DEPARTMENT OF EDUCATION

GRADE 12

PHYSICS

MODULE 2

TEMPERATURE AND HEAT

PUBLISHED BY FLEXIBLE OPEN AND DISTANCE EDUCATION
PRIVATE MAIL BAG, P.O. WAIGANI, NCD
FOR DEPARTMENT OF EDUCATION
PAPUA NEW GUINEA
2017

Writer
Giles Waken

Content Editors
Science Department
Subject Review Committee

Language Editor
Dr. Mirzi. L. Betasolo

Course Format Editor
Elizabeth. W. Aimundi

GRADE 12

PHYSICS

MODULE 2

TEMPERATURE AND HEAT

IN THIS MODULE, YOU WILL LEARN ABOUT:

12.2.1:	**TEMPERATURE**
12.2.2:	**THERMAL EXPANSION**
12.2.3:	**HEAT**
12.2.4:	**HEAT TRANSFER**
12.2.5:	**APPLICATIONS**

Acknowledgement

We acknowledge the contribution of all Lower and Upper Secondary teachers who in one way or another helped to develop this Course.

Our profound gratitude goes to the former Principal of FODE, Mr. Demas Tongogo for leading FODE towards this great achievement.

Special thanks are given to the staff of the Science Department of FODE who played active roles in coordinating writing workshops, outsourcing of module writing and editing processes involving selected teachers of Central Province and NCD.

We also acknowledge the professional guidance and services provided through-out the processes of writing by the members of:

Science Subject Review Committee-FODE
Academic Advisory Committee-FODE
Science Department- CDAD

This book was developed with the invaluable support and co-funding of the GO-PNG and World Bank.

DIANA TEIT AKIS
Principal-FODE

Flexible Open and Distance Education
Papua New Guinea

Published in 2017

Printed by the Flexible, Open and Distance Education
ISBN 978-9980-89-558-5
National Library Services of Papua New Guinea

TABLE OF CONTENTS

SECRETARY'S MESSAGE

Achieving a better future by individual students, their families, communities or the nation as a whole, depends on the kind of curriculum and the way it is delivered.

This course is part of the new Flexible, Open and Distance Education curriculum. The learning outcomes are student-centred and allows for them to be demonstrated and assessed.

It maintains the rationale, goals, aims and principles of the National Curriculum and identifies the knowledge, skills, attitudes and values that students should achieve.

This is a provision by Flexible, Open and Distance Education as an alternative pathway of formal education.

The Course promotes Papua New Guinea values and beliefs which are found in our constitution, Government policies and reports. It is developed in line with the National Education Plan (2005 – 2014) and addresses an increase in the number of school leavers affected by lack of access into secondary and higher educational institutions.

Flexible, Open and Distance Education is guided by the Department of Education's Mission which is fivefold;

- To develop and encourage an education system which satisfies the requirements of Papua New Guinea and its people
- To establish, preserve, and improve standards of education throughout Papua New Guinea
- To make the benefits of such education available as widely as possible to all of the people
- To make education accessible to the physically, mentally and socially handicapped as well as to those who are educationally disadvantaged

The College is enhanced to provide alternative and comparable path ways for students and adults to complete their education, through one system, two path ways and same learning outcomes.

It is our vision that Papua New Guineans harness all appropriate and affordable technologies to pursue this program.

I commend all those teachers, curriculum writers, university lecturers and many others who have contributed so much in developing this course.

UKE KOMBRA, PhD
Secretary for Education

MODULE 12.2: HEAT AND TEMPERATURE

Introduction

Heat is a form of energy that is very familiar to much of our experience. We rely on the heat produced by the chemical reaction of food during digestion to keep our bodies warm. The Earth's atmosphere requires heat to allow air to move and create weather patterns. These are just two examples of how much our lives depend on heat.

Temperature is the measure of the average kinetic energy in an object. In order to raise the temperature of an object, we must add energy to it. Likewise to decrease the temperature of an object, we must remove energy from that object. The energy that we add or remove from an object is termed as heat.

Throughout this module, we will discuss several basic aspects of both heat and temperature.

In the first part of this module, we will begin with a look at the particle kinetic theory of matter and its relationship to temperature. We then define temperature and look at the many ways in which we measure temperature.

In the second part of this module, we will look at the effect of temperature change on the size and dimensions of materials.

The third part of this module discusses heat as a form of energy, its units, and how materials absorb and release heat. We will also discuss latent heat and its implications for changes in state.

The fourth part looks at how heat is transferred from one place to another and how we can control the movement of heat.

The final part of this module allows us to apply some of the ideas and concepts of temperature, thermal expansion, heat and heat transfer to explain common practices and the operation of refrigerators and air conditioners.

A volcano is evidence of the high temperatures and heat energy beneath the Earth's crust.

Learning Outcomes

After going through this module, you are expected to:

- discuss temperature as a quantity and carry out temperature conversions between different temperature scales.
- discuss operating principles of various types of thermometers and identify practical uses for the various thermometers.
- explain thermal expansion of materials and perform calculations using thermal expansion formulae to solve problems.
- identify heat as a form of energy and discuss the various units for measuring heat including the conversion between these units.
- explain, discuss and apply the concepts of heat capacity, specific heat capacity, latent heat and specific latent heat capacities of various substances.
- calculate the amount of heat using the heat equation, latent heat equations and combinations of both changes in state and temperature of substances.
- describe the various methods of heat transfer and apply them in explaining natural phenomenon, artificial applications.
- solve problems involving heat transfer.
- apply concepts of temperature, heat and heat transfer to explain and discuss various applications.

Time Frame

Suggested allotment time: **9 weeks**

This module should be completed within 9 weeks.

If you set an average of 3 hours per day, you should be able to complete the module comfortably by the end of the assigned week.

Try to do all the learning activities and compare your answers with the ones provided at the end of the unit. If you do not get a particular exercise right in the first attempt, you should not get discouraged but instead, go back and attempt it again. If you still do not get it right after several attempts then you should seek help from your friend or even your tutor.

DO NOT LEAVE ANY QUESTION UNANSWERED.

12.2.1 Temperature

Temperature is one of the basic SI quantities used to measure how hot or cold an object is. We are all very familiar with this concept of temperature. However in this section we will look at temperature from a more scientific perspective.

In this section of our study we will look at temperature as a quantity, what it physically means and how it is measured in terms of units and instruments. We will look at the different units of measuring temperature as well as how each is related.

We will also look at various types of thermometers and the influence that temperature change has on the properties of many substances. The main emphasis is to identify how temperature influences the various properties.

Towards the end of this section, we will formally define temperature and look at the concepts of thermal contact and thermal equilibrium.

Temperature Units

The most common unit for temperature is **Degrees Celsius (°C)** also called **Degrees Centigrade**. This unit was made in such a way that the melting point of water is 0°C and the boiling point of water is 100°C at 1 atmosphere.

Another unit of temperature is the **Kelvin (K)**. The temperature 0K is called **absolute zero**. Absolute zero is the temperature that is conventionally thought to be the temperature at which there is no more heat in a body. That is, the motion of all particles ceases. Another important note is that degree celsius and kelvin have an equivalent scale. That is 1°C change in temperature is the same as 1K change in temperature.

Yet another unit for temperature is the **Degree Fahrenheit (°F)** which is used in some western nations. In the Fahrenheit scale, the freezing point of water is 32°F and the boiling point of water is 212°F. **The fahrenheit scale is not equivalent to that of degree celsius and kelvin.**

The conversion of between the temperature units is given below.

1. To convert from degrees celsius (°C) to kelvin (K) use the equation:

$$T_K = T_{^oC} + 273$$

2. To convert from degrees celsius (°C) to degrees fahrenheit (°F) use the equation:

$$T_{^oF} = \frac{9}{5} T_{^oC} + 32$$

Example 1

The temperature of a block of metal is 342K. What is the temperature in Degree Celsius?

Solution

$$T_{^0C} = T_K - 273$$

$$T_{^0C} = 342 - 273$$

$$T_{^0C} = 69^0C$$

Example 2

A normal human body temperature is 37°C. What is the temperature in Degrees Fahrenheit?

Solution

$$T_{^0F} = \frac{9}{5} T_{^0C} + 32$$

$$T_{^0F} = \frac{9}{5} \text{ x } 37 + 32$$

$$T_{^0F} = 98.6^0F$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 1

20 minutes

Read and answer the following questions accordingly on the spaces provided.

1. Convert the following temperatures from degree Celsius to Kelvin (°C→K)

a. 0°C	
b. 37°C	

c. -32°C	
d. 400°C	
e. -16°C	

2. What is the formula for converting temperatures from Kelvin to degrees Celsius?

3. Convert the following temperatures from Kelvin to degrees Celsius. (K→°C)

a. 197K	
b. 251K	
c. 465K	

d. 285.6K	
e. 28.8K	

4. Convert the following temperatures from degrees Celsius to degrees Fahrenheit. (°C→°F)

a. 0°C	
b. 37°C	
c. -32°C	
d. 400°C	
e. -16°C	

5. What is the formula for converting the temperatures from degree Fahrenheit to degree Celsius?

6. Convert the following temperatures from degrees Fahrenheit to degrees Celsius (°F→°C).

a. 98°F	
b. 102°F	
c. 212°F	
d. 158°F	
e. 50°F	

Thank you for completing learning activity 1. Now check your work. Answers are at the end of the module.

Thermometers

Thermometers are instruments which measure the change in temperature of an object by measuring the change in a physical property of the object.

The main physical properties that change with changes in temperature are;

(a) volume of a liquid
(b) length of a solid
(c) pressure of a gas at constant volume
(d) electrical resistance of a conductor
(e) radiation emitted by an object at high temperatures

We can establish temperature scales based on the range of temperatures and the way particular physical properties of a substance(s) change over the range of temperatures.

Types of thermometers
The following are some types of temperature measuring devices;

Liquid-in-glass thermometer
The liquid-in-glass thermometer makes use of the fact that liquid volume increases when temperature increases. Such thermometers are made by having a liquid, usually mercury or alcohol, sealed in a hollow glass rod. Temperature measurement is made when liquid expands. A draw back to the use of such thermometers is the limited range of temperatures. Most clinical thermometers are of this type.

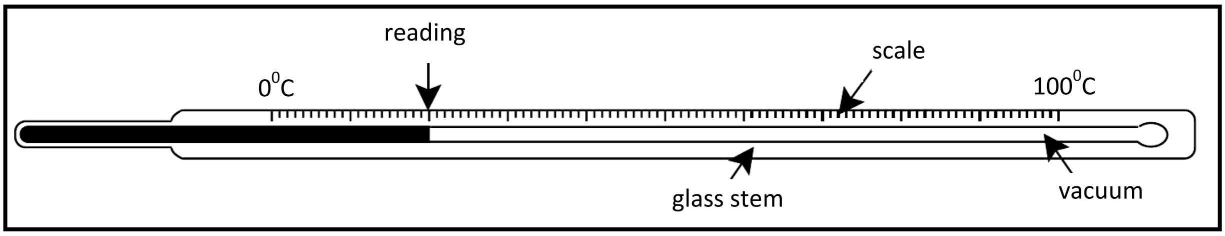


Figure 1 A typical liquid-in-glass thermometer. The liquid expands depending on temperature.

Bimetallic strip
The bimetallic strip **(or compound bar)** is composed of two different metals whose lengths expand at different rates when temperature increases and contract at different rates when temperature is decreased. The expansion and contraction at different rates causes the bimetallic strip to bend. It is often used in industries where high temperatures are measured. It may be limited to temperatures which are less than the melting point of both metals.

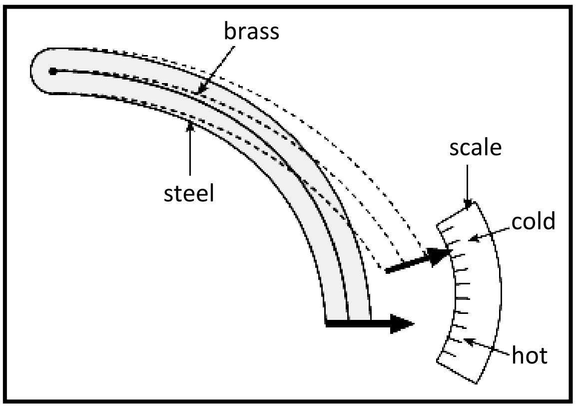


Figure 2 A bimetallic strip bends according to the different rates of expansion of brass and steel at different temperatures.

Thermocouple
The thermocouple consists of two different metal wires. One end is in a reference temperature (ice) while the other is used as a probe. Both wires are connected to a sensitive electric meter such as a galvanometer. When the probe-end is held at a higher temperature, the galvanometer gives a reading for the p.d. of both ends of a wire. The potential difference between these metals is proportional to the difference in temperature.

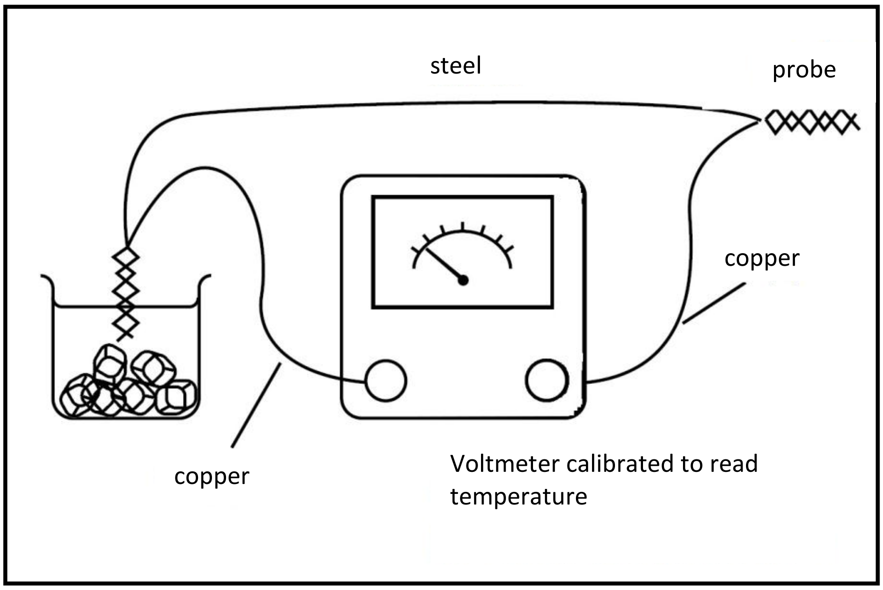


Figure 2 A thermocouple made from copper and steel wires.

Resistance thermometers
Resistance thermometers make use of the fact that resistance increases with an increase in temperature. A probe is made from a conducting wire and connected to a circuit with a meter which can give the reading of the resistance of the wire.

Pyrometers
Pyrometers make use of the fact that hot bodies give off electromagnetic (EM) radiation (infrared part of the EM spectrum).

Constant – volume gas thermometer
This thermometer makes use of the property of gases where if the volume of a gas is constant then temperature is proportional to pressure. Below is a diagram of such a thermometer. When the temperature of the gas is increased, its pressure is increased.

