UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER

GENERAL OBJECTIVES

On completion of this Module, students should:

1. understand the principles involved in the design and use of thermometers;
2. be aware of the thermal properties of materials and their practical importance in everyday life;
3. understand the various modes of heat transfer;
4. be familiar with the kinetic theory of gases and the equation of state of an ideal gas;
5. display a working knowledge of the first law of thermodynamics;
6. be aware of the mechanical properties of materials and their practical importance in everyday life.

SPECIFIC OBJECTIVES

1. Design and Use of Thermometers

Students should be able to:

1.1 discuss how a physical property may be used to measure temperature;

1.2 describe the physical features of specific thermometers;

1.3 discuss the advantages and disadvantages of these thermometers;

1.4 recall that the absolute thermodynamic scale of temperature does not depend on the property of any particular substance;

1.5 determine temperatures in kelvin, in degrees Celsius and on the empirical centigrade scales.

EXPLANATORY NOTES

Include both linear and non-linear variation with temperature.

Liquid-in-glass, resistance (including thermistor), thermocouple and constant volume gas thermometer.

Empirical scale

$$\theta = \frac{x_T - x_o}{x_{100} - x_o} \times 100°C$$

Kelvin scale

$$T = \frac{P}{P_o} \times 273.16 \text{ K}$$

$$\theta/°C = T/K = 273.15$$
### UNIT 1
**MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)**

### SPECIFIC OBJECTIVES

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td><strong>Thermal Properties</strong></td>
</tr>
</tbody>
</table>

Students should be able to:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>express the internal energy of a system as the sum of the kinetic and potential energies associated with the molecules of the system;</td>
</tr>
<tr>
<td>2.2</td>
<td>relate a rise in temperature to an increase in internal energy;</td>
</tr>
<tr>
<td>2.3</td>
<td>explain the terms ‘heat capacity’ and ‘specific heat capacity’;</td>
</tr>
<tr>
<td>2.4</td>
<td>perform experiments to determine the specific heat capacity of liquids and metals by electrical methods and by the method of mixtures;</td>
</tr>
<tr>
<td>2.5</td>
<td>explain the concepts of ‘melting’ and ‘boiling’ in terms of energy input with no change in temperature;</td>
</tr>
<tr>
<td>2.6</td>
<td>relate the concepts of melting and boiling to changes in internal potential energy;</td>
</tr>
<tr>
<td>2.7</td>
<td>explain the term ‘specific latent heat’;</td>
</tr>
<tr>
<td>2.8</td>
<td>use graphs of temperature against time to determine freezing or melting points and boiling points;</td>
</tr>
</tbody>
</table>

### EXPLANATORY NOTES

Both electrical methods and the method of mixtures are to be covered.
UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

SPECIFIC OBJECTIVES

Thermal Properties (cont’d)

Students should be able to:

2.9 perform experiments to determine the specific latent heats;

2.10 explain the cooling which accompanies evaporation;

2.11 Solve numerical problems using the equations $E_H = mc \Delta \theta$ and $E_H = mL$.

3. Heat Transfer

Students should be able to:

3.1 describe the mechanism of thermal conduction;

3.2 use the equation $\frac{Q}{A} = -kA \frac{\Delta \theta}{L}$ to solve problems in one-dimensional heat flow;

3.3 solve numerical problems involving composite conductors;

3.4 discuss the principles involved in the determination of thermal conductivity of good and bad conductors;

3.5 explain the process of convection as a consequence of a change of density, and use this concept to explain ocean currents and winds;

EXPLANATORY NOTES

Both electrical methods and the method of mixtures are to be covered. See suggested practical activity on page 34.

This should be done in terms of latent heat and in terms of the escape of molecules with high kinetic energy.

Restrict use to cases of one-dimensional heat flow.

Use of concept of equivalent conductor.
UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

SPECIFIC OBJECTIVES

Heat Transfer (cont’d)

Students should be able to:

3.6 discuss thermal radiation and solve problems using Stefan’s equation;        For a black body \( P = A\sigma T^4 \). Include net rate of radiation.

3.7 explain the greenhouse effect;

3.8 discuss applications of the transfer of energy by conduction, convection and radiation;    Include vacuum flasks and solar water heaters.

3.9 discuss the development of heating and cooling systems to reduce the Caribbean dependency on fossil fuels.

4. The Kinetic Theory of Gases

Students should be able to:

4.1 use the equation of state for an ideal gas expressed as \( pV = \frac{nRT}{N} \) and \( \frac{pV}{N} = kT \).

4.2 discuss the basic assumptions of the kinetic theory of gases;

4.3 explain how molecular movement is responsible for the pressure exerted by a gas;

4.4 derive and use the equation \( \sqrt{\frac{pV}{N}} = \sqrt{\frac{1}{3} N m \overline{c}^2} \);   Include calculations of r.m.s. speed, \( \overline{c^2} \) or \( <c^2> \)

4.5 use \( \sqrt{\frac{pV}{N}} = \sqrt{\frac{1}{3} N m \overline{c}^2} \) to deduce the equation for the average translational kinetic energy of monatomic molecules; \( E_k = \frac{3}{2} kT \)
## UNIT 1
**MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)**

### SPECIFIC OBJECTIVES

#### The Kinetic Theory of Gases (cont’d)

Students should be able to:

4.6 **deduce total kinetic energy of a monatomic gas.**

Total kinetic energy \[ E_k = \frac{3}{2} nRT \]

5. **First Law of Thermodynamics**

Students should be able to:

