Liquid in Glass Thermometry

What is thermometric property?

How to calibrate a thermometer?

What are the characteristics of a quality thermometer?

THERMOMETERS

Thermal Equilibrium in Daily Life

Hot air in oven and cake batter.

Clinical thermometer

Food in refrigerator

Drinks with ice

What is Temperature?

- **It is the measurement of the AVERAGE kinetic energy of the particles of matter.**

Temperature

- We associate the concept of temperature with how hot or cold an object feels
- Our senses provide us with a qualitative indication of temperature
- Our senses are unreliable for this purpose
- We need a reliable and reproducible method for measuring the relative hotness or coldness of objects
- We need a technical definition of temperature

Thermal Contact

Two objects are in thermal contact with each other if energy can be exchanged between them

- The exchanges we will focus on will be in the form of heat or electromagnetic radiation
- The energy is exchanged due to a temperature difference

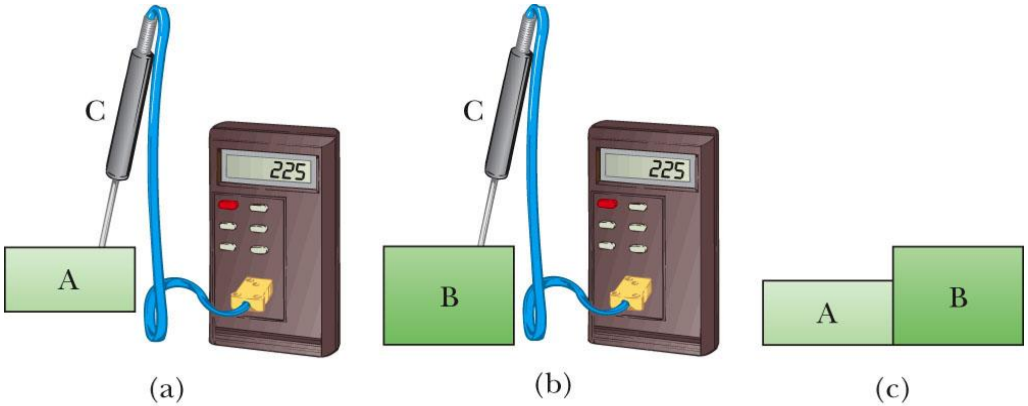
Thermal Equilibrium

- Thermal equilibrium is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact
- The thermal contact does not have to also be physical contact

Zeroth Law of Thermodynamics

- **If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other**
  - **Let object C be the thermometer**
  - **Since they are in thermal equilibrium with each other, there is no energy exchanged among them**

Zeroth Law of Thermodynamics, Example



- **Object C (thermometer) is placed in contact with A until they achieve thermal equilibrium**
  - **The reading on C is recorded**
- **Object C is then placed in contact with object B until they achieve thermal equilibrium**
  - **The reading on C is recorded again**
- **If the two readings are the same, A and B are also in thermal equilibrium**

Temperature

- Temperature can be thought of as the property that determines whether an object is in thermal equilibrium with other objects
- Two objects in thermal equilibrium with each other are at the same temperature
  - If two objects have different temperatures, they are not in thermal equilibrium with each other

Temperature Scales

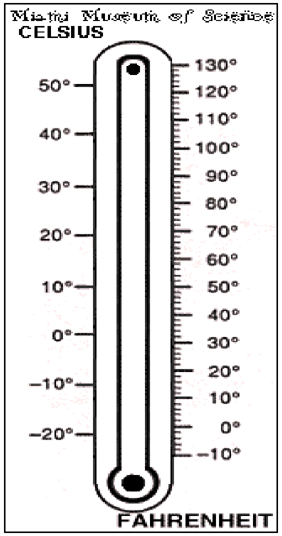
- Celsius
- Kelvin
- Fahrenheit
- Rankine

- ***The 3 main temperature scales***

- **Fahrenheit**
- **Celsius**
- **Kelvin**

Celsius Scale

- The fixed points on which this scale was created, were the Boiling and Freezing point of water.
- Original scale had boiling point = 100
- And the freezing point = 0

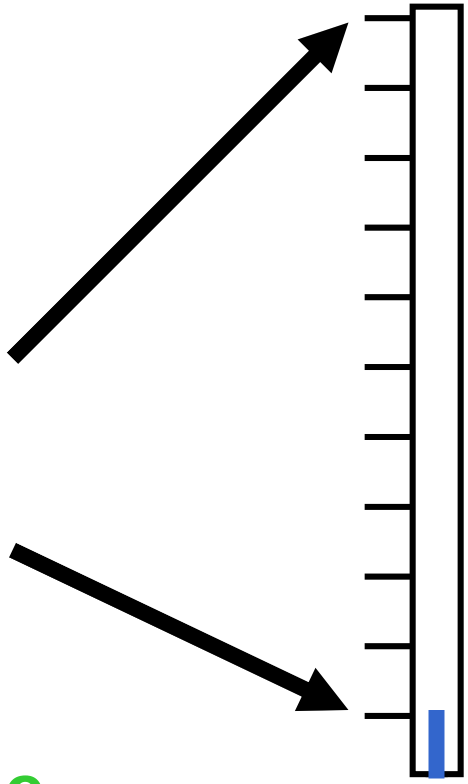


Celsius Scale …

- The ice point of water is defined to be 0 ^{0}C
- The steam point of water is defined to be 100
- The length of the column between these two points is divided into 100 increments, called degrees

Celsius Scale…

- These were later reversed so the
  - ***Boiling Point*** = 100 ^{0}C
  - ***Freezing Point*** = 0 ^{0}C



- The original name was the **CENTIGRADE** scale

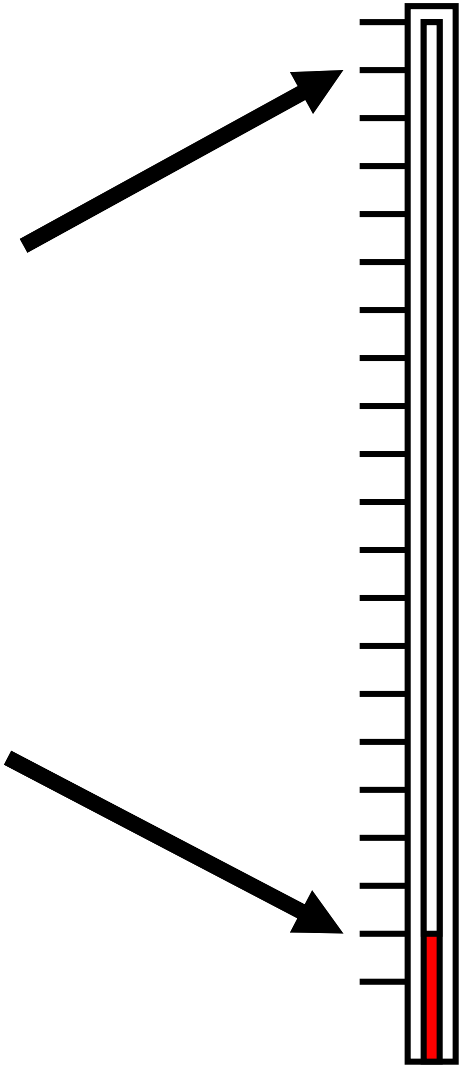
Fahrenheit Scale

- Named for Daniel Fahrenheit
- Temperature of the ice point is $32^{o}F$
- Temperature of the steam point is $212^{o}F$
- There are 180 divisions (degrees) between the two reference points

The Fahrenheit Scale

- ***Boiling point***
- ***became =*** ___212 ^{0}F___

- ***Freezing point***
- ***became =*** ___32 ^{0}F___



Absolute Temperature Scale

- **Absolute zero is used as the basis of the absolute temperature scale**
- **The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale**

Absolute Temperature Scale…

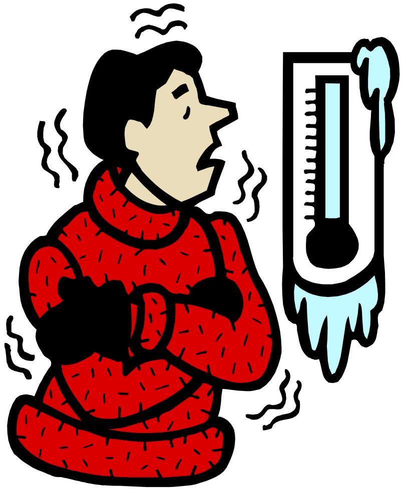
- The absolute temperature scale is now based on two new fixed points
  - One point is absolute zero
  - The other point is the triple point of water
    - This is the combination of temperature and pressure where ice, water, and steam can all coexist

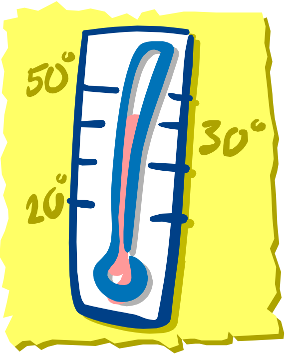
Kelvin Scale

- **This temperature is known as**
  - **ABSOLUTE ZERO**

- Absolute Zero = 0 K
- Boiling point of water = 373 K
- Freezing point of water = 273 K

Comparison of Temperature scales





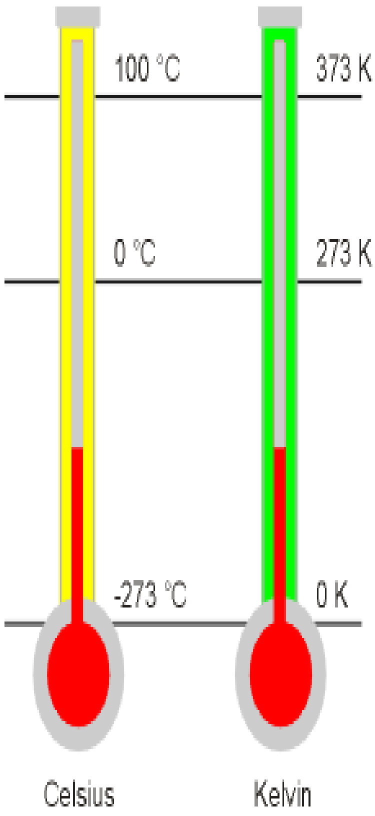
Temperature CONVERSION

Celsius to Kelvin:

$$K = C + 273$$

Kelvin to Celsius:

$$C = K - 273$$



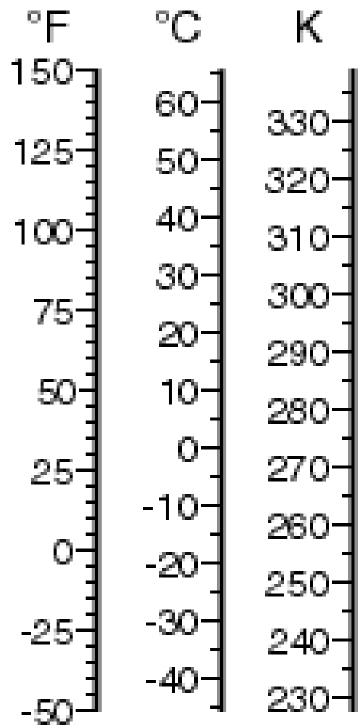
Temperature CONVERSION…

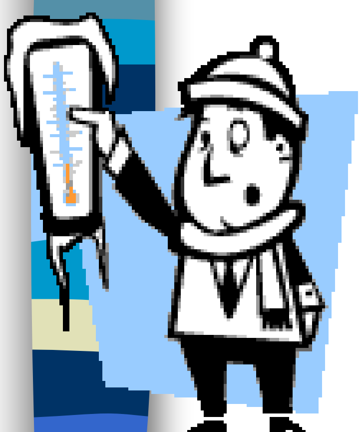
°F = 9/5(°C) +3

°C = 5/9[(°F) –32]

