N5 Engineering Physics

Gateways to Engineering Studies - Chris Brink

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Gateways to Engineering Studies

Engineering Physics

N5

Chris Brink

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Table of Contents

Module 1:
General Properties of Matter 9

1.1 Introduction 9

1.2 Newton's Law of Gravitation.. 10

1.2.1 Determination of gravitational constant, G.. 11

1.2.2 Calculation for G 12

1.2.3 Mass and Density of Earth 13

1.2.4 Gravitational and inertial mass.. 14

1.2.5 Mass of sun.. 15

1.2.6 Orbits round the earth 15

1.2.7 Parking Orbits 16

1.2.8 Weightlessness 17

1.3 Surface tension 18

1.3.1 Energy of liquid surface - molecular theory 19

1.3.2 Surface area and shape of drop 20

1.3.3 Some surface tension phenomena 21

1.3.4 Capillarity 22

1.3.5 Angle of contact 22

1.3.6 Measurement of surface tension by capillary tube.. 24

1.4 Elasticity.. 29

1.4.1 Proportional and elastic limits 30

1.4.2 Hooke's Law.. 31

1.4.3 Yield point, ductile and brittle substances, breaking stress 31

1.4.4 Tensile stress and strain, Young's Modulus.. 32

1.5 Diffusion.. 35

1.6 Viscosity.. 37

1.6.1 Newton's formula, coefficient of viscosity 37

1.6.2 Comparison of viscosities of viscous liquids.. 39

1.6.3 Molecular theory of viscosity 40

1.7 Osmosis.. 41

1.7.1 Water passing through a semi-permeable membrane.. 41

1.7.2 Plant cell under different environments. 41

Module 2:

Heat **48**
2.1 Introduction 48
2.2 Expansion of gases 48
2.2.1 Boyle's law 49
2.2.2 Charles's law 49
2.2.3 The pressure law (Gay-Lussac's law) 50
2.2.4 The combined gas laws 51
2.3 Amount of substance and molar mass 51
2.4 The general and characteristic gas equations 52
2.5 Standard temperature and pressure (STP) 52
2.6 Important formulae for gases 54
2.7 Calorimetric and specific heat capacity 54
2.7.1 Heat capacity 55
2.7.2 Specific heat capacity 55
2.7.3 Amount of heat energy 55
2.7.4 The law of conservation of energy 56
2.7.5 Experiment to determine the specific heat capacity or a copper calorimeter 57
2.7.6 Water equivalent 58
2.8 Important formulae for conservation of energy 60
2.9 Kinetic molecular theory 60
2.10 The concept of an ideal gas 61
2.11 Investigating the gas laws 62
2.11.1 The Kelvin scale 62
2.11.2 Direct and inverse proportion 62
2.11.3 Investigating the relationship between volume and temperature 64
2.11.4 Investigating the relationship between volume and pressure 65
2.12 Deducing relationships from graphs experimental results 67
2.12.1 The relationship volume and temperature constant 67
2.12.2 The relationship between volume and pressure of a trapped gas 68
2.12.3 Relationships between several variables in one equation 69

2.12.4 The relationship between the volume and amount of a gas 71
2.12.5 The ideal gas equation 72
2.12.6 Molar gas volume and gas type 73
2.13 Ideal gas laws and real gases 74
2.14 Heat transfer 74
2.14.1 Conduction 74
2.14.2 Convection 75
2.14.3 Radiation 76
2.15 Calculating heat 77
2.15.1 The first law of thermodynamics 77
2.16 Radiation 81
2.16.1 Good and bad absorbers 81
2.16.2 Good and bad emitters 81
2.16.3 The greenhouse effect 82
2.16.4 Thermos flask 83
2.17 Adiabatic processes 84

Module 3:

Light I 88

3.1 Introduction 88
3.2 Shadows and eclipses 89
3.3 The pinhole camera 90
3.4 Reflection of light 91
3.4.1 An image in a plane mirror 93
3.5 Refraction of light 95
3.5.1 Real and apparent depth 97
3.5.2 Refraction by prisms 97
3.6 Total internal reflection 98
3.6.1 Total internal reflection in prisms 99
3.6.2 Refraction and cars 100
3.6.3 Optical fibres 101
3.7 Converging lenses 102
3.7.1 Finding the image 103

3.8 Optical instruments 104
3.8.1 Camera 104
3.8.2 The slide projector 106
3.9 The human eye 107
3.9.1 Focusing the eye 108
3.9.2 Wearing spectacles 109
3.9.3 Binocular vision 109
3.10 The spectrometer 110
3.10.1 Adjustments of spectrometer 111
3.11 Photometry 112
3.11.1 Standard candle: the candela 112
3.11.2 Illumination and its units 112
3.11.3 Luminous Flux, *F* 113
3.11.4 Solid Angle 113
3.11.5 Luminous Intensity of Source, ***I*** 114

Module 4:

Light II 123

4.1 Introduction 123
4.1.1 Waves on slinkies 123
4.1.2 Describing waves 124
4.1.3 Wave velocities 125
4.2 Light as a wave 126
4.2.1 Microwave interference 126
4.2.2 Interference of light 127
4.3 Geometrical optics 129
4.3.1 Light as a transversal wave 129
4.3.2 Wave properties of light 130
4.3.3 Reflection 131
4.3.4 Refraction 137
4.3.5 Total internal reflection 140

Module 5:

Magnetism 145

5.1 Introduction 145
5.2 Magnets 145
5.3 Magnetic effect 148
5.4 Lines of a force when a current is passed through a coil 150
5.5 Electromagnetism 150
5.6 Electromagnetic force 151
5.7 Electromagnetic induction 152
5.7.1 Self-inductance 153
5.7.2 Mutual inductance 154
5.8 Ampere - turns 155
5.9 Magnetometers 155
5.10 Coulomb's Law of Force 156

Module 6:

Electricity 158

6.1 Introduction 158
6.2 Lenz's law 158
6.3 Moving coil instruments 159
6.3.1 The ampere meter 159
6.3.2 The volt meter 161
6.3.3 The ohmmeter 162
6.3.4 The analogue multi-meter 162
6.3.5 The digital multi-meter 164
6.4 The ac generator (alternator) 164
6.5 The dc generator (dynamo) 166
6.6 Producing power on a large scale 166
6.7 Transformers 167
6.7.1 Mutual inductance 167
6.7.2 The induction coil 168
6.7.3 The transformer 169
6.8 Transmitting power 170
6.8.1 Power in transformers 170
6.8.2 The national grid 171

Module 7:

Sound 178
7.1 Introduction 178
7.2 Properties of waves 179
7.2.1 Period 180
7.2.2 Frequency 181
7.2.3 Amplitude 181
7.2.4 Wavelength 182
7.2.5 Waves in everyday life 182
7.3 Nature of waves 183
7.4 Transversal and longitudinal waves 184
7.4.1 Transversal waves 184
7.4.2 Longitudinal waves 184
7.4.3 Differences between transversal and longitudinal waves 185
7.5 Displacement position graph 185
7.6 Calculations for a transversal wave 186
7.6.1 Wave speed 186
7.6.2 Wavelength 187
7.6.3 Calculating frequency and period 188
7.6.4 Density 188
7.6.5 Compressibility 189
7.6.6 Depth 189
7.7 Standing and moving waves 189
7.7.1 Superposition in standing waves 190
Past Examination Papers 190

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We use different icons to help you work with this book; these are shown in the table below.

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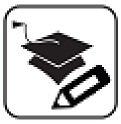
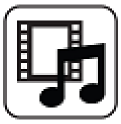
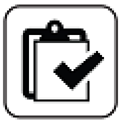
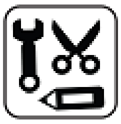
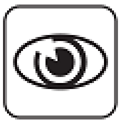
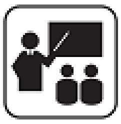
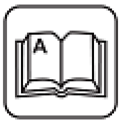
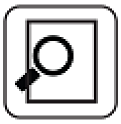
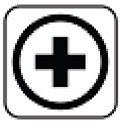
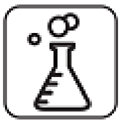
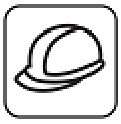
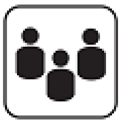
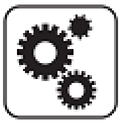
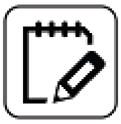
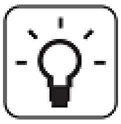
	Assessment / Activity		Multimedia
	Checklist		Practical
	Demonstration/ observation		Presentation/ Lecture
	Did you know?		Read
	Example		Safety
	Experiment		Site visit
	Group work/ discussions, role-play, etc.		Take note of
	In the workplace		Theoretical – questions, reports, case studies, etc.
	Keywords		Think about it

Module 1

General Properties of Matter

Learning Outcomes
On the completion of this module the student must be able to:

- Describe Newton's law of gravitation
- Describe elasticity
- Describe surface tension
- Describe capillarity
- Describe diffusion
- Describe viscosity
- Describe osmosis

1.1 Introduction

The motion of the planets in the heavens had excited the interest of the earliest scientists, and Babylonian and Greek astronomers were able to predict their movements fairly accurately.

It was considered for some time that the earth was the centre of the universe, but about 1542 Copernicus suggested that the planets revolved round the sun as centre.

Did you know?
A great advance was made by Kepler about 1609. He had studied for many years the records of observations on the planets made by Tycho Brahe, and he enunciated three laws known by his name.

Kepler's laws state:
- The planets describe ellipses about the sun as one focus.
- The line joining the sun and the planet sweeps out equal areas in equal times.
- The squares of the periods of revolution of the planets are proportional to the cubes of their mean distances from the sun.

The third law was announced by Kepler in 1619.

1.2 Newton's Law of Gravitation

About 1666, at the early age of 24, Newton discovered a universal law known as the law of gravitation.

He was led to this discovery by considering the motion of a planet moving in a circle round the sun S as centre. **Figure 1.1(i)**. The force acting on the planet of mass *m* is $mr\omega^2$, where *r* is the radius of the circle and ω is the angular velocity of the motion. Since $\omega = 2\pi/T$, where *T* is the period of the motion,

$$force\ on\ planet = \pi m\left(\frac{2\pi}{T}\right)^2 = \frac{4\pi^2 mr}{T^2}$$

This is. equal to the force of attraction of the sun on the planet. Assuming an inverse-square law, then, if *k* is a constant,

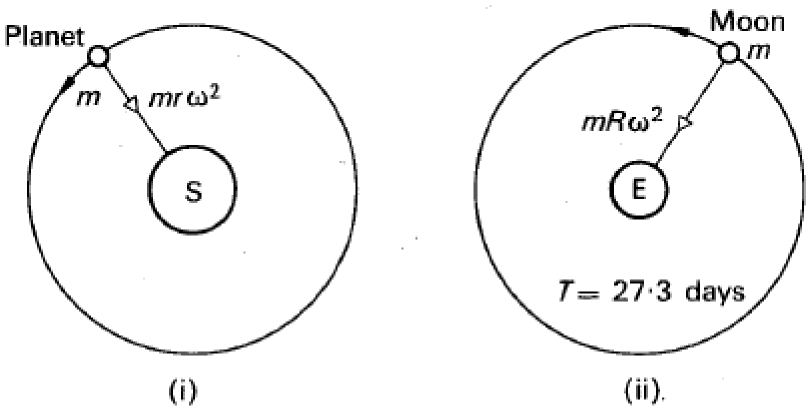


Figure 1.1 Satellites

$$\begin{aligned} force\ on\ planet &= \frac{km}{r^2} \\ \therefore \frac{km}{r^2} &= \frac{4\pi^2 mr}{T^2} \\ \therefore T^2 &= \frac{4\pi^2}{k} r^3 \\ \therefore T^2 &\propto r^3 \end{aligned}$$

since *k*, π are constants.

Now Kepler had announced that the squares of the periods of revolution of the planets are proportional to the cubes of their mean distances from the sun (see above).

Newton thus suspected that the force between the sun and the planet was inversely proportional to the square of the distance between them. The great scientist now proceeded to test the inverse-square law by applying it to the case of the moon's motion round the earth. (**Figure 1.1(ii)**)

The moon has a period of revolution, T_3, about the earth of approximately 27,3 days, and the force on it = $mr\omega^2$, where *R* is the radius of the moon's orbit and *m* is its mass.

$$\therefore force = mR\left(\frac{2\pi}{T}\right)^2 = \frac{4\pi^2 mR}{T^2}$$

If the planet were at the earth's surface, the force of attraction on it due to the earth would be *mg*, where *g* is the acceleration due to gravity - **Figure 1.1(ii)**.

Assuming that the force of attraction varies as the inverse square of the distance between the earth and the moon,

$$\therefore \frac{4\pi^2 mR}{T^2} : mg = \frac{1}{R^2} : \frac{1}{r^2}$$

where *r* is the radius of the earth.

$$\therefore \frac{4\pi^2 R}{T^2 g} = \frac{r^2}{R^2}$$

$$\therefore g = \frac{4\pi^2 R^3}{r^2 T^2} \quad \text{..} \quad (1)$$

Newton substituted the then known values of *R, r,* and *T,* but was disappointed to find that the answer for *g* was not near to the observed value, 9·8 m s^{-2}.

Some years later, he heard of a new estimate of the radius of the moon's orbit, and on substituting its value he found that the result for *g* was close to 9·8 m s^{-2}.

