1

In this chapter, we will learn about

- temperature and how it is measured
- different types of thermometers
- the Celsius temperature scale

Temperature and Thermometers

1.1 Measuring temperature

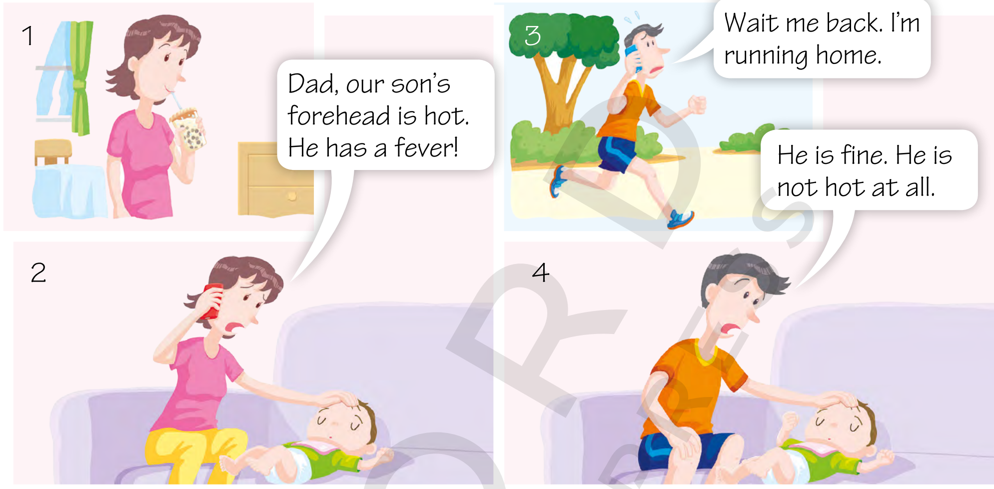


Fig 1.1a *Mum and dad arguing whether the baby has a fever.*

Is our feeling of different degrees of 'hotness' reliable? Why do the mum and dad in the story above have different judgements about whether the baby has a fever (Fig 1.1a)? Refer to the bottom of this page.

Flipped classroom

Watch this and answer the questions.

DSE goal

Realize temperature as the degree of hotness of object.

1 Temperature

Recall the experiment you did in junior science (Fig 1.1b).

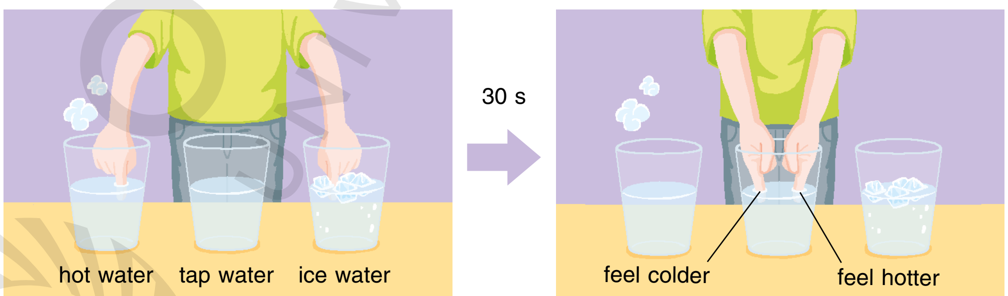


Fig 1.1b *Testing if our feeling of hot and cold is reliable.*

Your two fingers feel different degrees of hotness even if they are immersed in the same beaker of water. This shows that our senses are not reliable for comparing the 'hotness' of objects. Similar problem happens to the mum and dad in the story.

To make an accurate comparison of 'hotness', we need a **thermometer** to measure the **temperature** of objects.

Temperature is a measure of the degree of hotness of an object.

thermometer 溫度計　　temperature 溫度

Figure 1.1c shows the temperatures of various objects over a wide range of temperature in **degree Celsius** (°C), a commonly used unit of temperature. Note that the temperature in °C can be negative.

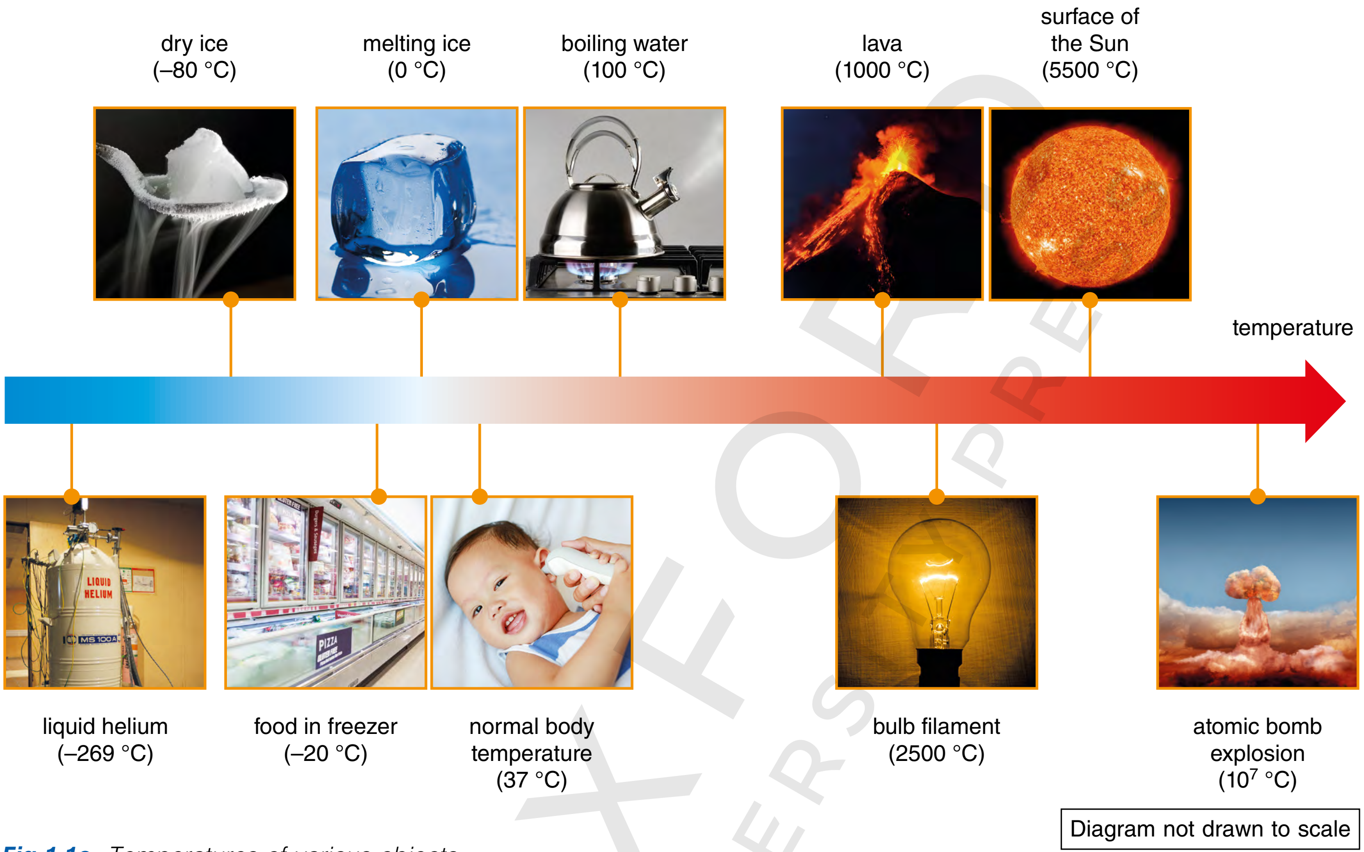


Fig 1.1c *Temperatures of various objects.*

DSE goal

Explain the use of temperature-dependent properties in measuring temperature.