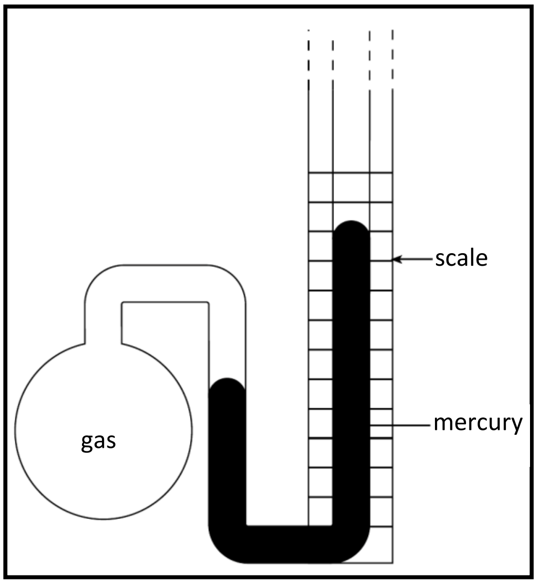


Figure 3 A constant-volume gas thermometer

The temperature in a constant-volume gas thermometer is measured by the change in pressure of the gas at different temperatures.

Example 3
A liquid thermometer is calibrated by immersing it in melting ice and then in boiling water. The column of the liquid is respectively 4cm and 29cm.

(a) What is the average change in length (cm) per unit change in temperature (°C) of the liquid?

Solution
This question is asking us to find by how much the length of the liquid column changes for every 1°C change in temperature. The melting point of water is 0°C while the boiling point of water is 100°C. We calculate this as follows;

$$\frac{\Delta L}{\Delta T} = \frac{29cm - 4cm}{100^0C - 0^0C} = 0.25cm/^0C$$

(b) Find the temperature when the column is 10.0cm long.

Solution
To find the temperature we divide the length by the answer in (a).

$$10cm \div 0.25cm/^0C = 40^0C$$

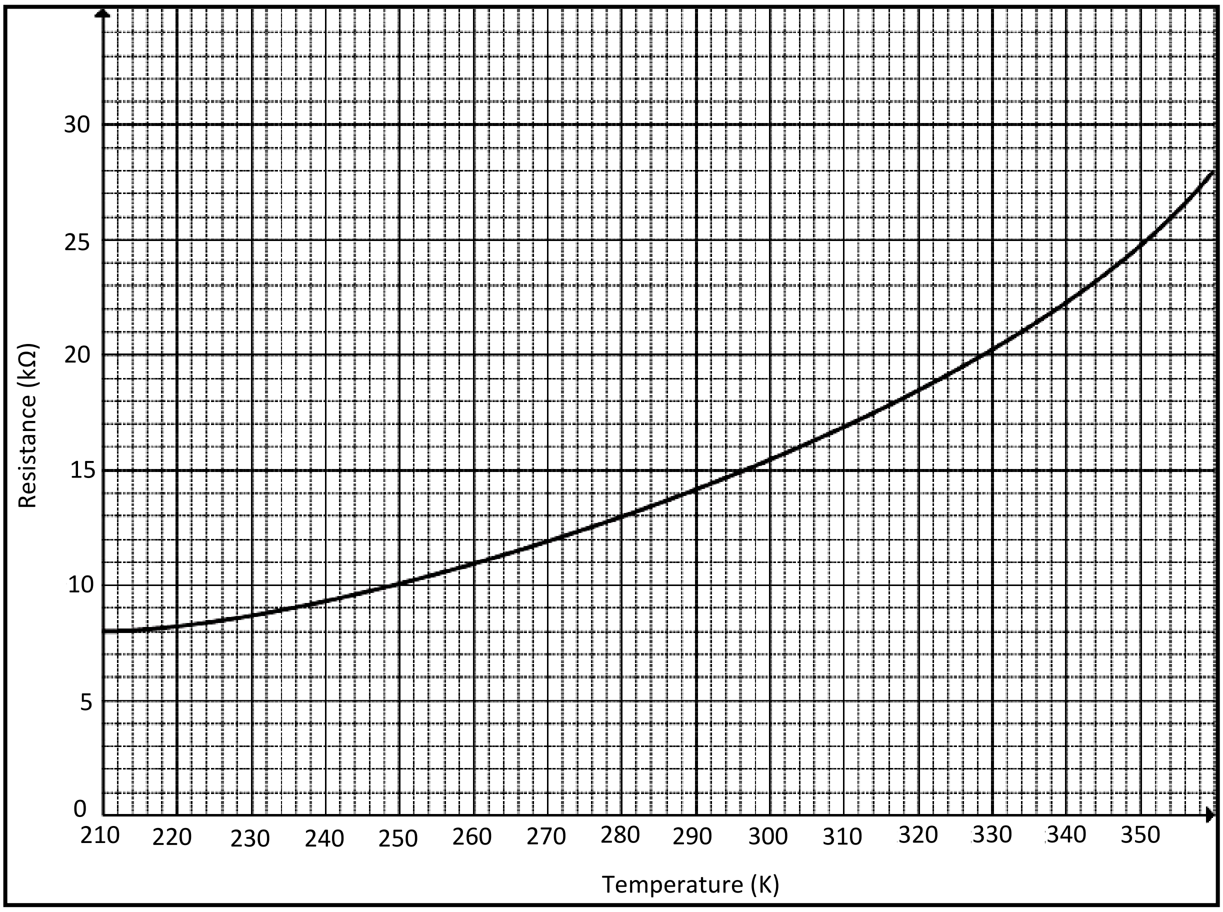
(c) What is the height of the column of liquid at 65^{0}C?

Solution
To find the height of the column, we multiply the result in (a) by the temperature.

$$0.25cm/^0C \times 65^0C = 16.25cm$$

Example 4
The following graph shows the change in resistance of a conductor as temperature increases.

RESISTANCE VERSUS TEMPERATURE GRAPH



(a) What is the resistance of the conductor at 280K?

Solution
From the graph the temperature 280K corresponds with 13Ω.

(b) If room temperature is 25°C, find the resistance of the conductor at that temperature.

Solution

$$T_K = T_{0_C} + 273$$

$$T_K = 25 + 273$$

$$T_K = 298K$$

According to the graph, the resistance of the conductor is approximately 15Ω at 298K.

Example 5
One end of a thermocouple probe is kept in an ice-water mixture at 0°C while the other is inserted into boiling water at 100°C. The reading on the meter is 64μA.

When one of the probes is kept in ice-water while the other is immersed in warm water, the reading on the thermocouple becomes 84μA.

What is the temperature of the warm water?

Solution
To answer this question we should note that the change in temperature (ΔT) is inversely proportional to the change in current (ΔI).

$$\Delta T \propto \frac{1}{\Delta I}$$

$$\Delta T = \frac{k}{\Delta I} \rightarrow k = \Delta T \text{ x } \Delta I$$

$$k = 100^0 C \text{ x } 64\mu A = 6400^0 C \cdot \mu A$$

$$\Delta T = \frac{6400^0 C \cdot \mu A}{84\mu\, A} = 76.2^0 C$$

Note: The change in temperature (ΔT) is 76.2°C which is the temperature that we are looking for. This is because one of the probes is in 0°C which is the reference. A reading will only be obtained in a thermocouple if there is a difference in temperature.

Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 2

20 minutes

Answer the following questions on the spaces provided.

1. List the main physical properties that are used in the construction of the thermometers discussed.

   i. ____________________
   ii. ____________________
   iii. ____________________
   iv. ____________________
   v. ____________________

---

2. Make a list of the thermometers discussed above, that rely on the expansion and or contraction of substances due to changes in temperature.

   ____
   ____
   ____
   ____

---

3. John constructs a liquid-in-glass thermometer using a thin glass tube and a liquid that expands at 0.3cm per degree Celsius change in temperature. At 0°C, the height of the liquid in the thermometer is 2.3cm.

   a) To what approximate height does the liquid rise when the thermometer is at 25°C?

   b) Suppose John wants to use his thermometer to measure temperatures from 0°C to 80°C, what should the minimum height of his glass tube be?

4. The resistance scale of temperature is defined by the equation below.

$$T^0C = \frac{R_T - R_0}{R_{100} - R_0} \text{ x } 100^0C$$

Where R_T is the resistance value at temperature T°C, R_{100} and R_0 are the resistance values at 100°C and 0°C respectively.

A resistance thermometer is calibrated by measuring the resistance of the thermometer at 0°C and then at 100°C. At 0°C, the resistance thermometer reads 10Ω. At 100°C, the thermometer reads 160Ω.

a) State how resistance, current and voltage generally change when temperature increases.

____

____

____

____

____

b) Using the formula and the information above, find the temperature when the resistance thermometer reads 80Ω?

c) What resistance value would we expect the thermometer to read at 40°C?

---

5. a) For a constant volume of gas, briefly explain how it's pressure changes when there is an increase or decrease in the gas temperature?

____

____

____

____

(b) 700g of a certain gas kept in a sealed container at 0°C has a pressure of 101 300Pa. At 30°C the gas pressure is double the pressure at 0°C.

What is the average change in pressure per degree celsius of this gas?

Thank you for completing learning activity 2. Now check your work. Answers are at the end of the module.

Temperature Definition

So far we have looked at the units of measuring temperature and the different instruments that we can use to measure temperature. Normally we would define temperature as a measure of how hot or cold an object is. This definition is not sufficient because it is based on our senses which cannot always be reliable or quantifiable. Let us now define temperature as a physical quantity.

Temperature and the kinetic theory of matter

In primary school you may have discussed the **Kinetic theory of matter**. This theory basically explains that all matter is composed of particles which have energy. Solid particles are held in close together and vibrate while in fixed positions. Liquid particles are able to move about freely and are further apart than those in solids. Gases move very quickly and very far apart. The particles in the three states of matter have energy called **kinetic energy** which is the energy possessed by any object that moves.

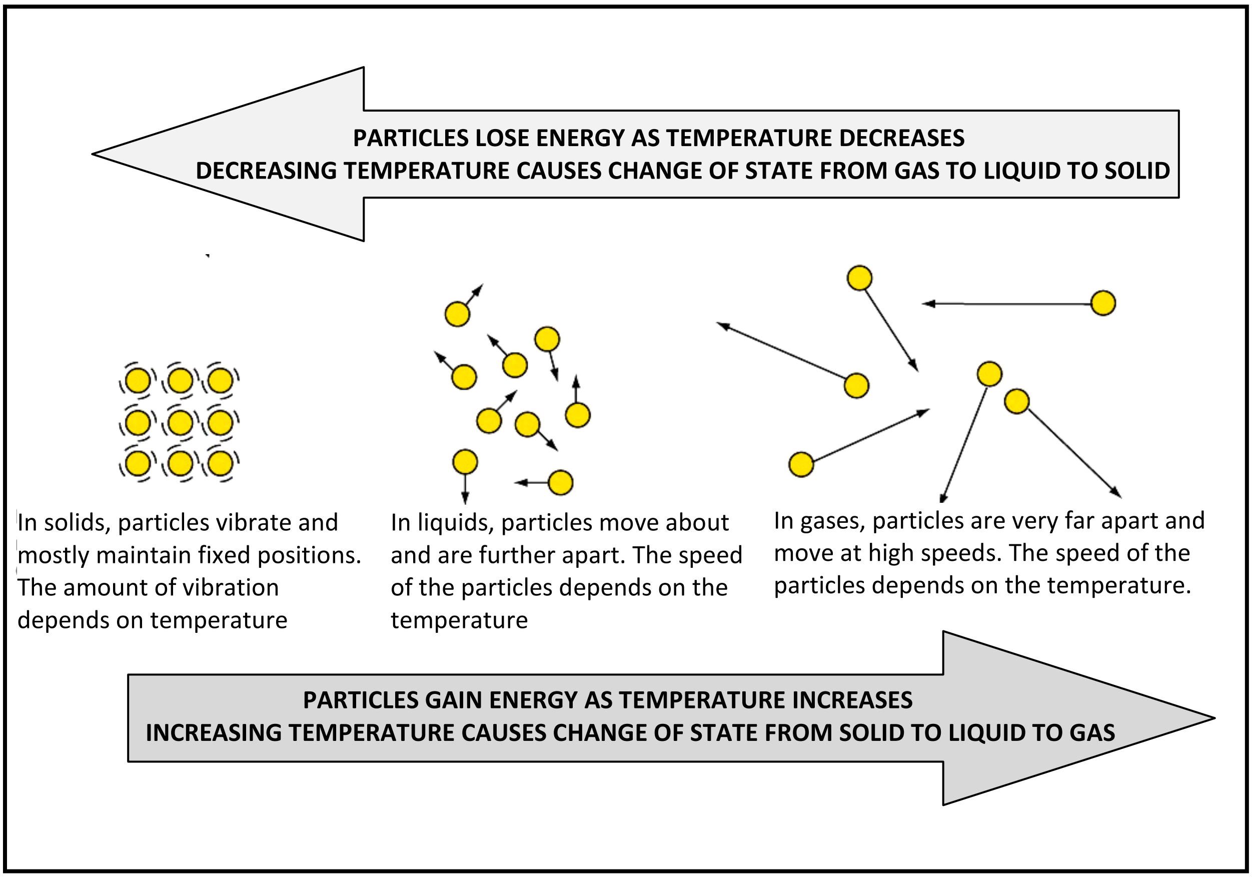


Figure 4 The kinetic theory of matter

In terms of the kinetic theory of matter, **temperature is defined as the average kinetic energy that each particle in an object possesses**. This means that an object which has a high temperature would have particles that have a high average kinetic energy or move very fast. Objects with low temperatures would have particles that have a low average kinetic energy or move slower.

Thermal equilibrium

> Temperature is a measure of whether or not two or more objects in **thermal contact** are in **thermal equilibrium**.

Two objects are in thermal equilibrium if their temperatures are the same. These two objects will be in thermal contact if there is a way in which the energy from one can be transferred to the other so that thermal equilibrium is reached.

The definition of temperature above tells us that if two objects that are in thermal contact are not in thermal equilibrium, then they have different temperatures and we can make a comparison of the temperatures for measurement.

Suppose we put a thermometer at 25°C in a cup of water which is kept at 50°C. Initially the water and thermometer are at different temperatures, when we put the thermometer into the water, we initiate the thermal contact between them. This means that there is energy transfer occurring between the water and the thermometer. After some time the thermometer reading changes from 25°C to 50°C and no further change in temperature is seen. We now say that the thermometer and water are at thermal equilibrium, because there is no more change in temperature and hence no more energy transfers between the water and the thermometer.

Note that being in thermal contact does not mean that objects must be in physical contact or "touching". Thermal contact can still occur even when objects are not touching. The idea of thermal contact will be further explained in the section on heat transfer later in this unit.

12.2.2 Thermal Expansion

When an object experiences a change in temperature, a change in length and size also occurs simultaneously. This changing in length and size when change in temperature occurs is called **thermal expansion**.

You probably have wondered why a corrugated iron roof creaks during the day or at night time or why bitumen roads and cement seem to crack after construction. All of these can be explained using the ideas of thermal expansion.

Figure 5 Effects of thermal expansion on roads (left) and railway tracks (right)

We have already looked at the effect that temperature has on the substances when we looked at thermometers. We will now expand this idea in general terms for some substances which change their physical dimensions when a temperature change occurs.

We will firstly look at the simplest case of thermal expansion which is linear thermal expansion and the formula for calculating changes in length. This deals with only changes in length that occurs when temperature is increased or decreased.

Second to this is area or superficial thermal expansion, where the area is changed due to a temperature change. It is important to note that linear and area expansions can only be applied to solids.

Lastly we will look at volume expansion which occurs for all substances whether they are solid liquid or gas. We will also look at how each of the three types of thermal expansion are related by their coefficients of thermal expansion.

