Physics

Year 1

SECTION

3

THERMOMETERS AND TEMPERATURE

ENERGY

Heat

INTRODUCTION

Welcome to this section where we will explore the types of thermometers and thermometric substances.

Thermometers are devices used to measure temperature. They are widely used in various fields, including scientific research, medicine, meteorology, cooking, and industrial applications. They rely on the principles of thermal expansion and contraction exhibited by specific substances called thermometric substances which allows us to make temperature measurements due to physical changes in these substances, temperature readings can be obtained accurately. Thermometric substances possess unique characteristics and features that make them suitable for temperature measurement. Different types of thermometers employ specific thermometric substances, each with its own advantages and limitations. Understanding the properties of these substances and the associated features of various types of thermometer is crucial for selecting the most appropriate instrument for a given purpose. In this discussion, you will have a comprehensive understanding of the thermometric substances used in thermometers and the factors to consider when choosing the right thermometer for your needs.

You will learn later in the section that thermometric substances exhibit different degrees of sensitivity to temperature changes, making them suitable for specific temperature ranges. By studying different thermometers, you will develop the skill of observation and description, identifying the physical features and functioning of each type, and measuring temperatures using each type. In this section you will learn about how these scales were created and what they are based on (for example, the Celsius scale is based on the freezing and boiling points of water). You will also learn how to convert between the three scales, a skill which can be useful when presenting information about temperature in different fields and applications.

At the end of this section, you should be able to;

- Explain thermometric substances and their associated characteristics.
- Describe the features and uses of different types of thermometers.
- Describe the various temperature scales and the construction of their corresponding thermometers.
- Derive the relationship between the Celsius, Fahrenheit and the Kelvin scales.

Key Ideas

- Thermometric substances are materials that exhibit changes in their physical properties in response to temperature variations. They possess certain characteristics that make them suitable for temperature measurement.
- Various types of thermometers have been developed to cater for different temperature measurement requirements.
- A temperature scale is a system used to measure and quantify the degree of hotness or coldness of an object or environment.
- Not all thermometers use the same temperature scale. The temperature scale used by a thermometer depends on the design and intended application of the instrument.
- The three main temperature scales used in thermometers: Celsius (°C), Fahrenheit (°F), and Kelvin (K) scales.
- Celsius to Fahrenheit conversion is given by the formula $°F = (\frac{9}{5} \times °C) + 32$.
- Celsius to Kelvin conversion is given by $K = °C + 273.15$ and Fahrenheit to Kelvin: $K = (°F + 459.67) \times$ [Equation]

THERMOMETRIC SUBSTANCES

Thermometric substances are materials that exhibit changes in their physical properties in response to temperature variations.

Examples of common thermometric substances include mercury, alcohol, bimetallic strips, etc. When these substances are subjected to temperature changes, they change their physical properties such as expansion, contraction, change in electrical resistance, or change in thermal conductivity. These changes are then measured and connected with temperature readings.

The selection of a specific thermometric substance depends on factors such as temperature range, accuracy requirements, response time and the application in which temperature measurement is needed.

Characteristics of Thermometric Substances

1. **Thermal Expansion Coefficient:** High coefficient allows significant expansion/contraction with temperature changes, enabling temperature measurement.
2. **Temperature Range:** Effective within specific ranges; some substances measure a wide range; others are limited to specific temperatures.
3. **Sensitivity:** Responsiveness to temperature changes; higher sensitivity means larger property changes for a given temperature difference, important for precise measurements.
4. **Repeatability**: Consistent and reliable response to temperature changes, ensuring reliable readings under repeated conditions.
5. **Stability:** Ability to maintain physical properties over time, ensuring accuracy and reliability with minimal degradation or drift.
6. **Accuracy:** Ability to closely measure actual temperature; requires calibration and proper handling to maintain precision.
7. **Compatibility:** Suitability with the measurement environment or system, including chemical resistance and stability under operating conditions.

Activity 3.1 Investigating heat conduction

1. Obtain a metal spoon and a wooden spoon.
2. Attach the shea butter to the ends of the spoons as demonstrated below.

3. Place the ends of the spoons in a container of hot water.
4. Observe what happens after a few minutes.
5. Share your observation with a friend.

Fig 3.1 Different spoons with shea butter on the handle in hot water

a. Why does the metal spoon become hot faster than the wooden spoon when placed in hot water?
b. Explain the properties of the metal and wooden spoon that led to this difference in heat conduction.
c. How would the heat conduction properties of the metal and wooden spoon affect their use in everyday kitchen tasks

Activity 3.2 Thermometric substances (mercury, alcohol, and water) and their response to temperature

Materials needed:

- Three small glass jars with lids
- Mercury thermometer
- Alcohol thermometer
- Water thermometer (or a clear container with a marked scale)
- Hot water
- Ice water
- Room temperature water
- Stopwatch

- Notebook and pen for observations

Safety Note: *Mercury is toxic. Ensure to handle mercury thermometers with care and under adult supervision.*

What to do:

Setup: Label each jar with the substance it will contain (Mercury, alcohol, water).

1. **Baseline Measurement:** Place all three thermometers in room temperature water and note the initial temperature readings. This will be your baseline.
2. **Hot Water Test:**
   a. Place all three thermometers in a container of hot water simultaneously.
   b. Start the stopwatch, and after 2 minutes, record the temperature readings for each thermometer.
3. **Ice Water Test:**
   a. Now place all three thermometers in a container of ice water simultaneously.
   b. Start the stopwatch, and after 2 minutes, record the temperature readings for each thermometer.
4. **Observation and Recording**:
   a. Note down the temperature changes observed in each thermometer when placed in hot and ice water.
   b. Compare how quickly each thermometric substance responds to the temperature changes.