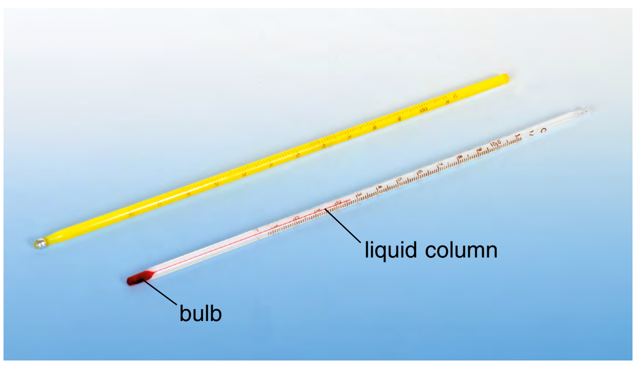
DSE exam

17(1B)Q1(a)

2 Thermometers

There are different types of thermometers (Fig 1.1d). We often use infra-red thermometers for measuring our body temperature. **Liquid-in-glass thermometers** and temperature sensors are commonly used for laboratory experiments.

(i) Infra-red thermometer.



(ii) Liquid-in-glass thermometers.

Fig 1.1d *Some common thermometers.*

degree Celsius (°C) 攝氏度   liquid-in-glass thermometer 玻管液體溫度計

a Temperature-dependent property

Video

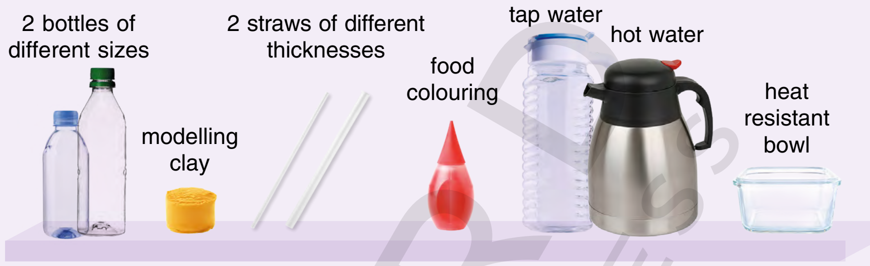
→ This video demonstrates the Hands-on activity.

Hands-on activity

Water-in-straw thermometer

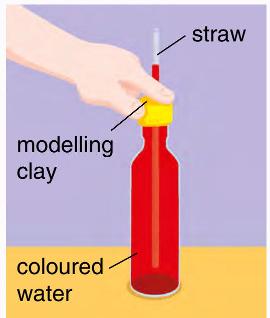
→ Worksheet is available on OUP web.

What you need



What to do

1 Add a few drops of food colouring into water and fully fill the smaller bottle with the coloured water.
2 Insert the lower part of the thicker straw into the bottle. Seal the bottle and fix the position of the straw using modelling clay. Add coloured water slowly into the straw until the water level reaches the middle of the part of straw outside the bottle.
3 Place the bottle in tap water and then in hot water. Observe the change.
4 Repeat with (a) a larger bottle; (b) a narrower straw. Make sure the hot water is at the same temperature each time.



Beware of the hot water.

What you find

1 What happens when the thermometer is placed in hot water?
2 Based on the results, can you suggest some methods to increase the sensitivity of a liquid-in-glass thermometer?

All thermometers make use of some **properties that change with temperature**. These properties are called the **temperature-dependent properties**. The volume of water is an example of temperature-dependent properties as shown by the results in the activity (Fig 1.1e).

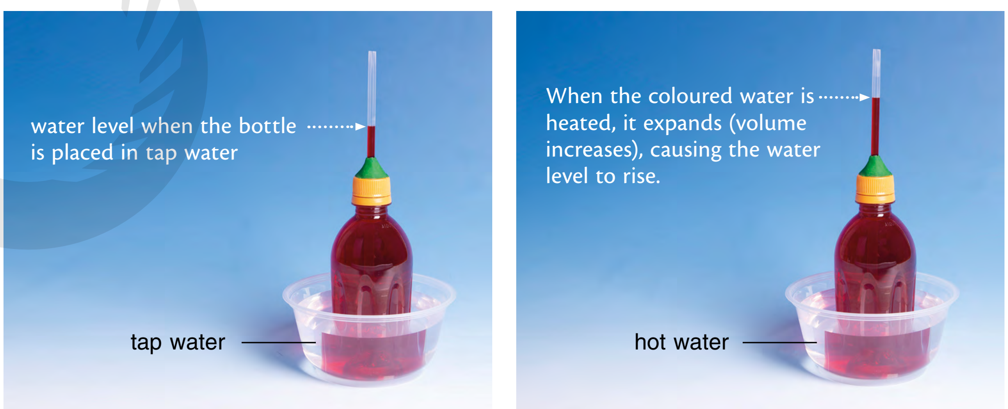


Fig 1.1e *The volume of water changes with temperature.*

temperature-dependent property 與溫度相關的物性

A liquid-in-glass thermometer also makes use of the volume of liquid as the temperature-dependent property. It consists of a bulb connected to a narrow glass tube and a liquid is inside them (Fig 1.1f). As the temperature of the bulb increases, the liquid expands and the liquid level in the tube rises. The corresponding temperature can be read from the scale marked on the tube.

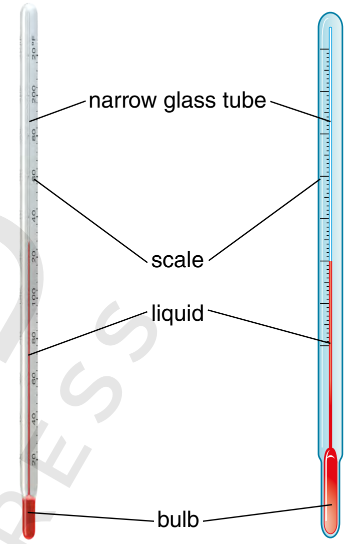


Fig 1.1f *A liquid-in-glass thermometer.*

A liquid-in-glass thermometer is more sensitive if the length of liquid column increases more for the same temperature rise. Thermometers with the following features are more sensitive (Fig 1.1g):

1. Larger bulb
2. Narrower glass tube
3. Containing liquid that expands more when temperature increases

In the activity on p.4, the water level rises more when a larger bottle or a narrower straw is used.