Linear Thermal Expansion

Experimentally it can be determined that for any material, the change in length is proportional to the temperature and the length of the material.

The equation for calculating the amount of change in the given length of object for an object is given by;

$$\Delta L = \alpha L_0 \Delta T$$

Where **α** is called the **coefficient of linear expansion** which is unique number for different materials where its **unit is per degree Celsius (°C)$^{-1}$, L_0** is the original length of the object**, ΔT** is the change in temperature.

Some alternative forms of the linear expansion formula are shown below;

$$L_1 = L_0 + \alpha L_0 \Delta T$$

$$L_1 = L_0(1 + \alpha \Delta T)$$

$$\frac{L_1}{L_0} = 1 + \alpha \Delta T$$

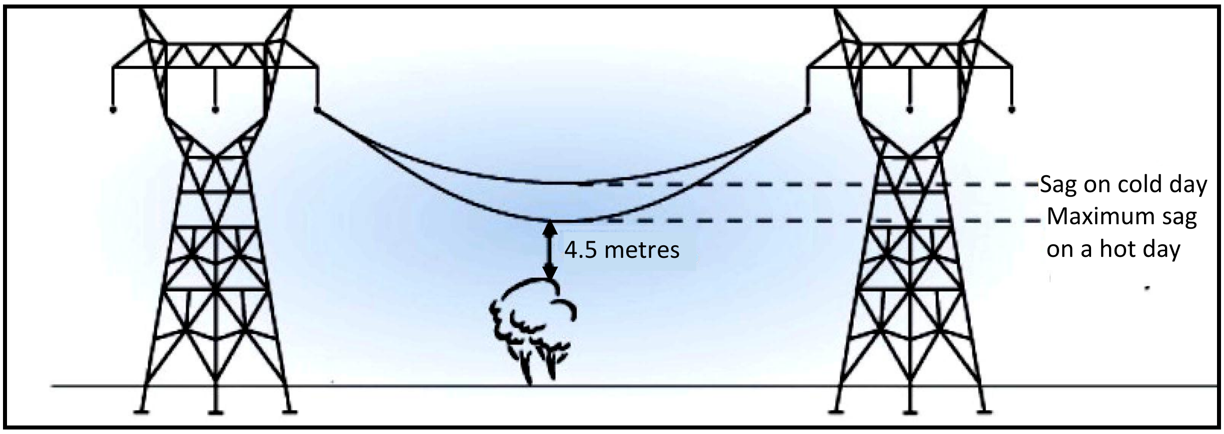


Figure 6 Sagging power lines is an example of thermal linear expansion

Below is a table showing the linear expansion coefficients for some materials.

Material	Coefficient of linear expansion, α (°C^{-1})
Aluminium	25 x 10^{-6}
Brass	19 x 10^{-6}
Copper	17 x 10^{-6}
Iron/steel	11 x 10^{-6}
Lead	29 x 10^{-6}
Glass	9 x 10^{-6}

Table 1 Linear expansion coefficients for some materials

Example 6

A steel beam is 20m long at 20°C. If the extremes of temperature to which it might be exposed to are -30°C and +40°C, how much will it contract and expand?

$$\left(\alpha_{steel} = 11 \text{ x } 10^{-6} \ (^{0}C)^{-1}\right)$$

Solution

Here we are to determine the change in length (expansion) when the temperature changes from 20°C to 40°C and the change in length (contraction) when the temperature changes from 20°C to -30°C.

Expansion;

$\Delta L = \alpha L_0 \Delta T$

$\Delta L = 11 \text{ x } 10^{-6} \text{ x } 20m \text{ x } (40^{0}C - 20^{0}C)$

$\Delta L = 0.0044m = 4.4mm$

Contraction;

$\Delta L = \alpha L_0 \Delta T$

$\Delta L = 12 \text{ x } 10^{-6} \text{ x } 20m \text{ x } (20^{0}C - -30^{0}C)$

$\Delta L = 0.011m = 11mm$

Area (Superficial) Thermal Expansion

Since the length and width of a flat sheet of material will change with temperature, the area must change and so we can define an equation to calculate this change in area.

Any change in area is given by the following formula.

$$\Delta A = 2\alpha A_0 \Delta T$$

ΔA is the change in area or $A_1 - A_0$, **α** is the coefficient of linear expansion, A_0 = **original area,** A_1 is the area after thermal expansion**;** **ΔT** is the change in temperature.

Alternate forms of this formula are;

$$A_1 = A_0 + 2\alpha A_0 \Delta T$$

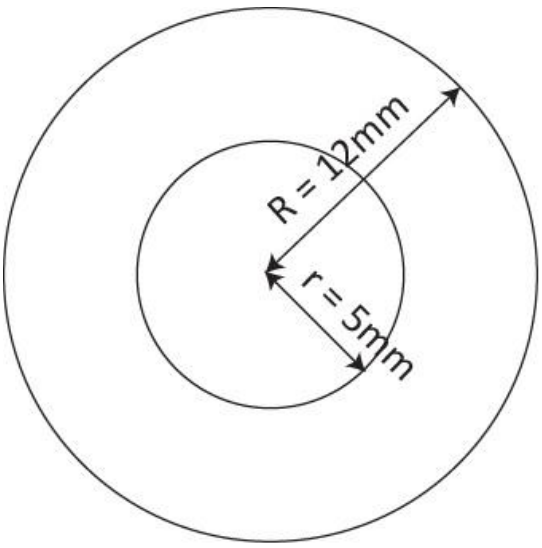
$$\frac{A_1}{A_0} = 1 + 2\alpha\Delta T$$

Each change in dimensions depends on the initial length. This means that for a shape such as a rectangle, the shortest side changes the least. However the rectangle itself experiences a change in Area.

Example 7

A circular aluminum washer (shown below) has an inner radius of 5mm and an outer radius of 12mm at 25°C. It is heated so that its temperature reaches 100°C.
(use π = 3.14, $\alpha_{Al} = 25 \times 10^{-6}\ °C^{-1}$)

.



(a) Determine the initial area of washer to two (2) decimal places.

(b) Determine the new area of the washer to two (2) decimal places

Solution

(a) We can calculate the area of the washer using the formula for the area of a circle.

$A = A_{Outer} - A_{Inner}$

$A = \pi R_0^2 - \pi r_0^2$

$A = 3.14 \times (12mm)^2 - 3.14 \times (5mm)^2$

$A = 452.16mm^2 - 78.5mm^2$

$A = 373.66mm^2$

(b) Let us calculate the new areas of both the inner and outer circles then subtract to find the new area.

New area of the outer circle

$A_1 = A_0 + 2\alpha\Delta T$

$A_1 = 452.16 + 452.16 \times 2 \times 25 \times 10^{-6} \times 75^0C$

$A_1 = 452.16mm^2 + 1.6956mm^2 = 453.86mm^2$

New area of the inner circle

$A_1 = A_0 + 2\alpha\Delta T$

$A_1 = 78.5 + 78.5 \times 2 \times 25 \times 10^{-6} \times 75^0C$

$A_1 = 78.5mm^2 + 0.294375mm^2 = 78.79mm^2$

New area of the washer is $A = 453.86mm^2 - 78.79mm^2 = 375.07mm^2$

Volume Thermal Expansion

The change in volume of a material which undergoes a temperature change is given by;

$$\Delta V = \beta V_0 \Delta T$$

Where **ΔV** is the change in volume (m^3), **β** is the coefficient of volume expansion with its unit **($°C^{-1}$)**, and ΔT is the change in temperature **(°C).**

The table below shows average expansion coefficients for some materials near room temperature

Material	Average linear expansion Coefficient (α) $(^oC)^{-1}$	Material	Average Volume Expansion Coefficient (β) $(^oC)^{-1}$
Aluminium	25×10^{-6}	Alcohol, ethyl	1.12×10^{-4}
Brass and bronze	19×10^{-6}	Benzene	1.24×10^{-4}
Copper	17×10^{-6}	Acetone	1.5×10^{-4}
Glass (ordinary)	9×10^{-6}	Glycerine	4.85×10^{-4}
Glass pyrex)	3.2×10^{-6}	10^{-6}Mercury	1.82×10^{-4}
Lead	29×10^{-6}	Turpentine	9.0×10^{-4}
Steel	11×10^{-6}	Gasoline (petrol)	9.6×10^{-4}
Invar (Ni-Fe alloy)	0.9×10^{-6}	Air at 0^oC	3.67×10^{-3}
Concrete	12×10^{-6}	Helium	3.665×10^{-3}

Table 2 Average expansion coefficients for some materials near room temperature

Relationship between α and β

From the study of dimensional analysis, we know that volume is length cubed (i.e. raised to the third power. The original volume V_0 can be expressed as the cube of initial length dimensions.

$$V_0 = L_0^3$$

Using the volume expansion formula, we can express the above equation with α and β.

$$V_1 = \beta V_0 \Delta T = ((L_1 - \alpha L_0 \Delta T)^3)$$

Expanding the expression on the right we get;

$$V_1 - \beta V_0 \Delta T = L_1^3 - 3\alpha L_1^2 L_0 (\Delta T) + 3\alpha^2 L_1 L_0^2 (\Delta T)^2 - \alpha^3 L_0^3 (\Delta T)^3$$

Since **α** is small number any terms that contain α^2 and α^3 will be very small (close to zero) and thus are negligible. The only terms that remain then are;

$$V_1 = \beta V_0 \Delta T = L_1^3 - 3\alpha L_1^2 L_0 (\Delta T)$$

We can identify and equate common terms on the left and right hand sides of the equation. The most important relationship that we have determined from the above equations is that between the coefficient of volume expansion (β) and the coefficient of linear expansion (α). The relationship is;

$$\beta = 3\alpha.$$

Example 8

The 70L steel petrol tank is filled to the top with gasoline at 20°C. The steel tank is then left to sit in the sun where it reaches a temperature of 50°C. How much petrol do you expect to overflow from the tank? (Use the coefficients of thermal expansion table on pg. 26)

Solution

To work out this problem we need to find the difference in the change in volume between the petrol tank and the petrol.

Expansion of petrol tank

$$\Delta V_{tank} = V_0\beta\Delta T$$

$$\Delta V_{tank} = 70L \times 11 \times 10^{-6} \times 15^0C$$

$$\Delta V_{tank} = 0.01155L$$

Expansion of petrol

$$\Delta V_{petrol} = V_0\beta\Delta T$$

$$\Delta V_{petrol} = 70L \times 9.6 \times 10^{-4} \times 15^0C$$

$$\Delta V_{petrol} = 1.008L$$

Difference in volume change between petrol tank and petrol

$$1.008L - 0.01155L = 0.996L = 996mL$$

We would expect almost 1L of fuel to overflow from the tank.

Now check what you have just learnt by trying out the learning activity on the next page!

Learning Activity 3

30 minutes

Answer the following questions on the spaces provided. For α and β values, use the table of thermal expansion coefficients on page 26.

1. State the three factors that determine the linear expansion of an object.

   a) ____________________
   b) ____________________
   c) ____________________

---

2. A strip of lead metal initially with a length of 35cm is heated so that its temperature changes by 80°C.

   Find the change in length of the lead and its new length at the new temperature.

---

3. Find the temperature range of a 25m aluminum cable that expands and contracts by 7mm each day.

---

4. A metallic axle with a diameter of 20mm has to be fitted into a wheel which has a circular hole at its center with diameter 18.5mm. To fit the axle into the hole, the axle is dipped into liquid nitrogen at a temperature of -200°C. Calculate the coefficient of linear expansion of the metal.

5. A square sheet of steel is heated from 25°C to 100°C. it experiences a change in area of $0.25cm^2$. Using the formula for area expansion, find the initial area of the steel sheet.

---

6. A brass cylinder with a radius of 5cm and height of 5cm is kept at a temperature of -10°C. if the cylinder is heated to a temperature of 50°C, calculate the new volume of the cylinder.

---

7. What temperature change is required to make 25mL of acetone expand to 30mL?

Thank you for completing learning activity 3. Now check your work. Answers are at the end of the module.

12.2.3 Heat

The transfer of thermal energy from one body to another by difference in temperature is called **heating**. The heat flow between two objects depends on their temperatures.

The word heat can be used to refer to the energy that is transferred between two objects before they reach thermal equilibrium. This should be distinguished from the energy that is possessed internally by all objects. We refer to the **internal energy** as **thermal energy**. In other words you can think of thermal energy as the energy that is contained in an object. Heat can be considered as any energy that is added or removed from the object. Thus when heating occurs, the thermal energy of a body is either increased or decreased.

In this section of our study we will firstly look at the units used in the measurement of heat. These units are used in a variety of contexts and it is worthwhile that we identify these units as well as the methods of conversion which is the main emphasis.

The second part of this section deals with heat capacity and the heat equation. This is also one of the main parts of our study on heat. In this part we look at how to calculate the amount of energy used in the process of changing the temperature of a substance.

We apply the law of conservation of energy to the concept of heat and in the use of the heat equations as well as with latent heat.

Finally also look at the concept of latent heat as it is applied when substances change state.

Heat Units

There are several units used in the measurement of heat as a quantity.

Units for heat
The three (3) units commonly used to measure heat are calorie, BTU and the joule.

1 **Calorie** (**cal**) is the amount of heat required to raise the temperature of 1 gram of water by 1°C. The **kilocalorie** (**kcal**) is a unit that is often used.

BTU stands for **British Thermal Unit** where 1 BTU is the amount of heat required to raise the temperature of one pound of water by 1°F.

The **Joule** is the SI unit for measurement of energy.

Conversions between heat units

To convert from Calories to Joules, the conversion factor is; 1 calorie = 4.2 Joules
To convert from BTU to Joule, the conversion factor is; 1 BTU = 1 055 Joules

Example 6

1 serving of butter is said to contain 1900 kcal of energy. How much energy is this in Joule and in BTU?

Solution

In this question we are simply converting the amount of energy already given in kilocalories to Joules and BTU.

From kcal to Joule

$$1900\text{kcal} = 1\,900\,000\text{cal} \times 4.2\text{J/cal} = 7\,980\,000\text{J}$$

From Joule to BTU

$$7\,980\,000\text{J} = \frac{7\,980\,000\text{J}}{1\,055\text{J/BTU}} = 7\,563.98\text{BTU}$$

Heat Capacity & Specific Heat Capacity

Equal amounts of heat applied to equal masses of different substances tend to produce unequal temperature rise. This is a common observation in cooking for instance. If we heat the same amount of cooking oil and water in the same type of saucepan with same amount of heat, we will find that the temperature of water will be lower than that of cooking oil. This observation can be explained by the concept of heat capacity.

Heat capacity

If we apply 1000J of energy to 100g of copper and 100g water, which one do you think will have the higher temperature?

This question can only be answered if we know how well each of these two substances is capable of absorbing energy. The ability of a substance to absorb and release heat is known as **heat capacity**.

Heat capacity is defined as the amount of heat gained (or lost) by a substance for a change in temperature of 1°C.

To calculate heat capacity (C) we use the following equation;

$$\mathbf{C} = \frac{\mathbf{Q}}{\mathbf{\Delta T}}$$

C is the heat capacity in **Joules per degree Celsius** (**J/°C**), **Q** is the amount of thermal energy in Joules and **ΔT** is the temperature in degree Celsius.