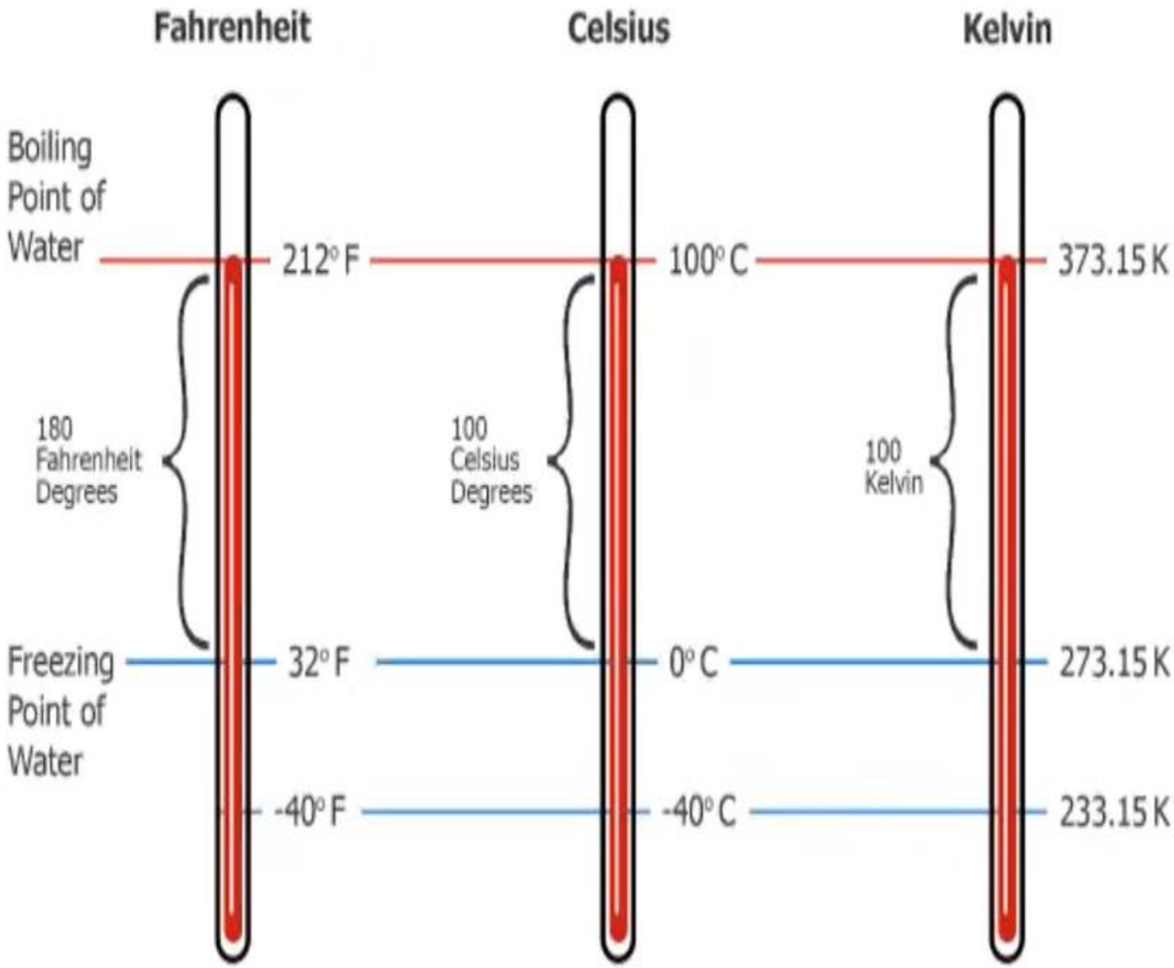
°F = °R – 459.67

°C = K – 273.15





What is Temperature Metrology?



Scales of Measurement

Thermometers

Temper

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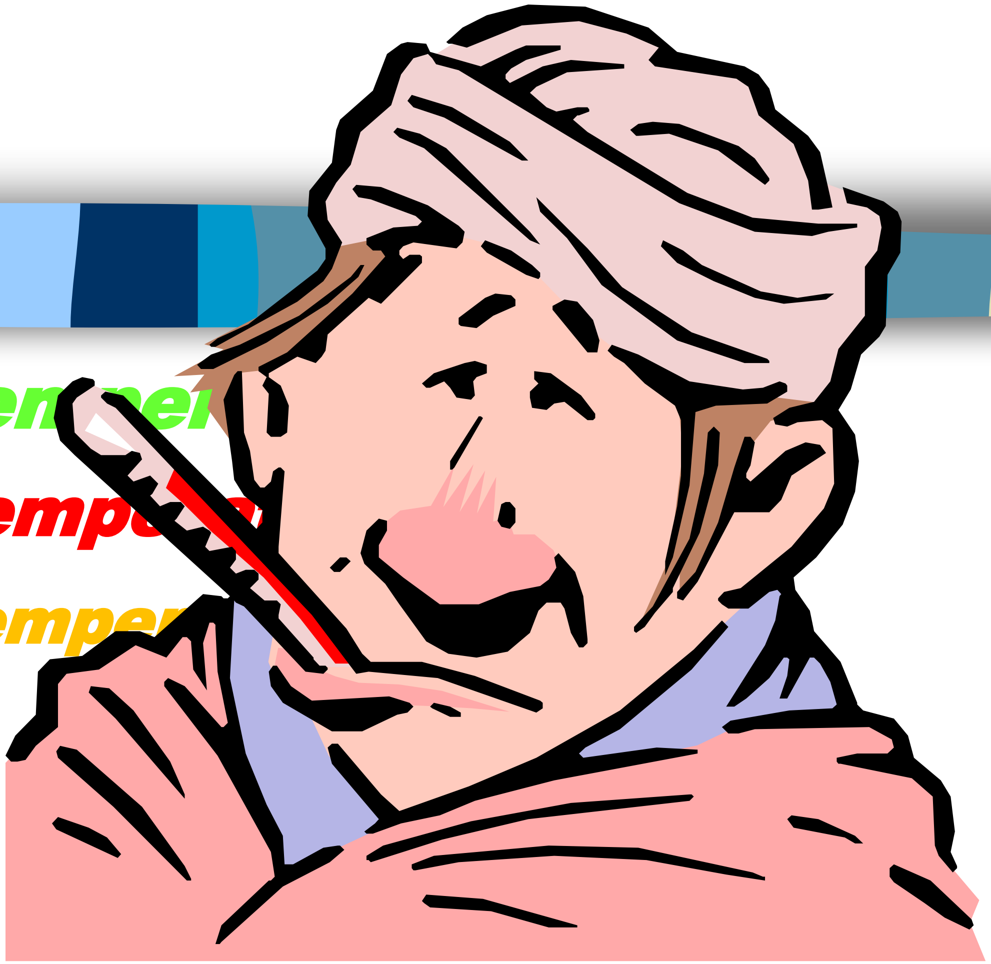
Temper



Thermometers

- A thermometer is a device that is used to measure the temperature of a system
- Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes

Thermometers, cont

- **These properties include:**
  - **The volume of a liquid**
  - **The dimensions of a solid**
  - **The pressure of a gas at a constant volume**
  - **The volume of a gas at a constant pressure**
  - **The electric resistance of a conductor**
  - **The color of an object**
- **A temperature scale can be established on the basis of any of these physical properties**

Calibrating a Thermometer

- A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature
- Common systems involve water
  - A mixture of ice and water at atmospheric pressure Called the ice point of water
  - A mixture of water and steam in equilibrium Called the steam point of water
- Once these points are established, the length between them can be divided into a number of segments

Principles of Thermometry

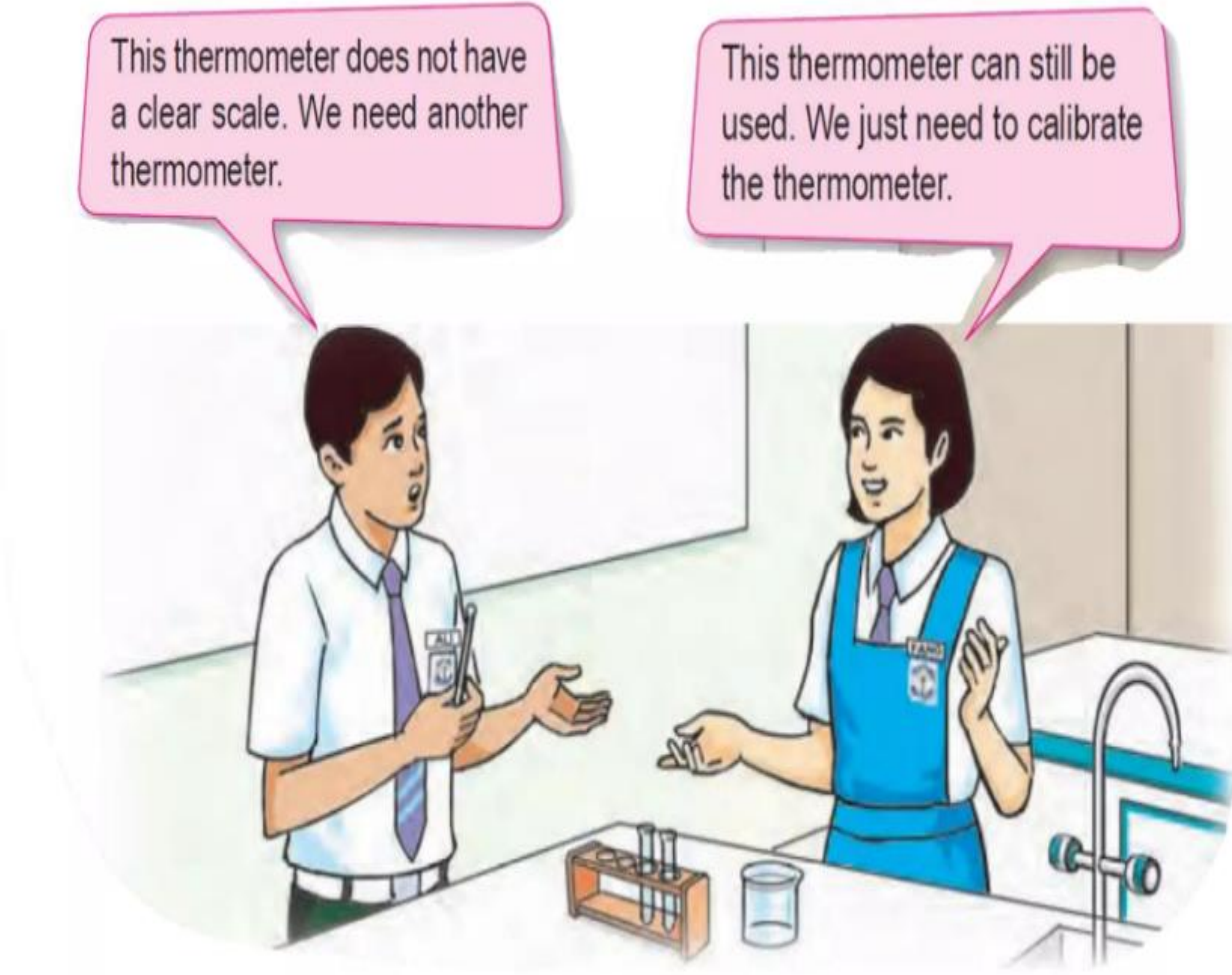
A **thermometer** is any instrument which is used to measure temperature.

The thermometer needs a scale to be used effectively.

There are several types of thermometers.

The choice of which to use is depend on

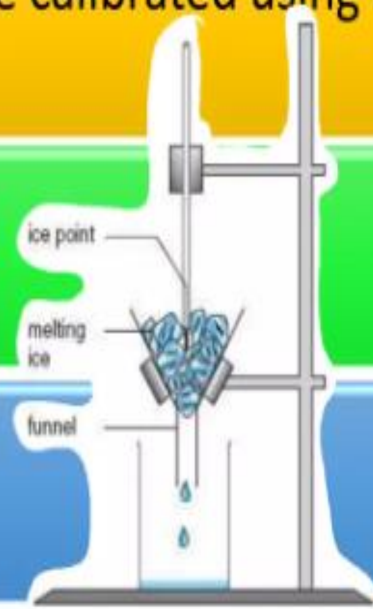
- the range of temperature to be measured,
- the accuracy required, and
- the physical conditions in which the thermometer will be used.


This thermometer does not have a clear scale. We need another thermometer.
This thermometer can still be used. We just need to calibrate the thermometer.