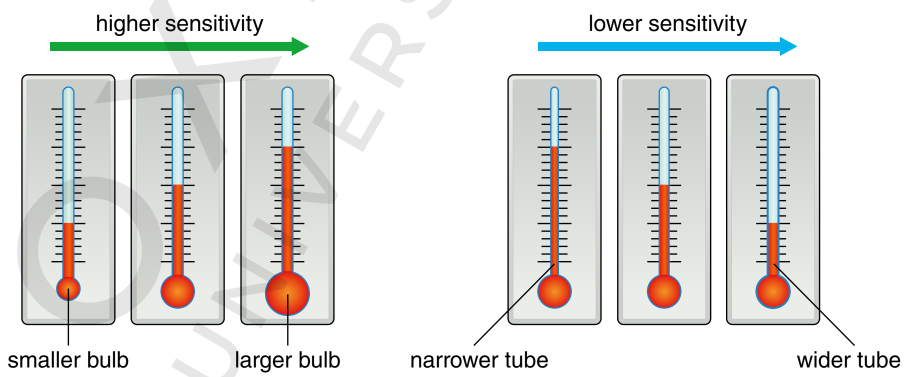


Fig 1.1g *Factors affecting the sensitivity of liquid-in-glass thermometers.*

An alcohol-in-glass thermometer can measure temperature down to –115 °C, the freezing point of alcohol.

A mercury-in-glass thermometer can measure temperature up to 357 °C, the boiling point of mercury.

In school laboratories, alcohol thermometers are preferred to mercury ones. This is because they are less hazardous to deal with when broken.

Know more

Liquid-in-glass thermometers

Liquid-in-glass thermometers are commonly filled with mercury or alcohol. Let us compare these two types of thermometer.

Alcohol-in-glass thermometer	Mercury-in-glass thermometer
Suitable for measuring low temperatures	Suitable for measuring high temperatures
Slow response to temperature changes (as alcohol is a poor conductor of heat)	Quick response to temperature changes (as mercury is a good conductor of heat)
Alcohol is non-poisonous.	Mercury is poisonous.

b Different types of thermometers

Different types of thermometers may use different temperature-dependent properties for measuring temperature. Figure 1.1h shows some examples.

$T\uparrow \Rightarrow$ volume$\uparrow$

Liquid-in-glass thermometer

temperature-dependent property:
volume of liquid

$T\uparrow \Rightarrow$ intensity$\uparrow$

Infra-red thermometer

temperature-dependent property:
intensity of infra-red radiation emitted by the concerned object

Types of thermometer

$T\uparrow \Rightarrow$ electrical resistance$\downarrow$

Thermistor thermometer

temperature-dependent property:
electrical resistance of thermistor

$T\uparrow \Rightarrow$ electrical resistance$\uparrow$

Resistance thermometer

temperature-dependent property:
electrical resistance of metal

Fig 1.1h *Temperature-dependent properties of various types of thermometers.*

thermistor thermometer 熱敏電阻溫度計 resistance thermometer 電阻溫度計

Different types of thermometers are suitable for different uses. For example, some types of thermometers can measure high temperatures, so they are used in ovens, furnaces, etc. Some thermometers have high sensitivity so they are used when precise measurement is required. We need to choose a suitable thermometer based on the purpose of usage.

Connected with an infra-red camera, a smartphone can capture a thermograph.

Know more

Infra-red thermography

Infra-red thermography is now commonly used in immigration checking (Fig a) and medical diagnosis (Fig b). Its working principle is based on the fact that a hotter object emits more infra-red radiation. A thermal camera is used to detect the amount of infra-red radiation emitted from different regions of an object. The result is displayed as different colours on an image, showing the variation of temperature in different regions.

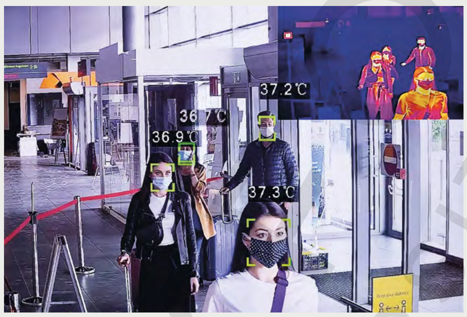


Fig a

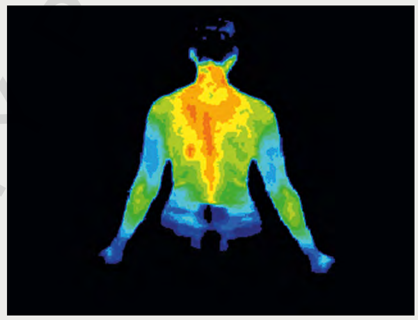


Fig b

Exercise 1.1

1 Determine whether each of the following thermometers makes use of thermal expansion and contraction to measure temperature.

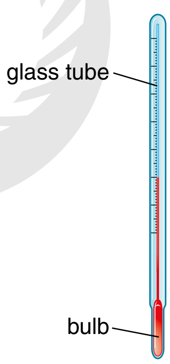
(a) Liquid-in-glass thermometer

(b) Resistance thermometer

2 State how a thermometer can have a higher sensitivity by considering each of the following factors.

(a) Diameter of glass tube

(b) Size of bulb



3 State the temperature-dependent property of each thermometer below.

(a) Infra-red thermometer

(b) Thermistor thermometer

1.2 The Celsius temperature scale

Just like a ruler must have a scale marked on it, a thermometer must work with a temperature scale. The **Celsius temperature scale** is one of today's most commonly used temperature scales.

DSE goal

Define and use degree Celsius as a unit of temperature.

DSE exam

13(1B)Q2(b)(i), 15(1B)Q1(a)

1 Defining a Celsius temperature scale

We need two 'fixed points' to define the Celsius temperature scale.

The ice point and steam point vary with pressure. Normal atmospheric pressure is the atmospheric pressure at sea level.

This can be regarded as the temperature of pure boiling water.

1. **Ice point (lower fixed point for Celsius scale): temperature of pure melting ice at normal atmospheric pressure**
2. **Steam point (upper fixed point for Celsius scale): temperature of steam over pure boiling water at normal atmospheric pressure**

It is necessary to define the temperature scale with 'pure' ice since ice with impurities melts at a different temperature. Similarly, it is necessary to define the scale with 'pure' boiling water.