Example 7

When 5 400J of thermal energy is added to a steel frying pan, the approximate change is temperature is 30°C. What is the heat capacity of the steel frying pan?

Solution
The amount of energy added (**Q**) is 5 400J while the change in temperature (**ΔT**) of the frying pan is 30°C.

$$\mathbf{C = \frac{Q}{\Delta T}}$$

$$C = \frac{5\ 400J}{30^0 C}$$

$$C = 180J^0C^{-1}$$

The heat capacity of the steel frying pan tells us that it requires 180J of energy to increase the temperature by 1°C. The heat capacity of an object depends on the type of substance it is made of and it's mass. The steel frying pan given in the above example would have a different heat capacity from an identical frying pan with the same mass but is made from copper.

Heat capacity must not be confused with heat conduction. A substance with a high heat capacity tends to absorb large amounts of energy to reach a temperature change of 1°C while a substance with a high heat conduction is able to transfer heat at a faster rate. The difference here is that heat capacity is not dependent on time whereas heat conduction is dependent on time.

Specific heat capacity
The concept of **specific heat capacity** (**c**) takes the idea of heat capacity one step further. Take note that specific heat capacity (c) and heat capacity (C) are two different quantities.

The specific heat capacity of a substance is the amount of energy that 1 kg of a substance gains (or loses) in order for a change in temperature of 1°C to occur.

Notice that specific heat capacity includes the mass of the substance as well. The unit for specific heat capacity is Joules per kilogram per degree Celsius (J/kg°C).

The relationship between heat capacity (**C**) and specific heat capacity (**c**) is given by the equation below.

$$\mathbf{C = mc}$$

Given the heat capacity of a substance we can determine the mass of a substance by using this relationship between heat capacity and specific heat capacity.

Example 8
Determine the mass of the steel frying pan in Example 7 if the specific heat capacity of steel is 450 J/kg°C.

(solution next page)

Solution

From example 7, C = 180J/°C while c = 450J/kg°C

$$m = \frac{C}{c}$$

$$m = \frac{180J/^0C}{450J/kg^0C} = 0.40kg$$

The table below shows the specific heat capacities of some substances at 25^{o}C and atmospheric pressure.

Specific heat capacity *c*		
Substance	**J/kg°C**	**Cal/g°C**
Elemental Solids		
Aluminium	900	0.215
Berrylium	1 830	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Gold	129	0.030 8
Iron	448	0.107
Lead	128	0.030 5
Silicon	703	0.168
Silver	234	0.056
Other Solids		
Brass	380	0.092
Glass	837	0.200
Ice (-5^{0}C)	2 090	0.50
Marble	860	0.21
Wood	1 700	0.41
Liquids		
Alcohol (ethyl)	2 400	0.58
Mercury	140	0.033
Water (15^{0}C)	4 186	1.00
Gas		
Steam (100^{0}C)	2010	0.48

Table 3 Specific Heat Capacity of some substances at 25^{o}C and atmospheric pressure

Example 9

A 1.5kg brass saucepan is heated on an open fire until it reaches a temperature of 250°C. If the specific heat capacity of brass is 380J/kg°C, what is the heat capacity of this saucepan?

Solution

$$\mathbf{C = mc}$$

$$C = 1.5kg \times 380J/kg^0C$$

$$C = 570J/^0C$$

Heat Equation

The heat equation allows us to determine the amount of thermal energy that is gained or lost (**Q**) to change the temperature of an object.

This amount of thermal energy is proportional to the mass of the object **m** and the temperature change (**ΔT**). This is expressed in the equation;

$$\mathbf{Q = mc\Delta T}$$

Where **c** is the specific heat capacity of the substance, and is defined as the amount of energy required to raise the temperature of 1 kg of the substance by 1°C. Unit for specific heat capacity is **Joule per kilogram per degree celsius (J/kg°C)**.

Example 10

How much energy is required to raise the temperature of 20kg of iron from 10°C to 90°C given that $\mathbf{c_{iron}}$ = 450 J/kg°C?

Solution

$$\mathbf{Q = mc\Delta T}$$

$$Q = 20kg \times 450J/kg^0C \times (90^0C - 10^0C)$$

$$Q = 720\,000J$$

The amount of energy is also equivalent if the 20kg iron in the example had cooled from 90°C to 10°C. That is the equation is valid for increase or decrease in thermal energy, with a corresponding increase or decrease in temperature.

Example 11

Water has a specific heat capacity of 4186J/kg°C. 125 000J of energy is given off by a mass of water when it cools from 100°C to 25°C. What is the mass of water that has cooled?

Solution

To find the mass of water, we must rearrange the heat equation and make **m** the subject.

$$\mathbf{m = \frac{Q}{c\Delta T}}$$

$$m = \frac{125580J}{4186J/kg^{0}C \times (100^{0}C - 25^{0}C)}$$

$$m = 0.398kg$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 4

20 minutes

Answer the following questions on the spaces provided.

1. Express the following energy values in calories and BTU.

Energy (Joules)	**Energy (Calories)**	**Energy (BTU)**
a) 500J		
b) 2500J		
c) 198000J		
d) 800kJ		
e) 1.2MJ		

---

2. Explain the difference between heat capacity and specific heat capacity.

____

____

____

____

3. 100g of copper is heated so that it experiences a 130°C rise in temperature.

   a) Given that copper has a specific heat capacity (c) of 387J/kg°C, find the amount of heat energy added.

   b) If we double the mass of copper, how would this affect the amount of energy needed to heat copper with the same temperature rise?

   ____
   ____
   ____
   ____

4. Lead has a specific heat capacity (c) of approximately 130J/kg°C. A sample of lead has a heat capacity (C) of 975J. Its temperature was decreased by 60°C.

   a) What is the mass (in kg) of the lead sample?

   b) How much energy has been removed from the lead sample in this decrease in temperature?

5. A 120g amount of sodium chloride is heated from 25°C to 100°C. The amount of energy added is calculated to be 7 920J.

   a) Determine the heat capacity of 120g of sodium chloride.

   b) Find the specific heat capacity of sodium chloride.

c) How much energy is required to cause the same temperature change for 200g of sodium chloride?

---

6. 50g of a metal at an initial temperature of 200°C is cooled to 40°C. The amount of energy that is given off in cooling this metal is 1872J.

   a) Find the specific heat capacity of the metal.

   b) Use the table of specific heat capacities to identify the metal whose specific heat capacity you found in a.

Thank you for completing learning activity 4. Now check your work. Answers are at the end of the module.

Calorimetry

Calorimetry is a field of study that looks at measuring the amount of thermal energy gained or lost by substances. It uses the heat equation and the law of conservation of energy to help determine amounts of energy as well as heat capacities and specific heat capacities of substances.

When two or more objects are at different temperatures in some sort of isolation, heat can flow from the one with the higher temperature to the one at a lower temperature until both objects are at equal temperature this is known as thermal equilibrium. This also satisfies the Law of Conservation of energy. In an isolated (or closed) system at thermal equilibrium conservation of thermal energy can be summarised by the equation below.

Heat lost = heat gained

The following examples illustrate the use of the law of conservation of energy in dealing with situations involving heat.

Example 12
200g of water at 95°C is poured into a 150g glass cup initially at 25°C. What will the final temperature of the mixture be when equilibrium is reached, assuming that no heat flows to the surroundings? ($\mathbf{c_{water}}$= 4200 J/kg°C , $\mathbf{c_{glass}}$ = 840J/kg°C)

Solution
At the beginning it is important that we analyse the question to determine which substance gains energy and which one loses energy. Since water has the higher temperature it is the one that loses energy to be cooler while the glass gains energy to become warmer. We should also be aware that since water and glass begin at different temperatures, they will have to reach equilibrium at the same temperature. With these ideas in mind let's calculate the final temperature.

$$\text{Heat gained} = \text{heat lost}$$

$$Q_{glass} = Q_{water}$$

$$m_{glass}\ c_{glass}\Delta T_{glass} = m_{water}C_{water}\Delta T_{water}$$

$$0.15\text{kg} \times 840\text{J/kg}^0\text{C} \times (T_f - 25^0\text{C}) = 0.200\text{kg} \times 4186\text{J/kg}^0\text{C} \times (95^0\text{C} - T_f)$$

Notice how $\Delta T_{glass} = T_f$ - 25°C, this is because we expect that the glass will 'warm-up' after we add the hot water into it. The final temperature T_f at equilibrium will then be higher than the initial temperature of the glass. A similar reasoning is applied for water $(\Delta_{water} = 95^0\text{C} - T_f)$ which will be at a lower temperature.

$$126T_f - 3150 = 79534 - 837.2T_f$$

Solving for T_f $\quad 126T_f + 837.2T_f = 79534 + 3150$

$$963.2T_f = 82684$$

$$T_f = \frac{82684}{963.2} = 85.84^0\text{C}$$

This answer makes sense because, glass having a lower specific heat capacity will reach a higher temperature (60°C more than initially). The specific heat capacity of water is about 4 times greater than that of glass and so it does not experience a lot of change in temperature.

Example 13

0.25kg of honey at 63°C is added to an aluminium container of mass 300g initially at 15°C. Assuming no energy is lost to the surroundings, calculate the specific heat capacity of honey if the specific heat capacity of aluminium is 900J/kg°C and the final temperature of the mixture is 48°C?

Solution

We can tell that the aluminium container gains heat because its temperature has increased. Therefore,

Heat gained by aluminium = Heat lost by honey

$$Q_{al} = Q_{hn}$$

$$m_{al}c_{al}\Delta T_{al} = m_{hn}c_{hn}\Delta T_{hn}$$

$$c_{hn} = \frac{m_{al}c_{al}\Delta T_{al}}{m_{hn}\Delta T_{hn}}$$

$$c_{hn} = \frac{0.300\text{kg x } 900\text{J/kg}^0\text{C x } 33^0\text{C}}{0.25\text{kg x } 15^0\text{C}}$$

$$c_{hn} = 2\ 376\text{J/kg}^0\text{C}$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 5

20 minutes

Answer the following questions on the spaces provided.

1. 50g of copper is heated by placing it in boiling water (100°C). It is then placed in a beaker containing 250 g of an unknown liquid at 20°C. The final temperature of the copper and the liquid is found to be 25°C.

   What is the specific heat of the liquid? (Assume no heat is lost to the surroundings. Specific heat capacity of copper = 390J/kg°C.)

2. A 1500W electric jug is used to heat 500mL of water. Calculate the time for the jug to raise the temperature of the water from room temperature, 20°C, to boiling point. (*Note:* 1500W means it supplies 1500J of heat energy every second. The density of water is $1000kgm^{-3}$, Use specific heat capacity of water = 4200J/kg°C)

3. In an experiment, 500g of copper at 80°C is dropped into 1kg of kerosene at 20°C. The mixture reached a temperature of 25°C. What is the specific heat capacity of kerosene? (use specific heat of copper = 390J/kg°C)

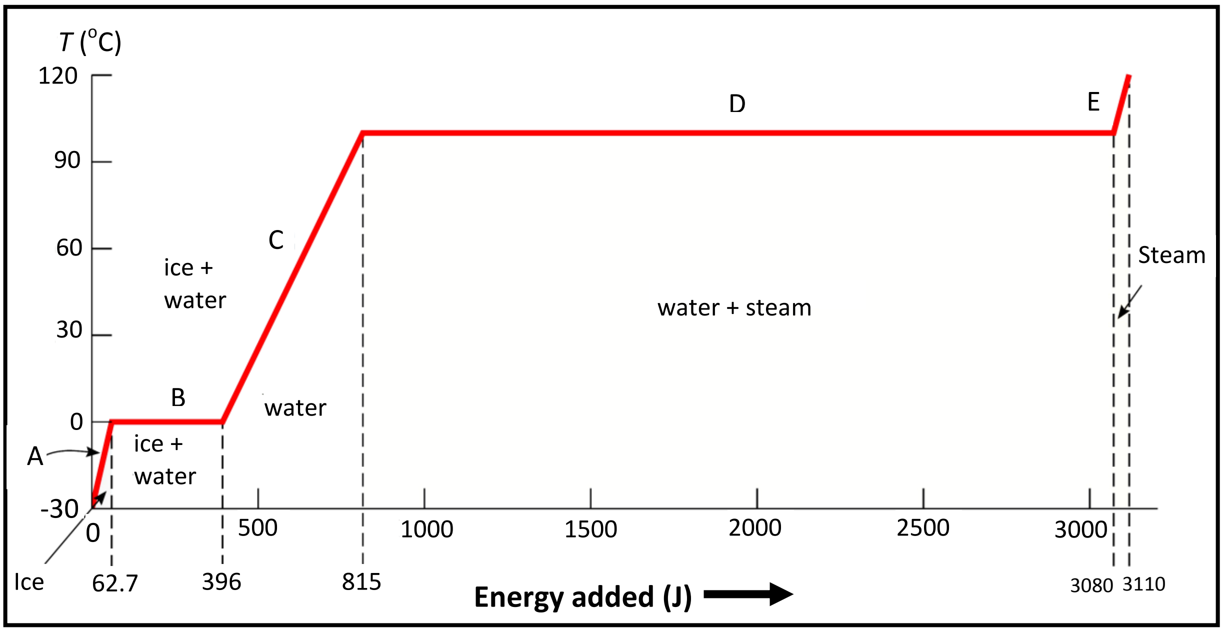
Thank you for completing learning activity 5. Now check your work. Answers are at the end of the module.

Latent Heat

The word **latent** from any dictionary would have a similar meaning to the word **hidden**. Latent heat is something that we observe when we change the state of a substance either from solid to liquid or from liquid to gas and vice versa.

When a material changes state (from solid to liquid or liquid to gas and vice versa) a certain amount of energy is involved in the change of state. Observe the graph below of thermal energy added to bring 1kg of ice at -30°C to steam at 120°C.

A GRAPH OF TEMPERATURE VERSUS ENERGY



Notice the flat areas B and D on the graph. In the two (2) areas (B and D), energy is being added, but temperature is not changing.

From the energy added in B and D are very large. The energy added in B and D is called **latent heat**. These two sections earn this name because we can see that energy is added but there is no change in temperature.

Latent heat capacity (Latent heat) is the energy required to change the state of a substance without a change in temperature. Latent heat capacity is measured in Joules (J).

In Figure 8, we can see that latent heat occurs at the melting point and boiling point of water. This means that we **add** about 330 000J of energy to change 1kg of ice to 1kg of water and about 2 260 000J of energy to change 1kg of water to 1kg of steam. If we reverse the process by changing 1kg of water to ice 330 000J of energy would have to be **removed** from water. Likewise, when changing 1kg of steam to water, 2 260 000J of energy will have to be removed.

Apart from latent heat, we also have **specific latent heat capacity**. The two (2) types of specific latent heat are described below.

The heat required to change 1.0kg of a substance from solid to liquid state without a change in temperature is called the **specific latent heat of fusion (L_f)**. The latent heat of fusion has the units **Joule per kilogram** (**J/kg**).

The heat required to change a substance from liquid to vapour (gas) state without a change in temperature is called the **specific latent heat of vaporization (L_v)**.

The latent heat in a change of state depends not only on the latent heats but also on the total mass of the substance.

Latent heat is given by; $\mathbf{Q = mL}$

Q refers to the latent heat (in Joules) required or given off to reach a particular state, **m** is the mass of the substance (in kilograms), and **L** is the specific latent heat of either fusion or vaporisation (given in Joules/kilogram).