Newton saw that a universal law could be formulated for the attraction between any two particles of matter. He suggested that: *The force of attraction between two given masses is inversely proportional to the square of their distance apart.*

1.2.1 Determination of gravitational constant, G

From Newton's law, it follows that the force of attraction, *F,* between two masses *m, M* at a distance *r* apart is given by $F \propto \frac{mM}{r^2}$.

$$\therefore F = G\frac{mM}{r^2} \quad \text{..} \quad (2)$$

where G is a universal constant known as the *gravitational constant.*

Note:
This expression for *F* is *Newton's law of gravitation.*

From (2), it follows that G can be expressed in ***N m²* *kg*⁻²**. The dimensions of G are given by:

$$[G] = \frac{MLT^{-2} \times L^2}{M^2} = M^{-1}L^3T^{-2}$$

Thus the unit of G may also be expressed as ***m³ kg⁻¹ s⁻²***.

Did you know?
A celebrated experiment to measure G was carried out by CV Boys in 1895, using a method similar to one of the earliest determinations of G by Cavendish in 1798.

Two identical balls, *a, b,* of gold, 5 mm in diameter, were suspended by a long and a short fine quartz fibre respectively from the ends, C, D, of a highly-polished bar CD, **Figure 1.2**.

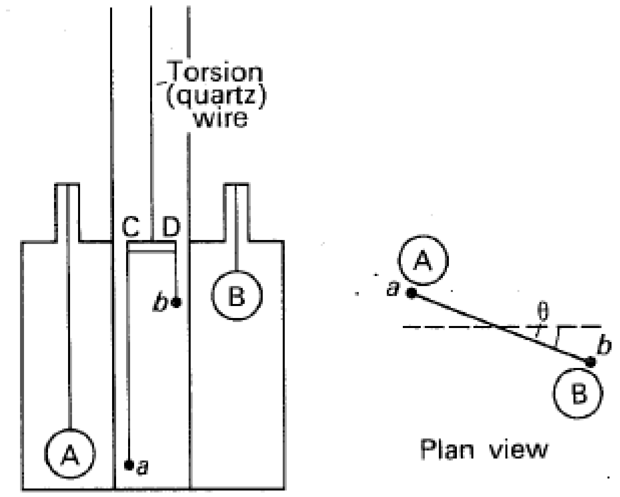


Figure 1.2

Two large identical lead spheres, A, B, 115 mm in diameter, were brought into position near *a, b* respectively. As a result of the attraction between the masses, two equal but opposite forces acted on CD. The bar was thus deflected, and the angle of deflection, *e*, was measured by a lamp and scale method by light reflected from CD.

Think about it!
The high sensitivity of the quartz fibres enabled the small deflection to be measured accurately, and the small size of the apparatus allowed it to be screened considerably from air convection currents.

1.2.2 Calculation for G

Suppose *d* is the distance between *a,* A, or *b,* B, when the deflection is *e*. Then if *m, M* are the respective masses of *a,* A,

$$torque\ of\ couple\ on\ CD = G\frac{mM}{d^2} \times CD$$

But $$torque\ of\ couple = c\theta$$

where c is the torque in the torsion wire per unit radian of twist.

$$G\frac{mM}{d^2} \times CD = c\theta$$

$$\therefore G = \frac{c\theta d^2}{mM \times CD} \text{ .... (1)}$$

The constant *c* was determined by allowing CD to oscillate through a small angle and then observing its period of oscillation, *T,* which was of the order of 3 minutes. If *I* is the known moment of inertia of the system about the torsion wire, then

$$T = 2\pi\sqrt{\frac{I}{c}}$$

The constant *c* can now be calculated, and by substitution in (i), G can be determined. Accurate experiments showed that G = 6,66 x 10^{-11} N m^2 kg^{-2} and Heyl, in 1942, found G to be 6,67 x 10^{-11} N m^2 kg^{-2}.

1.2.3 Mass and Density of Earth

At the earth's surface the force of attraction on a mass *m* is *mg,* where *g* is the acceleration due to gravity. Now it can be shown that it is legitimate in calculations to assume that the mass, *M,* of the earth is concentrated at its centre, if it is a sphere.

Assuming that the earth is spherical and of radius *r,* it then follows that the force of attraction of the earth on the mass *m* is GmM/r^2.

$$\therefore G\frac{mM}{r^2} = mg$$

$$\therefore g = \frac{GM}{r^2}$$

$$\therefore M = \frac{gr^2}{G}$$

Now, *g* = 9,8 m s^{-2}, *r* = 6·4 x 10^6 m, G = 6,7 x 10^{-11} N m^2 kg^{-2}.

$$\therefore M = \frac{9{,}8 \times (6{,}4 \times 10^6)^2}{6{,}7 \times 10^{-11}} = 6{,}0 \times 10^{24} kg$$

The volume of a sphere is $4\pi r^3/3$, where *r* is its radius. Thus the density, *p,* of the earth is approximately given by

$$\rho = \frac{M}{V} = \frac{gr^2}{4\pi r^3 G/3} = \frac{3g}{4\pi r G}$$

By substituting known values of *g*, G, and *r*, the mean density of the earth is found to be about 5500 kg m^{-3}. The density may approach a value of 10 000 kg m^{-3} towards the interior.

Did you know?

Gravitational force travels with the speed of light.

Thus if the gravitational force between the sun and earth were suddenly to disappear by the vanishing of the sun, it would take about 7 minutes for the effect to be experienced on the earth.

The earth would then fly off along a tangent to its original curved path.

1.2.4 Gravitational and inertial mass

The mass *m* of an object appearing in the expression $F = ma$, force = mass x acceleration, is the *inertial mass.*

It is a measure of the reluctance of the object to move when forces act on it. It appears in *F = rna* from Newton's second law of motion.

Definition: Gravitational mass
The 'mass' of the same object concerned in Newton's theory of gravitational attraction can be distinguished from the inertial mass. This is called the *gravitational mass.*

If it is given the symbol m_g, then $F = GMm_g/r^2$, where F_g is the gravitational force, *M* is the mass of the earth and *r* its radius. Now $GM/r^2 = g$, the acceleration due to gravity. Thus $F_g = m_g g = W$, the weight of the object.

In the simple pendulum theory, we can derive the period *T* using *W* = weight = $m_g g$ in place of the symbols adopted there.

Thus
$$-m_g g \frac{y}{l} = ma,$$
or
$$a = \frac{m_g g}{ml} . y = -\omega^2$$
$$\therefore T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{ml}{m_g g}}$$

Experiments show that to a high degree of accuracy, $T = 2\pi\sqrt{l/g}$ no matter what mass is used, that is, the period depends only on *l* and *g* .

Thus $m = m_g$, or the gravitational mass is equal to the inertial mass to the best of our present knowledge.

1.2.5 Mass of sun

Consider the case of the earth. Its period *T* is about 365 days or 365 x 24 x 3600 seconds.

Did you know?
The mass M_s of the sun can be found from the period of a satellite and its distance from the sun.

Earths distance r_s from the centre of the sun is about 1,5 x 10^{11} m. If the mass of the earth is *m,* then, for circular motion round the sun,

$$\frac{GM_s m}{{r_s}^2} = m r_s \omega^2 = \frac{m r_s 4\pi^2}{T^2},$$

$$\therefore M_s = \frac{4\pi^2 {r_s}^3}{GT^2} = \frac{4\pi^2 \times (1{,}5\times10^{11})^3}{6{,}7\times10^{11}\times(365\times24\times3600)^2} = 2\times10^{30} kg$$

1.2.6 Orbits round the earth

Satellites can be launched from the earth's surface to circle the earth. They are kept in their orbit by the gravitational attraction of the earth.

Figure 1.3 Orbits around earth

Consider a satellite of mass *m* which just circles the earth of mass *M* close to its surface in an orbit 1 in **Figure 1.3**. Then, if *r* is the radius of the earth,

$$\frac{mv^2}{r} = G\frac{Mm}{T^2} = mg$$

where *g* is the acceleration due to gravity at the earth's surface and *v* is the velocity of *m* in its orbit. Thus $v^2 = rg$, and hence, using *r* = 6,4 x 10^6m and *g* = 9,8 m s^{-2},

$$v = \sqrt{rg} = \sqrt{6{,}4\times10^6\times9{,}8} = 8\times10^3\, m\, s^{-1} \text{ (approx)},$$
$$= 8\, km\, s^{-1}$$

The velocity *v* in the orbit is thus about 8 km s^{-1}. In practice, the satellite is carried by a rocket to the height of the orbit and then given an impulse, by firing jets, to deflect it in a direction parallel to the tangent of the orbit. Its velocity is boosted to 8 km s^{-1} so that it stays in the orbit. The period in orbit

$$= \frac{circumference\ of\ earth}{v} = \frac{2\pi \times 6{,}4\times 10^{6}\ m}{8\times 10^{3}\ m\ s^{-1}}$$
$$= 5\ 000\ seconds\ (approx) = 83\ min$$

1.2.7 Parking Orbits

Consider now a satellite of mass *m* circling the earth in the plane of the equator in an orbit 2 concentric with the earth - **Figure 1.3**. Suppose the direction of rotation as the same as the earth and the orbit is at a distance *R* from the centre of the earth. Then if *v* is the velocity in orbit,

$$\frac{mv^2}{R} = \frac{GMm}{R^2}$$

But $GM = gr^2$, where *r* is the radius of the earth.

$$\therefore \frac{mv^2}{R} = \frac{mgr^2}{R^2}$$
$$\therefore v^2 = \frac{gr^2}{R}$$

If *T* is the period of the satellite in its orbit, then $v = 2\pi R/T$.

$$\therefore \frac{4\pi^2R^2}{T^2} = \frac{gr^2}{R}$$
$$\therefore T^2 = \frac{4\pi^2R^3}{gr^2} \quad \text{...(i)}$$

If the period of the satellite in its orbit is exactly equal to the period of the earth as it turns about its axis, which is 24 hours, *the satellite will stay over the same lace on the earth* while the earth rotates. This is sometimes called a 'parking orbit'.

Did you know?
Relay satellites can be placed in parking orbits, so that television programmes can be transmitted continuously from one part of the world to another.

Since *T* = 24 hours, the radius *R* can be found from (i). Thus from

$$R = \sqrt[3]{\frac{T^2gr^2}{4\pi^2}}$$ and *g* = 9·8 m s^{-2} , *r* = 6·4 x 10^6 m,

$$\therefore R = \sqrt[3]{\frac{(24\times 3600)^2\times 9.8\times(6.4\times 10^6)^2}{4\pi^2}} = 42400\ km$$

The height above the earth's surface of the parking orbit

$$= R - r = 42\ 400 - 6\ 400 = 36\ 000\ km$$

In the orbit, the velocity of the satellite

$$= \frac{2\pi R}{T} = \frac{2\pi \times 42\,400}{24 \times 3\,600\ seconds} = 3.1\ km\ s^{-1}$$

1.2.8 Weightlessness

When a rocket is fired to launch a spacecraft and astronaut into orbit round the earth, the initial acceleration must be very high owing to the large initial thrust required. This acceleration, *a,* is of the order of *15g,* where *g* is the gravitational acceleration at the earth's surface.

Suppose *S* is the reaction of the couch to which the astronaut is initially strapped. **Figure 1.4(i)**. Then, from *F = ma, S- mg = ma = m. 15g,* where *m* is the mass of the astronaut. Thus *S = 16mg.* This force is 16 times the weight of the astronaut and thus, initially, he experiences a large force.

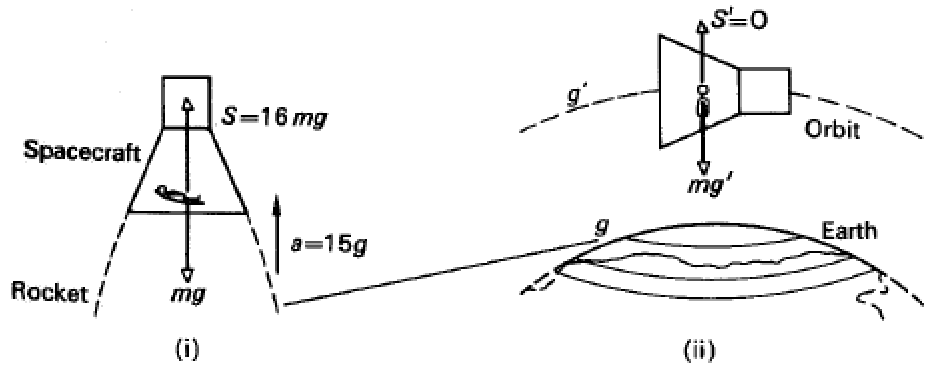


Figure 1.4

In orbit, however, the state of affairs is different. This time the acceleration of the spacecraft and astronaut are both *a*' in magnitude, where *g'* is the acceleration due to gravity outside the spacecraft at the particular height of the orbit. **Figure 1.4(ii)**. If S1 is the reaction of the surface of the spacecraft in contact with the astronaut, then, for circular motion,

$$F\ = mg' - S' = ma = mg'$$

Thus *S' = 0*. Consequently the astronaut becomes 'weightless'; he experiences no reaction at the floor when he walks about, for example.

Think about it!

At the earth's surface we feel the reaction at the ground and are thus conscious of our weight. Inside a lift which is falling fast, the reaction at our feet diminishes. If the lift falls freely, the acceleration of objects inside is the same as that outside and hence the reaction on them is zero. This produces the sensation of 'weightlessness'.

In orbit, as in **Figure 1.4(ii)**, objects inside a spacecraft are also in 'free fall' because they have the same acceleration *g'* as the spacecraft. Consequently the sensation of weightlessness is experienced.