These two fixed points are chosen because they are stable and can be reproduced easily. The lower fixed point is taken as 0 °C and the upper fixed point is taken as 100 °C (Fig 1.2a). The range between these fixed points is divided into 100 equal divisions. Each division is 1 °C.

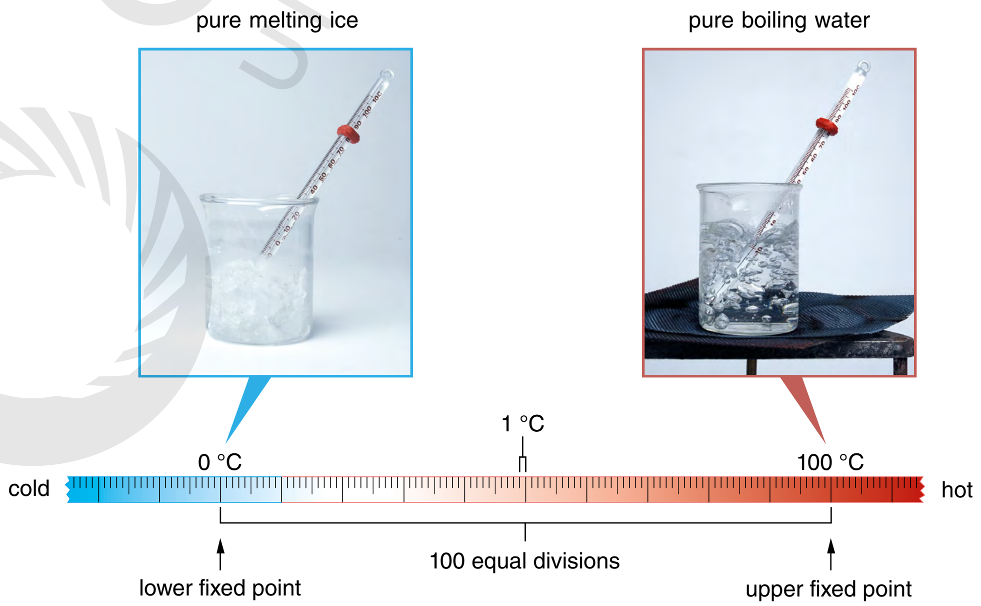


Fig 1.2a *The Celsius temperature scale.*

Celsius temperature scale 攝氏溫標

Know more

Anders Celsius (1701–1744)

The Celsius temperature scale is named after the Swedish scientist *Anders Celsius*. In 1742, he first proposed a temperature scale **with 0 representing the boiling point of water and 100 representing the freezing point**. The scale was originally called centigrade, meaning 100 steps. Later, the scale was reversed and renamed to honour Celsius.

OUP eResources

Know more

Fahrenheit temperature scale

The Fahrenheit scale is another commonly used temperature scale. It is widely used in the United States. It is measured in °F. The conversion between the Fahrenheit temperature (T_F) and the Celsius temperature (T_C) is as follows:

$$T_F = 1.8T_C + 32$$

There is the third temperature scale called Kelvin temperature scale. You will learn about it in Chapter 5.

Ts may tell Ss that the Kelvin temperature scale is widely used in physics. It is defined by a single fixed point, the triple point of water: The kelvin, unit of thermodynamic temperature, is the fraction $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water.

Google Forms Microsoft Forms

Quick check 1

→ E-version in OUP Exercise Platform is also available.

1 Which of the following are the fixed points on the Celsius temperature scale? Put a tick in the corresponding boxes.

☐ Steam point
☐ Boiling point
☐ Ice point
☐ Melting point

2 Which of the following is the upper fixed point on the Celsius temperature scale?

A The temperature of pure melting ice
B The temperature of pure boiling ice
C The temperature of pure melting water
D The temperature of pure boiling water

3 Which of the following statements about the Celsius temperature scale is/are correct? Put a tick in the corresponding box(es).

☐ The lower fixed point is 0 °C and the upper fixed point is 100 °C.
☐ The range between the lower fixed point and the upper fixed point is divided into 100 equal divisions. Each division is called 1 °C.
☐ It is the only temperature scale available.
☐ Temperatures can fall below 0 °C or rise above 100 °C.

Anders Celsius 攝爾修斯

2 Calibrating a thermometer

✎ Ts may compare the calibration of a thermometer to the calibration of a ruler.

We now have a defined scale (the Celsius scale) of temperature, but how can we **calibrate** an unmarked thermometer (i.e. to mark a scale on it)? The following shows the steps of calibrating a liquid-in-glass thermometer.

Simulation
Video

→ This simulation is a 'virtual expt' of the calibration of a liquid-in-glass thermometer.

→ This video demonstrates the calibration of a thermometer.

1 Put an unmarked liquid-in-glass thermometer in a beaker of pure melting ice (Fig 1.2b). Mark the liquid level.

2 Repeat step 1 with pure boiling water (Fig 1.2c).

3 Divide the length between two markings into 100 equal divisions.

The thermometer is now a calibrated thermometer with each division representing 1 °C.

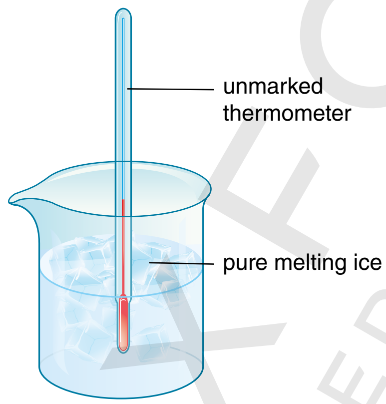


Fig 1.2b Producing the marking for ice point.

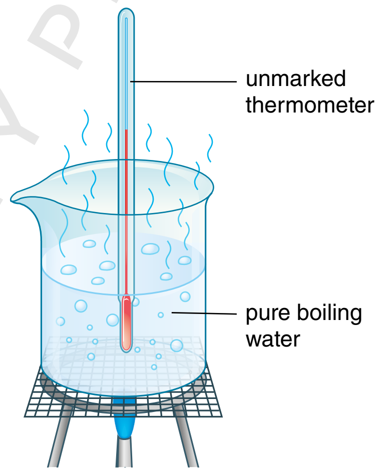


Fig 1.2c Producing the marking for steam point.

→ This is a Video Quiz about the experiment 'Calibrating a thermometer'.

If the length of the liquid column L varies linearly with temperature T, we can draw a straight line through the two fixed points in the L–T graph and obtain the calibration graph of the thermometer. The temperature of an object can then be determined by noting its length of liquid column in this graph (Fig 1.2d).

✎ Ts should point out that the same method applies to other thermometers by simply replacing the length of liquid column with values of the property which changes with temperature.

