves linearity by compressing any air in the system to an insignificant volume and by ensuring that the bourdon tube operates over its most linear range.

3 Gas expansion dial-type thermometers

3.1 General

In gas expansion dial-type thermometers the changes in pressure of a constant volume of an inert gas contained in a metal bulb, due to variation in its temperature, are transmitted to and indicated by a pressure gauge with a temperature scale, which is usually of the bourdon tube type. In these instruments the indicating gauge acts as a true pressure gauge and not as a volume measuring device as in a liquid expansion dial-type thermometer. The gas most frequently employed is nitrogen (– 150 °C to + 250 °C). For lower temperature use, helium is preferred to avoid liquefaction. For higher temperatures, argon is preferred to prevent "nitriding" of the bulb.

The bulb may contain the filling gas only, or it may also contain an adsorbent material such as activated carbon or a molecular sieve (a zeolite, silicate mineral). In the latter case the gas filling is partially condensed onto the surface of the material. The proportion of the gas released from this material and therefore the pressure in the system is a function of temperature. Bulbs containing this material can be made considerably smaller than bulbs containing the same mass of gas only.

¹⁾ 1 bar = 10⁵ N/m² = 10⁵ Pa.

3.2 Characteristics

The advantages of the gas expansion dial-type thermometer are as follows.

- a) The scales on simple gas-filled thermometers are substantially linear. Over large temperature spans the filling gases cannot be considered as perfect gases and some modification to the perfect gas laws is required. The form of the relationship is:

$$PV = ZRT$$

where

- P is the pressure;
 V is the molar volume;
 R is the molar gas constant the value of which is 8.3145 [in J/(mol K)];
 T is the absolute temperature;
 Z is a correction factor to the perfect gas laws depending upon the gas, the pressure and the temperature.

- b) The scales on bulbs partially filled with adsorbent material are non-linear but easily read throughout the entire range. The hysteresis error associated with this type, i.e. different release/re-adsorption characteristics on increase/decrease in temperature, can be maintained at less than 1 % of the range.
- c) A wide variation of temperature range is possible, the minimum being about 60 °C, and the instruments may be used for measuring temperatures from – 200 °C to + 700 °C.
- d) The filling gas is of much lower density than a liquid and “head” errors due to difference in height between bulb and gauge are negligible.
- e) Accuracy achievable is ± 1 % of range. (See BS 5235.)

A typical gas expansion dial-type thermometer is shown in Figure 1(a).

3.3 Sources of error

The response of a gas-filled thermometer to change in the temperature of the capillary and the indicating gauge is somewhat different to that of a liquid-filled expansion thermometer. In the gas-filled type there is a large transfer of filling gas from the bulb into the capillary and gauge during increase in bulb temperature. Variation in temperature of capillary and gauge therefore causes somewhat different errors at the low and high end of the temperature scale rather than the constant error caused in liquid expansion thermometers.

The method used to overcome the ambient temperature error, and also its variation from one end of the temperature scale to the other, is to ensure that the ratio of bulb volume to capillary plus gauge volume is large enough to reduce the errors to within the limits desired. This requires the bulb size to be increased with length of capillary. The larger pressure changes associated with greater temperature ranges also tend to reduce the effect of ambient temperature variations. Hence in theory the wider the temperature range the smaller the bulb can be. In practice most manufacturers standardize on one bulb volume and use this bulb for all ranges above their minimum range and for any length of capillary up to a maximum figure, which will cover possibly 90 % of their customers' requirements. For long lengths of capillary and low ranges, special, larger bulbs are supplied.