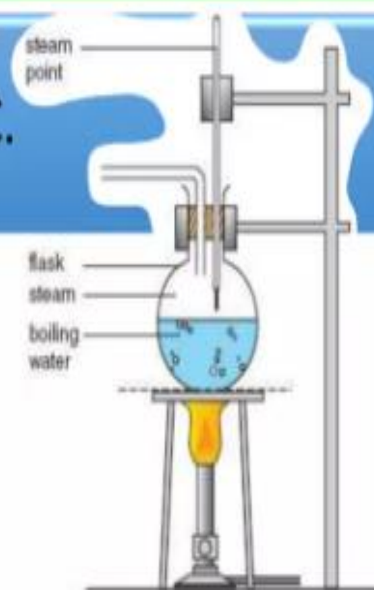
To calibrate a Liquid-in glass thermometer using two fixed points

A thermometer that does not have a scale can be calibrated using two fixed temperature points.

melting point of ice, 0°C

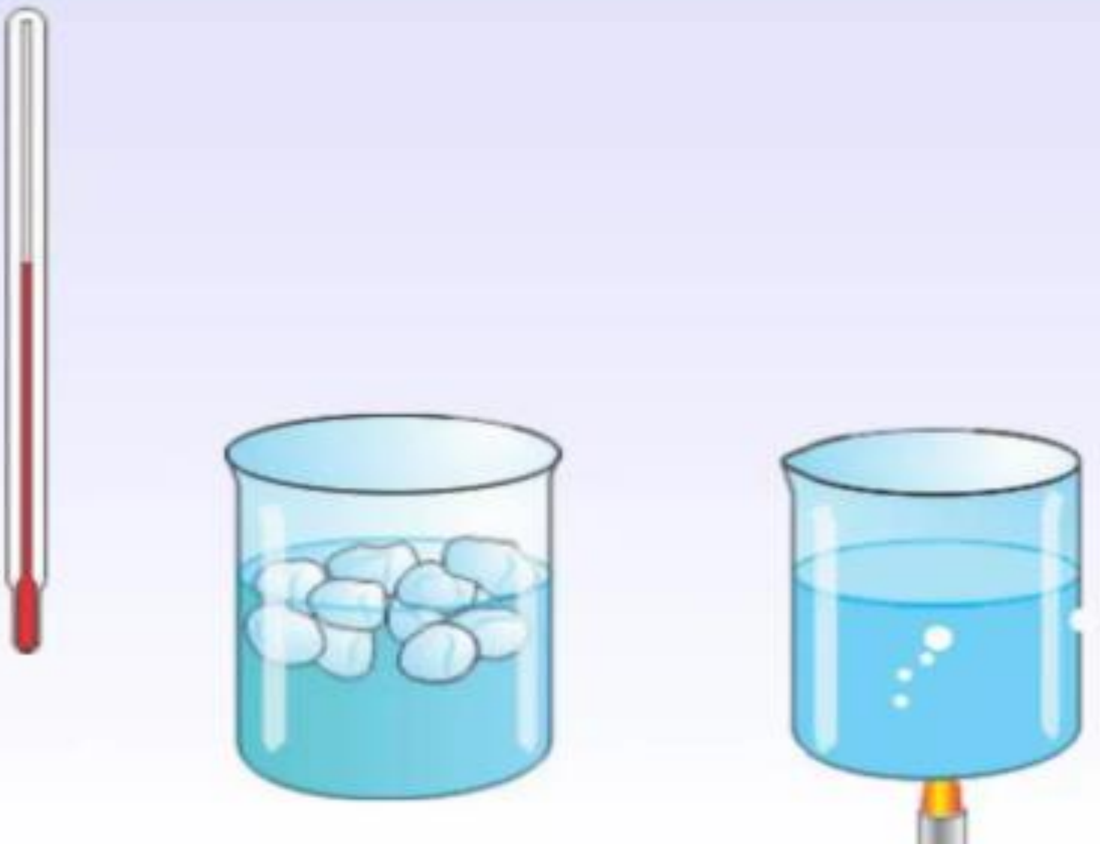


Boiling point of water, 100°C.



Calibrating a thermometer

Step 1a : Place the thermometer into a beaker of ice.



Discussion

The bulb of the thermometer should not touch the base or side wall of the beaker while taking measurement. Explain.

Formula

If the lengths of mercury thread at ice point (0 °C), at steam point (100 °C) and when immersed in a liquid of unknown temperature ϑ are l_0, l_{100} and l_ϑ respectively,

$$\theta = \frac{l_\theta - l_0}{l_{100} - l_0} \times 100\,°\mathrm{C}$$

the temperature ϑ can be calculated as follows:

Thermometric Properties

Some materials have properties that changes with temperature:

Liquids can expand if the temperature increases, or contract if it decreases;

Metals and alloys also expand and contract if the temperature changes;

Some substances change their colours when the temperature increases

Some substances change their electrical conductivity when its temperature rises

Thermometer

Responsiveness: How long it takes for the thermometer to react to a change in temperature

the larger the bulb, the less responsive it is, since there is more liquid in the larger bulb.

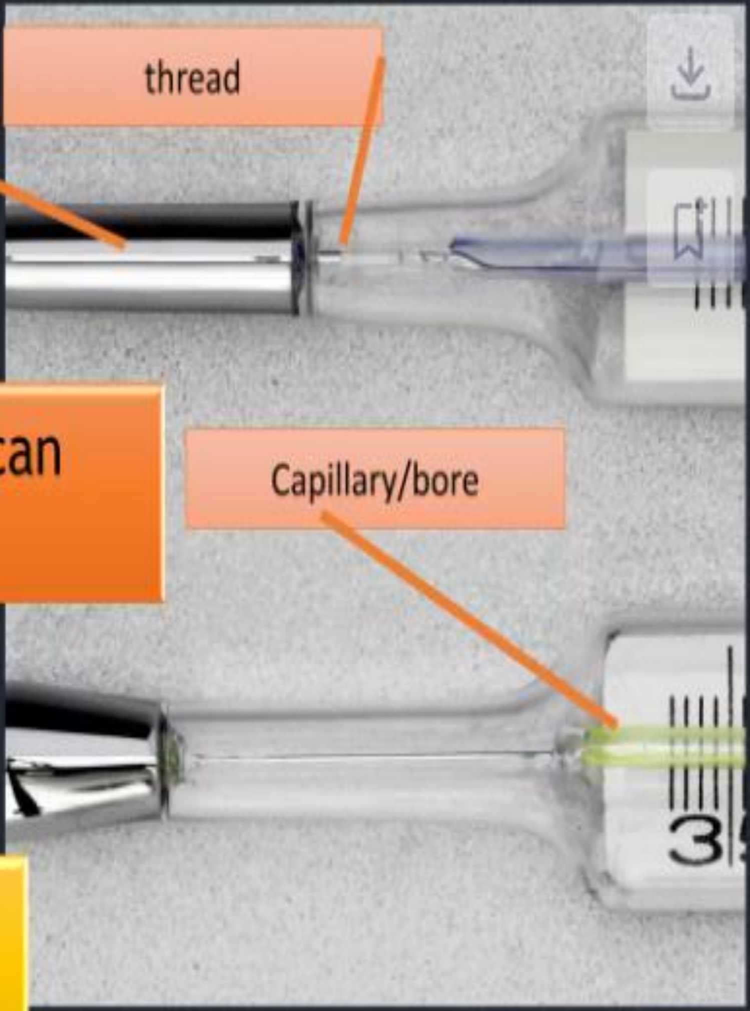
the bulb wall are usually made to be thin so that conduction of heat energy can occur as quickly as possible.

Thermometer

Sensitivity: this measures the amount of change in thermometric property per unit change in temperature.

a thermometer with a thicker bore will be less sensitive since the change in length of the thermometric liquid is lesser.

Thermometer



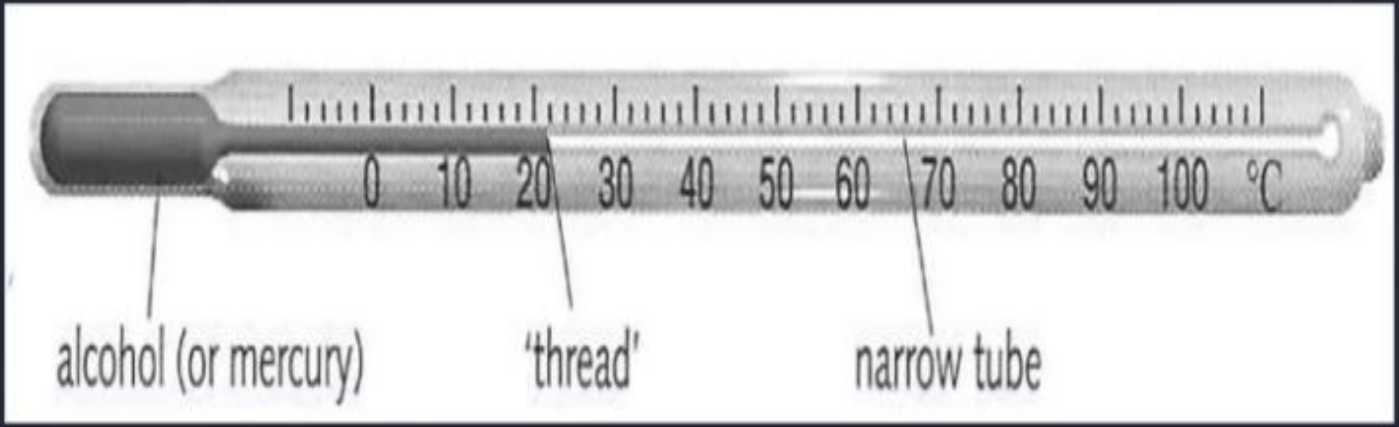
Range: refers to scope of temperature it can measure.

the longer the length of the stem, the larger the range of the thermometer

Thermometer

Linearity: is the uniform expansion of the liquid to temperature which give the reading.

mercury expand at a steady rate as it is heated.



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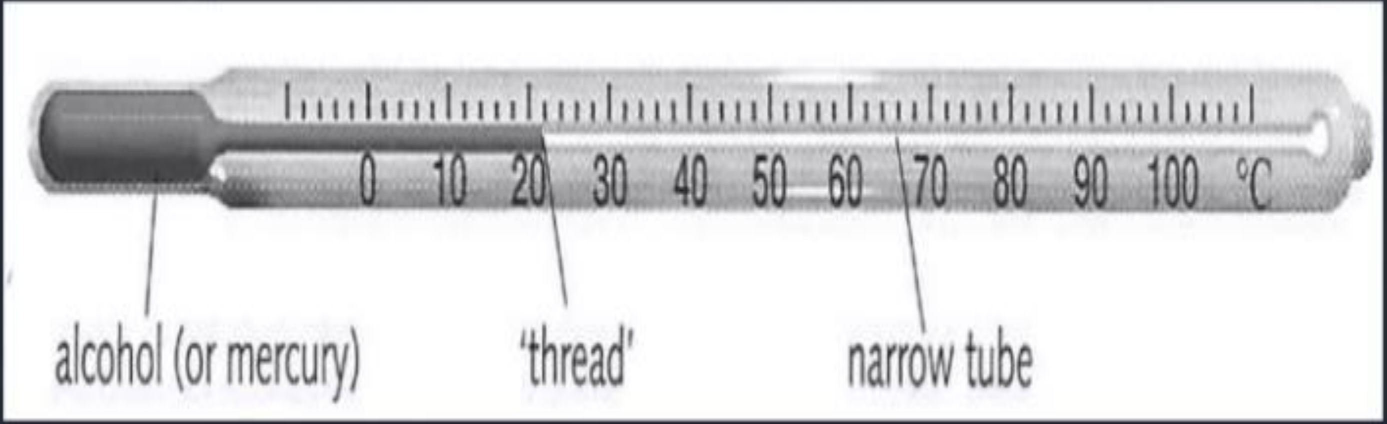
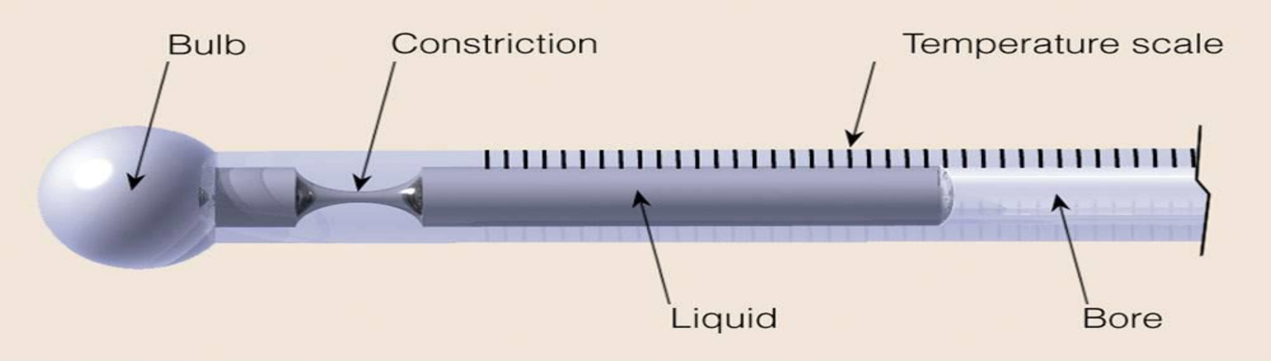


Liquid-in-glass-thermometer

Thin-wall glass bulb	• To allow conduction of heat quickly throughglass to the liquid
Small bulb	• Small amount of liquid responds more quickly to a change in temperature
Fine and uniform bore	• To allow noticeable movement of liquid • To ensure even expansion of liquid
Thick-wall tube	• Act as magnifying glass for easy reading
Smaller size	• More portable and cheap to produce

Liquid in glass



Liquid-in-glass thermometer: glass tube filled with liquid (often mercury or alcohol) that expands/contracts with air temperature

Liquid-in-glass Thermometry

Liquid-in-glass thermometers

one of the earliest types of thermometer developed.