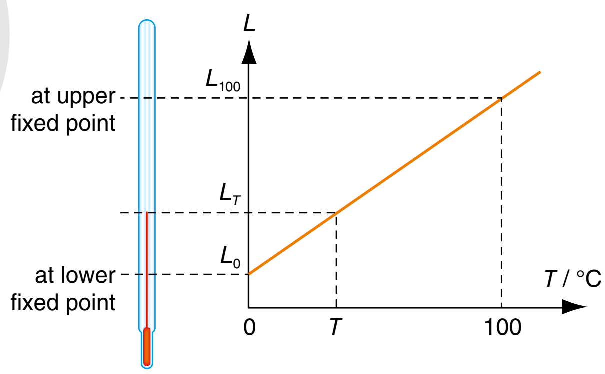


Fig 1.2d Calibration graph of a liquid-in-glass thermometer.

calibrate 校準

Skill
Graph

Elements of a graph

After plotting a graph, always check if:

1. Both axes have labels and units;
2. Data points and scale are correct;
3. A correct line is drawn through the points.

→ Teaching notes and exercises are available on OUP web.

Example 1 Finding temperature from a calibration graph

The liquid column in an unmarked liquid-in-glass thermometer has different lengths L at different temperatures T.

Position of temperature bulb	T / °C	L / cm
In melting ice	0	5.0
In boiling water	100	25.0

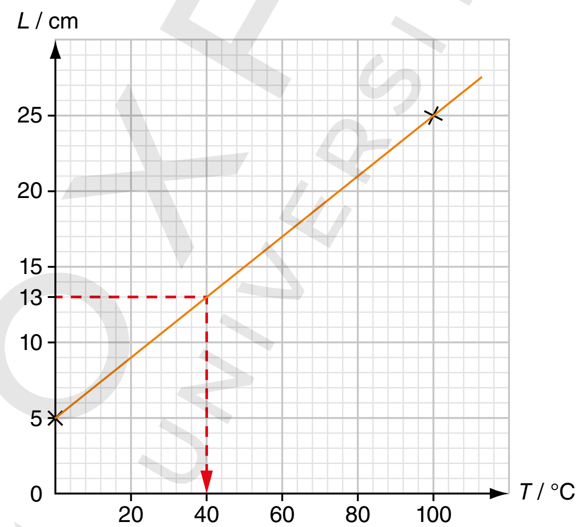
Assume L varies linearly with T. When the thermometer is put into warm water, L becomes 13.0 cm.

(a) Find the temperature of the warm water by drawing a graph of L against T.

(b) Find the temperature of the warm water by using proportion.

Solution

(a)



From the graph, the temperature of the warm water is 40 °C when L is 13.0 cm.

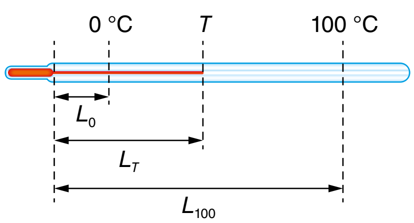
(b) Let T °C be the temperature of the warm water.

By proportion,

$$\frac{L_T - L_0}{L_{100} - L_0} = \frac{T - 0}{100 - 0}$$

$$\frac{13.0 - 5.0}{25.0 - 5.0} = \frac{T}{100}$$

$$T = 40 \text{ °C}$$



The temperature of the warm water is 40 °C.

Tip

Each 'temperature' on the right-hand side corresponds to the 'length' at the same position in the expression on the left-hand side:

$T \rightarrow L_T$

$0 \rightarrow L_0$

$100 \rightarrow L_{100}$

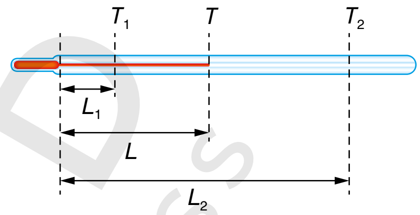
Google Forms Microsoft Forms

Quick check 2

→ E-version in OUP Exercise Platform is also available.

1 The length of liquid column in the figure varies linearly with the temperature. Complete the following table by using proportion.

	T_1 / °C	T_2 / °C	T / °C	L_1 / cm	L_2 / cm	L / cm
(a)	0	100		3.7	24.6	12.0
(b)	0	100	65	3.2	18.2	
(c)	0	80		6	21	12



[Hint: When the two temperatures given are not the two fixed points, the method of proportion can still be used.]

Learn by practice 1

1 The liquid column in an unmarked liquid-in-glass thermometer has different lengths when the temperature bulb is put at different places (Table a). Assume L varies linearly with T.

Position of temperature bulb	In 'pure' melting ice	In 'pure' boiling water
Temperature T / °C	0	100
Length of liquid column L / cm	5.0	30.0

Table a

(a) Draw a calibration graph in Figure a.

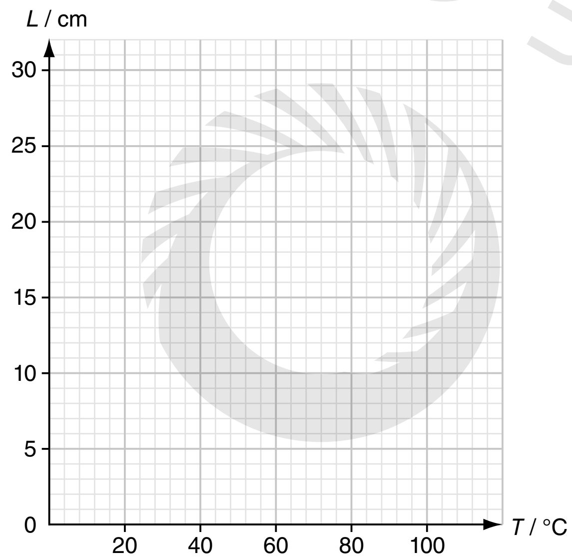


Fig a

(b) When the thermometer is put into warm water, L becomes 21.0 cm. What is the temperature of the warm water?

(c) What is the length of the liquid column if the thermometer is put into water at 12 °C?

2 When a resistance thermometer is put in pure melting ice and pure boiling water, the resistances are 100 Ω and 140 Ω respectively. Assume resistance R varies linearly with temperature T.

(a) Draw a calibration graph in Figure b.

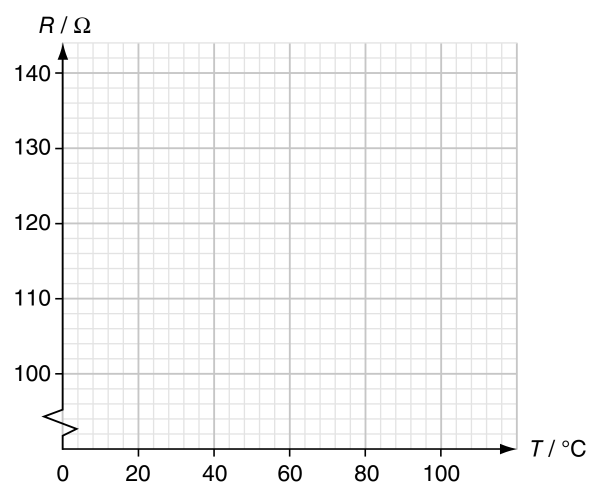


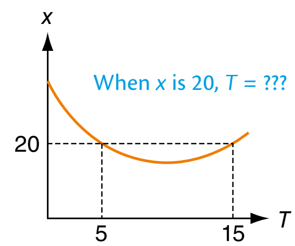
Fig b

(b) What temperature does the thermometer read when the resistance is 124 Ω?