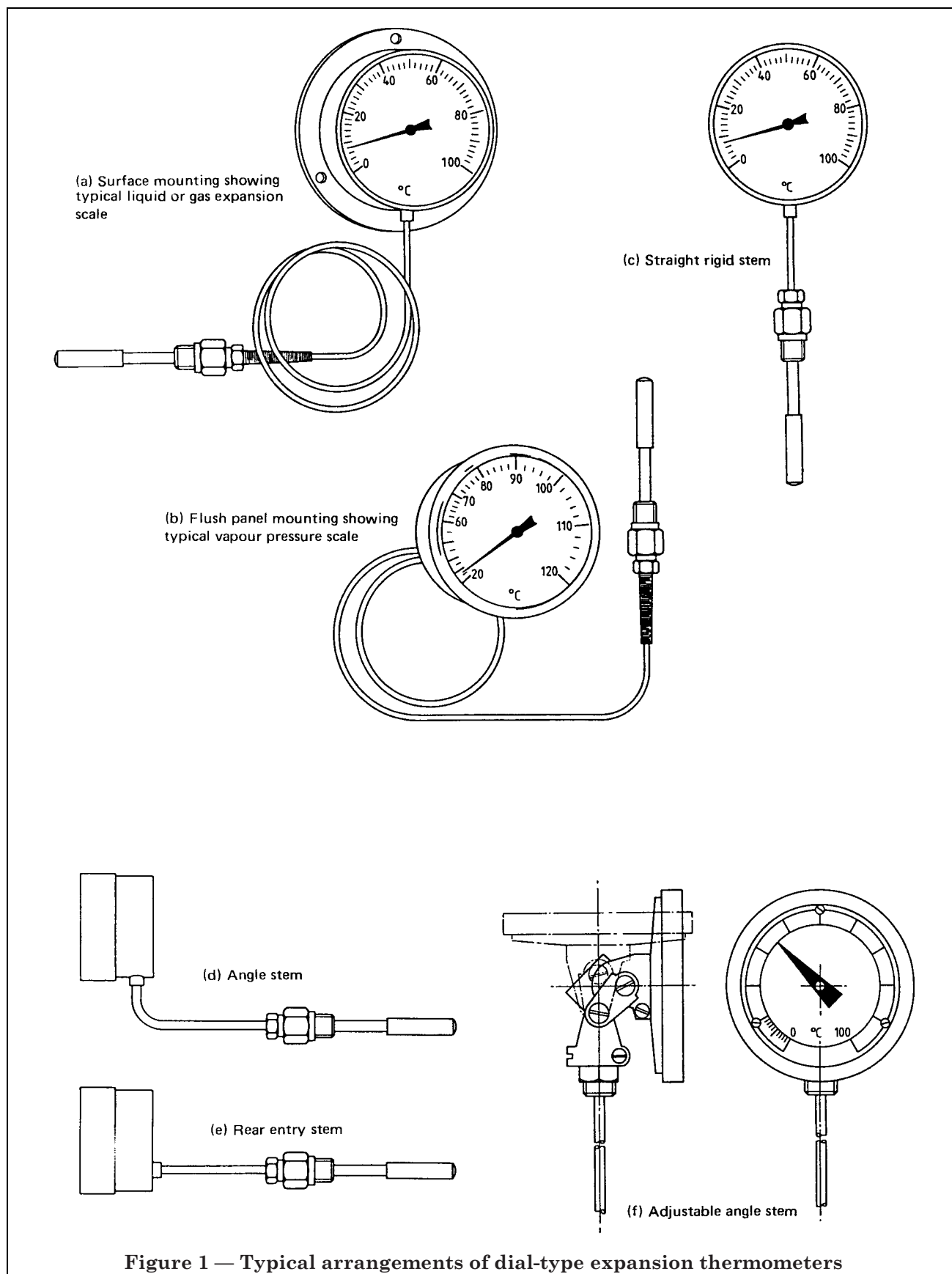
Gas-filled thermometers also suffer change in modulus of elasticity of the bourdon tube assembly with ambient temperature. As in the case of liquid expansion thermometers, the method used to minimize this effect is to employ a bi-metallic or high expansion linkage between the bourdon tube and the movement, in order to cause a negative zero shift with increase in temperature. This offsets a proportion of the error caused by the change in modulus of elasticity of the bourdon tube and the error caused by temperature variation of capillary and gauge. The value of the negative zero shift is chosen to offset the value of the errors found when the instrument is operating in the centre of the scale or at the normal operating point if known.

4 Vapour pressure dial-type thermometers

4.1 General

In these instruments a quantity of volatile liquid partially fills a metal bulb which is connected to a pressure gauge of the bourdon tube type by a stem or length of capillary tubing. Variations in temperature of the bulb cause corresponding variations in the pressure of the saturated vapour above the surface of the liquid in the bulb. These pressure variations are transmitted to the pressure gauge, the indication of which is therefore a measure of the temperature of the bulb.

When operating with the bulb at a higher temperature than the capillary and the gauge, the capillary and the bourdon tube are filled with liquid and a relatively small amount of liquid is present in the bulb at saturation pressure and temperature conditions.



When the bulb is operating below gauge and capillary temperature, all the liquid in the system is in the bulb with the vapour in the bulb at saturation conditions and the vapour in the capillary and bourdon tube in the super-heated condition.