Because their use has dominated thermometry for at least 250 years.

Liquid-in-glass thermometers have been developed to cover the temperature measurement range from −190 □C to 600 □C.

In spite of the fragile nature of glass and

the toxicity of mercury, the popularity of the thermometers continues, largely because of the chemical stability of glass,

the apparent ease of use

and the self-contained nature of the thermometer.

The trend was moved away from liquid-in-glass thermometers to

Platinum resistance thermometry: gives superior performance at lower

overall cost

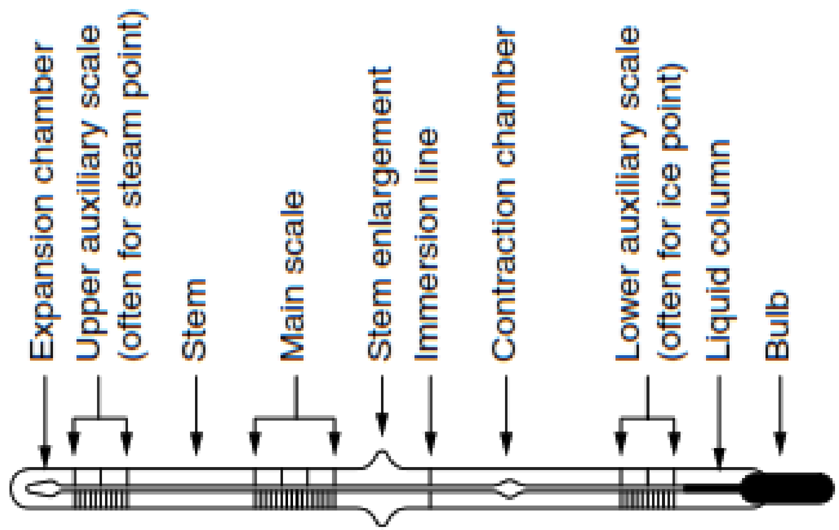
and is readily accessible with easy-to-use electronic resistance bridges

and high-quality probes available commercially.

now replace many liquid-in-glass thermometers.

However, liquid-in-glass thermometers are still specified in many documentary standards for test procedures, and they still represent a cost-effective solution where measurements are made over a narrow temperature range.

The various parts of a solid-stem liquid-in-glass thermometer.
Four of the parts are common to every thermometer:
the bulb,
the capillary,
the thermometric liquid and
the scale.
The operation of liquid-in-glass thermometers is based on the expansion of the liquid with temperature.
As the temperature of the liquid in the bulb increases, the liquid expands and is forced up the capillary.
The tempera- ture is indicated by the position of the top of the liquid column against the marked scale



The various thermometric fluids commonly used in liquid-in-glass thermometers are:

Liquid	Typical apparent expansion coefficient $(^\circ C)^{-1}$	Possible temperature range
Mercury	0.000 16	−35 °C to 510 °C
Ethanol	0.001 04	−80 °C to 60 °C
Pentane	0.001 45	−200 °C to 30 °C
Toluene	0.001 03	−80 °C to 100 °C

Mercury is the least sensitive of the liquids but the most linear.

Unlike other thermometers, which have a separate sensor and indicator, liquid-in-glass thermometers use the temperature sensor as the indicator.

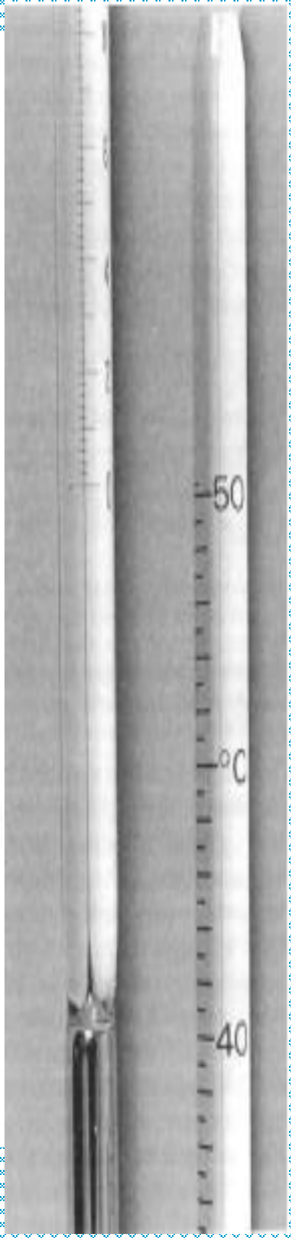
This feature compromises the immersion conditions of the sensor, and in some situations necessitates 'stem corrections' to account for the poor immersion.

Pointing marks are usually scratched at both ends of a thermometer's stem to locate the scale.

The proximity of the scale to the pointing marks is a good indicator of the quality of a thermometer.

In a good-quality thermometer (left), the 0 °C pointing mark is immediately along side the corresponding scale mark.

In a general-purpose thermometer (right), the 50 °C pointing mark is about one-quarter of a scale division above the scale mark

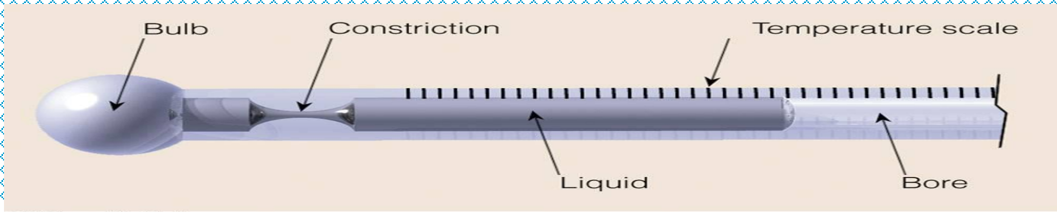


The volumetric thermal expansion of the mercury is well known since it is used as a density standard:

$$V = V_0\left(1 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4\right)$$

where V_0 is the volume of the liquid at 0 °C and the a_i are the coefficients of thermal expansion, with values

$$a_1 = 1.815\,868 \times 10^{-4}\ {}^\circ\mathrm{C}^{-1},$$
$$a_2 = 5.458\,43 \times 10^{-9}\ {}^\circ\mathrm{C}^{-2},$$
$$a_3 = 3.498 \times 10^{-11}\ {}^\circ\mathrm{C}^{-3},$$
$$a_4 = 1.5558 \times 10^{-14}\ {}^\circ\mathrm{C}^{-4}.$$



The expansion is about 625O times more fluid in the bulb than each 1 °C interval in the capillary.

The high-order terms of the volumetric equation show that the expansion is also slightly non-linear with temperature.

The capillary transforms the volumetric change of the liquid into a linear change that is interpreted in terms of temperature.

It is important that the bore of the capillary has a uniform diameter, and is clean and smooth.

In good-quality reference thermometers, the uniformity of the capillary used to make the thermometer is checked before hand by measuring the length of a small drop of mercury as it is moved up the capillary.

Any impediments or dirt within the bore will also cause a discontinuity in the thermometer reading and may cause the mercury column to stick as the temperature changes.

Not all glasses are suitable for thermometric use.

A ruling machine is then used to engrave, etch or print a scale onto the stem by linearly interpolating (i.e. marking equal subdivisions)

The main purpose of the expansion chamber at the top of the thermometer is not to allow the mercury to expand, but to prevent the build-up of pressure in those thermometers that are gas filled.

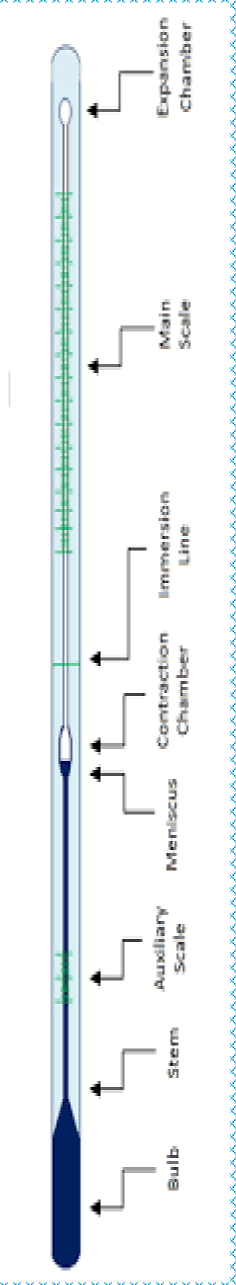
It is necessary for the thermometers to have contraction chambers between the different scales.

The chambers must be smooth to ensure that bubbles are not trapped as the mercury rises.

The main purpose of the expansion chamber at the top of the thermometer is not to allow the mercury to expand, but to prevent the build-up of pressure in those thermometers that are gas filled.

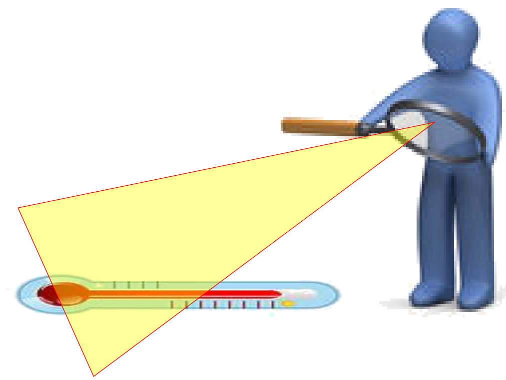
A visual inspection of the back of the thermometer will show whether the thermometer is gas filled or vacuous (sometimes referred to as ‘vacuum filled’).

The construction of most liquid-in-glass thermometers is covered by documentary standards published by several organisations. The ISO standards do not appear to be greatly followed, but many thermometers are manufactured and used according to the specifications of the British Standards Institution (BSI), the American Society for Testing and Materials (ASTM), or the Institute of Petroleum (IP).



Measuring temperature

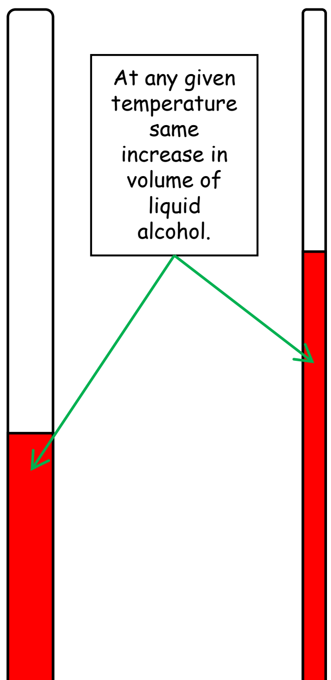
Features of liquid-in-glass thermometers



Most liquids expand slightly when heated. This property is put to use in thermometers filled with alcohol or mercury.

Sensitivity.

The narrower the tube, the more the liquid inside moves, making the thermometer more sensitive to changes in temperature. Alcohol expands more than mercury, so a mercury thermometer must have a narrower tube than an alcohol one.



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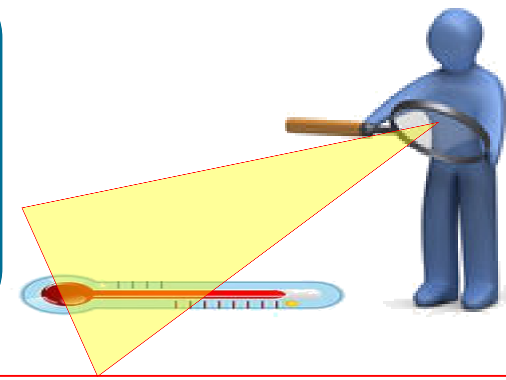

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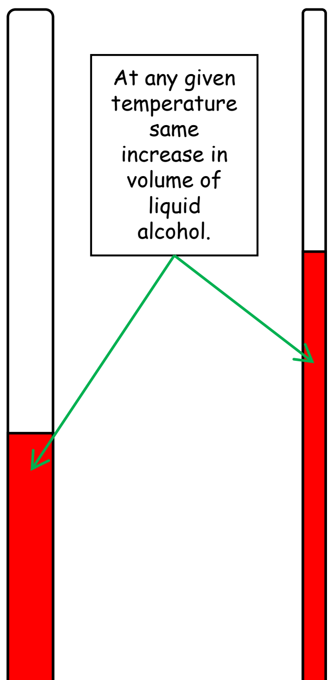

Range – mercury has a freezing point of -39°C and a boiling point of 356°C. Alcohol freezes at -115°C, but boils at 78°C.