Worked Example 1.1

A satellite is to be put into orbit 500 km above the earth's surface. If its vertical velocity after launching is 2 000 ms^{-1} at this height, calculate the magnitude and direction of the impulse required to put the satellite directly into orbit, if its mass is 50 kg. Assume $g = 10m\ s^{-2}$; radius of earth, R = 6 400 km.

Solution:
Suppose *u* is the velocity required for orbit, radius *r*. Then, with usual notation,

$$\frac{mu^2}{r} = \frac{GmM}{r^2} = \frac{gR^2m}{r^2}, as\ \frac{GM}{R^2} = g$$

$$\therefore\ u^2 = \frac{gR^2}{r},$$

Now R = 6 400 km, r = 6 900 km, g = 10ms^{-2}

$$\therefore u^2 = \frac{10\times(6400\times10^3)^2}{6900\times10^3}$$

$$\therefore u = 7\ 700\ ms^{-1} \text{ (approx)}$$

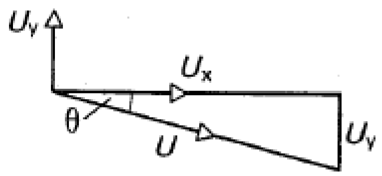


Figure 1.5

At this height, vertical momentum

$$U_Y = mv = 50 \times 2\ 000 = 100\ 000\ kg\ ms^{-1}$$

Horizontal momentum required

$$U_X = mu = 50 \times 7\ 700 = 385\ 000\ kg\ ms^{-1}$$

$$\therefore impulse\ needed, U, = \sqrt{U_Y{}^2 + U_X{}^2} = \sqrt{100\ 000^2 + 385\ 000^2}$$

$$= 4.0 \times 10^5 kg\ m\ s^{-1} \quad \text{.. (1)}$$

Direction. The angle θ made by the total impulse with the horizontal or orbit tangent is given by tan $\theta = U_Y/U_X$ = 100 000/385 000 = 0·260. Thus θ = 14·6°.

1.3 Surface tension

This phenomenon is due to intermolecular attraction.

It is a well-known fact that some insects, for example a water-carrier, are able to walk across a water surface; that a drop of water may remain suspended for some time from a tap before falling, as if the water particles were held together in a bag; that mercury gathers into small droplets when spilt; and that a dry steel needle may be made, with care, to float on water, **Figure 1.6**.

These observations suggest that *the surface of a liquid acts like an elastic skin covering the liquid or* is in *a state of tension*. Thus forces *S* in the liquid support the weight *W* of the needle, as shown in **Figure 1.6**.

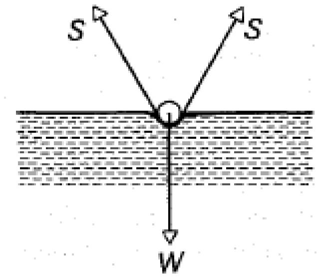


Figure 1.6 Needle floating on water

1.3.1 Energy of liquid surface - molecular theory

The fact that a liquid surface is in a state of tension can be explained by the intermolecular forces. In the bulk of the liquid, which begins only a few molecular diameters downwards from the surface, a particular molecule such as A is surrounded by an equal number of molecules on all sides.

This can be seen by drawing a sphere round A. **Figure 1.7**.

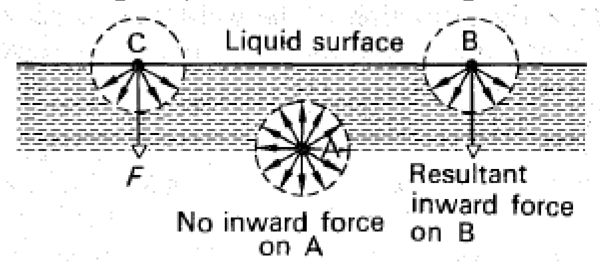


Figure 1.7 Molecular forces in liquid

The average distance apart of the molecules is such that the attractive forces balance the repulsive forces. Thus the average intermolecular force between A and the surrounding molecules is zero. **Figure 1.7**.

Consider now a molecule such as C or B in the surface of the liquid.

Note:
There are very few molecules on the vapour side above C or B compared with the liquid below, as shown by drawing a sphere round C or B.

Thus if C is displaced very slightly upward, a resultant attractive force *F* on C, due to the large number of molecules below C, now has to be overcome. It follows that if all the molecules in the surface were removed to infinity, a definite amount of work is needed.

Consequently molecules in the surface have potential energy. A molecule in the bulk of the liquid forms bonds with more neighbours than one in the surface. Thus bonds must be broken, ie work must be done, to bring a molecule into the surface.

> **Note:**
> Molecules in the surface of the liquid hence have more potential energy than those in the bulk.

1.3.2 Surface area and shape of drop

The potential energy of any system in stable equilibrium is a minimum Thus under surface tension forces, the area of a liquid surface will have the least number of molecules in it, that is, the surface area of a given volume of liquid is a minimum.

Mathematically, it can be shown that the shape of a given volume of liquid with a minimum surface area is a *sphere*.

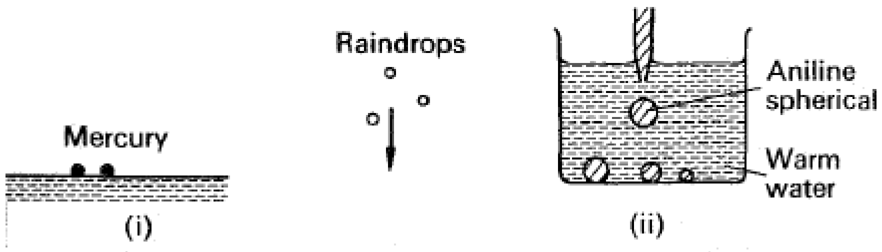


Figure 1.8 Liquid drops

This is why raindrops, and small droplets of mercury, are approximately spherical in shape. **Figure 1.8(i)**. To eliminate completely the effect of gravitational force, Plateau placed a drop of oil in a mixture of alcohol and water of the same density. In this case the weight of the drop is counterbalanced by the upthrust of the surrounding liquid.

He then observed that the drop was a perfect sphere. Plateau's 'spherule' experiment can be carried out by warming water in a beaker and then carefully introducing aniline with the aid of a pipette. **Figure 1.8 (ii)**.

At room temperature the density of aniline is slightly greater than water. At a higher temperature the densities of the two liquids are roughly the same and the aniline is then seen to form spheres, which rise and fall in the liquid.

> **Note:**
> A soap bubble is spherical because its weight is extremely small and the liquid shape is then mainly due to surface tension forces. Although the density of mercury is high, small drops of mercury are spherical.

The ratio of surface area ($4\pi r^2$) to weight (or volume, ($4\pi r^3/3$) of a sphere is proportional to the ratio r^2/r^3, or to l/r. Thus the smaller the radius, the greater is the influence of surface tension forces compared to the weight. Large mercury drops, however, are flattened on top.

This time the effect of gravity is relatively greater. The shape of the drop conforms to the principle that the sum of the gravitational potential energy and the surface energy must be a minimum, and so the centre of gravity moves down as much as possible.

Did you know?
Lead shot is manufactured by spraying lead from the top of a tall tower. As they fall, the small drops form spheres under the action of surface tension forces.

Note:
Surface tension can be defined also in terms surface energy.

1.3.3 Some surface tension phenomena

The effect of surface tension forces in a soap film can be demonstrated placing a thread B carefully on a soap film formed in a metal ring **Figure 1.9(i)**.

The surface tension forces on both sides of the thread counterbalance, as shown in **Figure1.9(i)**.

If the film enclosed by the thread is pierced, however, the thread is pulled out into a circle by the surface tension forces *F* at the junction of the air and soap-film, **Figure 1.9(ii)**. Observe that the film has contracted to a minimum area.

Another demonstration of surface tension forces can be made by sprinkling light dust or lycopodium powder over the surface of water contained in a dish.

If the middle of the water is touched with the end of a glass rod which had previously been dipped into soap solution, the powder is carried away to the sides by the water.

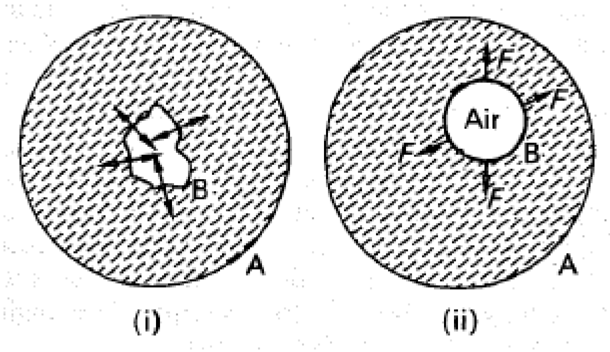


Figure 1.9 Contraction of surface

The explanation lies in the fact that the surface tension of water is greater than that of a soap-film.

The resultant force at the place where the rod touched the water is hence *away from* the rod, and thus the powder moves away from the centre towards the sides of the vessel.

Think about it!
A toy duck moves by itself across the surface of water when it has a small bag of camphor attached to its base. The camphor lowers the surface tension of the water in contact with it, and the duck is urged across the water by the resultant force on it.

1.3.4 Capillarity

When a capillary tube is immersed in water, and then placed vertically with one end in the liquid, observation shows that the water rises in the tube to a height above the surface. The narrower the tube, the greater is the height to which the water rises, **Figure 1.10(i)**.

This phenomenon is known as *capillarity,* and it occurs when blotting-paper is used to dry ink. The liquid rises up the pores of the paper when it is pressed on the ink.

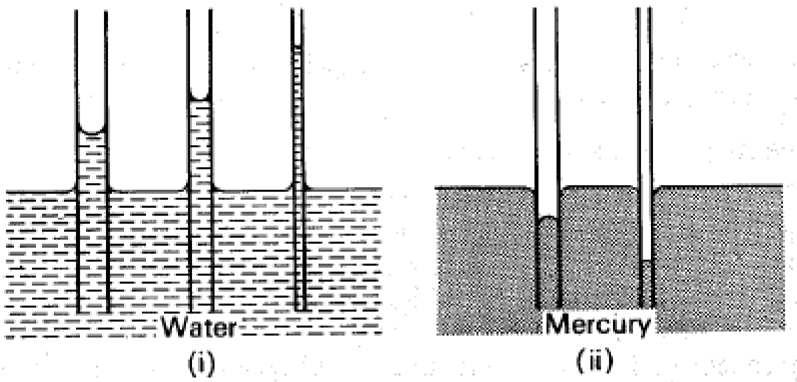


Figure 1.10 Capillary rise and fall

When a capillary tube is placed inside mercury, however, the liquid is depressed *below* the outside level, **Figure 1.10(ii)**. The depression increases as the diameter of the capillary tube decreases.

1.3.5 Angle of contact

In the case of water in a glass capillary tube, observation of the meniscus shows that it is hemispherical if the glass is clean, that is, the glass surface is tangential to the meniscus where the water touches it.

In other cases where liquids rise in a capillary tube, the tangent BN to the liquid surface where it touches the glass may make an acute angle θ with the glass; **Figure 1.11(i)**.

Did you know?
The angle θ is known as the *angle of contact* between the liquid and the glass, and is always measured *through the liquid*.

The angle of contact between two given surfaces varies largely with their freshness and cleanliness. The angle of contact between water and very clean glass is zero, but when the glass is not clean the angle of contact may be about 8º for example. The angle of contact between alcohol and very clean glass is zero.

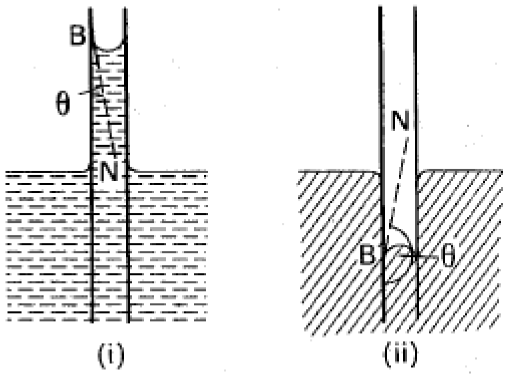


Figure 1.11 Angle of contact

When a capillary tube is placed inside mercury, observation shows that the surface of the liquid is depressed in the tube and is convex upwards. **Figure 1.11(ii)**.

The tangent BN to the mercury at the point B where the liquid touches the glass thus makes an obtuse angle, θ, with the glass when measured through the liquid.

Note:
A liquid will rise in a capillary tube if the angle of contact is acute, and a liquid will be depressed in the tube if the angle of contact is obtuse.

For the same reason, clean water spreads over, or 'wets', a clean glass surface when spilt on it, **Figure 1.12(i)**; the angle of contact is zero. On the other hand, mercury gathers itself into small pools or globules when spilt on glass, and does not 'wet' glass, **Figure 1.12(ii)**. The angle of contact is obtuse.

Figure 1.12 Water and mercury on glass

The difference in behaviour of water and mercury on clean glass can be explained in terms of the attraction between the molecules of these substances.

It appears that the force of *cohesion* between two molecules of water is less than the force of *adhesion* between a molecule of water and a molecule of glass; and thus water spreads over glass.

On the other hand, the force of cohesion between two molecules of mercury is greater than the force of adhesion between a molecule of mercury and a molecule of glass; and thus mercury gathers in pools when spilt on glass.

1.3.6 Measurement of surface tension by capillary tube
Suppose γ is the magnitude of the surface tension of a liquid such as water, which rises up a clean glass capillary tube and has an angle of contact zero.