Table 3.1: Observation Table

Substance	Room Temperature (°C)	Hot Water Temperature (°C)	Ice Water Temperature (°C)
Mercury			
Alcohol			
Water			

Questions:

i. Which thermometric substance showed the most significant change in temperature when placed in hot water?

ii. Which thermometric substance showed the most significant change in temperature when placed in hot water?

iii. Which thermometric substance showed the least change in temperature?

iv. How do the speed and amount of temperature change differ among the three substances?

v. Share your observations with a friend or subject teacher

Activity 3.3 Designing a simple thermometer with a bimetallic strip

Materials needed:

- Bimetallic strip
- Support stand
- Heat source (e.g. candle)
- Ruler
- Marker
- Thermometer (for comparison)

What to do:

1. Secure the bimetallic strip to the support stand in a vertical position.
2. Place the heat source at a consistent distance from the bimetallic strip.
3. Use the ruler and marker to create a scale along the length of the bimetallic strip.
4. Heat the bimetallic strip using the heat source.
5. Observe and record the point on the scale where the bimetallic strip bends or moves.
6. Compare the reading on the bimetallic strip thermometer with a conventional thermometer to calibrate.

THERMOMETERS

A thermometer is a device used to measure temperature.

There are several types of thermometers, each utilising different principles to measure temperature. They are widely used in a variety of settings, including weather monitoring, medical applications, industrial processes, cooking and scientific research.

There are many different types of thermometers. They include:

1. Liquid-in-glass thermometer
2. Bimetallic thermometer
3. pyrometers
4. Gas thermometers
5. Thermocouples
6. Resistance thermometers

The Liquid-in-Glass Thermometer

The laboratory thermometer is a thermometer that uses liquid as a thermometric substance, which contract when cooled and expands when heated. A liquid that expands or contracts appreciably with a small change in temperature is suitable for the construction of this thermometer, since it will be most sensitive provided that it remains a liquid over the range of temperature we wish to measure.

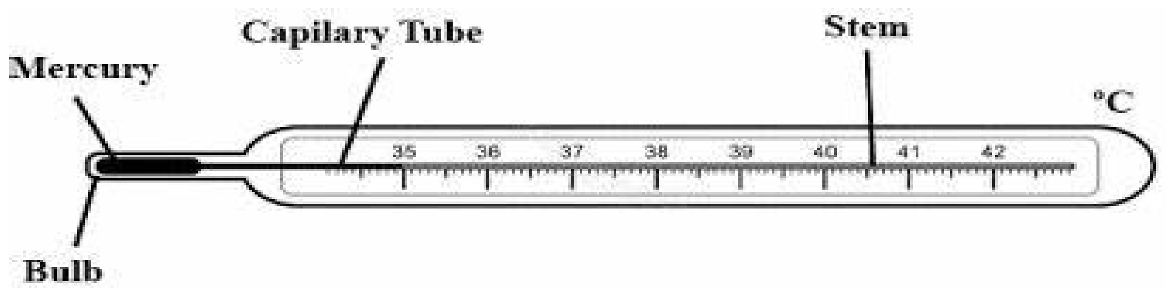


Fig. 3.2: A liquid–in–glass thermometer

The Clinical Thermometer

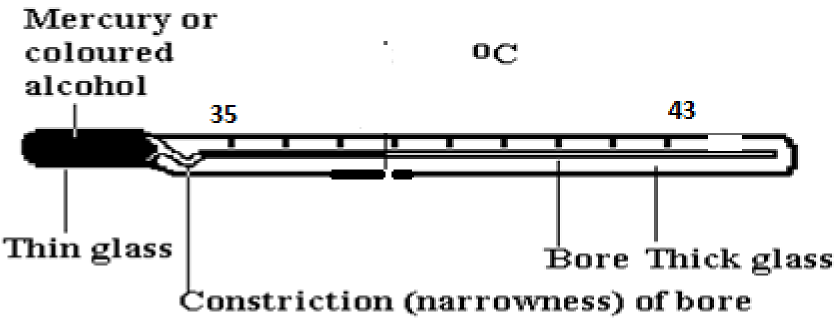


Fig. 3.3: A clinical thermometer

The clinical thermometer is a medical instrument which is specially designed to determine the temperature of a patient. It has a thin and short stem calibrated from 35 °C to 43 °C with a difference of 8 °C (43-35 = 8°C), which is used to measure the rise and fall in temperature of the human body (normal temperature of human body 37°C).

It is made of a **bulb** which serves as a reservoir of the thermometric liquid and a **stem** with fine capillary glass tubing. The capillary tube serves as a passage of the liquid when there is a change in temperature (rise or fall in temperature). The stem is calibrated to read the temperature scale of the thermometer. The **constriction/ kink** prevents the flow back of mercury.

How the clinical thermometer works

The clinical thermometer is inserted under the armpit of a patient and left for some time. The body temperature causes the thermometric liquid (mercury) to expand and rise along the tube. The mercury thread remains steady by the constriction or kink, which prevents the flow back of mercury and records the maximum temperature of the body. When the thermometer is removed from the armpit, the thermometer is shaken vigorously to force the liquid to flow back and enter the bulb (overcome the kink) before it is used again.

The clinical thermometer is normally sterilised by immersing it in an antiseptic solution before it is used again to prevent the spreading of disease from one patient to another. However, sterilising the thermometer in boiling water (100 °C) would break it. This is because water boils at 100°C which is higher than the temperature ranges of the thermometer (35 °C - 43 °C) and causes the bulb of the thermometer to expand and break/crack.

Features of the clinical thermometer and their functions

Table 3.2: Features and functions of features of a clinical thermometer

Features	Functions
Stem	It serves as a magnifying lens by magnifying the mercury thread.
Kink	It prevents backflow of mercury
Bulb	It keeps the mercury / it serves as a reservoir of mercury
Glass tube	It serves as a passage of mercury

The Gas Thermometer

There are two main types of gas thermometer, one operating at constant volume and the other at constant pressure. The constant-volume gas thermometer is by far the most widely used and so we will deal with it alone.

The ideal gas equation states that for n moles of a gas: PV= nRT and therefore for a gas at constant volume V the absolute temperature T is directly proportional to the pressure of the gas P.