A typical vapour pressure dial-type thermometer is shown in Figure 1(b).

4.2 Characteristics

The scale is not evenly divided. On typical instruments the initial 40 % of the temperature range of the instruments is confined to the first 20 % to 25 % of the scale. This lower part of the scale requires the divisions to have larger temperature increments and a different numbering system to that on the remaining part of the scale. On the first part of the scale therefore the resolution is less than on other dial-type thermometers of similar range. The part of the scale above the change in scale division increments is referred to as the effective scale range.

The relative volumes of the bulb and the capillary/bourdon tube assembly should be such that the bulb can never be completely full nor completely void of liquid under any condition of high or low bulb operating temperature or high or low capillary and gauge temperature within the operating parameters of the thermometer. On thermometers operating with bulb temperature always above ambient temperature, the bulb size can be somewhat smaller since it is never necessary that the bulb be able to accommodate the liquid from both capillary and bourdon tube.

By suitable choice of volatile liquid almost any temperature from $-70\text{ }^{\circ}\text{C}$ to $+250\text{ }^{\circ}\text{C}$ can be measured by a vapour pressure thermometer. The accuracy achievable is $\pm 1.5\%$ of effective scale range. (See BS 5235.)

Table 1 gives the volatile liquids most commonly used in vapour pressure thermometers.

4.3 Advantages

The cost of a vapour pressure instrument is considerably less than that of a mercury-filled or gas expansion type instrument covering the same range. This is due to the lower cost of the bore capillary and bourdon tubes used on this type of thermometer.

The vapour pressure dial-type thermometer is not subject to errors caused by variations in capillary temperature provided that:

- a) on above ambient temperature measurements the capillary installation should avoid hot spots above bulb temperature;

- b) on below ambient temperature measurement the capillary installation should avoid cold spots below bulb temperature, i.e. the bulb has to be the hottest part if used above ambient and the coldest part if used below ambient temperature.

No special compensation is necessary for temperature changes of capillary and bourdon tube assembly other than those standard on bourdon tube pressure gauges.

The length of divisions on the scale of the vapour pressure thermometers makes it particularly suitable where it is required to indicate temperature over a comparatively wide range and where at the same time it is required to make accurate readings in the upper portion of the scale.

The bulb of a vapour pressure thermometer can be smaller than that of a mercury-in-steel or gas-filled thermometer of similar range.

Most of the volatile liquids used are quite harmless and suitable for use in the food industry.

4.4 Limitations

The resolution (and therefore accuracy) on the lower part of the scale is poor. The accuracy on the effective scale range is similar to that for mercury-in-steel and gas expansion thermometers of the same total range.

This type of thermometer is sensitive to damage by over-heating even modestly above the maximum graduation, since because of the vapour pressure characteristic a small excess-temperature results in a large over-pressure in the system.

It is preferable if instruments of this type are used with the normal working temperature either always above ambient temperature or always below ambient temperature. During a temperature transient passing through ambient temperature the capillary and bourdon tube assembly has to either fill with liquid or empty of liquid depending on the direction of the transient. This process can be turbulent due to bubbles forming or collapsing in the capillary and bourdon tube, and causing oscillation of the instrument pointer over a significant portion of the scale range. If the length of capillary is large the instrument will be very sluggish when crossing ambient temperature.

As a result, instruments of this type are not suitable to measure temperature close to ambient.

If the filling liquid used is one of those chosen from the table then the effects of day-to-day barometric changes will not cause measurable inaccuracies.

However, instruments intended for use at altitudes above 1 000 m should be calibrated to compensate for the reduced barometric pressure.

The pressure range of vapour pressure thermometers is usually much smaller than for liquid expansion thermometers and hence differences in height between the bulb and indicator head can have larger effects. If the height difference between the bulb and the dial exceeds 2 m the instrument should be adjusted accordingly.

Table 1 — Examples of filling liquids used in vapour pressure dial-type thermometers

Liquid	Typical ranges available	Pressure
	°C	bar absolute
Methyl chloride (chloromethane)	0 to 50 20 to 120	2.5 to 11.0 4.8 to 46.0
Butane (n-butane)	20 to 80	2.1 to 10.1
Ethyl chloride (chloroethane)	30 to 100	1.9 to 11.7
Diethyl ether	60 to 160 20 to 120	2.3 to 21.2 0.6 to 11.1
Ethyl alcohol (ethanol)	100 to 180	2.2 to 19.6
Methyl alcohol (methanol)	50 to 200	0.6 to 40.2
Water	120 to 220	2.0 to 23.2
Benzene	50 to 250	0.4 to 29.8
NOTE Other substances used at low temperature include dichlorodifluoromethane, oxygen, argon, nitrogen, neon and hydrogen.		