Figure 1.13 shows a section of the meniscus M at B, which is a hemisphere.

Since the glass AB is a tangent to the liquid, the surface tension forces, which act along the boundary of the liquid with the air, act vertically downwards on the glass. By the law of action and reaction, the glass exerts an equal force in an upward direction on the liquid.

Now surface tension, γ, is the force per unit length acting in the surface of the liquid, and the length of liquid in contact with the glass is $2\pi r$, where *r* is the radius of the capillary tube.

$$\therefore 2\pi r \times \gamma \ = upward\ force\ on\ liquid\ldots\ldots\ldots\ldots\ldots \quad (1)$$

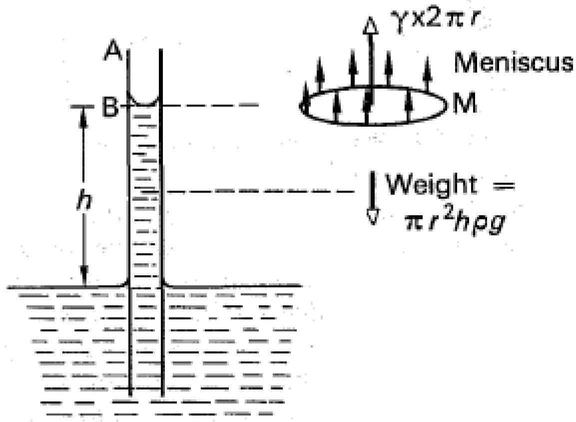


Figure 1.13 Rise in capillary tube – theory

If *y* is in newton metre -1 and *r* is in metres, then the upward force is in *newtons.*

This force supports the weight of a column of height *h* above the outside level of liquid. The volume of the liquid = $\pi r^2 h$, and thus the mass, *m,* of the liquid column = volume x density = $\pi r^2 hp$, where *p* is the density. The *weight* of the liquid = *mg* = $\pi r^2 h\rho g$.

If ρ is in kg m^{-3}, rand *h* in metres, and *g* = 9·8 m s^{-2}, then $\pi r^2 h\rho g$ is in *newtons.*

From (1), it now follows that

$$\therefore 2\pi r\gamma = \pi r^2 h\rho g$$
$$\therefore \gamma = \frac{rh\rho g}{2} \quad \text{.......} \quad (2)$$

If r = 0,2 mm = 0,2 x 10^{-3} m, *h* = 6,6 cm for water = 6,6 x 10^{-2} m, and *p* = 1 g cm^{-3} = 1 000 kg m^{-3}, then

$$\gamma = \frac{0.2\times10^{-3}\times6{,}6\times10^{-2}\times1\,000\times9.8}{2} = 6{,}5 \times 10^{-2} Nm^{-1}$$

In deriving this formula for *y* it should be noted that we have:
- assumed the glass to be a tangent to the liquid surface meeting it
- neglected the weight of the small amount of liquid above the bottom of the meniscus at B, **Figure 1.13**.

Experiment 1.1

In the experiment, the capillary tube C is supported in a beaker Y, and a pin P, bent at right angles at two places, is attached to C by a rubber band, **Figure 1.14**.

P is adjusted until its point just touches the horizontal level of the liquid in the beaker. A travelling microscope is now focussed on to the meniscus M in C, and then it is focussed on to the point of P, the beaker being removed for this observation.

In this way the height *h* of M above the level in the beaker is determined.

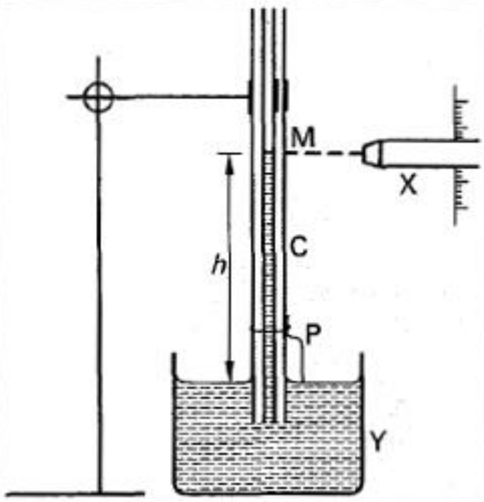


Figure 1.14 Surface tension by capillary rise

The radius of the capillary at M can be found by cutting the tube at this place and measuring the diameter by the travelling microscope; or by measuring the length, l, and mass, *m*, of a mercury thread drawn into the tube, and calculating the radius, *r*, from the relation $r = \sqrt{m/\pi l\rho}$, where *p* is the density of mercury.

The surface tension γ is then calculated from the formula $\gamma = rh\rho g/2$. Its magnitude for water at 15°C is 7,33 x 10^{-2} newton $metre^{-1}$.

Worked Example 1.2

Define surface tension of a liquid and describe a method of finding this quantity for alcohol.

It water rises in a capillary tube 5,8 cm above the free surface of the outer liquid, what will happen to the mercury level in the same tube when it is placed in a dish of mercury? Illustrate this by the aid of a diagram.

Calculate the difference in level between the mercury surfaces inside the tube and outside. (ST of water = 75 x 10^{-3} Nm^{-1}. ST of mercury = 547 x 10^{-3} N m^{-1}. Angle of contact of mercury with clean glass = 130°. Density of mercury = 13 600 kg m^{-3}.) (L)

Solution:
Suppose *r* is the capillary tube radius. The mercury is depressed a distance *h* below the outside level, and is convex upward, **Figure 1.15**.

For water, *h* = 5,8 cm = 5,8 x 10^{-2} m, 7 = 7,5 x 10^{-3} newton m^{-1}, ρ = 1 000 kg m^{-3}, *g* = 9,8 m s^{-2}.

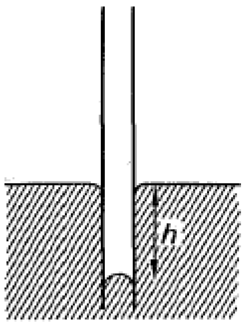


Figure 1.15

From $\gamma = rh\rho g/2$

$$\therefore 75 \times 10^{-3} = r \times 5{,}8 \times 10^{-2} \times 1\,000 \times 9{,}8/2 \quad (r \text{ in metre})$$

For mercury $\rho = 13{,}6 \times 10^{3} kg\ m^{-3}, \gamma = 547 \times 10^{-3}\ newton\ m^{-1}$

$$\therefore h = \frac{2\gamma \cos 50°}{r\rho g}$$

$$= \frac{2 \times 547 \times 10^{-3} \cos 50° \times 5{,}8 \times 10^{-2} \times 1\,000 \times 9{,}8}{13{,}6 \times 10^{3} \times 9{,}8 \times 75 \times 10^{-3} \times 2}$$

$$= 0{,}02\ m = 2\ cm$$

Worked Example 1.3

On what grounds would you anticipate some connection between the surface tension of a liquid and its latent heat of vaporization?

A vertical capillary tube 10 cm long tapers uniformly from an internal diameter of 1 mm at the lower end to 0,5 mm at the upper end. The lower end is just touching the surface of a pool of liquid of surface tension 6 x 10^{-2} N m^{-1}, density 1200 kg m^{-3} and zero angle of contact with the tube.

Calculate the capillary rise, justifying your method. Explain what will happen to the meniscus if the tube is slowly lowered vertically until the upper end is level with the surface of the pool.

Solution:
Suppose S is the meniscus at a height *h* cm above the liquid surface. The tube tapers uniformly and the change in radius for a height of 10 cm is (0,05-0,025) or 0,025 cm, so that the change in radius per cm height is 0,0025 cm.

Thus at a height *h* cm, radius of meniscus S is given by

$$r = (0,05-0,0025\,h) \times 10^{-2}\text{ m}$$

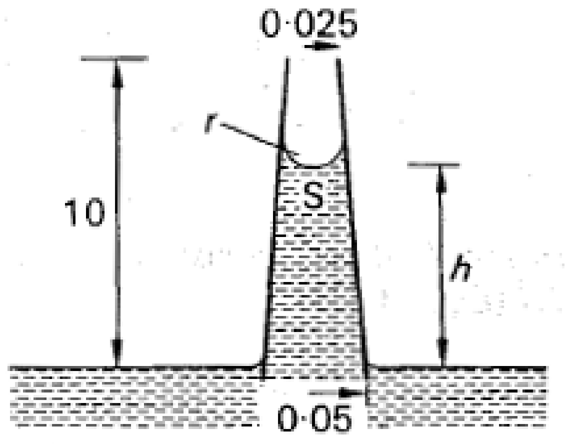


Figure 1.16

The pressure above S is atmospheric, *A*. The pressure below S is (A- *hpg)*.

$$\therefore pressure\ difference = (h \times 10^{-2})pg = \frac{2\gamma}{r} = \frac{200\gamma}{0.05-0.0025h}$$

$$\therefore 0{,}05h - 0{,}0025h^2 = \frac{200\gamma}{pg} = \frac{200\times6\times10^{-2}}{10^{-2}\times1\ 200\times9.8} = 0{,}102$$

$$\therefore h^2 - 20h = -40 \text{ (approx)}$$

$$\therefore (h-10)^2 = 100 - 40 = 60$$

$$\therefore h = 10 - \sqrt{60} = 2{,}2\ cm$$

If the tube is slowly lowered the meniscus reaches the top at some stage. On further lowering the tube the angle of contact changes from zero to an acute angle.

When the upper end is level with liquid surface the meniscus becomes plane.

Worked Example 1.4

'The surface tension of water is 7,5 x 10^{-2} newton m^{-1} and the angle of contact of water with glass is zero.' Explain what these statements mean.

Describe an experiment to determine *either* (a) the surface tension of water, *or* (b) the angle of contact between paraffin wax and water.

A glass U-tube is inverted with the open ends of the straight limbs, of diameters respectively 0,500 mm and 1,00 mm, below the surface of water in a beaker.

The air pressure in the upper part is increased until the meniscus in one limb is level with the water outside.

Find the height of water in the other limb. (The density of water may be taken as 1 000 kg m^{-3}). (L)

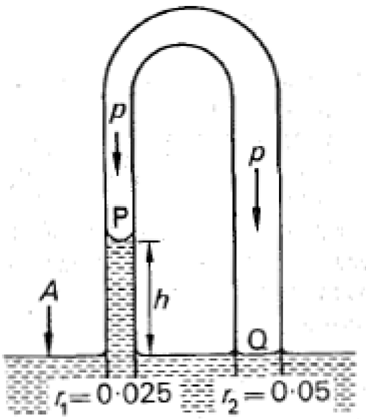


Figure 1.17

Solution:
Suppose *p* is the air pressure inside the U -table when the meniscus Q is level with the water outside and P is the other meniscus at a height *h*. Let *A* be the atmospheric pressure. Then, if r 1 is the radius at P,

$$\rho - (A - h\rho g) = \frac{2\gamma}{r_1} \text{ .... (i)}$$

since the pressure in the liquid below P is (A - *hpg)*.

The pressure in the liquid below Q = A. Hence, for Q,

$$\rho - A = \frac{2\gamma}{r_2} \quad \text{.......................................} \quad \text{(ii)}$$

where r_2 is the radius.

From (i) and (ii), it follows that

$$h\rho g = \frac{2\gamma}{r_1} - \frac{2\gamma}{r_2}$$

$$\therefore h = \frac{1}{\rho g}\left[\frac{2\gamma}{r_1} - \frac{2\gamma}{r_2}\right]$$

$$= \frac{1}{9\,800}\left[\frac{2\times 0{,}075}{0{,}25\times 10^{-3}} - \frac{2\times 0{,}075}{0{,}5\times 10^{-3}}\right]$$

$$= 3{,}1 \times 10^{-2}\ m \text{ (approx.)}$$

1.4 Elasticity

A bridge, when used by traffic during the day, is subjected to loads of varying magnitude. Before a steel bridge is erected, therefore, samples of the steel are sent to a research laboratory, where they undergo tests to find out whether the steel can withstand the loads to which it is likely to be subjected.

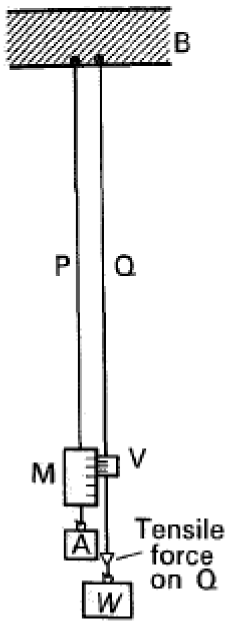


Figure 1.18 Tensile force

Figure 1.18 illustrates a simple laboratory method of discovering useful information about the property of steel we are discussing. Two long thin steel wires, P, Q, are suspended beside each other from a rigid support B, such as a girder at the top of the ceiling.

The wire P is kept taut by a weight A attached to its end and carries a scale M graduated in centimetres. The wire Q carries a vernier scale V which is alongside the scale M.

When a load *W* such as 1 -kgf is attached to the end of Q, the wire increases in length by an amount which can be read from the change in the reading on the vernier V.

If the load is taken off and the reading on V returns to its original value, the wire is said to be elastic for loads from zero to 1 kgf, a term adopted by analogy with an elastic thread.

When the load *W* is increased to 2 kgf the extension (increase in length) is obtained from V again; and if the reading on V returns to origin value when the load is removed the wire is said to be elastic at least for loads from zero to 2 kgf.