Measuring temperature

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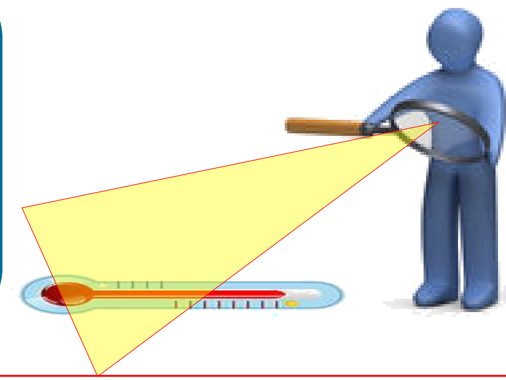

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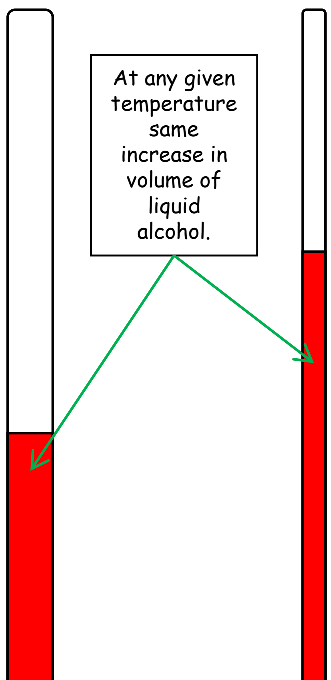

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Responsiveness – thermometers with large bulbs or thicker glass around the bulb respond less quickly to changes in temperature.

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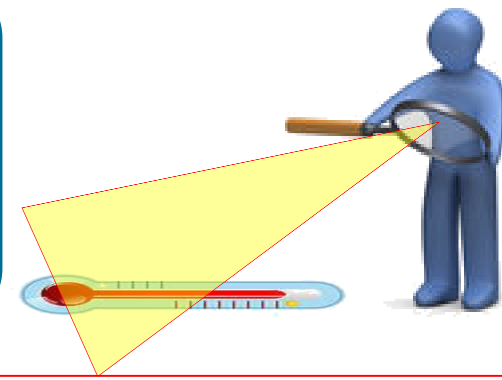

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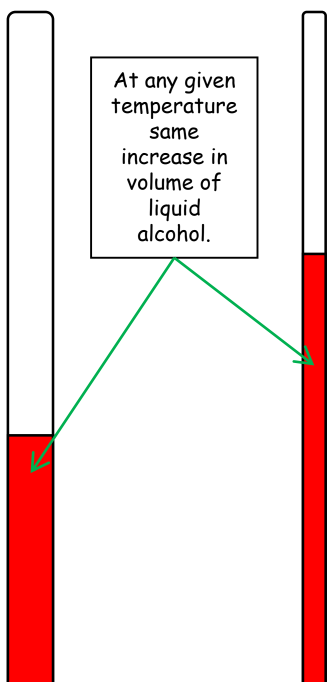

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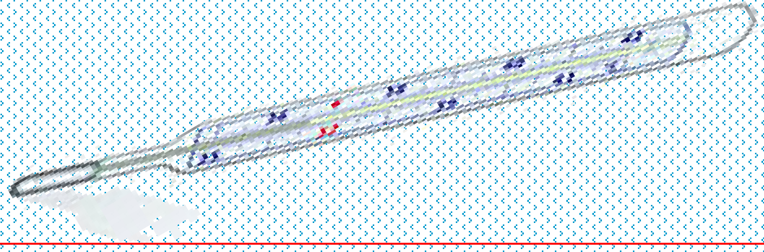
Responsiveness – thermometers with large bulbs or thicker glass around the bulb respond less quickly to changes in temperature.

Linearity – the expansion of mercury is not quite linear compared with alcohol – they differ slightly, but these differences are not significant between 0°C and 100°C.

Measuring temperature

- Examples of thermometers



Clinical thermometer.

- Measures human temperatures very accurately. Scale is restricted to a few degrees either side of the normal body temperature (37^{o}C). A restriction in the neck stops the mercury from dropping until the reading is taken.

Enclosed-scale thermometers

In a solid-stem thermometer, the capillary is very thick, and serves the additional purposes of supporting the scale and being the main structural member of the thermometer.

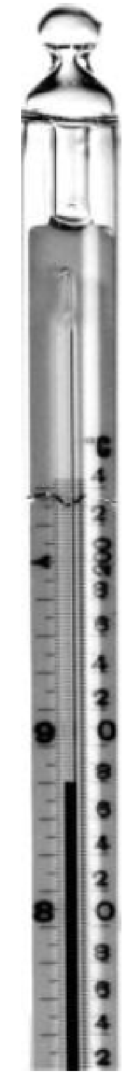
In an enclosed-scale thermometer the capillary serves no other purpose than to indicate the change in volume of the liquid.

The other purposes are satisfied by two separate structures.

The scale is marked on a flat strip of opaque glass that lies behind the capillary, and the whole assembly is contained within a larger glass tube.

The separation of the scale from the capillary in enclosed-scale thermometers makes slightly different compromises in performance from solid-stem thermometers.

The main advantage of enclosed-scale thermometers is that the parallax errors can be, depending on the design, much reduced.

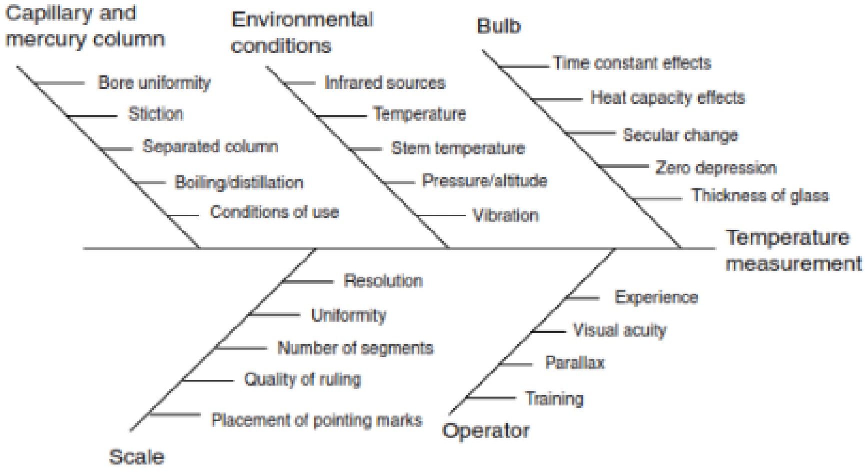


Errors in Liquid-in-glass Thermometry

The apparent simplicity and ease of use of liquid-in-glass thermometers belies the fact that they are extraordinarily difficult to use well.

The use of the thermometric fluid as both sensor and indicator compromises the performance, as does the involvement of a human in the reading

all the most significant sources of uncertainty in the use of liquid-in-glass thermometers.



A cause and effect diagram for liquid-in glass-thermometers

On the negative side, they are slightly more fragile,
there is the possibility that the scale separates from the capillary, and
the time constant to warm the mercury in the enclosed part of the column is longer.
The mounting of the capillary against the scale is usually the biggest problem with quite a number of different devices used including wire ties, glue, and glass end stops fixed to the capillary, with the last being the most satisfactory.

Overall, there seems to be very little difference in performance between the enclosed-scale and solid-stem thermometers.

Pressure effects

The volume of the bulb is very sensitive to pressure because the envelope is so thin. The typical pressure coefficient for a liquid-in-glass thermometer is about O.1 ° C per atmosphere. There are at least four possible sources of pressure that may affect performance in use.

One atmosphere of pressure corresponds to a 76O mm high column of mercury; thus the column of mercury itself is one source of pressure.

Thermometers are usually calibrated in the vertical position so measurements made in the horizontal plane can be in error by several hundredths of a degree.

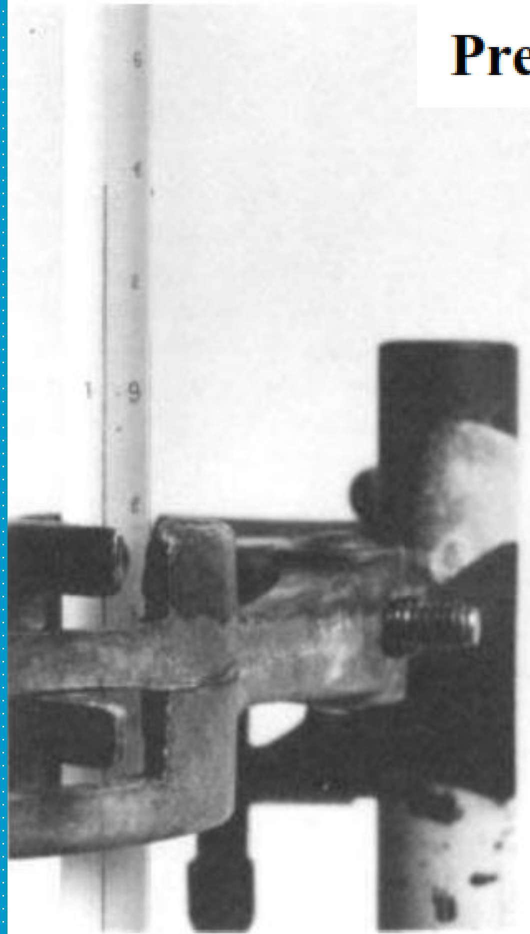
In high-precision thermometers, particularly those near room temperature, the bulbs are very thin making them sensitive to quite small pressure variations.

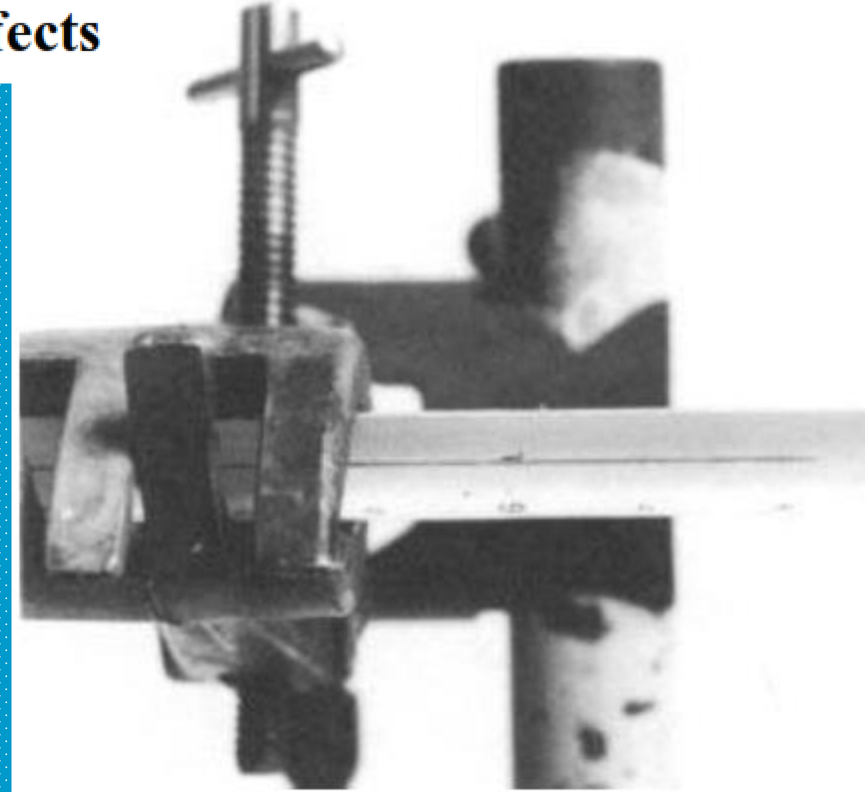
Pressure fluctuations associated with turbulence in a stirred bath are often visible, as are ice point shifts due to large changes in altitude.

Pressure variations may also be due to external mechanical forces, such as caused by resting the thermometer on its bulb or immersion at high pressures.