5 Bi-metal strip actuated dial-type thermometers

5.1 General

This type of instrument consists of a helically shaped coil of bi-metallic strip, suitably tempered, contained within a metallic tube. One end of the helix is attached to the end of the metal tube and the other end attached to a shaft connected to the pointer. A change in temperature causes a proportional rotational movement which is transmitted to the indicating pointer on the dial.

5.2 Characteristics

Scales are approximately linear between $-50\text{ }^{\circ}\text{C}$ and $+400\text{ }^{\circ}\text{C}$. A wide variation of temperature may be measured from $-70\text{ }^{\circ}\text{C}$ to $+500\text{ }^{\circ}\text{C}$, although continuous service above $450\text{ }^{\circ}\text{C}$ is not recommended; minimum spans are $60\text{ }^{\circ}\text{C}$ to $80\text{ }^{\circ}\text{C}$. Accuracy of $\pm 1\%$ of range can be achieved.

Bi-metal thermometers can only be made in rigid stem form, normally straight rigid stem or centre back stem (co-axial type). A popular hybrid type is commonly available with an adjustable angle section immediately behind the case on a co-axial type. The adjustable angle stem type has advantages in its variety of application and interchangeability of spares. [See Figure 1(c), Figure 1(d), Figure 1(e) and Figure 1(f).]

The normal maximum stem length is 1 m. Longer stems can be achieved if larger diameters are acceptable.

The bi-metal element is slower to respond to temperature changes than liquid-filled systems, due to the slow transfer of heat through the air surrounding it. This can be overcome by reducing the diameter of the detecting element.

5.3 Advantages

The potential for small diameter detecting elements (down to 4 mm) gives the bi-metal thermometer advantages over liquid, vapour and gas-filled thermometers which normally have bulkier elements.

Stainless steel is often the material of construction for the sheath and the indicating head, permitting use in many corrosive atmospheres.

The bi-metal thermometer has a low basic price.

6 Installation and use of dial-type expansion thermometers

The information to be supplied by the purchaser to the manufacturer is shown in Appendix A of BS 5235:1975.

The sensing bulbs on dial-type expansion thermometers are subject to minimum size limitations so that the bulb contains sufficient filling fluid to operate the instrument. The size of bulbs is the subject of agreement between the purchaser and manufacturer and is covered by BS 2765. The sensing bulbs are usually robust and suitable for direct installation into pipes containing low pressure non-corrosive fluids. (See Figure 2(a).)

High external pressure can cause damage to the bulbs or zero changes on liquid expansion thermometers due to compression of the bulb. The manufacturer should be consulted about the maximum pressure to which a bulb may safely be subjected.

The scale should be chosen so that the expected working temperature is from 30 % to 80 % of scale. Thermometers should never be subjected to temperatures above their range unless specially agreed with manufacturers.

Typical bulb installation methods are shown in Figure 2(b).

The use of a pocket (see BS 2765) will protect the bulb from the effects of pressure, corrosion, erosion and oscillation in high speed flows. A pocket allows a bulb to be withdrawn for calibration or replacement without shutting down and draining the process pipework.

The bulb should be inserted to the bottom of the pocket or hole. This is especially important on bearing metal temperature measurement. Consideration should be given to using a sliding gland so that it may be pushed fully in.

Heat transfer is more rapid if a fluid is moving than if a fluid is static. Thus, bulbs or pockets should be in the flow of a fluid and not in a dead corner.

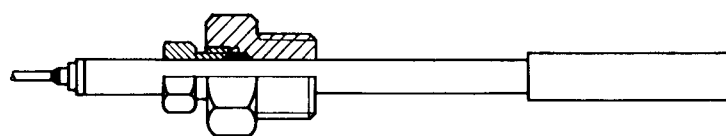
The time constant (the time required to complete 63.2 % of a step temperature change) for a dial-type expansion thermometer in a stirred liquid is typically between 3 s and 15 s. The use of a pocket can increase this to between 15 s and several minutes depending on the size and material of pocket. This can be minimized by a good fit of the sensing bulb in the pocket and the use of a heat transfer medium within the pocket.