In the graph on the previous page, we can see that water has a specific latent heat of fusion of approximately 333 000 J/kg (part labelled B). We can also see that the specific latent heat of vaporization of water is approximately 2 260 000 J/kg (part labelled D).

Latent heat is considered to be the energy required to break intermolecular bonds between molecules.

During the process of melting, energy is added so that particles can break free from the bonds that hold them while in solid state. During the process of freezing for instance, energy is removed from water until its molecules form the bonds that are necessary for water to become a solid. This is why the temperature of a mixture of ice and water remains at 0°C. During a change of state of a substance of water from solid (ice) to liquid (water), a mixture of both states is maintained while the latent heat is applied.

Latent heat has many important applications. Substances such as water have a very high specific latent heat of vaporisation. This can be very useful in removing heat from areas where it is not needed.

One application of latent heat is sweating. Sweating occurs when our body temperature. It is the body's mechanism for cooling. Water has a very high latent heat of vaporization. Thus when water in sweat evaporates, it removes heat from the skin allowing the body to remove excess heat.

Sweat, for instance, is an application of latent heat. When body temperature becomes higher than normal, a person's skin will release excess water to the skin's surface (in the form of sweat most of which is composed of water (up to 90%)). This excess water when evaporated (changes from liquid to gas) takes up a lot of heat from the skin. 1 gram of sweat can remove as much as 200kJ of energy. The cooling effect that one feels after a long walk in the sun is actually an effect of the removal of heat from the body by sweat. The rate of evaporation of sweat increases when a slight breeze blows.

Note that both the specific latent heats of fusion and vaporisation are unique for different substances. A table of specific latent heats for different substances is given in the table below.

The table below shows the latent heat of fusion and vaporisation of several substances.

LATENT HEATS OF FUSION AND VAPORISATION				
Substance	**Melting Point (^{0}C)**	**Latent Heat of Fusion (J/kg)**	**Boiling Point (^{0}C)**	**Latent Heat of Vaporisation (J/kg)**
Helium	-269.65	5.23×10^3	-268.93	2.09×10^4
Nitrogen	-209.97	2.55×10^4	-195.81	2.01×10^5
Oxygen	-218.79	1.38×10^4	-182.97	2.13×10^5
Ethyl Alcohol	-114	1.04×10^5	78	8.54×10^5
Water	0.00	3.33×10^5	0.100	2.26×10^6
Sulphur	119	3.81×10^4	444.60	3.26×10^5
Lead	327.3	2.45×10^4	1 750	8.70×10^5
Aluminium	660	3.97×10^5	2 450	1.14×10^7
Silver	960.80	8.82×10^4	2 193	2.33×10^6
Gold	1 063.00	6.44×10^4	2 660	1.58×10^6
Copper	1 083	1.34×10^5	1 187	5.06×10^6

Table 4 Latent heat of fusion and vaporisation of several substances

Most calculations involving latent heat will contain changes in state. The heat equation will also be considered in some cases where a change in phase is part of the change in temperature.

Example 14
How much energy is needed to change 0.120kg of solid sulphur to liquid at its melting point of 119°C?

Solution
This is a simple calculation since the 0.120kg of sulphur is already at 119°C and no other temperature is given. The energy involved is just the latent heat of fusion (Q). The specific latent heat of fusion of sulphur is 38 100J from the table above.

$Q = mL_f$
$Q = 0.120kg \times 38\ 100J$
$Q = 4\ 572J$

Example 15
Calculate the energy required to completely melt 10 grams of gold initially at room temperature (25°C).

Solution
This question is answered by calculating two parts. Firstly we must calculate the energy to raise the temperature of gold from 25°C to its melting point at 1063°C.
Let us call this Q_1. Secondly we must calculate the energy to change state from solid to liquid. Let us call this Q_2. The sum of Q_1 and Q_2 will give us the energy required to completely melt the gold. The specific latent heat of fusion (L_f) for gold is 64 400J from the table above.

$$Q = Q_1 + Q_2$$

$$Q = mc\Delta T + mL_f$$

$$Q = 0.010kg \times 129J/kg^0C \times 1038^0C + 0.010kg \times 64400J/kg$$

$$Q = 1339.02J + 644J = 1983.02J$$

Example 16
How much energy does a refrigerator have to remove from 1.5kg of water at 20°C to make ice at -12°C?

Solution
Care must be taken when solving problems such as this. In this example, notice that there are three parts to this problem.

First we must remove energy from water so that its temperature decreases from 20°C to 0°C. Let's call this Q_1. This part requires the heat equation.

The next part is to remove energy from water at 0°C so that it becomes ice to ice at 0°C. Let's call this Q_2. This part involves the latent heat of fusion.

Finally the energy removed to decrease the temperature of ice from 0°C to -12°C. Let's call this Q_3. This part requires the heat equation.

The total energy (**Q**) removed from water is then a sum of Q_1, Q_2 and Q_3.

$$\mathbf{Q} = Q_1 + Q_2 + Q_3$$

$$\mathbf{Q} = mc\Delta T + mL_v + mc\Delta T$$

$$\mathbf{Q} = 1.5kg \times 4186J/kg^0C \times 20^0C + 1.5kg \times 333\,000J/kg + 1.5kg \times 2090 \times 12^0C$$

$$\mathbf{Q} = 125\,580J + 499\,500J + 37\,620J = 662\,700J$$

Example 17
A 0.5kg chunk of ice at -10°C is placed in 3.0kg of water at 20°C.

a) How much heat is to be removed to bring 3.0kg of water from 20°C to 0°C?

b) How much heat is required to bring the 0.5kg chunk of ice from -10°C to 0°C?

c) In what state will the final mixture be?

d) What is the final temperature of the mixture?

Solution
a) $Q = mc\Delta T = 3.0kg \times 4186J/kg^0C \times 20^0C = 251\,160J$

b) $Q = mc\Delta T = 0.5kg \times 2090J/kg^0C \times 10^0C = 10\,450J$

c) The final state will be liquid water since the amount of energy to bring water from 20°C to 0°C is higher. The final temperature then must be less than 20°C but above 0°C.

d) Heat gain by ice = Heat loss by water

$$(mc\Delta T + mL) + mc\Delta T = mc\Delta T$$

$$0.5kg \times 2090J/kg^0C \times 10^0C + 0.5kg \times 333\,000J/kg) + 0.5kg \times 4186J/kg^0C \times (T_f)$$

$$= 3.0kg \times 4186J/kg \times (20^0C - T_f)$$

$$10\,450J + 166\,500J + 2\,093T_f = 251\,160J - 12\,558T_f$$

$$12\,558T_f + 2\,093T_f = 74\,210J$$

$$14\,651T_f = 74\,210J$$

$$T_f = 5.065^0C$$

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 6

20 minutes

Answer the following questions on the spaces provided. Use the tables on page 33 and 43 for values of specific heat capacity and specific latent heat capacity.

1. What is latent heat?

2. Find the energy required to melt 2.5 kg of gold at its melting point.

3. Copper has a melting point of 1083°C. Find the energy required to completely melt 200g of copper originally at room temperature of 22°C.

4. A 2.0kg bottle of water at 20°C is placed in the freezer of a refrigerator. How much heat must be removed by the refrigerator to completely freeze the 2.0kg of water?

5. A child wanting to make a cordial ice block, places 200g of cordial at 25°C in the freezer. If the freezer can remove energy at the rate of 250 joules per second, what time will it take for the cordial to freeze?
(Assume the specific latent heat and specific heat capacity of cordial are the same as water.)

6. Two solid ice blocks of mass 20g each at 0°C are placed in 500g of water at 40°C. What will be the final temperature of the mixture when both ice cubes have melted? (Assume no heat is lost to the container or the surroundings.)

Thank you for completing learning activity 6. Now check your work. Answers are at the end of the module.

12.2.4 Heat Transfer

Heat transfer is the process where thermal contact exists between two objects that are at different temperatures. Heat transfer between bodies occurs in three (3) different ways;

1. Conduction
2. Convection
3. Radiation

This means two objects are able to transfer energy only when one object at a higher temperature loses energy to another at a lower temperature. If two objects are both at the same temperature and are in thermal contact, they will have the same amount of thermal energy. In this case no energy is transferred between them. This occurs at **thermal equilibrium**.

If two objects have different amounts of thermal energy they will have different temperatures and it becomes possible for some of the energy in one object to move to the other but only if they are in thermal contact. The heat transfer continues until they both have the same temperature (i.e. they reach thermal equilibrium).

In this section, we will be looking at each of the three methods of heat transfer and using these to explain a variety of situations.

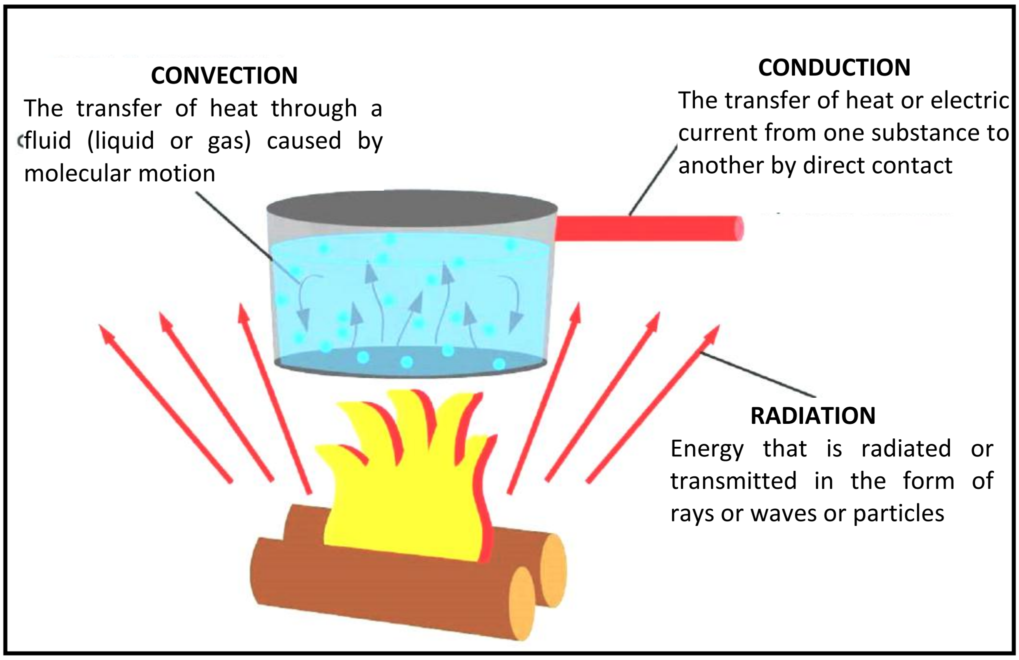


Figure 10 A summary of the three (3) methods of heat transfer.

Conduction

Energy is transferred in solid materials by conduction when bodies at different temperatures are in physical contact (i.e. touching).

Heat conduction is a fairly common experience. The figures 11 and 12 both illustrate heat conduction.

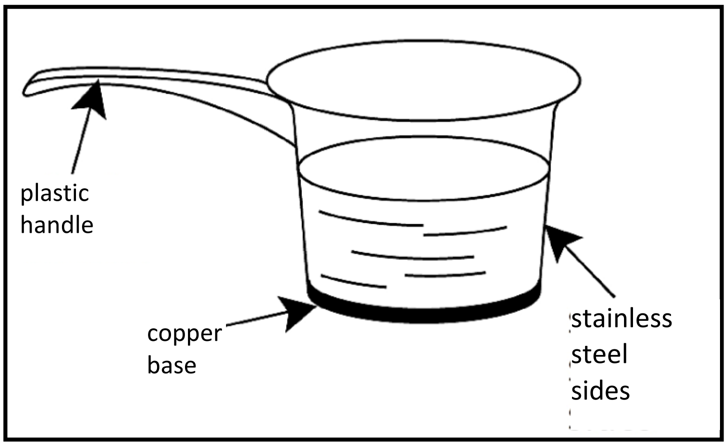


Figure 11 A metallic saucepan is an example of heat conduction.

The base of a saucepan is made of copper which is a good conductor of heat. The handle of the saucepan has to be made of plastic so that heat from the copper is not transferred to someone's hand when they touch the handle.

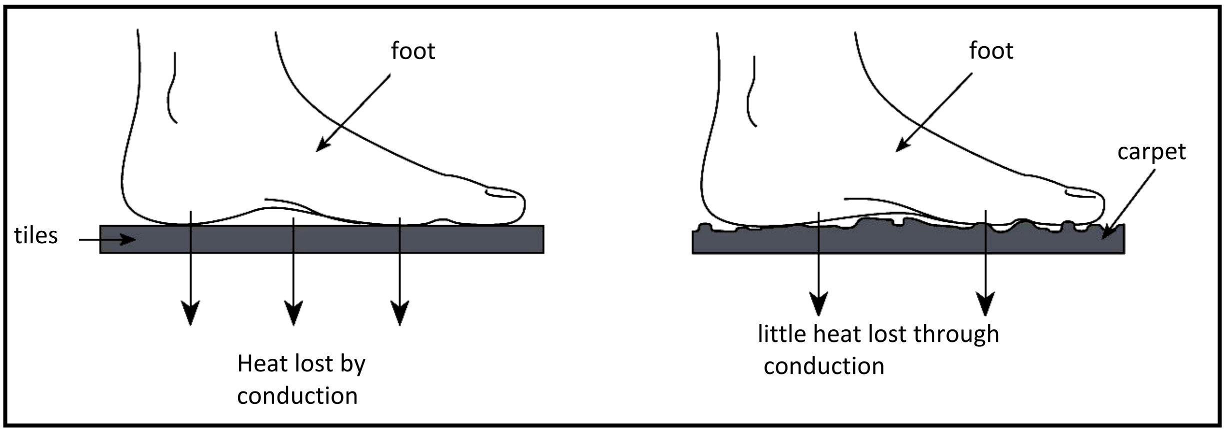


Figure 12 Conduction of heat from the body by a carpet compared to tiles

Carpet feels warmer that tiles when we stand barefooted because tiles conduct heat better than carpet can.

When an object at cooler temperature comes in contact with one at higher temperature, energy transfers from warmer object to cooler (eg; pick up a cube of ice)also the same in the opposite case (eg; touching a hot surface). This transfer occurs until both objects are at thermal equilibrium.

The rate of energy transfer (energy transferred (Q) in time (t) through a material depends on; length of the material (L), area of contact (A), the temperature gradient, $\left(\frac{T_2 - T_1}{L}\right)$ the nature of the conducting material. Equation is;

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_2 - T_1}{L}$$

k is the constant known as the **thermal conductivity** of the material and it is unique for different materials.

Below is a table showing the thermal conductivities of some common substances.

Substance	Thermal Conductivity, k (W/m.°C)
Metals (at 25^{0}C)	
Aluminium	238
Copper	397
Gold	314
Iron	79.5
Lead	34.7
Silver	427
Non-metals (approximate values)	
Asbestos	0.08
Concrete	0.8
Diamond	2 300
Glass	0.8
Ice	2
Rubber	0.2
Water	0.6
Wood	0.08
Gases (at 20^{0}C)	
Air	0.0234
Helium	0.138
Hydrogen	0.172
Nitrogen	0.0234
Oxygen	0.0238

Table 5 Thermal conductivities of some common substances.

Some materials are better **conductors** of energy than others. Most conductors will have high values of k, while poor conductors (**insulators**) will have low values of k.