The extension of a thin wire such as Q for increasing loads may be found by experiments to be as follows:

W (kgf)	0	1	2	3	4	5	6	7	8
Extension (mm)	0	0.14	0.28	0.42	0.56	0.70	0.85	1.01	1.19

Table 1.1

1.4.1 Proportional and elastic limits

When the extension, *e*, is plotted against the load, *W*, a graph is obtained which is a *straight line* OA, followed by a curve ABY rising slowly at first and then very sharply, **Figure 1.19(i)**.

Up to A, about 5 kgf, the results show that the extension increased by 0·14 mm per kgf added to the wire. A, then, is the *proportional limit*. Along OA, and up to L just beyond A, the wire returned to its original length when the load was removed.

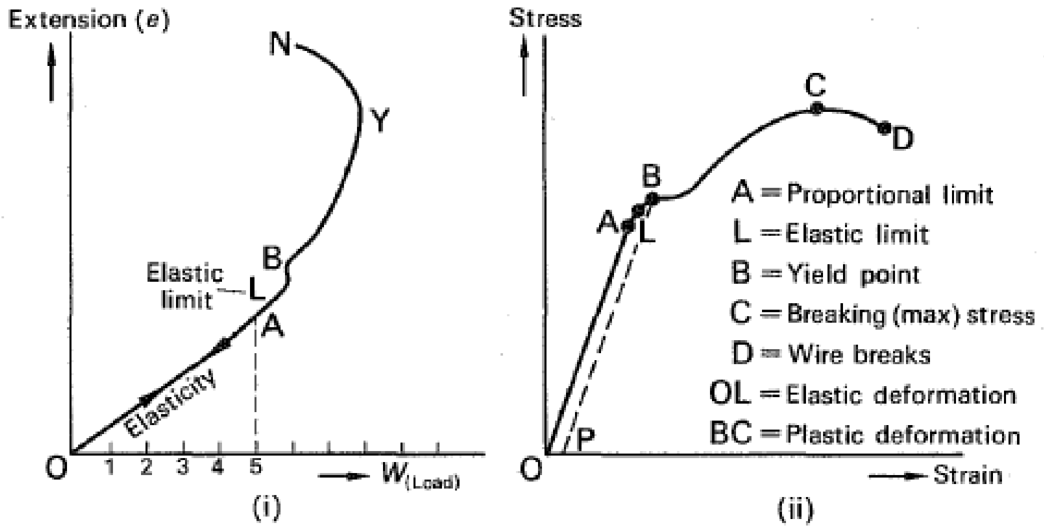


Figure 1.19 (i) Extension v. Load, (ii) Stress v. strain, ductile material

L is the *elastic limit.* Along OL the wire is said to undergo *elastic deformation*. Beyond L, however, the wire has a permanent strain OP when the stress is removed. **Figure 1.19(ii)**.

1.4.2 Hooke's Law

From the straight line graph OA, we deduce that *the extension is proportional to the load or tension in a wire if the proportional limit is not exceeded.* This is known as *Hooke's law*.

Did you know?
Hooke's law is named after Robert Hooke, founder of the Royal Society, who discovered the relation in 1676.

The law shows that when a molecule of a solid is slightly displaced from its mean position, the restoring force is proportional to its displacement. One may therefore conclude that the molecules of a solid are undergoing simple harmonic motion.

The measurements also show that it would be dangerous to load the wire with weights greater than the magnitude of the elastic limit, because the wire then suffers a permanent strain.

Similar experiments in the research laboratory enable scientists to find the maximum load which a steel bridge, for example, should carry for safety.

Did you know?
Rubber samples are also subjected to similar experiments, to find the maximum safe tension in rubber belts used in machinery.

1.4.3 Yield point, ductile and brittle substances, breaking stress

Careful experiments show that, for mild steel and iron for example, the molecules of the wire begin to 'slide' across each other soon after the load exceeds the elastic limit, that is, the material becomes *plastic;* This is indicated by the slight 'kink' at B beyond L in **Figure 1.36(i)**, and it is called the *yield point* of the wire.

The change from an elastic to a plastic stage is shown by a sudden increase in the extension, and as the load is increased further the extension increases rapidly along the curve YN and the wire then snaps.

The *breaking stress* of the wire is the corresponding force per unit area of cross-section of the wire. Substances such as those just described, which elongate considerably and undergo plastic deformation until they break, are known as *ductile* substances.

Lead, copper and wrought iron are ductile. Other substances, however, break just after the elastic limit is reached; they are known as *brittle* substances. Glass and high carbon steels are brittle.

Brass, bronze, and many alloys appear to have no yield point. These materials increase in length beyond the elastic limit as the load is increased without the appearance of a plastic stage.

The strength and ductility of a metal, its ability to flow, are dependent on defects in the metal crystal lattice. Such defects may consist of a missing atom at a site or a *dislocation* at a plane of atoms.

Plastic deformation is the result of the 'slip' of atomic planes. The latter is due to the movement of dislocations, which spreads across the crystal.

1.4.4 Tensile stress and strain, Young's Modulus

When a force or tension *F* is applied to the end of a wire of cross-sectional area *A*, **Figure 1.20**,

Figure 1.20 Tensile stress and tensile strain

$$the\ tensile\ stress\ = force\ per\ unit\ area = \frac{F}{A} \quad \text{..............................} \quad (1)$$

If the extension of the wire is *e*, and its original length is l,

$$the\ tensile\ strain\ = extension\ per\ unit\ length = \frac{e}{l} \quad \text{....................} \quad (2)$$

Suppose 2 kg is attached to the end of a wire of length 2 metres of diameter 0,64 mm, and the extension is 0,60 mm. Then

F = 2 kgf = 2 x 9,8 N, *A* = π x $0{,}032^2$ cm^2 = π x $0{,}032^2$ x 10^{-4} m^2

$$\therefore\ tensile\ stress\ = \frac{2\times 9{,}8}{\pi\times 0{,}032^2\times 10^{-4}} Nm^{-2}$$

and $$tensile\ strain\ = \frac{0{,}6\times 10^{-3} metre}{2\ metre} 0{,}3\times 10^{-3}$$

> **Note:**
> 'Stress' has units such as 'N m^{-2}; 'strain' has no units because it is the ratio of two lengths.

A *modulus of elasticity* of the wire, called Young's modulus (E), is defined as the ratio

$$E\ = \frac{tensile\ stress}{tensile\ strain} \quad \text{..} \quad (3)$$

Thus $\quad E = \frac{F/A}{e/l}$

Using the above figures

$$E = \frac{2\times9.8/(\pi\times0.032^2\times10^{-4})}{0.3\times10^{-3}}$$
$$= \frac{2\times9.8}{\pi\times0.032^2\times10^{-4}\times0.3\times10^{-3}}$$
$$= 2.0\times10^{11} Nm^{-2}$$

Note:
Young's modulus, *E,* is calculated from the ratio stress: strain only when the wire is under 'elastic' conditions, that is, the load does not then exceed the elastic limit.

Worked Example 1.5

Find the maximum load in *kgf* which may be placed on a steel wire of diameter 0,10 cm if the permitted strain must not exceed $\frac{1}{1000}$ and Young's modulus for steel is 2,0 x 10^{11} Nm^{-2}.

Solution:

We have $\quad \frac{\max stress}{\max stress} = 2\times10^{11}$

$$\therefore \max stress = \frac{1}{1\,000}\times2\times10^{11} = 2\times10^{8}\ Nm^2$$

Now area of cross section in $m^2 = \frac{\pi d^2}{4} = \frac{\pi\times0{,}1^2\times10^{-4}}{4}$

and $\quad stress = \frac{load\ F}{area}$

$$\therefore F = stress\times area = 2\times10^{8}\times\frac{\pi\times0{,}1^2\times10^{-4}}{4}\ newton$$
$$= 157\ newton = 15{,}7\ kgf \text{ (approx.)}$$

since $10\ newtons = 1\ kgf$ (approx.)

Worked Example 1.6

A 20 kg weight is suspended from a length of copper wire 1 mm in radius. If the wire breaks suddenly, does its temperature. increase or decrease?

Calculate the change in temperature; Young's modulus for copper= 12 x 10^{10} N m^{-2}; density of copper = 9 000 kg m^{-3}; specific heat capacity of copper = 0,42 J $g^{-1}K^{-1}$.) (CS)

Solution:
When the wire is stretched, it gains potential energy equal to the work done on it. When the wire is suddenly broken, this potential energy is released as the molecules return to their original position. The energy is converted into heat and thus the temperature rises.

$$Gain\ in\ potential\ energy\ of\ molecules = work\ done\ in\ stretching\ wire$$
$$= \frac{1}{2}\ force\ (F) \times extension(e)$$

With the usual notation, $F = EA\frac{e}{l}$

$$\therefore e = \frac{Fl}{E.A} = \frac{(20\times 9{,}8)\times l}{12\times 10^{10}\times \pi \times (10^{-3})^2} m = 5{,}2 \times 10^{-4}/m$$

$$\therefore potential\ energy\ gained = \frac{1}{2}\times 20 \times 9{,}8 \times 5{,}2 \times 10^{-4} \neq 5{,}1 \times 10^{-2}/J$$

$$Heat\ capacity\ of\ wire = mass \times specific\ heat\ capacity$$

$$= \pi \times (10^{-3})^2 \times \frac{9000}{\times(0{,}42\times 1000)} = 11{,}9/J\ K^{-1}$$

$$\therefore temperature\ rise = \frac{potential\ energy}{heat\ capacity} = \frac{5{,}1\times 10^{-2}/}{11{,}9l}$$
$$= 4{,}3 \times 10^{-3}\ \deg C$$

Definition: Specific heat capacity
Refers to how good a conductor a substance is, or how much heat energy it can transfer for its mass.

Worked Example 1.7

Define *stress* and *strain*. Describe the behaviour of a copper wire when it is subjected to an increasing longitudinal stress.

Draw a stress-strain diagram and mark on it the elastic region, yield point and breaking stress.

A wire of length 5 m, of uniform circular cross-section of radius 1 mm is extended by 1,5 mm when subjected to a uniform tension of 100 newton.

Calculate from first principles the strain energy per unit volume assuming that deformation obeys Hooke's law.

Show how the stress-strain diagram may be used to calculate the work done in producing a given strain, when the material is stretched beyond the Hooke's law region.

Solution:

$$\begin{aligned}
strain\ energy &= \tfrac{1}{2} tension \times extension \\
Tension &= 100\ newton. Extension = 1{,}5\ \times 10^{-3} m \\
\therefore\ energy &= \tfrac{1}{2} \times 100 \times 1{,}5 \times 10^{-3} = 0{,}075\ J \\
Volume\ of\ wire &= length \times area = 5 \times \pi \times 1 \times 10^{-6} m^3 \\
\therefore\ energy\ per\ unit\ volume &= \frac{0{,}075}{5 \times \pi \times 1 \times 10^{-6}} = 4{,}7 \times 10^3 J\ m^{-3} \text{ (approx.)}
\end{aligned}$$

1.5 Diffusion

In the animal kingdom it is evident that scent is capable of being detected over a great distance. This supports the idea that the scent is made up of molecules and also the idea that the molecules in a gas are moving.

Here are some simple experiments to show you more about the movement of molecules. In **Figure 1.21** you can see a long tube with all the air pumped out of it. It is closed with rubber tubing a tap.

On the other side of the tap is attached a small capsule of bromine inside some rubber tubing. The capsule is broken and then the tap opened.

Safety Warning!
Bromine is corrosive and very toxic. Standard safety procedures are necessary.

As soon as the tap is opened the bromine vapour fills the long tube. This tells us that the bromine molecules are moving quickly. They are actually moving at a speed of about 200m/ s.

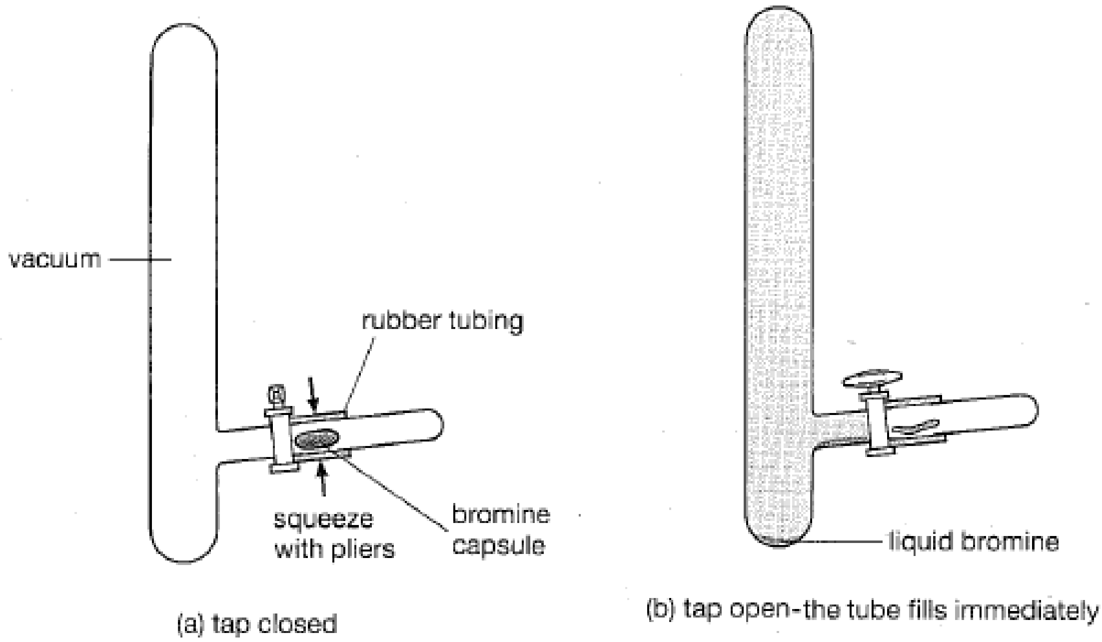


Figure 1.21 Bromine vapour filling a vacuum

Figure 1.22 shows what happens when the experiment is repeated with air inside.