(c) What is the resistance if the thermometer is in a room at 30 °C?

Other types of thermometers can also be calibrated in similar ways. However, some temperature-dependent properties may not vary linearly with temperature. The following gives an example.

Though a temperature-dependent property may not vary linearly with temperature, it should not show the same value at different temperatures. As shown below, when $x = 20$, T can be 5 or 15.



Example 2 Calibration graph of a resistance thermometer

Ginny calibrates a platinum resistance thermometer (Fig a). She measures its resistance at 0 °C and 100 °C and plots a calibration graph (solid line in Fig b). R represents the resistance and θ represents the temperature.

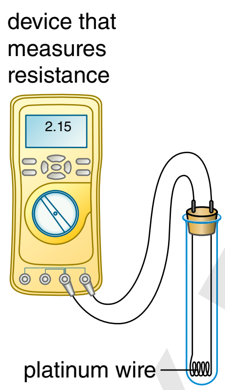


Fig a

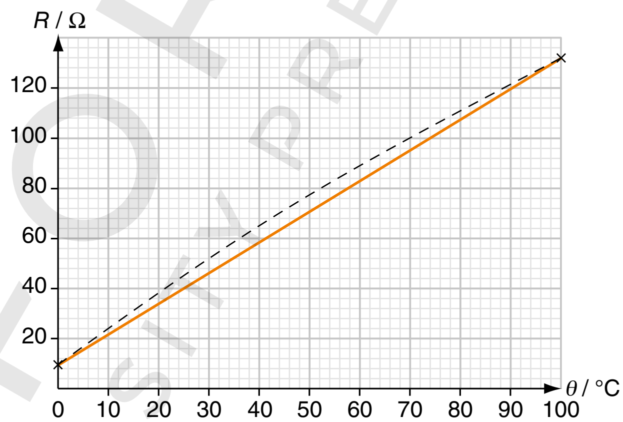


Fig b

(a) Describe how the calibration graph is obtained by an experiment.

(b) What assumption does Ginny make in constructing the calibration graph?

(c) Actually, the resistance of the platinum wire varies with temperature in the way shown by the dotted line in Figure b. If the thermometer reads 48 °C according to the calibration graph, what is the actual temperature?

Solution

(a) Place the platinum wire into a beaker of pure melting ice and record the resistance measured. Repeat with pure boiling water. Then plot a graph of resistance against temperature and draw a straight line passing through the two data points.

(b) The resistance of the platinum wire varies linearly with temperature.

(c) From the calibration graph, $\theta = 48$ °C corresponds to $R = 68\ \Omega$.

From the dotted-line graph, when $R = 68\ \Omega$, $\theta = 42$ °C in the actual situation.

Tip

The calibration graph matches each R with an estimated value of θ.

Tip

The dotted-line graph matches each R with the actual value of θ.

Exercise 1.2

★**1** Why do we **not** use our body temperature as a fixed point on the Celsius temperature scale?

(1) It is not stable.

(2) It varies from person to person.

(3) It is not easily reproducible.

A (1) only

B (2) only

C (1) and (2) only

D (2) and (3) only

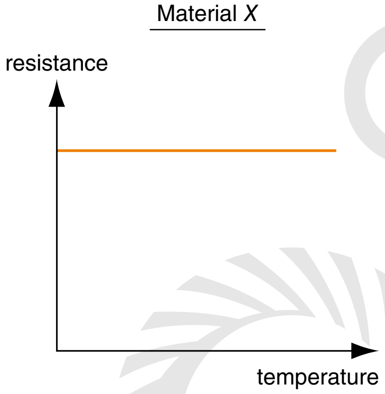
★**2** Describe how a liquid-in-glass thermometer is calibrated.

★**3** (a) Define the ice point and the steam point.

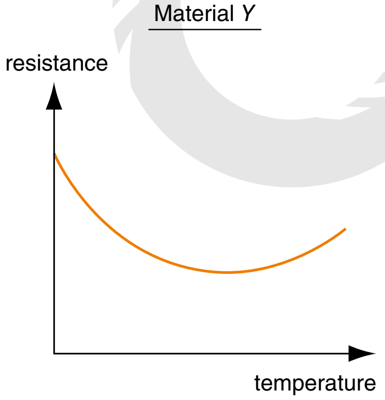
(b) Why are ice point and steam point chosen to be the fixed points on the Celsius temperature scale? Suggest one reason.

★**4** The graphs below show how the resistances of some materials change with temperature. Explain why each material is not suitable for making a resistance thermometer for measuring temperature within the temperature range shown in the graph.

(a)



(b)



★**5** Figure a shows the calibration graph of a mercury-in-glass thermometer. L represents the length of mercury column and T represents temperature.

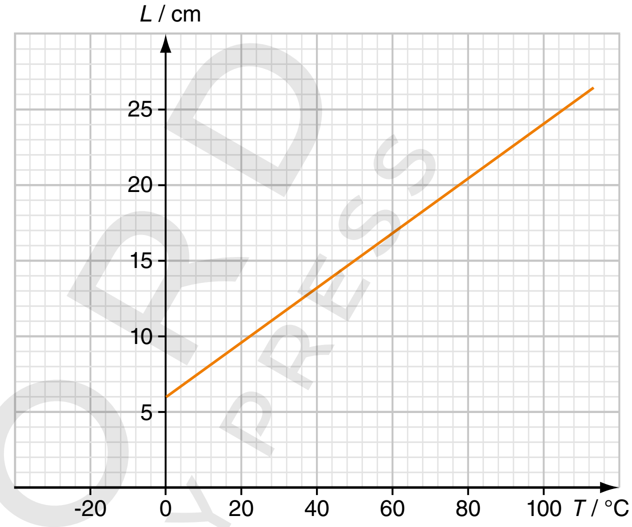


Fig a

(a) If the length of the mercury column is 16 cm, what is the temperature?

(b) Assume L varies linearly with T even when T is negative. What is the length of the mercury column if the temperature is −10 °C?

★**6** X and Y are two liquid-in-glass thermometers. Figure b shows how the lengths of the liquid columns L of the two thermometers change with temperature T. X (represented by black line) shows a linear relationship between L and T but Y (represented by orange line) does not.