Solids are better conductors than liquids and gases. This can be explained by the fact that the particles are more closely packed. They are able to transfer energy better because of this.

Metals conduct better than solid non-metals because their particles are not set in covalent bonded structures such as in non-metals. Covalent bonds cannot allow for transfer of heat. However, an exception to this is graphite.

Example 18
Determine the rate of energy conduction through a rectangular glass block of area $1.2m^2$ and 5.0mm thick. The temperature on one side is 20°C while the temperature on the other side is 8°C.

Solution
For calculation of the rate of conduction it is important that we must make sure that all measurements are in the same units. That is all lengths must be in metres, all areas in square metres and so on.
k = 0.8W/m.°C from the table on the previous page, T_1 = 20°C, T_2 = 8°C, L = 5mm = 0.005m

$$\frac{\Delta Q}{\Delta t} = k\,\frac{T_2 - T_1}{L}$$

$$\frac{\Delta Q}{\Delta t} = 0.8\text{W/m}\cdot{}^0\text{C x }\frac{20^0\text{C} - 8^0\text{C}}{0.005\text{m}}$$

$$\frac{\Delta Q}{\Delta t} = 1920\text{W} = 1920\text{J/s}$$

The rate of heat conduction value tells us that the difference in temperature causes 1920J every second until the temperature on both sides is equal.

Convection

Convection is the transfer of heat by a mass movement of molecules from high temperature zones or regions to low temperature zones or regions.

Convection is observed only in fluids (liquids and gases). Fluid molecules are farther apart than molecules in solids, hence they are not very good conductors of heat. However, when heated, molecules tend to move further apart causing the warmer part of the fluid to become less denser. The warmer part of the fluid rises while the colder (more denser) part sinks (E.g. convection in liquid being boiled, fire heating the air). As the warmer part rises it loses its energy and sinks, while the colder part gains energy and rises. This continuous cycle of losing and gaining energy by molecules in a fluid leads to the formation of **convection currents**. Figures 13, 14 and 15 show three examples of convection.

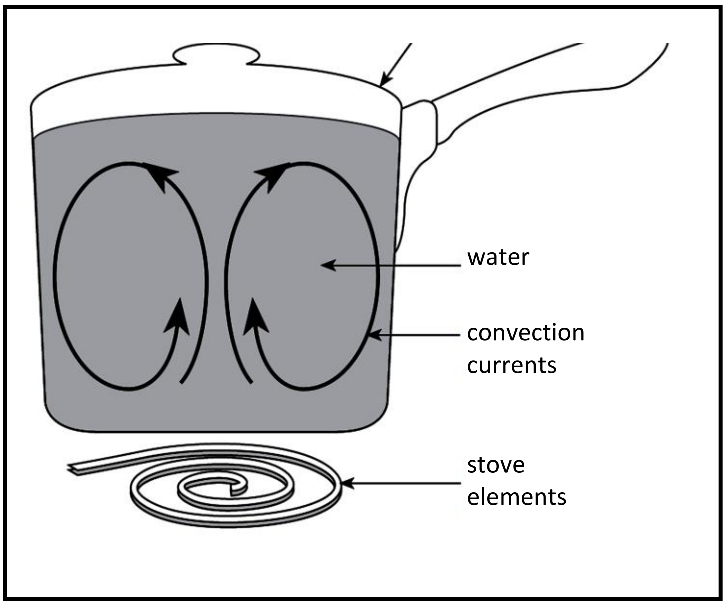


Figure 13 Water in a saucepan

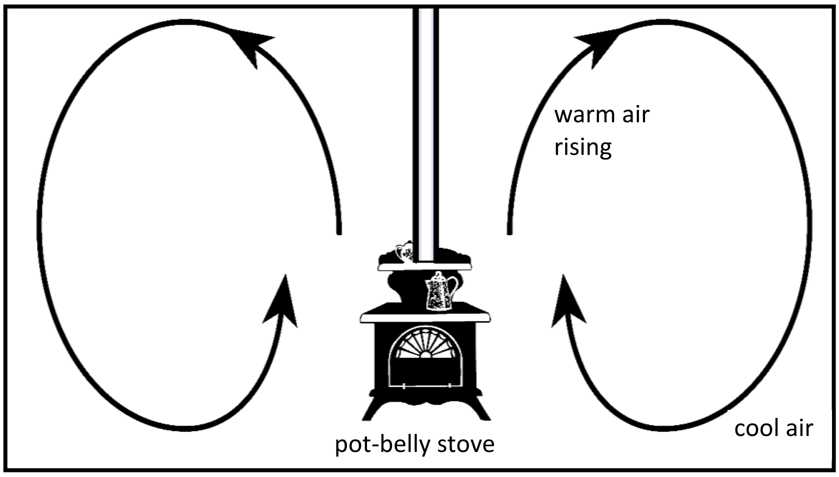


Figure 14 Heating air in a house using a stove

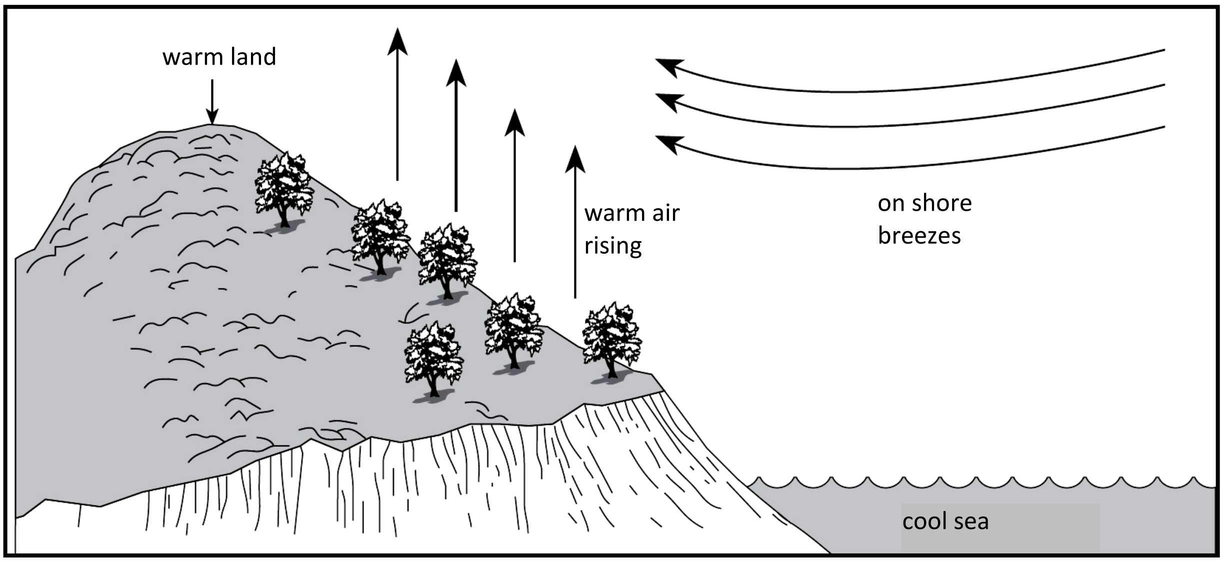


Figure 15 The formation of local sea breezes

Some other examples of convection are;

Heat in the body is brought just below the skin surface to be released to the atmosphere by convection in blood. When the body is cold, any energy from outside the body (such as a fire) is taken by convection in blood to the rest of the body.

Houses can be cooled/heated by making use of convection currents in air.

Global winds (Trade winds and monsoon winds), **local winds** (such as land-sea breezes, mountain-valley breezes) and **ocean currents** which influence our climates and weather patterns are caused mostly by convection. Weather patterns such as El Nino and La Nina are caused by changes in the direction and temperature of ocean currents in the Pacific Ocean.

Radiation

Radiation is a way of transmission of heat energy through a vacuum by electromagnetic waves (infra-red part of the EM spectrum). The Earth gets its heat from the Sun in this way. Most of the heat we feel when near a fire is due to radiation of heat.

When a metal is heated, it emits radiation in the form of heat. As we continue to heat the metal its colour changes from dull red to brilliant white. This can be seen when heating stones for a mumu. Temperatures above 1500K are needed to achieve this for most metals.

Radiated heat energy can be absorbed, reflected or transmitted in a material. Glass for instance, reflects some heat radiation, absorbs a little and allows some to pass through. **Absorbers** are objects which soak up radiated heat. **Radiators** or **emitters** are objects which emit give off radiated heat. Reflectors are objects which absorb a little heat but transmit most of the radiation.

Generally, dark or dull objects are good absorbers and radiators, while shiny and light-coloured objects are poor absorbers and radiators.

You would notice the effect of absorbing radiation by the colour of clothes you wear. On a hot day, most people would advise against wearing dark coloured clothing because dark colours are good absorbers of radiation.

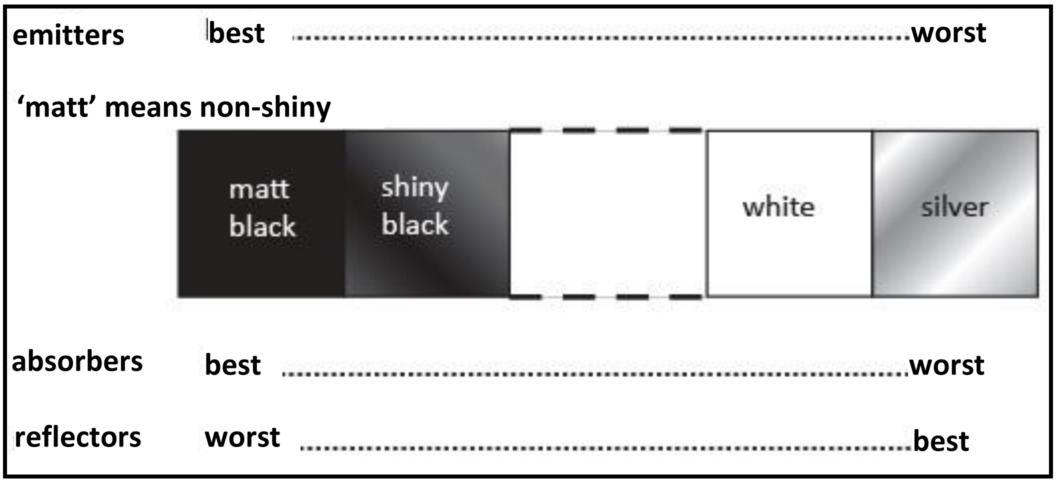


Figure 16 The best absorber and emitter of heat radiation is black, while silver is the worst absorber and emitter. All other colours come in between these two extremes

The net rate of energy radiated $\left(\frac{\Delta Q}{\Delta t}\right)$ by a hot object depends on its temperature, as well as the type of surface and is given by the Stefan-Boltzmann equation;

$$\frac{\mathbf{\Delta Q}}{\mathbf{\Delta t}} = \boldsymbol{\varepsilon\sigma A}\left(\mathbf{T_1^{\,4}} - \mathbf{T_{04}}\right)$$

T_1 and T_0 are final and initial absolute temperatures (in K), **A** is the area of the radiating surface, **σ** is the **Stefan-Boltzmann constant** which is $\mathbf{5.7 \times 10^{-8}\ W\ m^{-2}\ K^{-4}}$.

The factor **ε** is called the **emissivity**, which is a number between 0 and 1 that varies from material to material. A dark, dull surface will have an emissivity close to 1 while a shiny surface will have an emissivity close to 0.

It is important to note that any object that emits radiation must also absorb radiation and vice versa. If this did not occur, the object that emits radiation will continue to lose all its energy and never reach thermal equilibrium with its surroundings. Likewise any object that absorbs radiation also emits some until it reaches thermal equilibrium.

Example 19
Estimate the net rate of heat loss by radiation from an unclothed person's body if they are in a closed room at a temperature of 25°C and their skin temperature is 34°C.
Let the emissivity be ε = 0.70 and the surface area of the skin be 1.5m^2.

Solution
First we must make sure that all temperatures are given in Kelvin (K).

Thus 34°C = 273 + 34 = 307K and 25°C = 273 + 25 = 298K

The net rate of energy transfer is calculated below.

$$\frac{\Delta Q}{\Delta t} = \varepsilon\sigma A\left(T_1{}^4 - T_0{}^4\right)$$

$$\frac{\Delta Q}{\Delta t} = 0.7 \text{ x } 5.7 \text{ x } 10^{-8} \text{ x } 1.5 \text{ x } (307^4 - 298^4)$$

$$\frac{\Delta Q}{\Delta t} = 59.65\text{W}$$

More on emissivity
Emissivity (ε) is a measure of the efficiency in which a surface emits thermal energy. It is defined as the fraction of energy being emitted relative to that emitted by a thermally black surface (a black body).

A **black body** is a theoretical object that is the perfect absorber and emitter of heat energy with an emissivity value of 1. In theory, a black body would be capable absorbing 100% of the thermal energy available.

A material with an emissivity value of 0 would be considered a perfect **thermal mirror**. It would not absorb any radiated thermal energy but would reflect the thermal energy.

$$\textbf{Emissivity }(\boldsymbol{\varepsilon}) = \frac{\textbf{Thermal energy radiated by object with surface area A}}{\textbf{Thermal energy radiated by black body with the same surface area A}}$$

For example, would have an emissivity value of 0.90 if it absorbs or emits 90J of energy with its given surface area. A black body with an equal surface area would absorb or emit 100J of energy.

In the real world there are no perfect "black bodies" and very few perfect infrared mirrors so most objects have an emissivity between 0 and 1.

Example 20
A black body sphere of radius of 12cm is heated to a temperature of 950K. What would be its final temperature after 3 minutes if it loses heat energy by radiation at a rate of 500W? (Assume that the sphere does not absorb any radiation while emitting)

Solution
The surface area of the sphere is calculated using the formula: $A = 4\pi r^2$
$A = 4\pi \times (0.12m)^2 = 0.181m^2$

After 3 minutes, the total amount of energy lost is; $-500W \times 180s = -90000J$

$$\frac{\Delta Q}{\Delta t} = \varepsilon \sigma A \left(T_1^{\ 4} - T_0^{\ 4}\right)$$

Rearrange this equation to make T_1 the subject of the equation.

$$T_1^4 = \sqrt[4]{\frac{\frac{\Delta Q}{\Delta t}}{\varepsilon \sigma A}} + T_0^4$$

$$T_1 = \sqrt[4]{\frac{-500}{1 \text{ x } 5.7 \text{ x } 10^{-8} \text{ x } 0.181}} + 950^4 = 935.54K$$

Note that the amount of energy lost and the rate of energy loss in this question have been given a negative sign. This is to ensure that the final temperature we get from the equation is positive and lower than the initial temperature.

Now check what you have just learnt by trying out the learning activity below!

Learning Activity 7

20 minutes

Answer the following questions on the spaces provided.

1. List the factors that affect the rate of heat conduction of any substance.

   a) ____

   b) ____

   c) ____

   d) ____

2. One end of a copper rod of length 30cm and thickness of 0.25cm is placed in such a way that one end is exposed to a temperature of 120°C while the other end is at 25°C. Calculate the rate of heat transfer by conduction along the rod.

---

3. A room is designed to maintain a temperature of 25°C. Outside the room on a cold night the temperature is measured as 10°C. The room is separated from the outside by a glass slab of area $0.25m^2$ and thickness of 8mm.

   a) Find the rate of heat loss by conduction of the room.

   b) Suppose the owners of the room wish to replace the glass slab with another transparent material that will allow for a rate of heat transfer of 150W. Determine the thermal conductivity of this material.