This time when the tap is opened the bromine does not fill the tube quickly.

After about 20 minutes the bottom half of the tube is coloured dark brown, but the top is only light brown. So although the bromine molecules travel very quickly it takes a long time for them to reach the top.

The reason for this is that the air molecules are also moving quickly. The air molecules get in the way of the bromine molecules. When two molecules bump into each other they will change direction. The bromine molecules keep changing direction and so take a long time to reach the top.

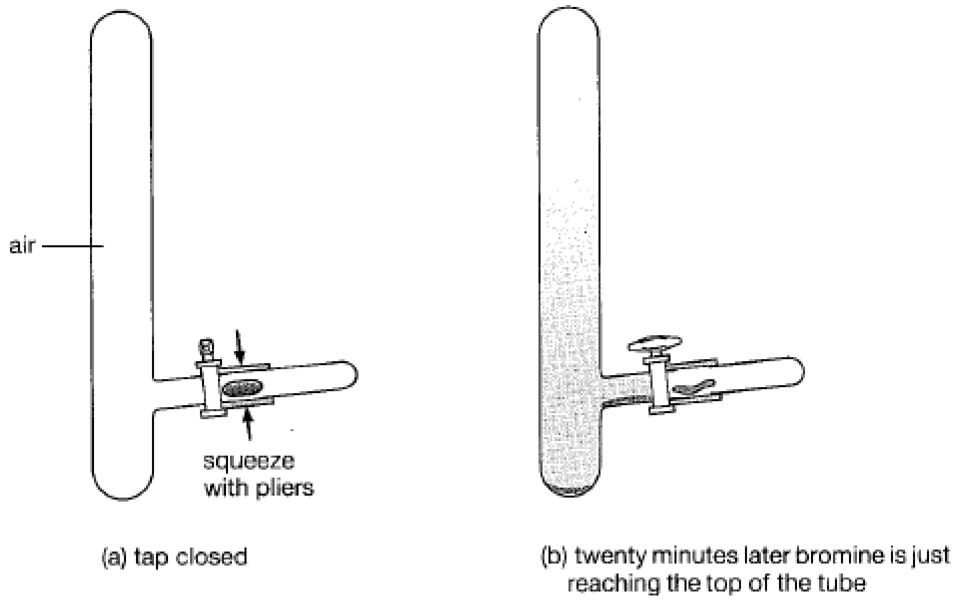


Figure 1.22 The bromine molecules bump into the air molecules, and are slowed down

Definition:
This process of one substance spreading through another is called diffusion.

Diffusion also occurs in liquids, but only very slowly in solids. Diffusion is very important for all living things. When animals have eaten a meal, food is digested and diffuses into the blood. Blood then carries the food all round the body.

Plants need nitrogen, potassium, phosphorus and other elements. These diffuse through the soil to the plants' roots.

1.6 Viscosity

If we move through a pool of water we experience a resistance to our motion. This shows that there is a *frictional force* in liquids. We say this is due to the viscosity of the liquid. If the frictional force is comparatively low, as in water, the viscosity of the liquid is low; if the frictional force is large, as in glue or glycerine, the viscosity of the liquid is high.

We can compare roughly the viscosity of two liquids by filling two measuring cylinders with each of them, and allowing identical small steel ball-bearings to fall through each liquid. The sphere falls more slowly through the liquid of higher viscosity.

Note:
The viscosity of a lubricating oil is one of the factors which decide whether it is suitable for use in an engine and viscosity values are listed to which lubricating oils for aero-engines must conform.

1.6.1 Newton's formula, coefficient of viscosity

When water flows slowly and steadily through a pipe, the layer A of the liquid in contact with the pipe is practically stationary, but the central part C of the water is moving relatively fast, **Figure 1.23**.

At other layers between A and C; such as B, the water has a velocity less than at C, the magnitude of the velocities being represented by the length of the arrowed lines in **Figure 1.23**.

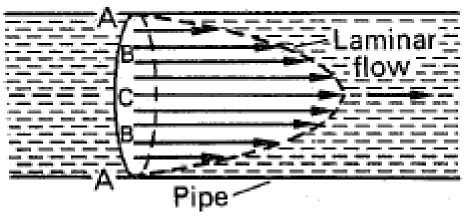


Figure 1.23 Laminar (uniform) flow through pipe

Now as in the case of two solid surfaces moving over each other, a frictional force is exerted between two liquid layers when they move over each other.

Thus because the velocities of neighbouring layers are different, as shown in **Figure 1.23**, a frictional force occurs between the various layers of a liquid when flowing through a pipe.

Did you know?

The basic formula for the frictional force, *F,* in a liquid was first suggested by Newton. He saw that the larger the *area* of the surface of liquid considered, the greater was the frictional force *F*.

He also stated that *F* was directly proportional to the *velocity gradient* at the part of the liquid considered. This is the case for most common liquids, called *Newtonian liquids.*

If v_1, v_2 are the velocities of C, B respectively in **Figure 1.23**, and *h* is their distance apart, the velocity gradient between the liquids is defined as $(v_1 - v_2)/h$. The velocity gradient can thus be expressed in (m/s)/m, or as 's^{-1}'.

Thus if *A* is the area of the liquid surface considered, the frictional force *F* on the surface is given by

$$F \propto A \times velocity\ gradient$$

or

$$F = \eta A \times velocity\ gradient \quad \ldots\ldots\ldots\ldots \quad (1)$$

where η is a constant of the liquid known as the *coefficient of viscosity.* This expression for the frictional force in a liquid should be contrasted with the case of solid friction, in which the frictional force is independent of the area of contact and of the relative velocity between the solid surfaces concerned.

Worked Example 1.8

Explain as fully as you can the phenomenon of viscosity, using the viscosity of a gas as the basis of discussion.

Show by the method of dimensions how the volume of liquid flowing in unit time along a uniform tube depends on the radius of the tube, the coefficient of viscosity of the liquid, and the pressure gradient along the tube.

The water supply to a certain house consists of a horizontal water main 20 cm in diameter and 5 km long to which is joined a horizontal pipe 15 mm in diameter and 10m long leading into the house.

When water is being drawn by this house only, what fraction of the total pressure drop along the pipe appears between the ends of the narrow pipe?

Assume that the rate of flow of the water is very small.

Solution:

$$volume\ per\ second = \frac{\pi p a^4}{\eta 8 l}, \text{ with usual notation}$$

$$Thus\ volume\ per\ second = \frac{\pi p_1 . 0{,}1^4}{8\eta . 5 \times 10^3} = \frac{\pi p_2 . 0{,}0075^4}{8\eta . 10}$$

Where ρ_1, ρ_2 are the respective pressures in the two pipes, since the volume per second is the same.

$$\therefore \frac{\rho_1}{\rho_2} = \frac{0{,}0075^4}{0.1} \times \frac{5\times10^3}{10} = \frac{1}{63} \text{ (approx)}$$

$$\therefore \rho_1 = \frac{1}{64} \times total\ pressure = 0{,}016 \times total\ pressure$$

1.6.2 Comparison of viscosities of viscous liquids

Stokes' formula can be used to compare the coefficients of viscosity of very viscous liquids such as glycerine or treacle.

Experiment 1.2

A tall glass vessel G is filled with the liquid, and a small ball-bearing P is dropped gently into the liquid so that it falls along the axis of G, **Figure 1.24**. Towards the middle of the liquid P reaches its terminal velocity v_0 , which is measured by timing its fall through a distance AB or BC.

The upthrust, *U*, on P due to the liquid = $4\pi a^3\sigma g/3$, where *a* is the radius of P and *a* is the density of the liquid. The weight, *W*, of P is $4\pi a^3 pg/3$, where *p* is density of the bearing's material.

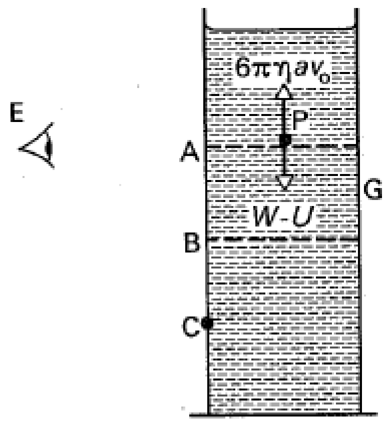


Figure 1.24 Stokes' law

The net downward force is thus $4\pi a^3 g(p-\sigma)/3$. When the opposing frictional force grows to this magnitude, the resultant force on the bearing is zero. Thus for the terminal velocity v_0 , we have

$$6\pi\eta a v_o = \frac{4}{3}\pi a^3 g(p-\sigma)$$

$$\therefore \eta = \frac{2ga^2(p-\sigma)}{9v_o} \text{ .... (i)}$$

When the experiment is repeated with a liquid of coefficient of viscosity η_1 and density σ_1, using the same ball-bearing, then

$$\eta_1 = \frac{2ga^2(p-\sigma_1)}{9v_2} \text{ .... (ii)}$$

where *v1* is the new terminal velocity. Dividing (i) by (ii),

$$\therefore \frac{\eta}{\eta_1} = \frac{v_1(p-\sigma)}{v_o(p-\sigma_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

Thus knowing $v_1, v, \rho, \sigma_1, \sigma$, the coefficients of viscosity can be compared.

Note:
In very accurate work a correction to (iii) is required for the effect of the walls of the vessel containing the liquid.

1.6.3 Molecular theory of viscosity

Viscous forces are detected in gases as well as in liquids. Thus if a disc is spun round in a gas close to a suspended stationary disc, the latter rotates in the same direction.

The gas hence transmits frictional forces. The flow of gas through pipes, particularly in long pipes as in transmission of natural gas from the North Sea area, is affected by the viscosity of the gas.

The viscosity of *gases* is explained by the transfer of momentum which takes place between neighbouring layers of the gas as it flows in a particular direction. Fast-moving molecules in a layer X cross with their own velocity to a layer Y say where molecules are moving with a slower velocity. **Figure 1.25**.

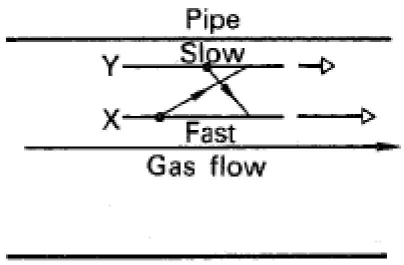


Figure 1.25 Viscosity of gas-momentum effect

Molecules in Y likewise move to X. The net effect is an increase in momentum in Y and a corresponding decrease in X, although on the average the total number of molecules in the two layers is unchanged.

Thus the layer Y speeds up and the layer X slows down, that is, a *force* acts on the layers of the gas while they move.

This is the viscous force. We consider the movement of molecules in more detail shortly.

Although there is transfer of momentum as in the gas, the viscosity of a *liquid* is mainly due to the molecular attraction between molecules in neighbouring layers. Energy is needed to drag one layer over the other against the force of attraction. Thus a shear stress is required to make the liquid move in laminar flow.

1.7 Osmosis

Osmosis is the movement of a solvent across a semipermeable membrane toward a higher concentration of solute. In biological systems, the solvent is typically water, but osmosis can occur in other liquids, supercritical liquids, and even gases.

When a cell is submerged in water, the water molecules pass through the cell membrane from an area of low solute concentration to high solute concentration.

For example, if the cell is submerged in saltwater, water molecules move out of the cell. If a cell is submerged in freshwater, water molecules move into the cell.

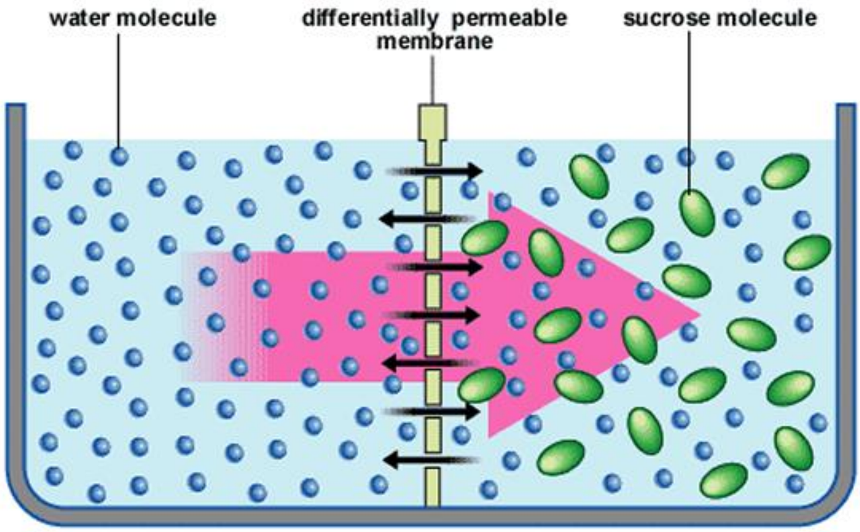


Figure 1.26

1.7.1 Water passing through a semi-permeable membrane

When the membrane has a volume of pure water on both sides, water molecules pass in and out in each direction at exactly the same rate. There is no net flow of water through the membrane.