In fact, this can give rise to long-term problems if mechanical stress is introduced into the bulb. This becomes evident from inexplicable increases in the standard deviations from

Pressure effects





The pressure effect of the mercury column can be quite large for a long ther- mometer. Shown here is a bomb calorimeter thermometer with a mercury column about 400 mm long. The vertical reading at the top (as usual in calibration and use) is 19.374 ° C. The horizontal reading (bottom) is 19.451 ° C. The difference of 0.077 ° C is mostly due to the internal pressure change in the bulb

Bulb hysteresis and drift

A liquid-in-glass thermometer has two moving parts: the thermometric liquid and the glass bulb. The liquid expands and follows temperature changes rapidly, but the glass does not.
The non-crystalline nature of glass means that the most stable atomic arrangement of its constituents varies almost continuously with temperature.

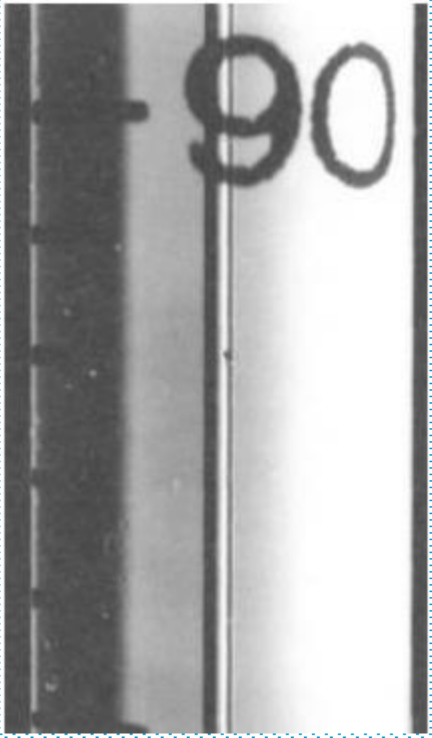
As a result the bulb volume, and hence the thermometer reading, depends on its thermal history. Since an accuracy of 0.05 °C implies reproducibility in bulb volume of better than 1 part in 100 000, this is one of the major sources of error in liquid-in-glass thermometry.

There are two main effects to be considered:
bulb contraction with time and
hysteresis.
A good glass exhibits a hysteresis effect of no more than O.1 °C change for each 1OO °C rise in temperature, or equivalently about O.1% hysteresis.
The hysteresis effect is worst if the thermometer is subject to rapid cooling so the structural change in the glass is 'frozen' in, and can be greatly reduced by cooling the thermometer slowly.

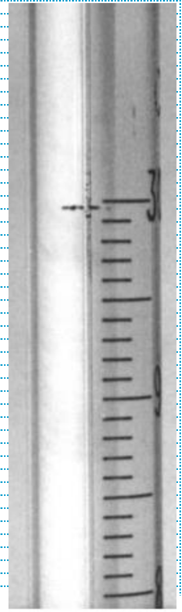
Bore non-uniformity effects

The bore of the capillary must be smooth and uniform, with the cross-sectional area not varying by more than a few per cent for high-precision applications such as with calorimetric thermometers.

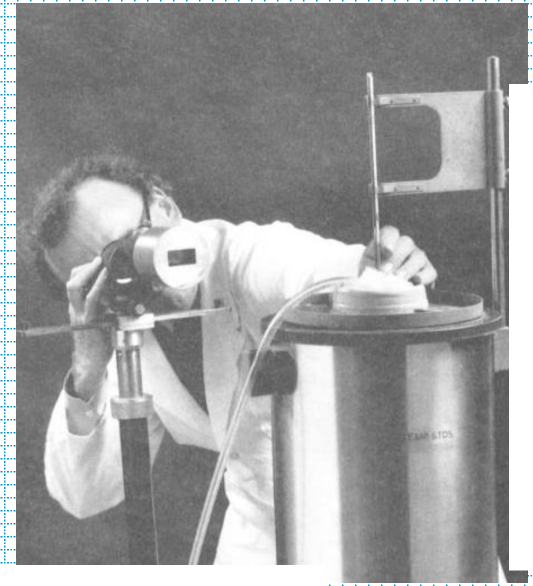
Changes in the bore can be recognised by a change in the length of the column. After manufacture thermometer bore errors cannot be assessed so directly and instead possible errors are controlled by visual inspection. If irregularities in the bore smoothness or uniformity, are noticeable then the thermometer should be discarded.

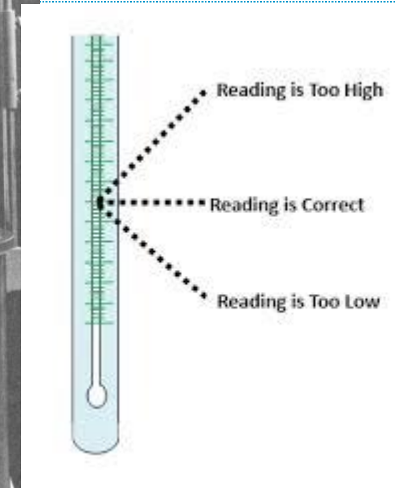


Stiction

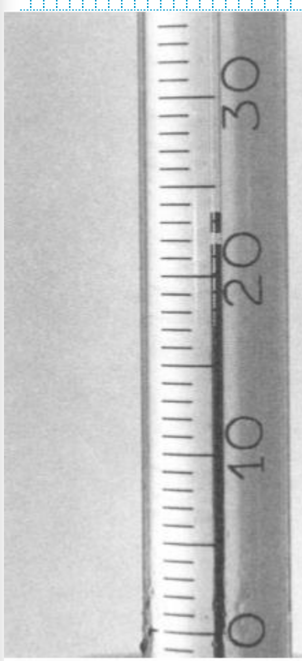


Errors in reading





Separated columns



Immersion errors

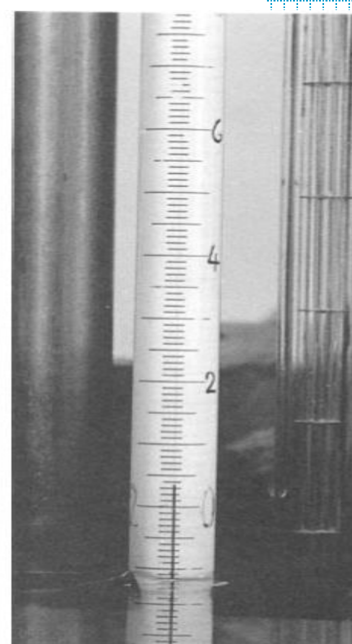
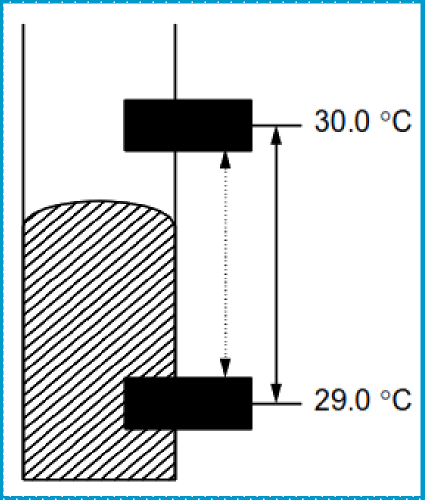
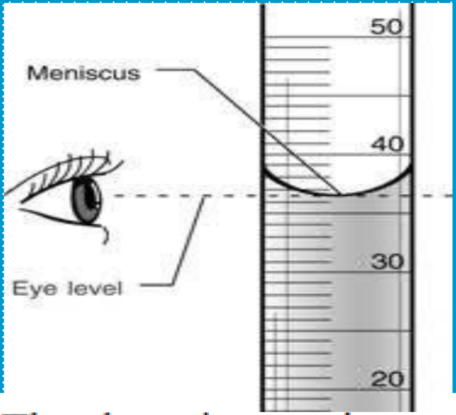
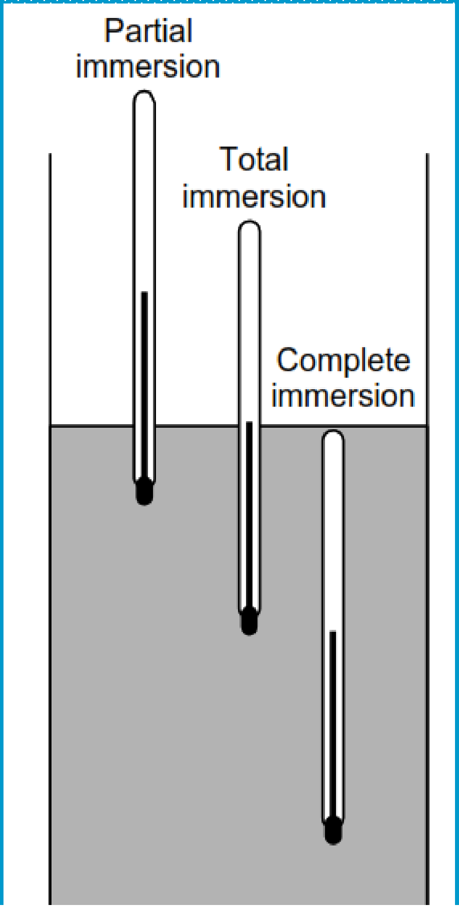


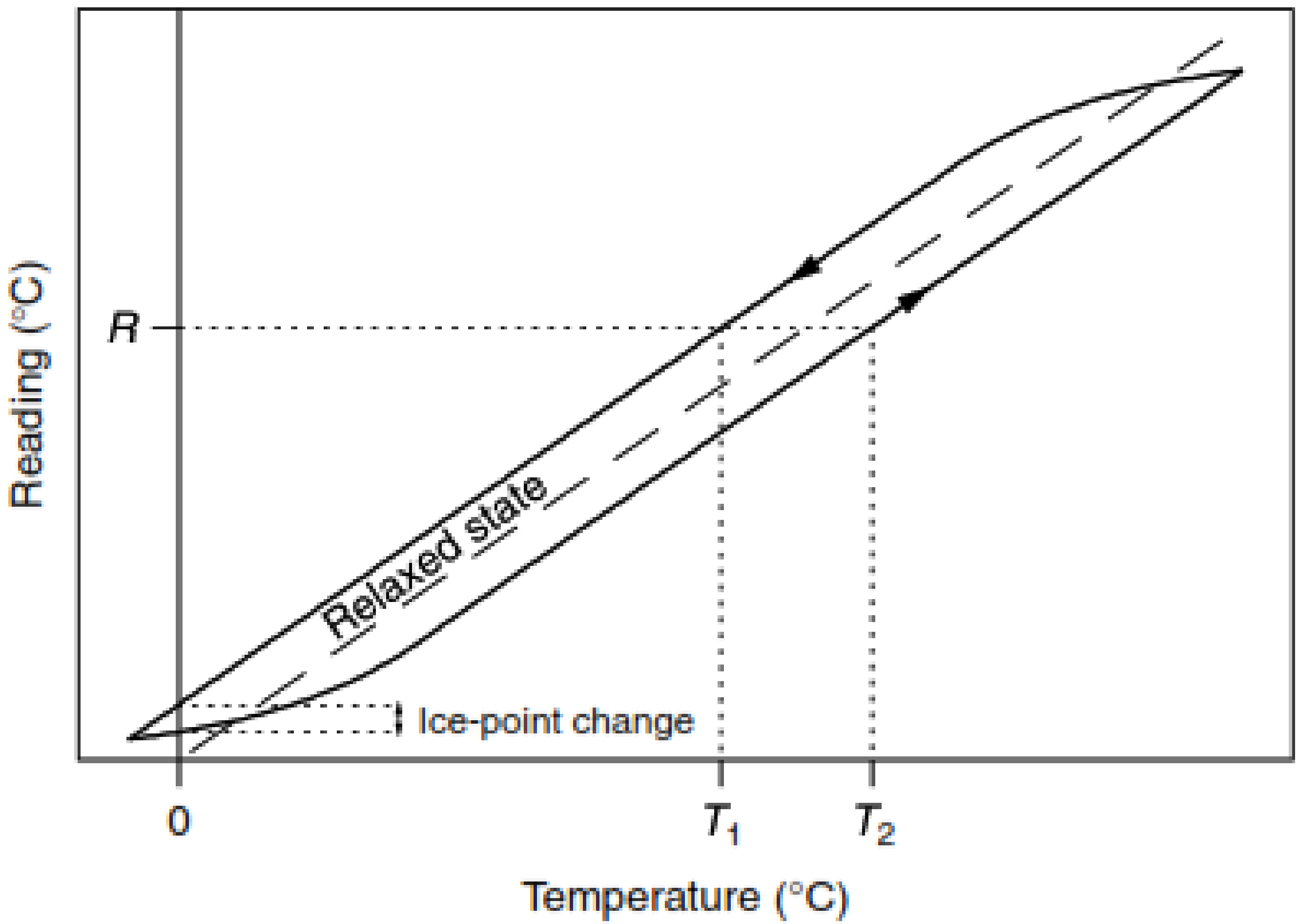
Diagram of a mercury meniscus in a bore and the scale markings. The tendency is for an observer to subdivide the interval between the inside edges of the scale markings (the dotted line). The interval should be divided between the centres of the marks (solid line). In this instance, the first method would give 29.9 °C whereas the correct method gives 29.8 °C