A simple form of constant-volume gas thermometer is shown in Figure below

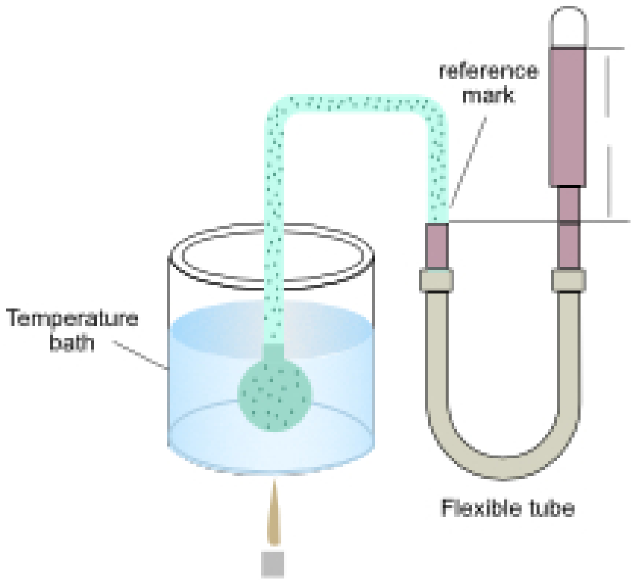


Fig 3.4: A constant-volume gas thermometer

When the bulb containing gas is heated, the air or gas in the bulb expands and forces the mercury in the manometer to rise in the calibrated limb. The air is returned to its original volume by adjusting the level of the mercury by lowering or raising the opening tube. The difference in height between the two mercury levels is then measured to provide a pressure reading for the gas from the expression.

$p = \rho g h$

where

p = pressure of the gas

p = density of mercury

h = difference between mercury levels

g = acceleration due to gravity

Advantages of the gas thermometer

1. It is very accurate
2. It is very sensitive to temperature changes
3. It has a wide temperature range of about 270 - 1064°C.

Disadvantages of the gas thermometer

1. It is bulky
2. It has a long response time

Thermoelectric thermometer (Thermocouple)

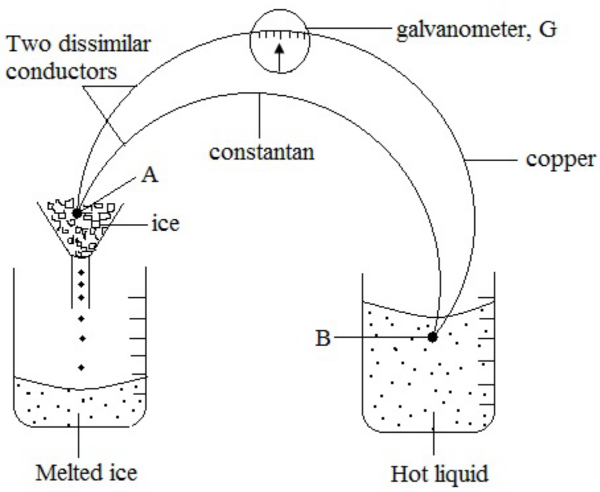


Fig 3.5: A thermocouple

A thermocouple is a temperature-measuring device that consists of two dissimilar metal wires (copper and constantan wires) joined together at both ends or junction A and B. When this junction is exposed to a temperature difference (hot and cold junction), it generates a small voltage that can be measured and converted into a temperature reading.

The phenomenon where two different wires are joined together and their junctions kept at different temperatures, setting up an e.m.f to cause current to flow through them is known as **thermoelectric effect** or **seebeck effect.**

Components of a thermocouple

The key components of a thermocouple are:

1. Thermocouple wires: These are the two dissimilar metal wires, such as chromel (nickel-chromium alloy) and alumel (nickel-aluminium alloy) or copper and constantan (copper-nickel alloy).
2. Hot junction: This is the end where the two wires are joined and placed in the environment whose temperature is to be measured.
3. Cold junction: This is the other end of the thermocouple wires, which is connected to the measuring device.
4. Measuring device: This could be a voltmeter, temperature indicator, or a data acquisition system that can interpret the thermoelectric voltage and display the corresponding temperature.

Uses of the thermocouple

Industries that use aluminium and steel use thermocouples constructed from metals of very high melting point to measure the temperature of molten aluminium or steel respectively. Wires of platinum alloy and platinum are used in measuring the temperature of the molten aluminium.

Advantages of the thermocouple

1. It can measure temperature of small bodies
2. It has very wide temperature range of about –200°C – 1260°C.
3. It is sensitive
4. It is portable and durable
5. It responds quickly to changes in temperature

Disadvantages of the thermocouple

1. It is not accurate
2. It is difficult to read

Resistance Thermometers

A resistance thermometer, also called an RTD, uses metals to measure temperature. Metals have a special property–their electrical resistance changes as temperature changes. This is the key principle behind how a resistance thermometer works.

Metals like platinum, nickel, and copper have a predictable, linear relationship between their electrical resistance and temperature. As the temperature increases, the metal's resistance also increases. And as the temperature goes down, the resistance goes down. This relationship is described by a simple equation. Resistance at θ°C is , then = R_0 $(1 + \alpha\theta)$,