---

4. Explain the term convection.

   ____
   ____
   ____
   ____
   ____

---

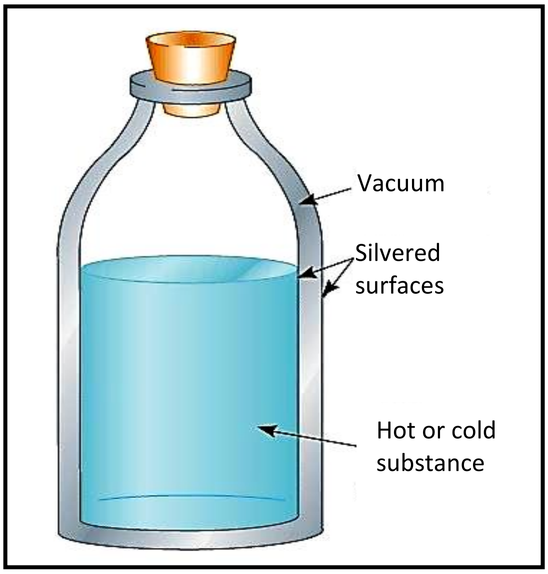
5. In a tropical place such as in PNG a shiny vehicle is more comfortable to drive. Explain why this statement is valid.

   ____
   ____
   ____
   ____
   ____
   ____

6. The surface of the Sun has a temperature of about 5800K. The radius of the Sun is 6.96 × 10^8m. Calculate the total energy radiated by the Sun each second. (Assume that ε = 0.965).

---

7. The picture below shows a thermos flask which is a common household item. The thermos flask can be used to keep hot liquids hot and cold liquids cold for longer periods of time than usual.



a) Give a reason why there is a vacuum between the inner and outer surfaces.

____

____

____

b) Give a reason why the inner and outer surfaces are "silvered".

____

____

____

Thank you for completing learning activity 7. Now check your work. Answers are at the end of the module.

12.2.5 Applications of Heat and Temperature

The following are some applications of the principles of heat and temperature as we have seen throughout this module.

As we go through this part, take note of the ideas that we have covered in this module for each application.

As you also read through you can go back to parts in the module to revisit basic explanations.

Fire Walking

Some cultures around the world walk on fire during ceremonial occasions. One such culture is that of the Baining people in East New Britain province.

During firewalking, a person walks barefooted on glowing coals (at about 600°C). This gives people the impression that they are doing the impossible by walking on fire without being burnt.

Figure 17 Firewalking is prevalent in many cultures

Some of these ideas that we have discussed in this unit can help us explain why it may be possible to walk on fire without being severely burnt.

Low specific heat capacity of hot coals
Coals from wood have a low specific heat capacity. Objects with low specific heat capacities tend to absorb small amounts of energy and then give off small amounts of energy for temperature changes. This means that a hot coal may be at a high temperature but it may not have so much energy to transfer. Sometimes stones are used but again they are mostly those with a low specific heat capacity (e.g. pumice)

Mass of hot coals
The mass of hot coals is significantly less since a lot of the material is already burned away. According to the heat equation, objects with greater mass, can absorb more energy from

heating. This is not the case with hot coals since, small mass absorb and give off only small amounts of heat. Also in relation to the low mass, this will also result in a low heat capacity.

Surface area of hot coals
Coals will have to transfer heat to a person's feet by conduction. We have seen that one factor that affects the rate of heat transfer by conduction is the area of contact between two objects at different temperatures. Because the areas of the coals are small, they cannot pass on as much heat onto a person's feet although there is a high temperature difference. Because feet come in contact with coals with small areas, the amount of heat transferred by conduction is low.

Amount of time spent in contact with hot coals
The amount of time spent on top of the coals is also one possible explanation. Some people might run over the coals instead of walking. Heat from the fire is transferred mostly by conduction. Conduction is also described as a rate of energy transfer. This means that time is closely related with the amount of heat that is transferred. Therefore the amount of time spent in contact with the coals determines how much energy is actually transferred to a person's feet during firewalking.

Liedenfrost effect
The Liedenfrost effect is also another possible explanation. The Liedenfrost effect occurs when water droplets from sweat and moisture in the air settle on the skin forming a layer of steam which protects the skin from burns. We often observe something similar when we pour water on a hot barbecue plate or frying pan.

Although some of the explanations above explain how fire walking is possible, it is advisable not to practice fire walking unless you are absolutely sure about what you are doing!

Mumu

The mumu is a traditional method of cooking food by heat that is given off from hot stones. The stones are heated in a hot fire and then removed while they are hot, a parcel of food is then placed in a pit surrounded by the hot stones. The food is cooked by the thermal energy from the stones after some time.

The stones that are used during a mumu have some special characteristics that we could use to explain how a mumu is able to get food cooked. Generally speaking, the stones used during a mumu are large, heavy, smooth and dull in colour. Let us look at some of these characteristics of the stones in relation to what we have studied in this unit.

Figure 18 (Left) Stones being prepared for a mumu. (Right) Food ready for hot stones.

Mass and specific heat capacity of the stones

The stones that are used in a mumu must be able to absorb a great amount of heat and release this energy when cooking food. From the heat equation, we learnt that objects with greater mass, can absorb a lot of heat. Smaller stones will absorb less heat and so give off less heat. The disadvantage of this is that such massive stones require a lot of heat initially to reach the right temperature. Thus a lot of wood is needed to make a fire to heat up the stones.

One other concept applied here is the idea of specific heat capacity. All the stones that are used must have a high specific heat capacity. The most common types of stones used are igneous rock types which tend to have specific heat capacities. In combination with large mass, the mumu stones have very high heat capacities.

Use of smooth stones

The stones that are preferred for use during a mumu are mostly smooth stones. Such stones are better at transferring heat by conduction and also by radiation. To conduct heat energy, the stones used have to be smooth because smooth stones are able to conduct energy better to the food. Smooth stones also have higher emissivities than rough stones.

Use of dull coloured stones

The use of dull coloured stones in mumu can also be explained using the concepts of heat transfer by radiation. Dull coloured objects are better heat absorbers and emitters. A dull coloured stone is able to absorb more heat from the initial fire by absorbing energy in the form of infra-red radiation. When in the pit with food, the stones will emit the energy to cook the food.

Apart from the stones, cooking would not be possible without some form of Insulation.

Insulation
Aluminium foil or other leaves are used to cover the food. This helps to insulate by reflecting heat from stones inward to the food so that less heat is lost. Because the stones have a high specific heat capacity they give of large amounts of energy. If this energy is not properly directed or is lost to the air, then food is not cooked properly.

Thermal expansion of rocks
Stones sometimes crack and break during heating. This is can explained by thermal expansion.

Refrigeration and Air Conditioning

Refrigerators work in reverse of the natural process of heat. Heat flows from high temperature to low temperature areas. In reverse, both refrigerators and air conditioners take heat from a low temperature area to a high temperature area. This cools the low temperature area.

The **refrigerant** is a substance that transfers heat when it evaporates inside the refrigerator. It absorbs heat to create the cold temperatures. It normally has a high latent heat of vaporisation. It changes between gas and liquid at different stages of the **refrigeration cycle**.

There are four (4) basic components to any refrigerator. They are the:

1. **compressor** which is a pump that circulates the refrigerant. It helps to increase the refrigerant pressure and temperature. In the compressor, cool refrigerant gas at low pressure is changed to warm gas at high pressure.

2. **condenser** which is a coiled set of pipes normally found **outside a refrigeration unit**. This is where the refrigerant releases heat to the surrounding air. The refrigerant passes through this part as a high pressure, high temperature gas. It loses its heat to the atmosphere before becoming a high pressure, high temperature liquid.

3. **expansion valve** which helps to decrease the pressure and temperature of the refrigerant. The refrigerant enters the expansion valve as a warm liquid at high pressure. When its pressure is decreased, its temperature decreases. It leaves the expansion valve as a low pressure, low temperature liquid.

4. **evaporator** is also a coiled set of pipes **inside a refrigeration unit.** This is the part where the refrigerant absorbs heat and reduces the surrounding temperature. The refrigerant passes through this part as a low pressure, low temperature liquid and absorbs heat to become a low pressure, low temperature gas.

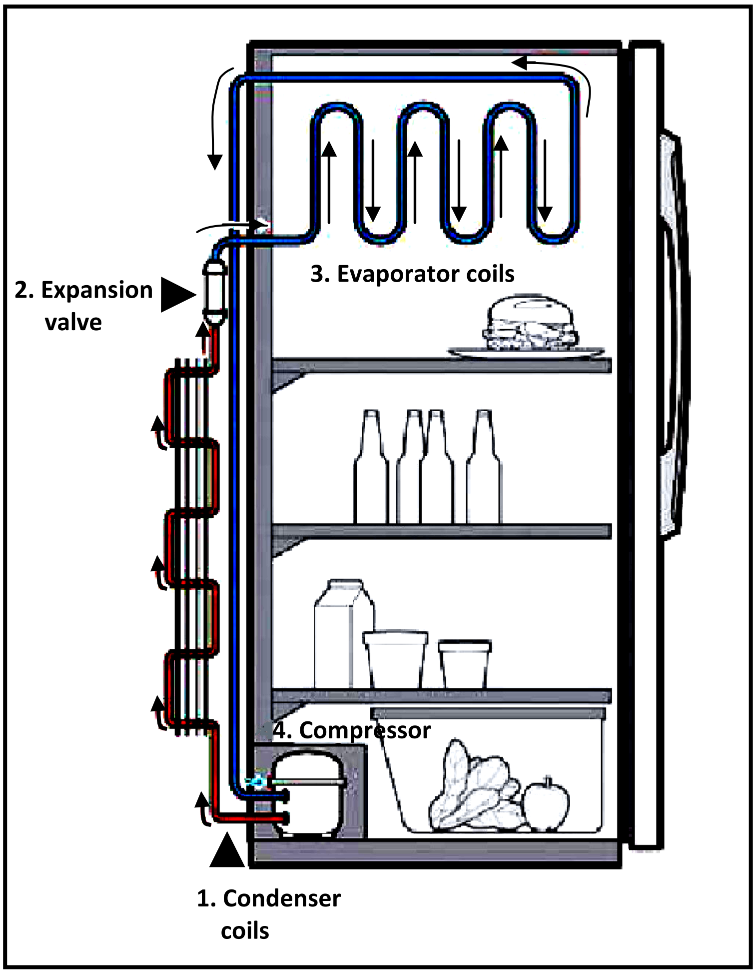


Figure 19 Main parts of the common household refrigerator

The refrigeration cycle

From the parts of the refrigerator above, let's follow the refrigerant through one cycle.

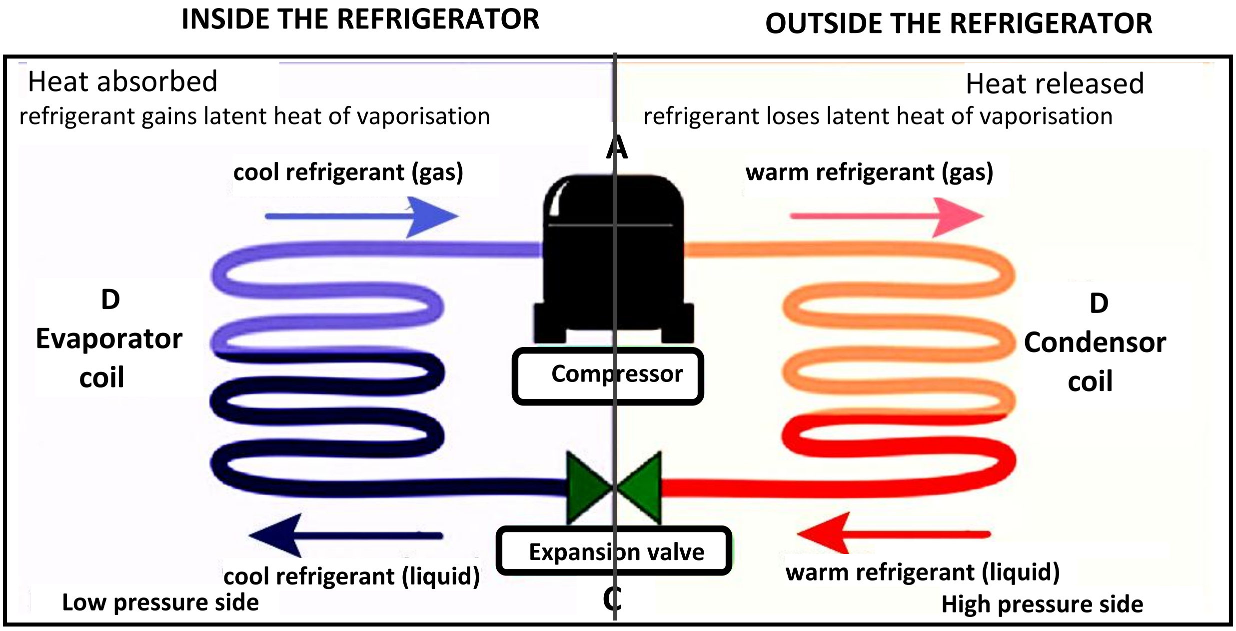


Figure 20 The refrigeration cycle

A. The refrigerant enters the compressor as a low pressure, low temperature gas. The compressor increases the pressure and the temperature of the gas.

B. The refrigerant now continues through the condenser as a low temperature, low pressure gas and loses heat by convection and radiation. Condenser coils are mostly made of metal and are painted black to radiate as much heat as possible. At the end of the condenser coil, the refrigerant loses most of its heat and becomes a high pressure, high temperature liquid.

C. The high pressure, high temperature refrigerant liquid passes through the expansion valve which decreases the refrigerant's pressure and temperature.

D. The refrigerant moves through the evaporator as a low pressure, low temperature liquid. Any heat in the surrounding area is immediately absorbed by the refrigerant until it becomes a low pressure, low temperature gas at the end of the evaporator. The refrigerant then moves on to the compressor and the cycle begin again.

Humidity control
Air conditioners work in much the same way are refrigerators do. They normally cool air by passing it over evaporator coils which remove heat from the air and transfer it to a refrigerant which removes the heat out of a building.

Some air conditioning equipment also provides reductions in the humidity of the air processed by the system. The relatively cold (below the dew point) evaporator coil condenses water vapour from the processed air. This similar to how a cold drink will condense water on the outside of a glass. The water is drained, removing water vapour from the cooled space and thereby lowering its relative humidity.

Since humans perspire to provide natural cooling by the evaporation of perspiration from the skin, drier air (up to a point) improves the comfort provided. Most air conditioners are designed to create 40% to 60% relative humidity in the occupied space.

NOW REVISE WELL USING THE MAIN POINTS ON THE NEXT PAGE.

SUMMARY

You will now revise this module before doing **ASSESSMENT 2**.
Here are the main points to help you revise. Refer to the module topics if you need more information.