5.1 **use the term ‘molar heat capacity’;**

\[ E_{II} = n \ C_v \ \Delta \theta \] or \[ E_{II} = n \ C_p \ \Delta \theta \]

5.2 **discuss why the molar heat capacity of a gas at constant volume is different from that of a gas at constant pressure;**

\[ C_p = C_v + R \]

5.3 **calculate the work done on a gas using the equation** \[ W = p \ \Delta V \; ; \]

5.4 **deduce work done from a p-V graph;**

5.5 **express the first law of thermodynamics in terms of the change in internal energy, the heat supplied to the system and the work done on the system;**

\[ \Delta U = Q + W \]

5.6 **solve problems involving the first law of thermodynamics.**
UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

SPECIFIC OBJECTIVES

6. Mechanical Properties of Materials

Students should be able to:

6.1 explain and use the terms ‘density’ and ‘pressure’;

6.2 derive and use the equation \[ \Delta p = \rho g \Delta h \] for the pressure difference in a liquid;

6.3 relate the difference in the structures and densities of solids, liquids and gases to simple ideas of the spacing, ordering and motion of their molecules;

6.4 describe a simple kinetic model for the behaviour of solids, liquids and gases;

6.5 distinguish between the structure of crystalline and non-crystalline solids, with particular reference to metals, polymers and glasses;

6.6 discuss the stretching of springs and wire in terms of load extension;

6.7 use the relationship among ‘stress’, ‘strain’ and ‘the Young modulus’ to solve problems;

6.8 perform experiments to determine the Young modulus of a metal in the form of a wire;

6.9 demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials;

6.10 deduce the strain energy in a deformed material from a force-extension graph;

EXPLANATORY NOTES

\[ p = \frac{F}{A} \quad \rho = \frac{M}{V} \]

Make particular reference to metals, polymers and glasses.

For example, copper, glass, rubber.

Hooke’s law

Spring constant

\[ E = \frac{\text{stress}}{\text{strain}} \]
UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

SPECIFIC OBJECTIVES

Mechanical Properties of Materials (cont’d)

Students should be able to:

6.11 distinguish between elastic and inelastic deformations of a material;

Only qualitative knowledge is required.
See suggested practical activity on page 35.

6.12 discuss the importance of elasticity in structures.

Consider what happens to tall buildings, bridges and bones when large forces are applied.

EXPLANATORY NOTES

Suggested Teaching and Learning Activities

To facilitate students’ attainment of the objectives of this Module, teachers are advised to engage students in teaching and learning activities listed below.

1. Investigate how three different physical properties vary with temperature.

2. Investigate the suitability of using iron, copper or aluminum as the metal used for making an engine block.

3. Investigate the heat flow through different materials of the same thickness and recommend the use of one in the construction industry, for example, brick, concrete, glass and wood.

4. Investigate this statement: heat flow in textiles can occur by all three methods of heat transfer, but for metals only conduction is possible.

5. Investigate the effect of greenhouse gases on global warming.

6. Investigate heat transfer processes in the solar water heater.

7. Construct a model of a solar crop dryer.

8. Construct a model of a solar air conditioner.


10. Construct a model of a solar refrigerator.

11. Investigate the role of thermodynamics in the operation of the four-stroke petrol engine.
UNIT 1

MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

12. Investigate the uses of crystalline and non-crystalline solids in the semiconductor industry.

13. Investigate the uses of polymers and glasses.


PRACTICAL ACTIVITIES

The teacher is urged to reinforce the relevant approved codes and safety practices during the delivery of all practical activities in the Module.

LATENT HEAT

Refer to Specific Objective 2.9

Aim: To determine:

(i) the specific latent heat of vaporization of a liquid by an electrical method: and

(ii) the specific latent heat of fusion of ice by the method of mixtures.

Method: (a) The more sophisticated apparatus in the text may not be available, in which case the apparatus shown below can be used. The principle is the same. The energy supplied after the liquid has started to boil is equal to the heat required to boil off a mass m of liquid plus the heat to the surroundings, \( H \), that is, \( Vt = mL + H \).

If the procedure is repeated with different values of \( V \) and \( I \) but with the same time, \( t \), then the last term may be eliminated by subtraction. (Explain why the heat loss is the same in both cases, provided the time is the same).
UNIT 1
MODULE 3: THERMAL AND MECHANICAL PROPERTIES OF MATTER (cont’d)

(b) A Styrofoam cup, which has a negligible heat capacity, is to be used as the calorimeter.

Carefully consider the possible errors in this method before starting. A good way of reducing the effect of the surroundings is to start the experiment with the water in the cup above room temperature and add small pieces of dried ice until the temperature is same amount below room temperature.

STRETCHING GLASS AND RUBBER

Refer to Specific Objective 6.11

Aims: (a) To compare the breaking stress of glass with that of rubber.
(b) To investigate the behaviour of rubber when it is loaded and unloaded.

Method: Stretching glass could be dangerous so this part of the experiment will be performed by the laboratory assistant. Warning: BE VERY CAREFUL with the glass. Do not have your eyes near it at any time.

You will be provided with a piece of rubber band. Add loads to it until it breaks and make other necessary measurements so that you can work out the breaking stress.

Using a similar piece of rubber to that in (a) add masses in 100 g increments until the load is 300 g less than the maximum. For each load measure the extension of the rubber. Continue measuring the extension as the load is removed. Plot a graph to illustrate your results.

Note: It is best not to measure the length of the rubber between the support and the knot because the rubber might slip. Instead use two fine ink marks drawn on the band.

(Preparation: Glass rod is heated and a hook made. Then it is heated in the centre and stretched to produce a thin section.)

(soda glass)