1.7.2 Plant cell under different environments.

Osmosis, unlike diffusion, requires a force to work. This force is supplied by the solute's interaction with the membrane.

Solute particles move randomly due to Brownian motion. If they move towards pores in the membrane, they are repelled, and in being repelled, acquire momentum directed away from the membrane.

The momentum is rapidly transferred to surrounding water molecules, driving them away from the membrane as well.

Did you know?
Osmotic pressure is the main cause of support in many plants. The osmotic entry of water raises the turgor pressure exerted against the cell wall, until it equals the osmotic pressure, creating a steady state.

Osmosis is responsible for the ability of plant roots to draw water from the soil. Plants concentrate solutes in their root cells by active transport, and water enters the roots by osmosis. Osmosis is also responsible for controlling the movement of guard cells.

Osmosis can be demonstrated when potato slices are added to a high salt solution. The water from inside the potato moves out to the solution, causing the potato to shrink and to lose its 'turgor pressure'. The more concentrated the salt solution, the bigger the difference in size and weight of the potato slice.

Did you know?

In unusual environments, osmosis can be very harmful to organisms. For example, freshwater and saltwater aquarium fish placed in water of a different salinity than that to which they are adapted to will die quickly, and in the case of saltwater fish, dramatically.

Another example of a harmful osmotic effect is the use of table salt to kill leeches and slugs.

Suppose an animal or a plant cell is placed in a solution of sugar or salt in water.

- If the medium is hypotonic relative to the cell cytoplasm — the cell will gain water through osmosis.
- If the medium is isotonic — there will be no net movement of water across the cell membrane.
- If the medium is hypertonic relative to the cell cytoplasm — the cell will lose water by osmosis.

Essentially, this means that if a cell is put in a solution which has a solute concentration higher than its own, it will shrivel, and if it is put in a solution with a lower solute concentration than its own, the cell will swell and may even burst.

Activity 1.1

1. What are the following a) diffusion, b) viscosity and c) osmosis?
2. Calculate the force of attraction between two small objects of mass 5

and 8 kg respectively which are 10 cm apart. *(G* = 6,7x 10^{-11} N m^2 kg^{-2}.)

3. If the acceleration due to gravity is 9,8 m s^{-2} and the radius of the earth is 6 400 km, calculate a value for the mass of the earth. *(G* = 6,7 x 10^{-11} N m^2 kg^{-2}.) Give the theory.
4. Assuming that the mean density of the earth is 5 500 kg m^{-3}, that the constant of gravitation is 6,7 x 10^{-11} N m^2 kg^{-2}, and that the radius of the earth is 6 400 km, find a value for the acceleration due to gravity at the earth's surface. Derive the formula used.
5. How do you account for the sensation of 'weightlessness' experienced by the occupant of a space capsule *(a)* in a circular orbit round the earth, *(b)* in outer space? Give one other instance in which an object would be 'weightless'.
6. State Newton's law of universal gravitation. Distinguish between the gravitational constant (G) and the acceleration due to gravity *(g)* and show the relation between them. Describe an experiment by which the value of *g* may be determined. Indicate the measurements taken and how to calculate the result. Derive any formula used. (L.)
7. State *Newton's law of gravitation*. What experimental evidence is there for the validity of this law? A binary star consists of two dense spherical masses of 10^{30} kg and 2 x 10^{30} kg whose centres are 10^7 km apart and which rotate together with a uniform angular velocity ω about an axis which intersects the line joining their centres. Assuming that the only forces acting on the stars arise from their mutual gravitational attraction and that each mass may be taken to act at its centre, show that the axis of rotation passes through the centre of mass of the system and find the value of ω. *(G* = 6,7 x 10^{-11} m^3 kg^{-1} s^{-2}.)
8. Assuming that the planets are moving in circular orbits, apply Kepler's laws to show that the acceleration of a planet is inversely proportional to the square of its distance from the sun. Explain the significance of this and show clearly how it leads to Newton's law of universal gravitation. Obtain the value of *g* from the motion of the moon, assuming that its period of rotation round the earth is 27 days 8 hours and that the radius of its orbit is 60,1 times the radius of the earth. (Radius of earth= 6,36 x 10^6 m)

Activity 1.2

1. A rectangular plate of dimensions 6 cm by 4 cm and thickness 2 mm is placed with its largest face flat on the surface of water. Calculate the force due to surface tension on the plate. What is the downward force due to surface tension if the plate is placed vertical and its longest side just touches the water? (Surface tension of water= 7,0 x 10^{-2} N m^{-1}.)
2. What are the *dimensions* of surface tension? A capillary tube of 0,4 mm diameter is placed vertically inside (i) water of surface tension 6,5 x 10^{-2} N m^{-1} and zero angle of contact, (ii) a liquid of density 800 kg m^{-3}, surface tension 5,0 x 10^{-2} N m^{-1} and angle of contact 30°. Calculate the height to which the liquid rises in the capillary in each case.

3. Explain what is meant by surface tension, and show how its existence is accounted for by molecular theory. Find an expression for the excess pressure inside a soap-bubble of radius *R* and surface tension *T*. Hence find the work done by the pressure in increasing the radius of the bubble from *a* to *b*. Find also the increase in surface area of the bubble, and in the light of this discuss the significance of your result.
4. A clean glass capillary tube, of internal diameter 0,04 cm, is held vertically with its lower end below the surface of clean water in a beaker, and with 10 cm of the tube above the surface. To what height will the water rise in the tube? What will happen if the tube is now depressed until only 5 cm of its length is above the surface? The surface tension of water is 7,2 x 10^{-2} N m^{-1}. Describe, and give the theory of some method, other than that of the rise in a capillary tube, of measuring surface tension.
5. Explain *(a)* in terms of molecular forces why the water is drawn up above the horizontal liquid level round a steel needle which is held vertically and partly immersed in water, *(b)* why, in certain circumstances, a steel needle will rest on a water surface. In each case show the relevant forces on a diagram. (N)
6. The force between two molecules may be regarded as an attractive force which increases as their separation decreases and a repulsive force which is only important at small separations and which there varies very rapidly. Draw sketch graphs *(a)* for force-separation, *(b)* for potential-energy separation. On each graph mark the equilibrium distance and on *(b)* indicate the energy which would be needed to separate two molecules initially at the equilibrium distance. With the help of your graphs discuss briefly the resulting motion if the molecules are displaced from the equilibrium position.
7. Describe how the surface tension of water at room temperature may be determined by using a capillary tube. Derive the formula used to calculate the result. A hydrometer has a cylindrical glass stem of diameter 0,50 cm. It floats in water of density 1 000 kg m^{-3} and surface tension 7,2 x 10^{-2} N m^{-1}. A drop of liquid detergent added to the water reduces the surface tension to 5.0 x 10^{-2} N m^{-1}. What will be the change in length of the exposed portion of the glass stem? Assume that the relevant angle of contact is always zero. (N)
8. The lower end of a vertical clean glass capillary tube is just immersed in water. Why does water rise up the tube? A vertical capillary tube of internal radius *r* m has its lower end dipping in water of surface tension *T* newton m^{-1}. Assuming the angle of contact between water and glass to be zero, obtain from first principles an expression for the pressure excess which must be applied to the upper end of the tube in order just to keep the water levels inside and outside the tube the same. A capillary of internal diameter 0,7 mm is set upright in a beaker of water with one end below the surface; air is forced slowly through the tube from the upper end, which is also connected to a U-tube manometer containing a liquid of density 800 kg m^{-3}. The difference in levels on the manometer is found to build up to 9,1 cm, drop to 4,0 cm, build up to 9,1 cm again, and so on.

Estimate *(a)* the depth of the open end of the capillary below the free surface of the water in the beaker, *(b)* the surface tension of water. [State clearly any assumptions you have made in arriving at these estimates.]

9. It is sometimes stated that, in virtue of its surface tension, the surface of a liquid behaves as if it were a stretched rubber membrane. To what extent do you think this analogy is justified? Explain why the pressure inside a spherical soap bubble is greater than that outside. How would you investigate experimentally the relation between the excess pressure and the radius of the bubble? Show on a sketch graph the form of the variation you would expect to obtain. If olive oil is sprayed on to the surface of a beaker of hot water, it remains as separated droplets on the water surface; as the water cools, the oil forms a continuous thin film on the surface. Suggest a reason for this phenomenon.
10. How does simple molecular theory account for surface tension? Illustrate your account by explaining the rise of water up a glass capillary. A light wire frame in the form of a square of side 5 cm hangs vertically in water with one side in the water-surface. What additional force is necessary to pull the frame clear of the water? Explain why, if the experiment is performed with soap-solution, as the force is increased a vertical film is formed, whereas with pure water no such effect occurs. (Surface tension of water is 7,4 x 10^{-2} Nm^{-1}.)
11. Define *surface tension* and state the effect on the surface tension of water of raising its temperature. Describe an experiment to measure the surface tension of water over the range of temperatures from 20 °C to 70 °C. Why is the usual capillary rise method unsuitable for this purpose? Two unequal soap bubbles are formed one on each end of a tube closed in the middle by a tap. State and explain what happens when the tap is opened to put the two bubbles into connection. Give a diagram showing the bubbles when equilibrium has been reached. (L)

Activity 1.3

1. Find the extension produced in a copper wire of length 2 m and diameter 3 mm when a load of 3 kgf is applied. (Young's modulus for copper = 1.1 x 10^{11} Nm^{-2}.)
2. What is meant by (i) elastic limit, (ii) Hooke's law, (iii) yield point, (iv) perfectly elastic? Draw sketches of stress v. strain to illustrate your answers.
3. '*In an experiment to determine Young's modulus, the strain should not exceed 1 in 1000.*' Explain why this limitation is necessary and describe an experiment to determine Young's modulus for the material of a metal wire.
   In such an experiment, a brass wire of diameter 0.0950 cm is used. If Young's modulus for brass is 9,86 x 10^{10} newton m^{-2}, find in kilogram force the greatest permissible load.
4. Define *stress* and *strain,* and explain why these quantities are useful in studying the elastic behaviour of a material. State one advantage and

one disadvantage in using a long wire rather than a short stout bar when measuring Young's modulus by direct stretching.
Calculate the minimum tension with which platinum wire of diameter 0.1 mm must be mounted between two points in a stout invar frame if the wire is to remain taut when the temperature rises 100K. Platinum has coefficient of linear expansion 9×10^{-6} K^{-1} and Young's modulus 17×10^{10} Nm^{-2}. The thermal expansion of invar may be neglected.

5. Explain the terms stress, *strain, modulus of elasticity* and *elastic limit*. Derive an expression in terms of the tensile force and extension for the energy stored in a stretched rubber cord which obeys Hooke's law.
The rubber cord of a catapult has a cross-sectional area 10 mm^2 and a total unstretched length 10,0 cm. It is stretched to 12,0 cm and then released to project a missile of mass 5,0 g. From energy considerations, or otherwise, calculate the velocity of projection, taking Young's modulus for the rubber as $5,0 \times 10^8$ N m^{-2}. State the assumptions made in your calculation.
6. State Hooke's law, and describe in detail how it may be verified experimentally for copper wire. A copper wire, 200 cm long and 1,22 mm diameter, is fixed horizontally to two rigid supports 200 cm long. Find the mass in grams of the load which, when suspended at the mid-point of the wire, produces a sag of 2 cm at that point Young's modulus for copper = 12.3×10^{10} N m^{-2}. (L)
7. Define coefficient of viscosity of a fluid.
When the flow is orderly the volume V of liquid which flows in time *t* through a tube of radius rand length l when a pressure difference *p* is maintained between its ends is given by the equation $\frac{V}{t} = \frac{\pi p r^4}{8 l \eta}$ where η is the coefficient of viscosity of the liquid.
Describe an experiment based on this equation either (a) to determine the value of η for a liquid, or (b) to compare the values of η for two liquids, pointing out the precautions which must be taken in the experiment chosen to obtain an accurate result.
Water flows steadily through a horizontal tube which consists of two parts joined end to end; one part is 21 cm long and has a diameter of 0,225 cm and the other is 7,0 cm long and has a diameter of 0,075 cm. If the pressure difference between the ends of the tube is 14 cm of water find the pressure difference between the ends of each part. (L)

Self-Check		
I am able to:	**Yes**	**No**
• Describe Newton's law of gravitation		
• Describe elasticity		
• Describe surface tension		
• Describe capillarity		
• Describe diffusion		
• Describe viscosity		
• Describe osmosis		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 2

Heat

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the gas laws
- Describe expansion and compression to the law $PV^h = C$
- Describe elementary kinetic theory
- Describe van der Waals' equation of state
- Describe critical constants
- Describe the first law of thermodynamics
- Describe conduction
  - Determine conductivities
- Describe radiation
  - The laws of radiation
  - Emission
  - Absorption
  - Reflection

2.1 Introduction

In physics, heating is transfer of energy, from a hotter body to a colder one, other than by work or transfer of matter. It occurs spontaneously whenever a suitable physical pathway exists between the bodies. The pathway can be direct, as in conduction and radiation, or indirect, as in convective circulation.

Heat is a form of energy. The unit of energy and therefore of heat is the joule. Heat may be used to do work.

2.2 Expansion of gases

As already mentioned, each solid or liquid has its own particular coefficient of expansion.

The coefficient of expansion of gases differs from that of solids and liquids in the following respects:

- All gases have the same coefficient of expansion: $\frac{1}{273}$ of the original volume at 0 °C per degree Celsius.