- Common units used when measuring temperature are; degree Celsius (°C), Kelvin (K) and Degree Fahrenheit (°F). Degree Celsius is also known as degree centigrade.
- The conversion of temperature from degree Celsius to kelvin is $T_K = T_{°C} + 273$.
- The conversion of temperature from degree Celsius to Fahrenheit is $T_{°F} = 1.8 \times T_{°C} + 32$.
- Thermometers are devices used to measure changes in temperature by the changes in a physical property of the substance. Some of the main properties of substances that change with temperature are;
  - Length of a solid.
  - Volume of a liquid and gas.
  - Pressure of a gas with constant volume.
  - Electrical resistance and conductivity.
  - Radiation emitted by substances.
- Formally we define temperature as the average kinetic energy of the particles contained in an object.
- Thermal equilibrium occurs when two or more objects in thermal contact cannot transfer thermal energy because they are at the same temperature.
- Thermal contact is the situation where two objects are able to transfer any available thermal energy between each other.
- Thermal expansion is a feature of many substances. The three main types of thermal expansion are; Linear, Area (superficial) and volume expansion.
- The change in length (ΔL) of a substance by linear thermal expansion is given by the formula

  $$\Delta L = \alpha L_0 \Delta T.$$

  Where L_0 is the original length, α is the linear expansion coefficient and ΔT is the difference in temperature.
- The change in area (ΔA) of a substance by area (superficial) thermal expansion is given by the formula

  $$\Delta A = 2\alpha A_0 \Delta T$$

  Where A_0 is the original area, α is the linear expansion coefficient and ΔT is the difference in temperature.
- The change in volume (ΔV) of a substance by volume thermal expansion is given by the formula

  $$\Delta V = \beta V_0 \Delta T$$

Where V_0 is the original volume, β is the volume expansion coefficient and ΔT is the difference in temperature.

- The relationship between the linear expansion coefficient (α) and the volume expansion coefficient (β) is; β = 3α.
- Heat is the term given to the form of thermal energy that is exchanged between objects in thermal contact and at different temperatures.
- Heat is measured in Joules (J). Other units of heat include the Calorie (cal) and British Thermal unit (BTU).
- Heat Capacity (C) is the amount of energy gained or lost by a substance in changing its temperature by 1°C. It is related to the total amount heat by the equation; Q = CΔT, where Q is the amount of energy in Joules (J), C is the heat capacity in Joules per degree Celsius and ΔT is the change in temperature in degree Celsius. Different substances have different heat capacities depending on what they are made of and their mass.
- Specific Heat Capacity (c) is the amount of heat energy gained or lost by 1kg of a substance in changing its temperature by 1°C. It is related to heat capacity by the following equation; C = mc, where C is the heat capacity, m is the mass of the substance and c is the specific heat capacity of the substance. Most substances has unique values of specific heat capacity. The unit for specific heat capacity is Joule per kilogram per degree Celsius (J/kg°C).
- The heat equation gives a relationship between the total amount of energy absorbed or lost by an object (Q) and the mass of the object (m), the specific heat capacity of the object (c) and the change in temperature (ΔT). The heat equation is; Q = mcΔT.
- When two objects are contained in an isolated location, they have the tendency to reach thermal equilibrium by transferring thermal energy. If no thermal energy is lost to the surroundings, the amount of energy lost by one object is equal to the amount of energy gained by the other. This is an illustration of the Law of conservation of energy.
- The latent heat of a substance is the amount of energy required to change the state of the substance without a change in temperature. The latent heat of a substance depends on the specific latent heat of the substance (L) and the mass of the substance (m).
- The specific latent heat of fusion of a substance (L_f) is the amount of energy gained or lost by 1kg of a substance in changing from solid to liquid or liquid to solid.
- The specific latent heat of vaporization of a substance (L_v) is the amount of energy gained or lost by 1kg of a substance in changing from liquid to vapour or vapour to liquid.
- Heat transfer is the movement of thermal energy from one object to another when both objects are in thermal contact. Heat transfer continues between both objects until thermal equilibrium is reached.
- The three (3) main methods of heat transfer are conduction, convection and radiation.
- Conduction is the transfer of heat when objects are in physical contact. The rate of heat transfer by conduction is dependent on cross-sectional area (A), the temperature difference ($T_1 - T_2$) and the thickness of the conductor (l).
- The equation of the rate of heat transfer by conduction is;

$$\frac{\Delta Q}{\Delta t} = kA\frac{T_2 - T_1}{l}$$

- The constant k stands for the thermal conductivity of a substance which has the units W/m°C. Thermal conductivity depends on the type of substance.
- Generally, metals are better conductors than non-metals and solids are better conductors that liquids and gases.
- Convection is the transfer of heat energy by the mass movement of molecules. It is mostly observed in liquids and gases.
- Radiation is the transfer of heat energy by electromagnetic waves. Radiation can be transmitted in three (3) ways; by being absorbed, radiated or reflected.
- In general, dark colored objects are good absorbers and radiators while light colored and shiny objects are poor absorbers and radiators of thermal radiation.
- The net rate of heat transfer by radiation is given by the equation;

$$\frac{\Delta Q}{\Delta t} = \varepsilon\sigma A\left(T_1^{\,4} - T_0^{\,4}\right)$$

Where $\frac{\Delta Q}{\Delta t}$ is the rate of heat transfer by radiation, ε is the emissivity of the object, σ is the Stefan-Boltzmann constant with a value of 5.7×10^{-8} W/m°C, A is the cross-sectional area, T_1 and T_0 are the final and initial temperatures in Kelvin (K).

- Emissivity (ε) is the comparison of the thermal energy absorbed or emitted by an object with surface area A with that of the thermal energy absorbed or emitted by a black body.
- A black body is a perfect absorber and emitter of thermal radiation. It has an emissivity value of 1.
- The principles of heat and temperature are useful in explaining the many situations involving thermal energy.

We hope you have enjoyed studying this module. We encourage you to revise well and complete Assessment 2.

NOW YOU MUST COMPLETE ASSESSMENT TASK 2 AND RETURN IT TO THE PROVINCIAL CENTRE CO-ORDINATOR

✓ Answers to Learning Activities 1 - 7

Learning Activity 1

1. a. 273K b. 310K c. 241K
   d. 673K e. 257K

2. $T_{°C} = T_K - 273$

3. a. -76°C b. -22°C c. 192°C
   d. 12.6°C e. -244°C

4. a. 32°F b. 98.6°F c. -25.6°F
   d. 752°F e. 3.2°F

5. $T_{^0C} = \frac{5}{9} \text{ x } \left(T_{^0F} - 32\right)$

6. a. 36.67°C b. 38.89°C c. 100°C
   d. 70°C e. 10°C

Learning Activity 2

1 i. Volume of Liquid
  ii. Length of solid
  iii. Pressure of gas with constant volume
  iv. Electrical Resistance of conductor
  v. Radiation emitted by an object

2. Main ones are liquid-in-glass thermometer, constant-volume gas thermometer and bimetallic strip.

3. a. 9.8cm

b. 26.3cm

4. a. Generally as temperature increases, resistance increases, current decreases and voltage increases. On the other, hand as temperature decreases, resistance decreases, current increases and voltage decreases.

   b. 46.67°C
   70Ω

5. a. At constant volume, gas pressure increases when temperature increases. Also at constant volume, gas pressure decreases when temperature decreases.

   b. 3376.67 Pa/°C

Learning Activity 3

1. a. initial length

   b. the type of material

   c. the change in temperature

2. Change in length is 8.12×10^{-3}cm, new length is 35.00812cm

3. 11.67°C

4. 3.75×10^{-4}/°C

5. 151.51cm^2

6. 392.99cm^3

7. 1333.33°C

Learning Activity 4

1.

Energy (Joules)	Energy (Calories)	Energy (BTU)
a) 500J	2100cal	0.474BTU
b) 2500J	10500cal	2.37BTU
c) 198000J	831 600cal	187.67BTU
d) 800kJ	3360kcal	758.29BTU
e) 1.2MJ	5.04 Mcal	1137.41BTU

2. Heat capacity is the amount of energy gained or lost in changing the temperature of a substance by 1°C. Specific heat capacity is the amount of energy gained or lost in changing the temperature of 1kg of a substance by 1°C. The main difference is that specific heat does not depend on mass, while heat capacity does depend on mass.

3. a. 5031J
   b. Amount of energy is doubled.

4. a. 7.5kg
   b. 58 500J

5. a. 66000J/kg
   b. 880J/kg°C
   c. 13200J

6. a. 234J/kg°C
   b. Silver

Learning Activity 5

1. 1170J/kg°C

2. 112 seconds

3. 2145J/kg°C

Learning Activity 6

1. Latent heat is the energy gained or lost when a substance changes state with no noticeable change in temperature.

2. 161 000J

3. 109 558J

4. 834 000J

5. 350.4 seconds

6. 31.16°C

Learning Activity 7

1. a. Area of contact

   b. Nature of Substance

   c. Temperature difference

   d. thickness or length of conductor

2. 0.61W

3. a. 375W

   b. 0.32Wm/°C

4. Convection is the transfer of heat by mass movement of particles.

5. Shiny vehicles absorb less heat than dull vehicles.

6. 3.35×10^{12}W

7. a. Vacuum allows for little or no heat transfer by conduction or convection.

   b. silvered surface allows for little or no heat to be absorbed or emitted.

If you have queries regarding the answers, then please visit your nearest FODE provincial centre and ask a distance tutor to assist you.

References

http://www.thermoworks.com/emissivity_table.html

Emissivity Table from: http://www.engineeringtoolbox.com/emissivity-coefficients-d_447.html

GIANCOLI, D.C., (1985), PHYSICS PRINCIPLES WITH APPLICATIONS, 2nd Edition, PRENTICE-HALL, LONDON, United Kingdom

KORIMAS. M & SOTO. R., (2005), A TEXT FOR FIRST YEAR PHYSICS AT UNIVERSITY OF PAPUA NEW GUINEA, Revised ed., University of Papua New Guinea, Port Moresby

POPLE, S, (1982), EXPLAINING GCSE PHYSICS, OXFORD UNIVERSITY PRESS, OXFORD, United Kingdom

"Resistance", http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

TSOKOS, K.A., (2008) PHYSICS FOR IB DIPLOMA, 5th EDITION, CAMBRIDGE UNIVERSITY PRESS, CAMBRIDGE, United Kingdom

YONG, P.L., (2006), PACIFIC PHYSICS A LEVEL, Volume 2, PANPAC EDUCATION LTD, SINGAPORE

FODE PROVINCIAL CENTRES CONTACTS

PC NO.	FODE PROVINCIAL CENTRE	ADDRESS	PHONE/FAX	CUG PHONES	CONTACT PERSON		CUG PHONE
1	DARU	P. O. Box 68, Daru	6459033	72228146	The Coordinator	Senior Clerk	72229047
2	KEREMA	P. O. Box 86, Kerema	6481303	72228124	The Coordinator	Senior Clerk	72229049
3	CENTRAL	C/- FODE HQ	3419228	72228110	The Coordinator	Senior Clerk	72229050
4	ALOTAU	P. O. Box 822, Alotau	6411343 / 6419195	72228130	The Coordinator	Senior Clerk	72229051
5	POPONDETTA	P. O. Box 71, Popondetta	6297160 / 6297678	72228138	The Coordinator	Senior Clerk	72229052
6	MENDI	P. O. Box 237, Mendi	5491264 / 72895095	72228142	The Coordinator	Senior Clerk	72229053
7	GOROKA	P. O. Box 990, Goroka	5322085 / 5322321	72228116	The Coordinator	Senior Clerk	72229054
8	KUNDIAWA	P. O. Box 95, Kundiawa	5351612	72228144	The Coordinator	Senior Clerk	72229056
9	MT HAGEN	P. O. Box 418, Mt. Hagen	5421194 / 5423332	72228148	The Coordinator	Senior Clerk	72229057
10	VANIMO	P. O. Box 38, Vanimo	4571175 / 4571438	72228140	The Coordinator	Senior Clerk	72229060
11	WEWAK	P. O. Box 583, Wewak	4562231/ 4561114	72228122	The Coordinator	Senior Clerk	72229062
12	MADANG	P. O. Box 2071, Madang	4222418	72228126	The Coordinator	Senior Clerk	72229063
13	LAE	P. O. Box 4969, Lae	4725508 / 4721162	72228132	The Coordinator	Senior Clerk	72229064
14	KIMBE	P. O. Box 328, Kimbe	9835110	72228150	The Coordinator	Senior Clerk	72229065
15	RABAUL	P. O. Box 83, Kokopo	9400314	72228118	The Coordinator	Senior Clerk	72229067
16	KAVIENG	P. O. Box 284, Kavieng	9842183	72228136	The Coordinator	Senior Clerk	72229069
17	BUKA	P. O. Box 154, Buka	9739838	72228108	The Coordinator	Senior Clerk	72229073
18	MANUS	P. O. Box 41, Lorengau	9709251	72228128	The Coordinator	Senior Clerk	72229080
19	NCD	C/- FODE HQ	3230299 Ext 26	72228134	The Coordinator	Senior Clerk	72229081
20	WABAG	P. O. Box 259, Wabag	5471114	72228120	The Coordinator	Senior Clerk	72229082
21	HELA	P. O. Box 63, Tari	73197115	72228141	The Coordinator	Senior Clerk	72229083
22	JIWAKA	c/- FODE Hagen		72228143	The Coordinator	Senior Clerk	72229085

FODE SUBJECTS AND COURSE PROGRAMMES

GRADE LEVELS	SUBJECTS/COURSES
Grades 7 and 8	1. English
	2. Mathematics
	3. Personal Development
	4. Social Science
	5. Science
	6. Making a Living
Grades 9 and 10	1. English
	2. Mathematics
	3. Personal Development
	4. Science
	5. Social Science
	6. Business Studies
	7. Design and Technology- Computing
Grades 11 and 12	1. English – Applied English/Language& Literature
	2. Mathematics - Mathematics A / Mathematics B
	3. Science – Biology/Chemistry/Physics
	4. Social Science – History/Geography/Economics
	5. Personal Development
	6. Business Studies
	7. Information & Communication Technology

REMEMBER:

- For Grades 7 and 8, you are required to do all six (6) subjects.
- For Grades 9 and 10, you must complete five (5) subjects and one (1) optional to be certified. Business Studies and Design & Technology – Computing are optional.
- For Grades 11 and 12, you are required to complete seven (7) out of thirteen (13) subjects to be certified.

Your Provincial Coordinator or Supervisor will give you more information regarding each subject and course.

GRADES 11 & 12 COURSE PROGRAMMES

No	Science	Humanities	Business
1	Applied English	Language & Literature	Language & Literature/Applied English
2	Mathematics A/B	Mathematics A/B	Mathematics A/B
3	Personal Development	Personal Development	Personal Development
4	Biology	Biology/Physics/Chemistry	Biology/Physics/Chemistry
5	Chemistry/ Physics	Geography	Economics/Geography/History
6	Geography/History/Economics	History / Economics	Business Studies
7	ICT	ICT	ICT

Notes: You must seek advice from your Provincial Coordinator regarding the recommended courses in each stream. Options should be discussed carefully before choosing the stream when enrolling into Grade 11. FODE will certify for the successful completion of seven subjects in Grade 12.

CERTIFICATE IN MATRICULATION STUDIES		
No	**Compulsory Courses**	**Optional Courses**
1	English 1	**Science Stream:** Biology, Chemistry, Physics
2	English 2	**Social Science Stream:** Geography, Intro to Economics and Asia and the Modern World
3	Mathematics 1	
4	Mathematics 2	
5	History of Science & Technology	

REMEMBER:
You must successfully complete 8 courses: 5 compulsory and 3 optional.