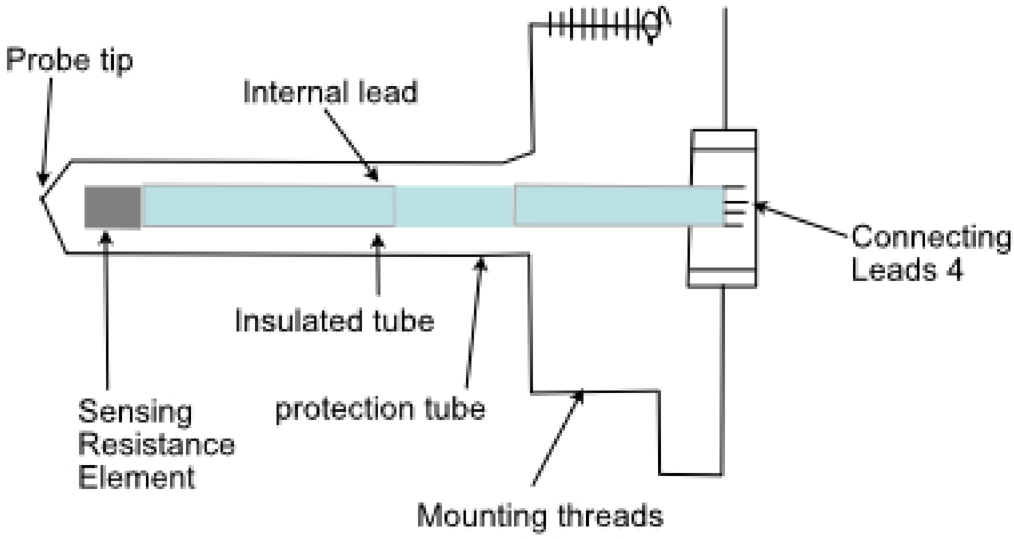


Fig 3.6: A resistance thermometer

Measuring Resistance

The resistance thermometer has a metal wire or film inside.

The resistance of this metal part is measured using special electrical circuits.

The measured resistance value is then converted to a temperature value.

Advantages of the platinum resistance thermometer

1. It is small and portable.
2. It is sensitive.
3. It has a wide temperature range (-200 °C to + 650 °C).
4. The measurement is very accurate.
5. It has a lot of flexibility with regard to the choice of measuring equipment.
6. Indicators, recorders or controllers can also be operated.

7. Extremely accurate temperature sensing.
8. Stability of performance over long periods of time.

Disadvantages of the platinum resistance thermometer

1. It has a long response time.
2. It has a high heat capacity.
3. It is fragile.
4. It is difficult to read.

The Thermistor

The thermistor is made of a small bead of semiconducting material. As in the platinum resistance thermometer, an electrical circuit measures the resistance, and this is converted into a temperature reading.

Fig 3.7: A Thermistor

Advantages of the thermistor

1. It is portable.
2. It is cheap to manufacture.
3. It is very sensitive.
4. It has a short response time.

Disadvantages of the thermistor

1. It is less accurate.
2. It is less stable.
3. It has a small temperature range.

Table 3.3: Thermometers with their thermometric substances and physical properties.

Thermometer	Thermometric substance	Physical properties
Constant volume gas	Gas	Pressure
Thermocouple	A pair of constant wires	Emf
Liquid in glass	Mercury / Alcohol	Volume / Length

Activity 3.4 Exploring different types of thermometers

Materials needed:

- Liquid-in-glass thermometer
- Digital thermometer
- Thermocouple thermometer (with a suitable probe)
- Resistance thermometer (RTD) (with a suitable interface and measurement device)
- Bimetallic strip thermometer
- Temperature source (e.g., hot water, ice water, room temperature water)
- Notebook and pen for recording observations

What to do:

Note: Perform this activity under the guidance of your teacher.

1. Familiarise yourself with each type of thermometer, including their structure, and operation
2. Select a temperature source, such as hot water, ice water, or room temperature water.
3. Start with the first thermometer (e.g., liquid-in-glass thermometer) and measure the temperature of the water source.
4. Record the temperature reading in your notebook.
5. Repeat the process with the other thermometers

6. Record, compare, and analyse the results as in the table below:

Observation Table:

Table 3.4: represents observations made throughout Activity 3.3 above.

Types of thermometers	Room Temperature water (°C)	Hot Water Temperature (°C)	Ice Water Temperature (°C)
Liquid-in-glass thermometer			
Digital thermometer			
Thermocouple thermometer (with a suitable probe)			
Resistance thermometer (RTD) (with a suitable interface and measurement device)			
Bimetallic strip thermometer			

Discuss and share your findings with others, highlighting the characteristics of each type of thermometer.

Activity 3.5 Constructing a home-made model thermometer

Materials needed: Clear plastic bottle, drinking straw, modelling clay/putty, rubbing alcohol or coloured water, food colouring, clear plastic tubing (optional), thermometer for calibration, ruler, permanent marker, safety goggles, and gloves.

What to do:

1. **Prepare Liquid**: Fill the bottle one-quarter full with rubbing alcohol or coloured water.
2. **Insert Straw:** Place the straw into the bottle without touching the bottom and seal the bottle's neck with modelling clay or putty to make it airtight.
3. **Calibrate:**
   a. Mark the straw at the liquid level with the current temperature.

- **b.** Place the bottle in ice-cold water, mark the new level, and label it.
- **c.** Place the bottle in hot water, mark the level, and label it.
- **d.** Create Scale: Measure the distance between the marks, divide them into equal parts, and create a temperature scale on the straw with the permanent marker.

4. **Test Thermometer**: Place the thermometer in different environments to observe the liquid movement and compare readings with a real thermometer for accuracy.

Safety Tip: Use safety goggles and gloves when handling rubbing alcohol and ensure adult supervision if needed.

TEMPERATURE SCALES

This lesson will introduce you to the three main types of temperature scales, how these scales were created and what they are based on (for example, the Celsius scale is based on the freezing and boiling points of water). You will also learn how to convert between the three scales, a skill which can be useful when presenting information about temperature in different fields and applications.

Temperature scales are used to calibrate a thermometer. There are three (3) main types of temperature scales in use today: the **Fahrenheit**, **Celsius** and **Kelvin** scales. They comprise an upper fixed point and a lower fixed point and are subsequently divided into a specific number of intervals.

Temperature scales are used to measure the temperature of a body.