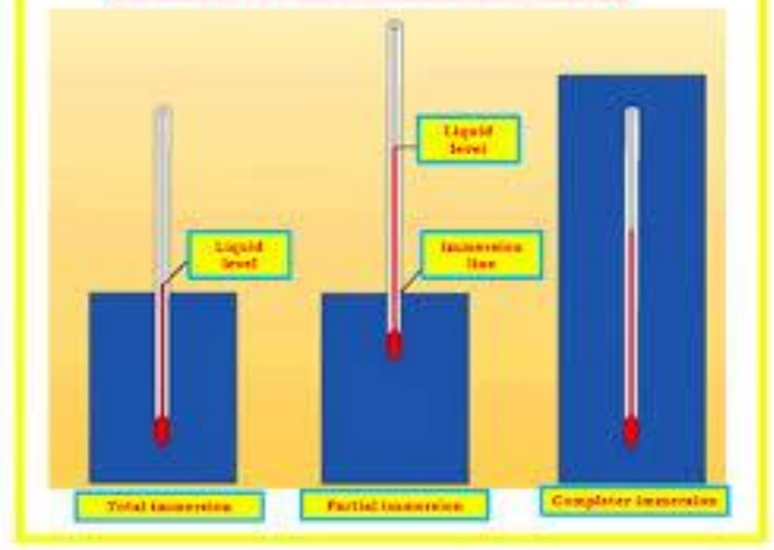






The three immersion conditions used for liquid-in-glass thermometers. The preferred immersion condition is often determined by the application, and for partial-immersion thermometers is usually marked as a line or distance on the stem


Reading (°C)
R
Relaxed state
Ice-point change
0
T_1
T_2
Temperature (°C)



$$t = t_i + N(t_2 - t_1)\kappa,$$

where:

t_i is the indicated temperature;

N is the length of the emergent column expressed in degrees, as determined by the thermometer's scale;

t_2 is the mean temperature of the emergent column when calibrated (i.e. the stem temperature on a certificate for partial immersion or the thermometer reading for a total-immersion certificate);

t_1 is the mean temperature of the emergent column in use;

κ is the coefficient of expansion of the thermometric liquid used, in the glass of which the thermometer stem is made

Liquid	Typical apparent expansion coefficient $(°C)^{-1}$	Possible temperature range
Mercury	0.000 16	−35 °C to 510 °C
Ethanol	0.001 04	−80 °C to 60 °C
Pentane	0.001 45	−200 °C to 30 °C
Toluene	0.001 03	−80 °C to 100 °C

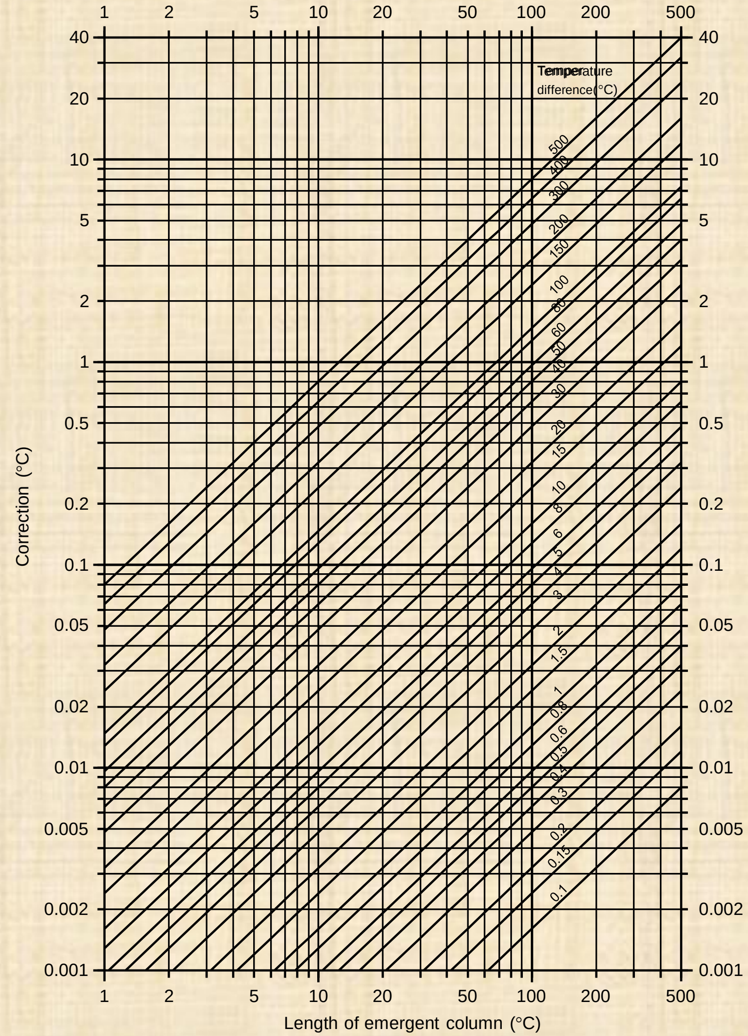
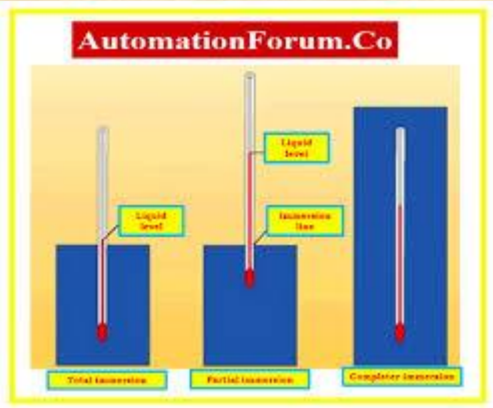
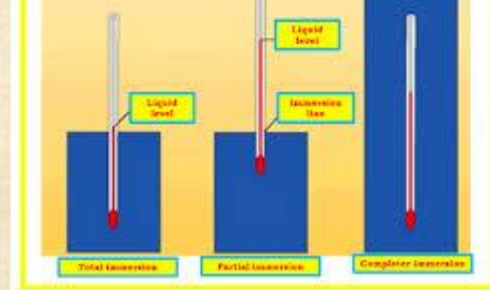


Chart of stem exposure corrections for mercury-in-glass thermometers with $\kappa = 0.00016\ ^{\circ}C^{-1}$





$$t = t_i + N(t_2 - t_1)\kappa,$$

A partial-immersion thermometer indicates a temperature of 200.0 °C after the certificate corrections have been applied. In use, it has an emergent-column length of 100 °C with a mean stem temperature of 70 °C. In calibration it had an emergent-column length of 50 °C and a mean stem temperature of 90 °C. Calculate the true temperature.

Correction to total immersion for calibration

$$\Delta t = 50 \times (200 - 90) \times 1.6 \times 10^{-4}\,^{\circ}\mathrm{C}$$
$$= +0.88\,^{\circ}\mathrm{C}.$$

Correction to total immersion for use

$$\Delta t = 100 \times (200 - 70) \times 1.6 \times 10^{-4}\,^{\circ}\mathrm{C}$$
$$= 2.08\,^{\circ}\mathrm{C}.$$

Since the correction in use is greater than when calibrated the thermometer is reading low. Hence the correction must be positive, that is

$$\Delta t = 2.08 - 0.88 = +1.2\,^{\circ}\mathrm{C}.$$

Hence the true temperature is 201.2 °C.

Scale errors

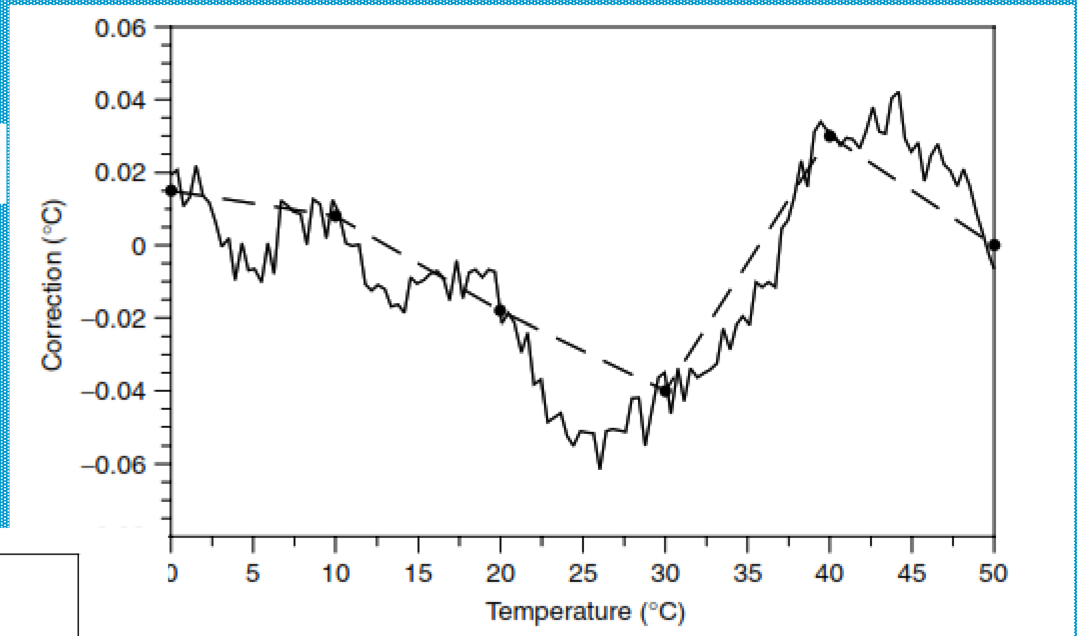
The scale on a liquid-in-glass thermometer serves not only to indicate the temperature but also to linearise the temperature response of the mercury and glass. Errors arising from the placement and ruling of the scale are a major source of uncertainty in liquid-in-glass thermometry and have a significant impact on the design of calibrations. A

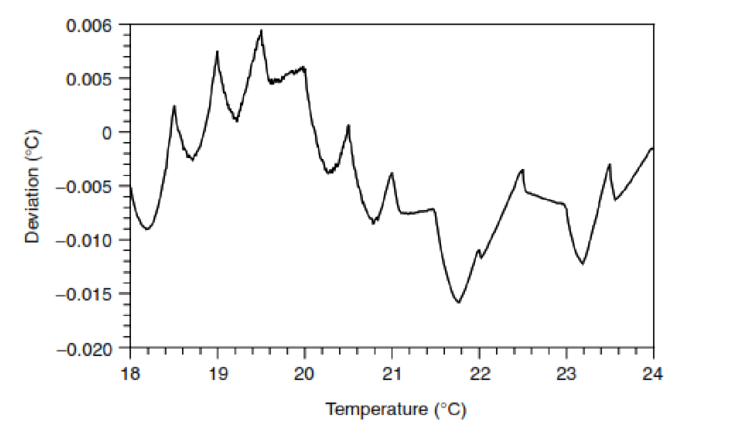
Linearisation errors

Misplacement of pointing marks

Misalignment errors

Ruling errors



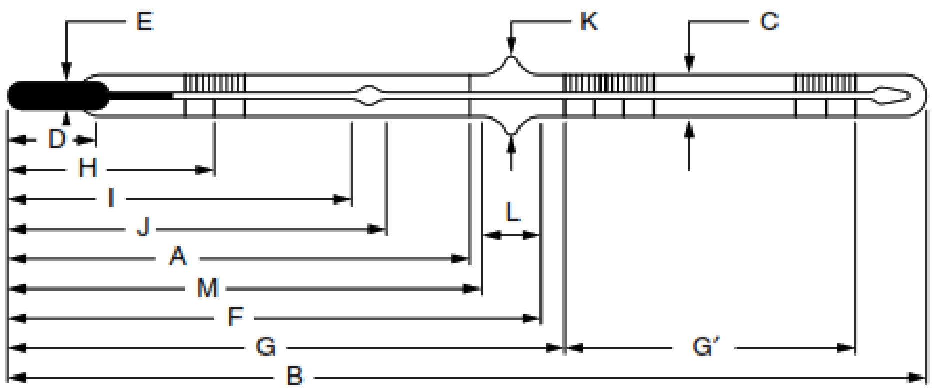


Summary of requirements for ASTM precision thermometers

ASTM thermometer number	Range (°C)	Maximum length (mm)	Graduations (°C)	Maximum error (°C)
62C	−38 to +2	384	0.1	0.1
63C	−8 to +32	384	0.1	0.1
64C	−0.5 to +0.5 and 25 to 55	384	0.1	0.1
65C	−0.5 to +0.5 and 50 to 80	384	0.1	0.1
66C	−0.5 to +0.5 and 75 to 105	384	0.1	0.1
67C	−0.5 to +0.5 and 95 to 155	384	0.2	0.2
68C	−0.5 to +0.5 and 145 to 205	384	0.2	0.2
69C	−0.5 to +0.5 and 195 to 305	384	0.5	0.5
70C	−0.5 to +0.5 and 295 to 405	384	0.5	0.5

Acceptance

Once a thermometer has been received from a supplier, you should subject it to a thorough visual inspection, preferably under magnification up to 20x. Figure gives an example checklist of the main physical dimensions to be checked. In principle, the supplier should have carried out this inspection but unless it was written into the purchase contract, with evidence supplied, then it is unlikely. Suppliers may request a premium for carrying out such an inspection, but the cost will usually repay itself in reducing the time wasted on a bad thermometer and the cost of a calibration.