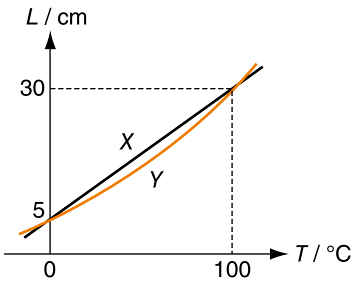


Fig b

(a) When X is put into an object, L is 25 cm. Find the temperature of the object.

(b) When Y is put into another object, L is also 25 cm. Would this object's temperature higher than, lower than or equal to the value found in (a)?

Key concepts 1

1 Temperature

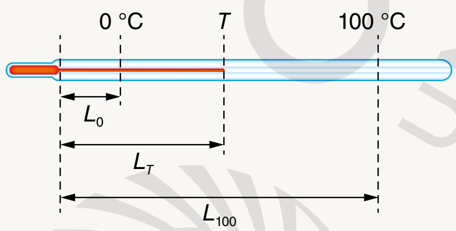
- A measure of the degree of hotness of an object

2 Thermometer

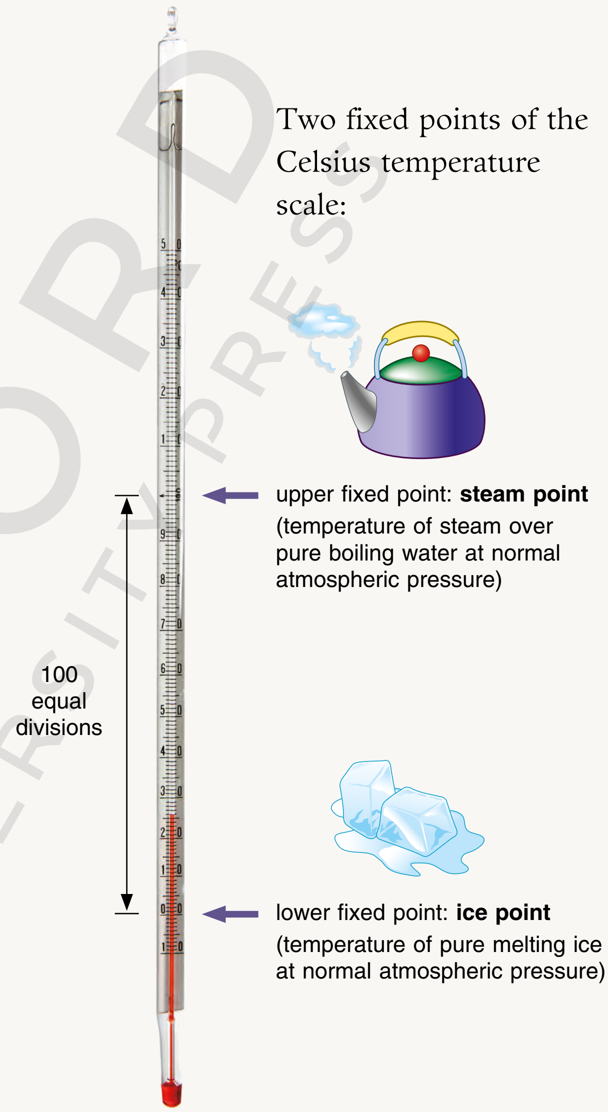
- Makes use of a **temperature-dependent property** in measuring temperature

3 Calibration of thermometers

- Calibration graph
- Calculation: $\dfrac{L_T - L_0}{L_{100} - L_0} = \dfrac{T - 0}{100 - 0}$



Two fixed points of the Celsius temperature scale:



Key terms

Revision 1

Multiple-choice questions

1.2 **1** Which of the following correctly describes the lower fixed point on the Celsius temperature scale?

A The temperature of pure melting ice

B The temperature of ice in freezer

C The temperature of steam

D The temperature of pure boiling water

1.2 **2** Which of the following is **not** a step to calibrate a liquid-in-glass thermometer on the Celsius temperature scale?

A Put the thermometer in pure melting ice.

B Heat the thermometer with a Bunsen flame.

C Mark the liquid level at the upper fixed point.

D Divide the range between the upper and lower fixed points into 100 equal parts.

★**3** Which of the following properties is the **least**
1.1 likely to be used to make a thermometer?

A Size

B Colour

C Mass

D Ability to conduct electricity

★**4** The graph below shows how the length L of a
1.2 liquid column of a liquid-in-glass thermometer varies with temperature T (Fig a).

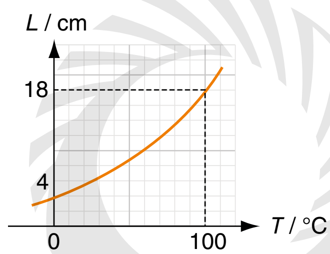


Fig a

Which of the following statements is/are correct?

(1) L does not change linearly with T within this temperature range.

(2) L is less than 11 cm when T is 50 °C.

(3) T is lower than 14.3 °C when L is 6 cm.

A (1) only

B (1) and (2) only

C (2) and (3) only

D (1), (2) and (3)

★★**5** A thermometer is calibrated incorrectly. The
1.2 thermometer with a uniform scale reads 10 °C and 90 °C when it is placed in melting ice and steam over boiling water respectively. What should the true temperature be if the thermometer reads 40 °C? Assume the length of the liquid column varies linearly with temperature.

A 27.5 °C

B 32 °C

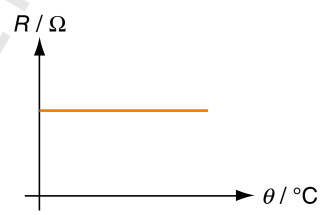
C 37.5 °C

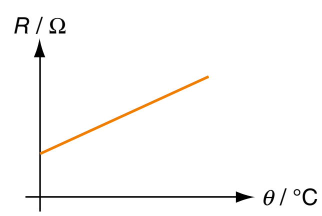
D 40 °C

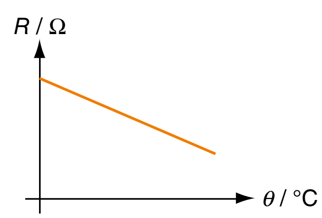
Refer p.11

1.2 **6** **HKDSE Practice Paper 2012 Paper 1A Q1**

The graphs below show how the electrical resistances R of three different circuit elements change with temperature θ. Which of the circuit elements can be used to measure temperature?

(1)


(2)


(3)


A (1) only

B (2) only

C (1) and (3) only

D (2) and (3) only

Conventional questions

★7 Misc Winnie wants to measure the temperature of warm water with a resistance thermometer. Before the measurement, she puts the thermometer in a bowl of pure melting ice for calibration (Fig b).