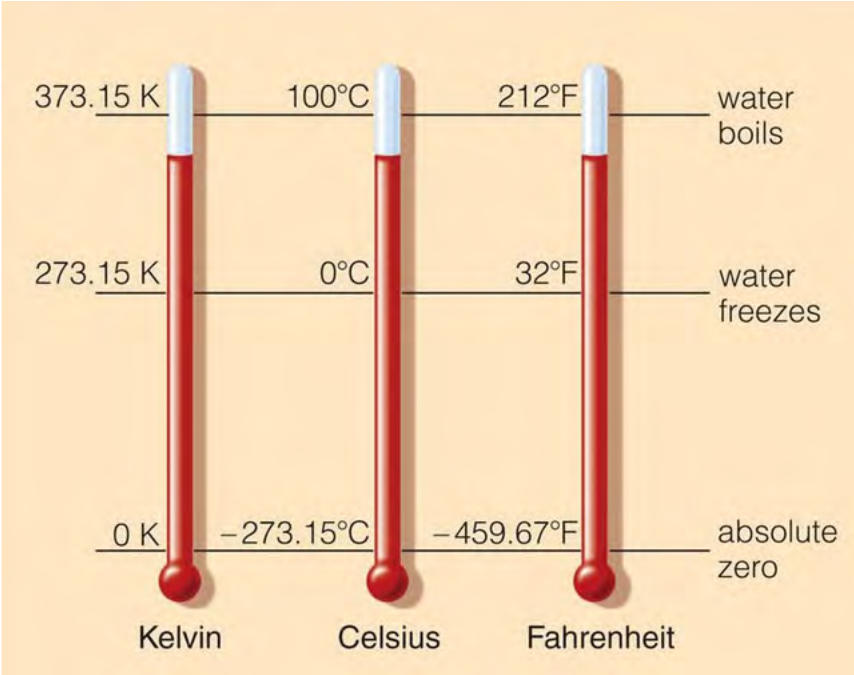


Fig. 3.8 Temperature Scales

Activity 3.6 Exploring the history and key points of temperature scales

Objectives:

a. Learner's research the origins and historical context of the Celsius, Fahrenheit, and Kelvin temperature scales.

b. Identify the key reference points for each temperature scale.

c. Learners will compare and contrast the three temperature scales.

Materials needed:

- Computers or tablets for learner research
- Worksheet for learners to record their findings

Steps:

1. **Introduction:** What temperature scale are you most familiar with and why?
2. **Research and fact sheet production:** In a group of no more than 4 students, research the following:
   a. The origins and historical context of the Celsius, Fahrenheit, and Kelvin scales.
   b. Identify the freezing and boiling points of water for each scale.

c. Describe how the scales are defined and related to each other.

Produce a fact sheet summarising your findings. This should be no more than one A4 page and should include diagrams to illustrate the temperature scales.

3. Class Discussion:

a. Share with the class any similarities or differences you noticed between the scales.

b. Share your thoughts on which scale you find most practical or useful.

Activity 3.7 Simulating gas particles at decreasing temperatures

Fig 3.9

Objective: You will physically model the movement and behaviour of gas particles as the temperature decreases.

Materials needed:

- Open classroom space or gymnasium
- Thermometer

What to do:

You are going to pretend to be gas particles and act out how their movement and behaviour would change as temperature drops.

1. Stand up and spread out in the open space, each of you representing a gas particle at a high temperature.
2. Now, adjust your motion to represent the effect of decreasing temperature on the particles.

Consider: How your speed should be affected. How should your direction of motion be affected?

3. Next, behave as though your temperature has reduced even further and you have 'liquefied'.
4. Finally, behave as though you have reached a freezing point and have solidified. Consider: do particles in a solid move in the same way as those in a liquid or a gas? Do they have a different kind of motion?

Note: Solutions to this activity and others can be found in **Annex 3.1.**

Conclusions and Discussions:

i. Discuss with a peer how the model links with the Celsius scale and its lower and upper fixed points.

ii. Summarise the key learnings from the activity.

Activity 3.8 Constructing and calibrating a homemade thermometer

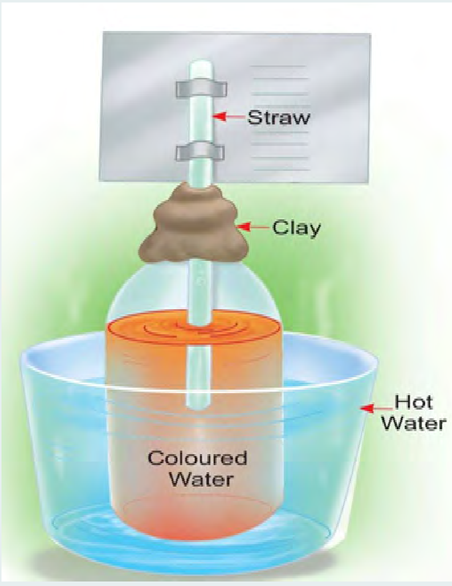


Fig 3.10

Materials needed:

- Clear straw (one per learner or group)
- Clear plastic or glass bottle
- Modelling clay
- Coloured liquid (equal parts water and rubbing alcohol)

- Bucket of ice water (0°C)
- Kettle of boiling water (100°C)
- Permanent markers or stickers

Steps:

1. **Introduction:** With a peer or in a small group discuss the importance of temperature measurement.

2. **Thermometer construction:**
   a. Half-fill the clear bottle with your coloured liquid mixture and insert your straw into the top.
   b. Secure the straw in place using modelling clay without blocking the top of the straw.
   c. Place the bottle into the bucket of icy water and mark the level of the liquid in the straw using a marker.
   d. Now, place the bottle into the boiling water and mark the level of the liquid in the straw using a marker, being careful not to scald yourself.
   e. Divide the space between the two marks into ten equal increments, each representing 10 degrees on the Celsius scale.
   f. Obtain a Celsius temperature scale thermometer and compare their experimental scale with the true values.

3. **Discussion:**
   a. What challenges did you face in creating your thermometer?
   b. How did your experimental scale compare to the true Celsius scale?
   c. What factors might have influenced the accuracy of your thermometer?
   d. How can this activity help you better understand the Celsius temperature scale?