Thermometer ID:	Type: ______	Name: ______	No: ______

General observations:		Gas bubbles	______
		Globules of liquid	______
		Foreign matter	______
Scale specifications:		Temperature range	______
		Scale divisions	______
		Long lines at	______
		Numerals at	______
		Max scale error	______
	A	Immersion	______
Expansion chamber:		Permits heating to	______
Dimensional specifications:		**(in mm)**	______
	B	Total length	______
	C	Stem outer diameter	______
	D	Bulb length	______
	E	Bulb diameter	______
Scale:	F	Length to bottom of scale	______
	G	Length to top of scale	______
	G′	Scale length	______
Ice point:		Range	______
	H	Bottom of bulb to ice point	______
Contraction chamber:	I	distance to bottom, min	______
	J	Distance to top, max	______
Stem enlargement:	K	Outer diameter	______
	L	Length	______
	M	Distance to bottom	______

The points to watch for are:

- breaks and bubbles in the mercury which may be repairable
- any foreign matter in the capillary;
- distortions in the capillary or scale;
- the presence of fine scale markings, less than one-fifth of a division;
- the scale markings to be at multiples of one, two or five;
- the dimensions to match the specifications;
- the required markings to be on the stem; for example, possible markings include:
    - — temperature scale;
    - — immersion condition;
    - — immersion line;
    - — gas fill or vacuum;
    - — bulb glass;
    - — serial number;
    - — vendor's name;
    - — specification body;
    - — type number.

Calibration

Traditionally calibration procedures for liquid-in-glass thermometers have not used statistical techniques to evaluate the uncertainty of the calibration. Instead, a variety of tests are carried out to verify that the thermometer conforms to the standard specification. There are several reasons for this.

- Some of the tests are necessary because many liquid-in-glass thermometers have highly specific applications that impose dimensional and structural constraints, besides the accuracy of the temperature measurements.
- Other tests were, in effect, the basis of Type B assessments of uncertainty that were used to classify the performance of thermometers.
- At the time, liquid-in-glass thermometers were the most cost-effective way of maintaining temperature scales and some of the practices had developed to obtain the very best performance from them.
- Until relatively recently, there was no universally accepted uncertainty treatment on which to base an alternative approach.

Nowadays, since we have the required uncertainty treatment and PRTs for maintaining the temperature scale, we can adopt a simpler and more systematic approach to the calibration of liquid-in-glass thermometers.

Outline of a liquid-in-glass calibration procedure

Step 1: Start record keeping

Include in the records any information as to why and how this liquid-in-glass thermometer is being used as this may point to documentary standard specifications that the thermometer must satisfy.

Step 2: General visual inspection

Besides checking for any broken glass or loose mercury, examine the column for any breaks. Rejoin any breaks found . Consult with the client if you are likely to risk the integrity of the thermometer in the process of rejoining the column (especially if heating is found to be necessary). Check that the thermometer has a serial number; if not then engrave a suitable number or identifying mark . This will be used to identify the thermometer in the calibration certificate.

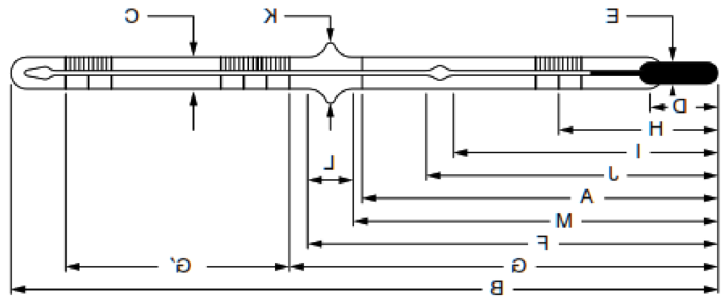
Step 3: Conditioning and adjustment

Adjustments are not possible with the liquid-in-glass thermometers described here.

Thermally cycle any thermometer that is to be used over 300 °C and check for stability at the ice point. Also thermally cycle brand-new thermometers as a small percentage are commonly not annealed properly. This will show as a very unstable ice-point reading. In extreme cases, the ice-point reading may move several scale divisions.

Step 4: Generic checks

Carry out a detailed visual check at 20× magnification. Reject any thermometer with bore or scale irregularities. The scale markings need to be clear and marked according to their documentary standard. Check that the quality is consistent with the client's requirements.



Thermometer ID: Type: ______ Name: ______ No: ______

General observations:		Gas bubbles	______
		Globules of liquid	______
		Foreign matter	______
Scale specifications:		Temperature range	______
		Scale divisions	______
		Long lines at	______
		Numerals at	______
		Max scale error	______
	A	Immersion	______
Expansion chamber:		Permits heating to	______
Dimensional specifications:		**(in mm)**	______
	B	Total length	______
	C	Stem outer diameter	______
	D	Bulb length	______
	E	Bulb diameter	______
Scale:	F	Length to bottom of scale	______
	G	Length to top of scale	______
	G'	Scale length	______
Ice point:		Range	______
	H	Bottom of bulb to ice point	______
Contraction chamber:	I	distance to bottom, min	______
	J	Distance to top, max	______
Stem enlargement:	K	Outer diameter	______
	L	Length	______
	M	Distance to bottom	______

Step 5: The comparison

There are two essential features for a liquid-in-glass comparison:

(1) use increasing temperatures for measurements; and
(2) ensure visual access to the scale.

An overflow bath is ideal for total-immersion thermometers as it allows viewing across the liquid surface and hence a very short emergent column. Otherwise, a window is required to view the thermometer. Provide a means to lower the thermometers physically during the calibration in order to keep the meniscus at the same height as the viewing telescope. A firm clip will be needed to prevent the thermometer dropping into the bath, but not so firm as to stress the glass.

Fix a partial-immersion thermometer so that the telescope can be moved up and down without any blockage in the line of sight. Arrange for a stem-temperature measurement. Alternatively, the partial-immersion thermometer could be calibrated as a total-immersion thermometer and the stem corrections applied later. This can only be done where the 10% uncertainty in the stem correction (Equation (7.2)) will not be the dominant contribution to the total uncertainty.

To keep the *k* factor for the expanded uncertainty low, choose a minimum of six measurements for each calibration point, with the measurements dispersed over plus or minus three scale divisions. For a least-squares fit, a minimum of 12 points distributed evenly over the range of interest is satisfactory. If the number of scale segments on the thermometer can be identified then try to choose a minimum of two points per segment, with points at the end and middle of each segment. If the thermometer has few segments, more points should be chosen.

Step 6: Analysis

Make any necessary corrections arising from the stem temperature not being at its designated value. This may apply to a total-immersion thermometer if the column was too far above the bath liquid.

Step 7: Uncertainty

If a fitting procedure was used, obtain the uncertainty from the standard deviation of the fit (Section 2.12.1). Otherwise, use the standard deviation of the residuals from the calculation of all of the corrections.

The hysteresis uncertainty can be estimated from the change in ice-point values before and after the calibration (see Example 2.10).

Include an assessment of the uncertainty in any immersion corrections (see Example 2.18).

Step 8: Complete records

Decide if the thermometer's performance warrants issue of a calibration certificate. If it does, prepare the certificate. Report the ice-point value on the certificate. The ice point may be on an auxiliary scale and not the main scale.

A table of correction terms can be drawn up for the thermometer.

A completed certificate for the short-range style of calibration is sho

A certificate for the deviation function style will look more like that

CALVIN, DEGRIES AND CO

1 TRACEABILITY PLACE, PO BOX 31-310, LOWER HUTT, NEW ZEALAND
TELEPHONE (64) 4 569 0000 FAX (64) 4 569 0003

CALIBRATION CERTIFICATE

Report No: T92-2001.

Client: ACME Thermometer Co, 100 Celsius Avenue, P O Box 27-315, Wellington, New Zealand.

Description of Thermometer: ASTM 121C kinematic viscosity thermometer divided to 0.05 °C, serial number 2925, manufactured by Zeal.

Date of Calibration: 22 to 23 January 2000.

Method: The thermometer was compared with standard thermometers held by this laboratory. All measurements are traceable to the New Zealand National Standards. The temperature scale used is ITS-90.

Conditions: The thermometer was calibrated in total immersion.

Results:

Thermometer Reading (°C)	Correction (°C)
0 (ice point)	+0.02
100.04	+0.06
101.02	+0.05

Note: Corrections are added to the reading to obtain the true temperature.

Accuracy: The uncertainty in the corrected thermometer readings is ±0.026°C at the 95% confidence level.

Checked:____________________ Signed:____________________

W Thomson R Hooke

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CALVIN, DEGRIES AND CO

1 TRACEABILITY PLACE, PO BOX 31-310, LOWER HUTT, NEW ZEALAND
TELEPHONE (64) 4 569 0000 FAX (64) 4 569 0003

CALIBRATION CERTIFICATE

Report No: T92-2002.

Client: ACME Thermometer Co, 100 Celsius Avenue, P O Box 27-315, Wellington, New Zealand.

Description of Thermometer: An electronic platinum resistance thermometer, model RT200, manufactured by PEL, serial number 001, probe serial number SDL11.

Date of Calibration: 13 to 16 July 2000.

Method: The thermometer was compared with standard thermometers held by this laboratory. All measurements are traceable to the New Zealand National Standards. The temperature scale used is ITS-90.

Conditions: The probe was immersed to a minimum depth of 200 mm.

Results:

Thermometer Reading (°C)	Correction (°C)
−19.60	0.00
−7.46	+0.01
5.05	0.00
17.54	0.00
30.02	0.00
42.50	0.00
54.98	−0.01
67.55	−0.01
80.01	−0.01
92.49	−0.01
104.97	−0.02
117.44	−0.02
129.92	−0.02
142.39	−0.01
154.86	−0.01
167.31	0.00
179.76	+0.01
0 (ice point)	0.00

Note: Corrections are added to the reading to obtain the true temperature.

Accuracy: The uncertainty in the corrected thermometer readings is ±0.013°C at the 95% confidence level.

Checked:__________________ Signed:__________________

W Thomson R Hooke

Further Reading

ASTM in its standards on Temperature Measurement Vol 14.03 includes two standards related to liquid-in-glass thermometers:

E 1-91 *Specification for ASTM Thermometers.*

E 77-89 *Test Method for Inspection and Verification of Liquid-in-Glass Thermometers.*

BSI publishes a series of documentary specifications for thermometers including:

BS 593 *Laboratory Thermometers.*

BS 791 *Thermometers for Bomb Calorimeters.*

BS 1704 *General Thermometers.*

BS 1900 *Secondary Reference Thermometers.*

Calibration practice for liquid-in-glass thermometers is covered in:

J A Wise (September 1988) *Liquid-in-glass thermometer calibration service*, NIST Spec. Publ. 250-23, US Department of commerce.

ISO issues documentary standards related to the liquid-in-glass thermometers:

ISO 386-1977 *Liquid-in-Glass Laboratory Thermometer–Principles of Design, Construction and Use.*

ISO 651-1975 *Solid-Stem Calorimeter Thermometers.*

ISO 653-1980 *Long Solid-Stem Thermometers for Precision Use.*

ISO 654-1980 *Short Solid-Stem Thermometers for Precision Use.*

ISO 1770-1981 *Solid-Stem General Purpose Thermometers.*

R E Bentley (1998) Handbook of Temperature Measurement, Vols 1, 2 and 3, Springer Verlag, Singapore.