Fig b

(a) State one precaution during calibration. (1 mark)

(b) Which property does the resistance thermometer make use of to measure temperature? How does this property change with temperature? (2 marks)

★8 1.1 A thermometer using infra-red thermography is installed in a commercial buildings to check visitors' body temperatures (Fig c). The thermometer takes the images of visitors with a camera and their images are shown on a monitor as colour patches. Different colours indicate different intensities of infra-red radiation emitted by the visitors.

Fig c

(a) Which temperature-dependent property does the thermometer use? How does this property change with temperature? (2 marks)

(b) Suggest two benefits in using the infra-red thermometer to measure visitors' body temperature during a pandemic. (2 marks)

★9 1.2 X is a resistance thermometer. Figure d shows how its resistance R change with temperature T.

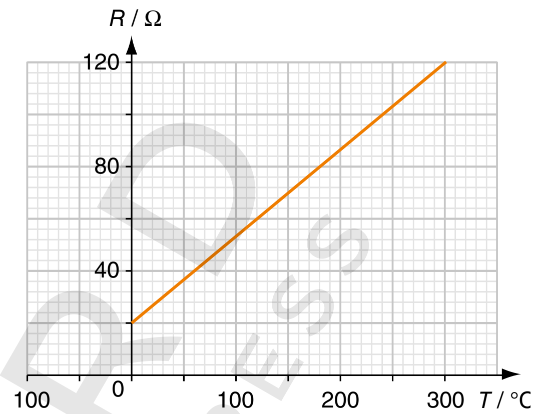


Fig d

(a) Find the temperature when R = 80 Ω. (1 mark)

(b) Calculate the resistance when the temperature is −30 °C. Assume R varies linearly with T even when T is negative. (2 marks)

(c) Y is another resistance thermometer. Figure e shows how its resistance R change with temperature T.

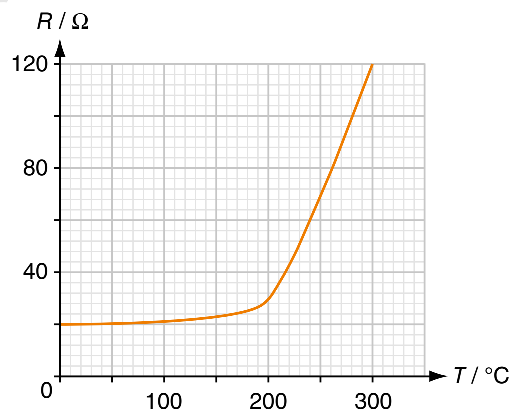


Fig e

State a disadvantage of Y compared with X in measuring temperature. (1 mark)

★10 1.2 Samuel makes his own thermistor thermometer. He calibrates his thermometer and obtains the following results (Table a). The resistance R of thermistor decreases as temperature T increases.

T / °C	0	100
R / Ω	116	20

Table a

Q12 Exam Report: This question tested the variation of resistance with temperature using a resistance thermometer, assuming a linear resistance-temperature relationship. Parts (a) and (b) were in general well answered.

(a) Describe briefly how Samuel obtains 0 °C and 100 °C during calibration. (2 marks)

(b) Assume R and T are in a linear relationship. Find the temperature if a resistance of 92 Ω is measured. (2 marks)

(c) Samuel collects more data points at different temperatures and plots a graph of R against T as shown (Fig f).

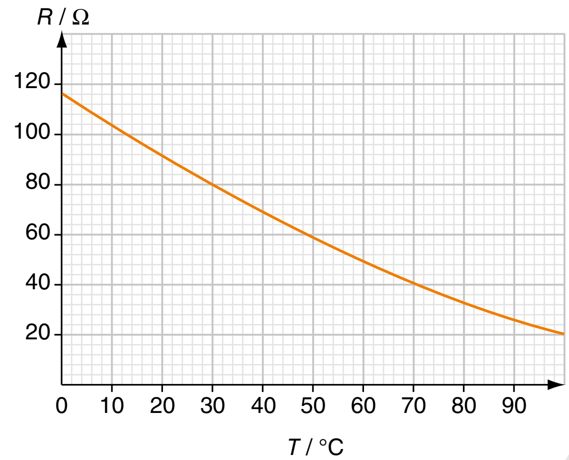


Fig f

Find the actual temperature if a resistance of 92 Ω is measured. (1 mark)

11 Misc

Figure g shows the relationship between the volume and the temperature of mercury in a mercury-in-glass thermometer.

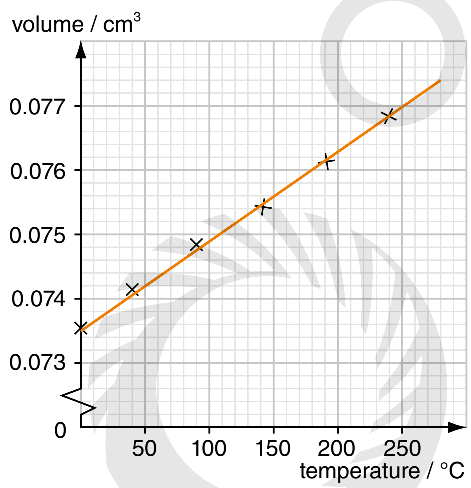


Fig g

When the thermometer is put in pure melting ice, the length of the mercury column is 3.6 cm. The cross-sectional area of the column is 0.01 mm^2. The thermometer is then put into pure boiling water.

(a) Using the graph above, find the change in volume of the mercury. (1 mark)

(b) Hence, find the final length of the mercury column. (2 marks)

(c) How does the cross-sectional area of the mercury column affect the sensitivity of the thermometer? Explain your answer. (2 marks)

Refer p.5, 11

1.2 **12** **HKDSE 2015 Paper 1B Q1(a)**

The solid curve in Figure h shows how the resistance of a metallic resistance thermometer varies with temperature. This thermometer is calibrated at standard atmospheric pressure for the melting point of ice and the steam point of boiling water. The dotted calibration line represents how the resistance of the thermometer varies with temperature if a linear resistance-temperature relationship is assumed. The deviation of the curve from linearity has been exaggerated in the figure.

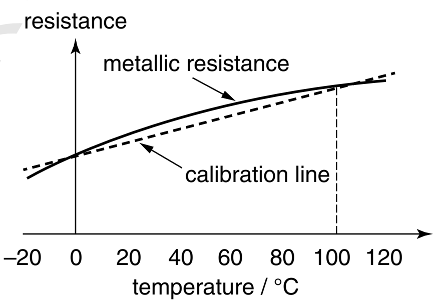


Fig h

(a) Using the resistances at the calibration points tabulated below (Table b), calculate the expected resistance at 60 °C if the resistance varies linearly with temperature. (2 marks)

Temperature / °C	Resistance / Ω
0	102.00
100	140.51

Table b

(b) Now if the resistance of the resistance thermometer is the value found in (a), is the actual temperature higher than, lower than or equal to 60 °C? (1 mark)