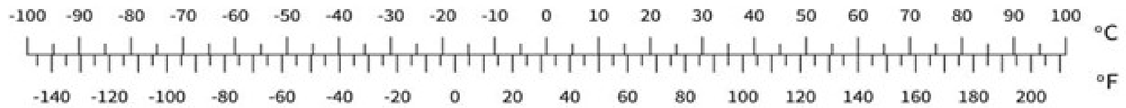
4. **Extension:** If time allows research the history and development of thermometers and temperature measurement.

TEMPERATURE SCALES AND CONVERSIONS

Celsius and Fahrenheit

The Celsius (θ) and the Fahrenheit (F) scales are related by the equation,

$F = \frac{5}{9}\theta + 32$



Celsius and Kelvin

The Celsius (θ) and the Kelvin (T) scales are related by the equation,

$T = \theta + 273.15$

Fahrenheit and Kelvin

The Fahrenheit (F) and the Kelvin (T) scales are related by the equation,

$K = (F + 459.67) \times \frac{5}{9}$

Activity 3.9 Exploring temperature conversion scales

Use a temperature conversion chart to practise converting between Celsius, Fahrenheit, and Kelvin temperature scales.

Materials needed: Temperature conversion chart (see example below)

What to do:

1. Use the image below to fill in the table with equivalent temperature values in each of the three scales. The first one has been done for you.
2. Optional extension: Use your results to revise the relationships between the three temperature scales.

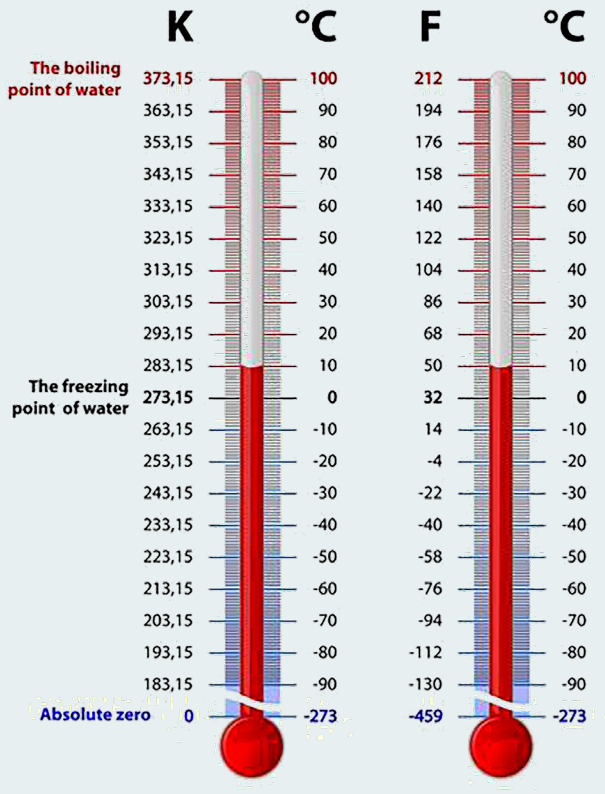


Fig. 3.11: Temperature Scales: Fahrenheit, Celsius, and Kelvin

Celsius (°C)	Fahrenheit (°F)	Kelvin (K)
40	-40	233.15
	-22	
		253.15
-10		
0		
	50	

Activity 3.10 Temperature data collection and conversion

Collect temperature data from various sources, then convert the temperatures between the three main scales.

Materials needed:

- Access to the internet, weather websites, news reports, or other sources of temperature data
- Spreadsheet or data collection template

Steps:

1. Create a spreadsheet or data collection template with the following columns:
   - **a.** Location
   - **b.** Date
   - **c.** Temperature (Original Scale)
   - **d.** Celsius
   - **e.** Fahrenheit
   - **f.** Kelvin
2. Research and gather at least ten (10) temperature measurements from various locations, sources, and dates. Record the original temperature scale used (this will likely be in Celsius or Kelvin, depending on the country of origin).
3. For each temperature measurement, convert the value to the other two temperature scales using the appropriate conversion formulas.

Discussion: Why do meteorologists not give values in Kelvin?

Activity 3.11 Absolute zero and pressure

Materials needed:

- Access to the internet
- Spreadsheet software or paper/digital templates for data collection
- Spreadsheet software or graph paper

What to do:

1. Open the link via the QR code below:
2. Select 'Ideal'.
3. Switch the temperature scale from K to °C, the pressure gauge from atm to kPa, and select 'Hold constant – Volume'.
4. Use the pump to insert some particles into the container and allow them to spread out. Do not add any more particles for the remainder of the activity.
5. Record the temperature and pressure.
6. Use the heat source at the bottom of the container to increase the temperature and then record the new temperature and pressure.
7. Repeat this several times until you have at least 5 data point across a large temperature range.
8. Plot a graph of your results with temperature on the x axis and pressure on the y axis. Then add a line of best fit using a ruler.
9. Extrapolate (extend) the line until it reaches the x axis (at a very negative temperature value).
10. Read off this value.

Discussion: What is the significance of the x-intercept of the graph? What does it tell us about the meaning of 'absolute zero'?

SOLUTIONS TO SOME ACTIVITIES AND FURTHER INFORMATION

Annex 3.1: Solution to Activity 3.7

1. When behaving as particles in a high-temperature gas, you should have moved with a range of (but generally high) speeds and in random directions. You will occasionally have collided with one another.
2. As your temperature decreased, your speed should have slowed, but your directions will still have been random.
3. At the point of liquefaction, you will have all moved closer together and will be moving more slowly past one another, with some of you touching. Your directions of motion will still be random.
4. Finally, at the point of freezing/solidification, you will have arranged yourselves into a lattice-like structure (rows and columns) and will vibrate in this fixed position.