The bulb or pocket should be sited carefully. There can be considerable variations of temperature within large tanks or ovens. The bulb or pocket should be long enough to prevent the bulb being cooled by heat flow from the bulb or pocket into the wall of the vessel. The temperature of a bulb is affected by radiant heat, and so when a bulb is measuring the temperature of a slow moving gas it might be necessary to fit a heat shield to prevent radiation cooling of the bulb by heat flow into the wall or radiation heating by oven wall heaters.

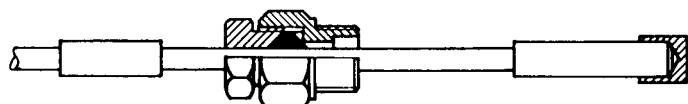
On many liquid expansion and gas expansion thermometers a pointer adjuster is provided to set the instrument reading to a known ambient or other temperature to correct for head effects and ambient temperature effects.

Capillaries should be securely clipped in place on cable trays rather than on the outside of pipework. Indicator gauges should be mounted so as to avoid severe vibration unless they are specially manufactured to cope with this situation.

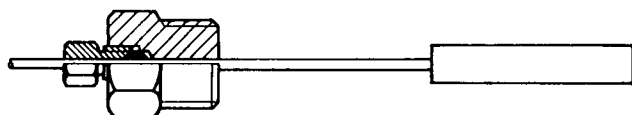
In common with all other measuring instruments, thermometers should have their calibration checked at regular intervals.



Fixed union or sliding gland

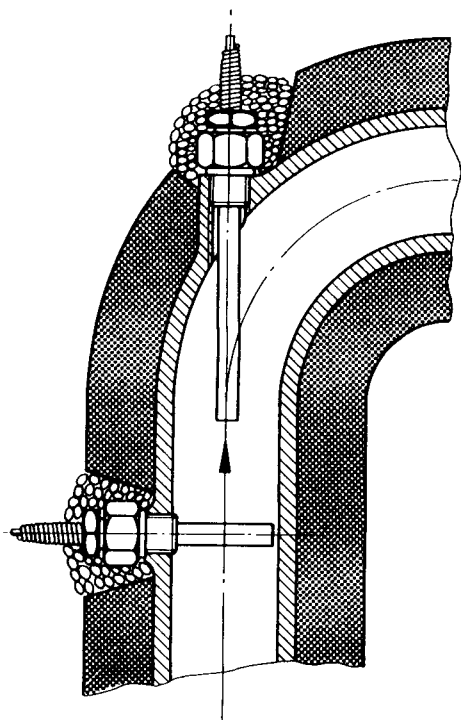


Insulated for electrical machine bearings

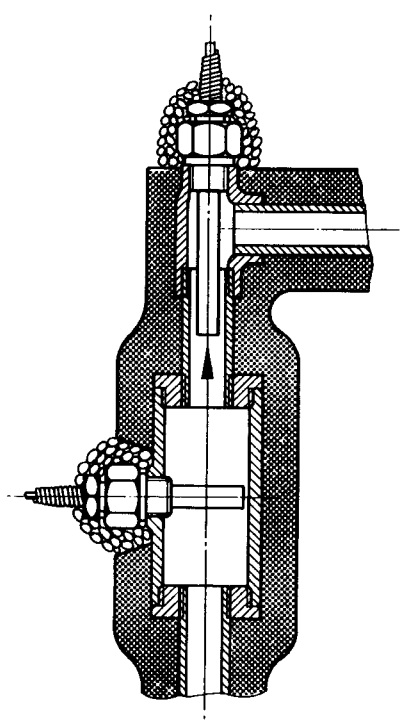


With bendable neck for awkward installations, long pockets and for minimum conduction losses

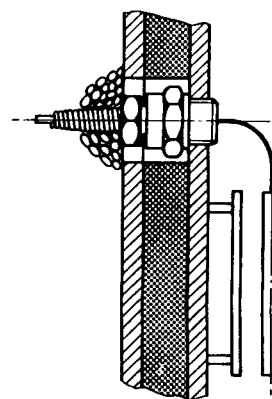
(a) Bulbs



Large pipe



Small pipe



Air

(b) Installations

Figure 2 — Typical types of bulbs and installations

Publications referred to

BS 2765, *Specification for dimensions of temperature detecting elements and corresponding pockets.*

BS 5235, *Specification for dial-type expansion thermometers.*

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