Annex 3.2: Expected solution to Activity 3.9

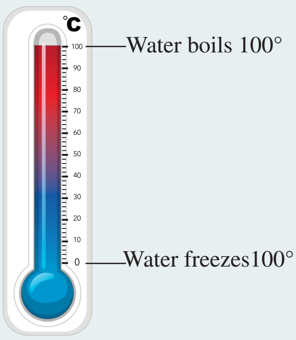
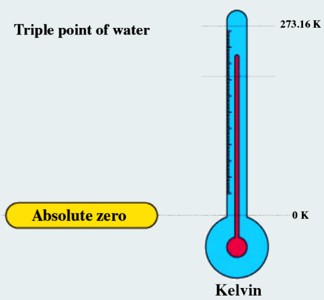
Celsius (°C)	Fahrenheit (°F)	Kelvin (K)
40	-40	233.15
-30	-22	243.15
-20	-4	253.15
-10	14	263.15
0	32	273.15
10	50	283.15

Annex 3.3: Expected Discussion to Activity 3.11

The x-intercept should give a value of approximately -273.15°C. This is equivalent to 0K. This tells us that 0K or ‘absolute zero’ is the temperature at which particles have zero energy and do not move, thus exerting no pressure on the sides of the container.

Annex 3.4: Further Information

Temperature Scales and Thermometers

	Celsius (°C)	Kelvin (K)	Fahrenheit (°F)
Creation	Named after Swedish astronomer Anders Celsius in 1742.	Named by renowned British physicist Lord Kelvin.	Developed by German physicist Daniel Gabriel Fahrenheit in the early 18^{th} century.
Lower fixed point	0°C, the **temperature of pure melting ice**	**Absolute zero** (0 K or minus 273.15°C)	**Freezing point of a brine solution** (0°F) (later redefined as 32°F – freezing point of water)
Upper fixed point	100°C, the **boiling point of water** at standard atmospheric pressure.	The **triple point of water** (273.16 K or 0.01°C)	The average **human body temperature** (96°F) (later redefined at 212°F – boiling boiled of water at standard atmospheric pressure)
Diagram			

Thermometers typically use mercury or alcohol as the working fluid, which expands and contracts linearly with changes in temperature.

Temperature Scales and Conversions

Conversion of Temperature Scales

To convert between **Kelvin (T) and Celsius (θ)**, use the relationships:

$$T = \theta + 273.15$$

or

$$\theta = T - 273.15$$

To convert between **Fahrenheit (F) and Celsius (θ)**, use the relationships:

$$F = \frac{9}{5}\theta + 32$$

or

$$\theta = \frac{5}{9}(F - 32)$$

To convert between **Fahrenheit (F) and Kelvin (T)**, use the relationships:

$$K = \frac{5}{9}(F + 459.67)$$

or

$$F = \frac{9}{5}K - 459.67$$

Uses of temperature scales

Global Communication: The use of standardised temperature scales, such as Celsius and Fahrenheit, facilitates clear and unambiguous communication of temperature measurements around the world.

This allows for seamless exchange of weather data, climate information, and temperature-related specifications across borders and languages.

Consistent temperature scales enable effective collaboration on global issues like climate change monitoring and weather forecasting.

Scientific Research: Standardised temperature scales are essential for accurate data collection, analysis, and comparison in scientific experiments and studies.

Researchers can reliably share and interpret temperature-dependent results and findings across disciplines and geographies.

The universal adoption of scales like Kelvin enables coherent communication of absolute temperature measurements critical for fields like thermodynamics and cryogenics.

Technological applications: Temperature scales underpin the design, manufacturing, and operation of numerous technologies - from home appliances to industrial equipment.

Consistent temperature ratings and specifications allow for interoperability and cross-compatibility of components and systems globally.

Shared temperature scales facilitate the international trade and distribution of temperature-sensitive products like pharmaceuticals and perishable goods.

REVIEW QUESTIONS

Review Questions 3.1

1. Explain why certain substances are suitable for use in thermometers.
2. Describe the characteristics of an ideal thermometric substance.
3. Name and explain one example of a thermometric substance.
4. How does the choice of thermometric substance affect the design and accuracy of a thermometer?

Review Questions 3.2

1. Compare and contrast liquid-in-glass thermometers and bimetallic strip thermometers.
2. Explain how a gas thermometer measures temperature.
3. Describe the working principle of a thermocouple and how it differs from a resistance thermometer.
4. Analyse the advantages and disadvantages of using a gas thermometer compared to a liquid-in-glass thermometer.
5. Evaluate the effectiveness of using a bimetallic strip thermometer in environments with varying temperature ranges.
6. Predict how changes in the electrical resistance of a conductor affect the accuracy of a resistance thermometer.
7. Design an experiment to compare the accuracy and reliability of liquid-in-glass thermometers and thermocouples.
8. Develop a mathematical model to predict the behaviour of a bimetallic strip thermometer under specific temperature conditions.
9. Propose improvements to existing resistance thermometer designs to enhance their performance in extreme temperature environments.

Project

Design and construct a homemade model thermometer using any available thermometric substance.

Review Questions 3.3

1. Describe the Celsius (°C) temperature scale and explain how a Celsius thermometer is constructed.
2. Describe the Kelvin (K) temperature scale and the construction of a Kelvin thermometer.
3. Explain the Fahrenheit (°F) temperature scale and the construction of a Fahrenheit thermometer.
4. How can you convert between the Celsius, Kelvin, and Fahrenheit temperature scales?
5. **a.** Express on the absolute scale.

   b. Express as a temperature on the absolute scale.

   c. Convert 25 °C into K.

   d. Convert -73 °C into K.

ANSWERS TO REVIEW QUESTIONS

Review Questions 3.1

1. Certain substances are suitable for use in thermometers because they exhibit a predictable and consistent change in their physical properties with temperature. This change allows for accurate measurement of temperature variations.
2. An ideal thermometric substance should have the following characteristics:
   - Wide temperature range of sensitivity.
   - Consistent and predictable change in physical property with temperature.
   - Low thermal expansion to minimise errors.
   - Quick response to temperature changes.
   - Stability and durability for repeated use.
   - Non-toxicity and safety for handling.
3. One example of a thermometric substance is mercury. Mercury is a liquid metal that expands uniformly with temperature changes. It has a wide temperature range of sensitivity and is commonly used in traditional glass thermometers.
4. The choice of thermometric substance affects the design and accuracy of a thermometer because different substances have varying properties and sensitivities to temperature changes. For example, substances with a wide temperature range of sensitivity and quick response times are preferred for accurate measurements. Additionally, the physical state of the substance (e.g., solid, liquid, or gas) may influence the design of the thermometer.

Review Questions 3.2

1. Liquid-in-glass thermometers and bimetallic strip thermometers both measure temperature but operate on different principles. The former uses the expansion of a liquid in a glass tube, while the latter uses the differential expansion of two metals bonded together.

2. A gas thermometer measures temperature by monitoring the pressure of a gas, which is directly proportional to its temperature according to the ideal gas law.
3. A thermocouple works based on the Seebeck effect, producing a voltage at the junction of two dissimilar metals when subjected to a temperature gradient. A resistance thermometer, however, measures temperature based on the change in electrical resistance of a conductor with temperature.
4. Advantages of using a gas thermometer include its wide temperature range and high accuracy, while disadvantages may include complexity and sensitivity to external conditions. Liquid-in-glass thermometers, on the other hand, are simple and inexpensive but may have a limited temperature range.
5. Bimetallic strip thermometers are effective in environments with varying temperature ranges due to their ability to accurately measure temperature changes. However, their response time may be slower compared to other types of thermometers.
6. Changes in the electrical resistance of a conductor affect the accuracy of a resistance thermometer, with higher resistance resulting in lower accuracy. However, compensation techniques can be applied to improve accuracy in extreme temperature environments.
7. Answers may vary but could include designing an experiment to compare temperature readings from liquid-in-glass thermometers and thermocouples under controlled conditions and analysing the data to determine accuracy and reliability.
8. Developing a mathematical model would involve considering factors such as the materials used in the bimetallic strip, the dimensions of the strip, and the temperature range of interest to predict its behaviour accurately.
9. Proposals for improvements to resistance thermometer designs could include using materials with higher temperature coefficients of resistance, enhancing insulation to minimise external influences, or implementing advanced signal processing techniques to compensate for inaccuracies.

Review Questions 3.3

1. The Celsius scale is based on the freezing point of water (0°C) and the boiling point of water (100°C) at standard atmospheric pressure.

- The scale is divided into 100 equal intervals between these two points, with each interval representing one degree Celsius.
- Celsius thermometers typically use mercury or alcohol as the working fluid, which expands and contracts linearly with changes in temperature.

2. The Kelvin scale is an absolute temperature scale with its zero point set at absolute zero (-273.15°C or -459.67°F).

- The unit of the Kelvin scale is the Kelvin, which is the base unit of temperature in the International System of Units (SI).
- Kelvin thermometers often use the same materials as Celsius thermometers, such as mercury or alcohol, but the scale is defined differently.

3. The Fahrenheit scale is based on the freezing point of a brine solution (0°F) and the average human body temperature (96°F).

Fahrenheit thermometers commonly use mercury or alcohol as the working fluid, like Celsius and Kelvin thermometers.

4. $F = \frac{9}{5}\theta + 32$

$T = \theta + 273.15$

$K = (F + 459.67) \times 5/9$

5. **a.** 218.93 K

b. 348.38 K

c. 298.15 K

d. 200.15 K

EXTENDED READING

1. Thermometric substance

   https://byjus.com/question-answer/what-is-the-thermometric-substance-used-in-a-clinical-thermometer/#:~:text=Mercury%20is%20the%20is%20the,be%20read%20from%20the%20scale

2. Thermometers

   https://en.m.wikipedia.org/wiki/Thermometer#:~:text=A%20thermometer%20has%20two%20important,value%20(e.g.%20the%20visible%20scale

Thermometers video

   https://youtube.com/watch?v=K2CH1cUkMgs&feature=shared

3. Thermometers: https://www.britannica.com/technology/thermometer

   This link from Britannica provides an overview of thermometers, including their history, types, and principles of operation. It covers various types of thermometers, such as mercury-in-glass, digital, infrared, and thermocouple thermometers.

4. Thermometric Substances:

   https://www.khanacademy.org/science/chemistry/states-of-matter-and-intermolecular-forces/introduction-to-states-of-matter/a/thermometric-substances

   This Khan Academy article focuses on thermometric substances, which are materials used in thermometers to measure temperature. It explains the properties and characteristics of different thermometric substances, such as mercury, alcohol, and platinum.

   These resources will provide you with a more in-depth understanding of thermometers, their types, and the substances used in temperature measurement.

REFERENCES

Global Communication:

World Meteorological Organization (WMO) standards for reporting weather and climate data.

IEEE Standard for Temperature Measurements and Calibration - Helps enable international exchange of temperature data.

Scientific Research:

BIPM's International Temperature Scale of 1990 (ITS-90) - Establishes global standard for temperature measurements in research.

Journal of Research of the National Institute of Standards and Technology - Publishes research on temperature measurement and standards.

Technological Applications:

ISO Standard 80000-5 on Quantities and units – Part 5: Thermodynamics - Provides international guidelines for temperature-related specifications.

ASTM International standards on temperature measurement instrumentation - Supports global product development and testing: https://www.astm.org/Standards/temperature-measurement-standards.html

Celsius (°C) Scale:

"Celsius Temperature Scale." Encyclopædia Britannica, Encyclopædia Britannica, Inc., www.britannica.com/science/Celsius-temperature-scale.

"The Celsius scale is based on the freezing point of water (0 °C) and the boiling point of water (100 °C) at standard atmospheric pressure."

Kelvin (K) Scale:

"Kelvin Temperature Scale." Encyclopaedia Britannica, Encyclopaedia Britannica, Inc., www.britannica.com/science/Kelvin-temperature-scale.

Fahrenheit (°F) Scale:

"Fahrenheit Temperature Scale." Encyclopaedia Britannica, Encyclopaedia Britannica, Inc., www.britannica.com/science/Fahrenheit-temperature-scale.

ACKNOWLEDGEMENTS

Ghana Education Service (GES)

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