- The expansion of a gas is relatively large in comparison with that of solids and liquids.

Gases, because of their great compressibility and thermal expansiveness, occupy volumes that depend very sensitively on pressure and temperature. All gases obey three simple laws that relate volume to pressure and temperature.

2.2.1 Boyle's law

Boyle's law indicates the relation between volume and pressure at constant temperature and reads as follows:

- The volume of a given mass of gas is inversely proportional to the pressure to which it is subjected, if the temperature remains constant.

$$Volume\ (V)\ \propto \frac{1}{pressure\ (P)}$$

or $V = constant \times \frac{1}{P}$

$PV = constant$

Boyle's law is represented graphically in **Figure 2.1**.

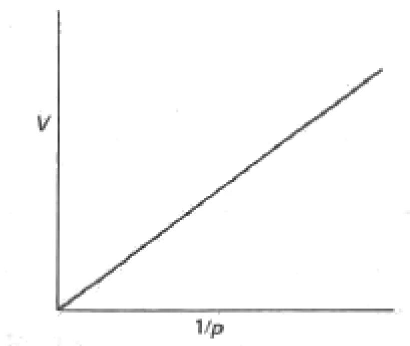


Figure 2.1

As any two readings of pressure and corresponding volume give the same constant, this relation may be expanded further:

$P_1V_1 = constant$ and

$P_2V_2 = constant$

$P_1V_1 = P_2V_2 = P_3V_3$

Where V_1 = volume of gas in m³ at pressure P_1 in Pascal

V_2 = volume of gas in m³ at pressure P_2 in Pascal

V_3 = volume of gas in m³ at pressure P_3 in Pascal

2.2.2 Charles's law

This law indicates the relation between volume and temperature at constant pressure and reads as follows:

- The volume of a given mass of gas changes by a fraction, $\frac{1}{273}$ of its volume at 0 °C for 273 each Celsius degree rise in temperature if the pressure remains constant. or:
- The volume of a given mass of gas at constant pressure is directly proportional to its thermodynamic temperature (T), where T is the thermodynamic temperature in kelvin: ($T = t + T_o$).

Charles's law is shown graphically in **Figure 2.2**.

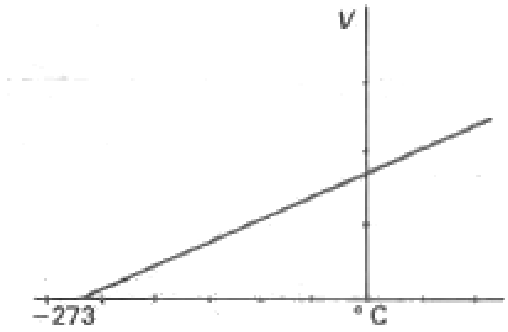


Figure 2.2

The coefficient of cubic expansion of a gas at constant pressure is given by:

ךo $= \frac{V_1 - V_o}{V_o t_1}$

$= \frac{1}{273}$

V_o = volume of gas at 0 °C
V_1 = volume of gas at t_1 °C
ךo = cubic expansion coefficient per degree Celsius
t_1 = temperature change from 0 °C

From the above formula it follows:

$\frac{V_1}{V_2} = \frac{T_1}{T_2}$ = constant

Where $T_1 = t_1 + 273$
$T_2 = t_2 + 273$

2.2.3 The pressure law (Gay-Lussac's law)

This law gives the relation between pressure and temperature at constant volume and reads as follows:

- The pressure of a given mass of gas changes by a constant fraction, 2~3 of its pressure at 0 °C, for each degree change in temperature if the volume is kept constant.

The coefficient of pressure increase at constant volume is given by

ךp $= \frac{P_1 - P_o}{P_o t_1}$

$= \frac{1}{273}$

Where:

P_o = pressure of gas at 0 °C
P_1 = pressure of gas at t_1 °C
ךp = coefficient of pressure change per degree Celsius
t_1 = temperature change from 0 °C

From the above formula it follows:

$\frac{P_1}{P_2} = \frac{T_1}{T_2}$ = constant

Where $T_1 = t_1 + 273$
$T_2 = t_2 + 273$

2.2.4 The combined gas laws

These gas laws give the relation between volume, pressure and thermodynamic temperature.

Consider a gas with volume V_1 at a thermodynamic temperature T_1 and pressure P_1. If the temperature is kept constant while the pressure increases to P_2, the volume will change to V.

According to Boyle's law:

$P_1V_1 = P_2V$

$V = \frac{P_1V_1}{P_2}$ ………………………………. (1)

Now consider the same gas with volume V at the same pressure P_2 but heated to a thermodynamic temperature T_2. The gas will expand to a volume V_2.

According to Charles's law:

$\frac{V}{V_2} = \frac{T_1}{T_2}$

$V = \frac{T_1V_2}{T_2}$ …………………………………. (2)

From (1) and (2) it follows that:

$\frac{P_1V_1}{P_2} = \frac{T_1V_2}{T_2}$ or

$\frac{P_1V_1}{T_1} = \frac{P_sV_2}{T_2}$ = constant

These equations are known as the general gas equations and are also written as $\frac{PV}{T}$ constant.

2.3 Amount of substance and molar mass

One mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0,012 kg (exactly) of ^{12}C (carbon -12).

A mole of substance is therefore a very large number of particles of that substance. This number is known as the Avogadro constant, which is represented by the symbol NA.

The molar mass of any substance is the mass per mole of that substance (the mass of N_A particles of that substance) and is represented by the symbol *M*. The molar mass of ^{12}C is 12 g/mole.

2.4 The general and characteristic gas equations

The general gas equation

From **Point 2.2.4** it follows that P; =constant.
The symbol used for this constant is R. R is known as the general or universal gas constant and is the same for all gases provided one mole is used. For a mole it follows that:

$$PV = \pi RT$$

Where R = 8,31 JK^{-1} $mole^{-1}$

The characteristics gas equation

The density and molar mass differ from gas to gas, so that th13 specific gas constant differs too.

For a specific gas, the general gas equation may also be written as:

$$PV = \pi RT$$

Where
P = pressure in Pa
V = volume in m^3
m = mass of gas in kg
R = specific gas constant in J/kg.K
T = thermodynamic temperature in K.

The specific gas constant for air is 287 J/kg.K.

2.5 Standard temperature and pressure (STP)

STP is a set of standard conditions for reference purposes and is a pressure of 101,3 Pa and a temperature of 273 K (0 °C).

Worked Example 2.1

Dry gas with a volume of 0,4 m 3 at a temperature of 10 °C is heated to a temperature of 125 °C while the pressure remains constant. Calculate the new volume.

Solution:

Given: V_1 = 0,4 m^3; t_1 = 10°C; t_2 = 125°C

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0,4}{(10+273)} = \frac{V_2}{(125+273)}$$

V_2 = 0,53 m³

Worked Example 2.2

A certain mass of gas has a volume of 50 m³ at an absolute pressure of 100 kPa and a temperature of 210 °C.

Calculate:

(a) the volume of the gas when the temperature is lowered to -50°C while the pressure remains constant

(b) the thermodynamic temperature of the gas when the volume is reduced to 20m³ and the absolute pressure is increased to 210 kPa.

Solution:

Given: (a) V_1 = 50 m³; P_1 = 100 kPa;
t_1 = 210°C; t_2 = 50°C
(b) V_2 = 50 m³; V_2 = 20 m³;
P_1 = 100 kPa; P_2 = 210 kPa
t_1 = 210°C

(a)
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\frac{50}{210+273} = \frac{V_2}{(-50+273)}$$
V_2 = 23,085 m³

(b)
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{100\times 50}{(210+273)} = \frac{210\times 20}{T_2}$$
T_2 = 405,72 m³

Worked Example 2.3

Calculate the mass of gas, having a gas constant of 287 J /kg.K, that can be compressed in a cylinder so that the temperature is 100 °C, the pressure 550 kPa, and the volume 0,6 m³.

Solution:

Given: R = 287 J/kg.K; t = 100 °C; P = 550 kPa·, V = 0,6 m³; m = ?

$PV = mRT$

550 x 0,6 = m x 287 x (100 + 273)

m = 3 kg

2.6 Important formulae for gases

- Boyle's law (constant temperature):

$$P_1V_1 = P_2V_2$$

- Charles's law (constant pressure):

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- Pressure law (constant volume):

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

- Combined law

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

- General gas equation: $PV = nRT$
- Characteristic gas equation: $PV = mRT$
- Volume expansion coefficient:

$$\gamma o = \frac{V_1V_o}{V_o t}$$

- Coefficient of pressure expansion:

$$\gamma p = \frac{P_1 - P_o}{P_o t}$$

2.7 Calorimetric and specific heat capacity

Calorimetry is the measurement of the amount of heat and heat transferred. One of the instruments used to measure heat transfer is the calorimeter (**Figure 2.3**).

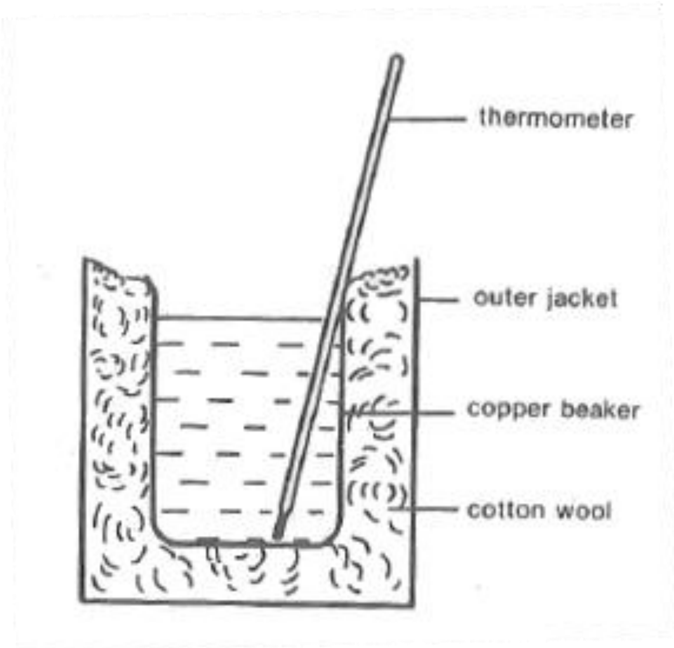


Figure 2.3

It consists of a small shiny copper or aluminium beaker in which substances are mixed.

The beaker is placed in cotton wool in large beaker to minimise loss of heat.

2.7.1 Heat capacity

The heat capacity of a substance is the amount of heat required to raise the temperature of the substance by 1 °C or 1 K.

It may also be defined as the amount of work done on the substance per degree temperature change. The unit of heat capacity is the joule per kelvin (J/K) and the symbol for heat capacity is C.

2.7.2 Specific heat capacity

Specific heat capacity is the heat capacity per unit mass.

It may also be defined as the amount of heat required to raise the temperature of 1 kg (unit mass) of the substance by 1 °C or 1 K (unit temperature). The unit for specific heat capacity is the joule per kilogram kelvin (J /kg.K) and the symbol that is used is *C*.

Note:
The word *specific* means *per unit mass*. The specific heat capacity of pure water is 4,187 kJ/kg. °C.

Heat capacity = mass x specific heat capacity

$\therefore C = m.c$

2.7.3 Amount of heat energy

The amount of heat (Q) absorbed or emitted by a substance depends on the following factors:

- *The mass of the substance*. A greater mass of a particular substance absorbs more heat than a smaller mass for the same change in temperature.
- *The specific heat capacity of the substance*. Different materials need different amounts of heat to raise their temperature by one degree Celsius or kelvin.
- *The change in temperature*. More heat is required to give a greater change in temperature.

Heat energy = mass x specific heat capacity x temperature change.

Heat absorbed or emitted = mass x specific heat capacity x temperature change, or

$$Q = m \times c \times \Delta t$$

where Q = heat energy in joule

m = mass of substance in kg

c = specific heat capacity in kJ /kg.K or kJ /kg. °C

$\Delta t = t_2 - t_1$

= temperature change in K or °C

The amount of heat energy that a body contains per kelvin (°C) is called the heat capacity of the body. A body containing 1 000 J heat energy at a temperature of 100 K therefore has a heat capacity of 10 J/K.

Worked Example 2.4

A piece of steel of mass 50 kg is cooled down so that its temperature decreases from 973 K to 298 K. If the specific heat capacity of steel is 0,377 kJ/kg.K, calculate the amount of heat energy released by the steel.

Solution:

Given: m = 50 kg; T_2 = 973; T_1 = 298;

c = 0,377 kJ/kg.K; Q = ?

Q = m x c x Δt

= 50 x 0,377 x (973 - 298)

= 12,724 MJ

2.7.4 The law of conservation of energy

Energy cannot be created or destroyed; it can, however, be converted from one form into another.

Energy may also be transferred from one substance to another. The heat energy emitted by one substance is equal to the heat energy absorbed by the other substance. Heat flows from a hot body to a cold body until both bodies have the same temperature.

When solving problems where different substances at different temperatures are added together, the law of conservation of energy must be applied.

Worked Example 2.5

Iron bars with a total mass of 3,5 kg are heated to 500 K and placed immediately in 28 kg water at 285 K. Calculate the final temperature of the iron bars and water. The heat capacity of steel is 461 kJ /kg.K.

Solution:

Given:

Mass of iron bars = 3,5 kg

temperature of iron bars = 500 K

mass of water = 28 kg

initial temperature of water = 285 K

c = 461 kJ /kg.K

Heat released by iron bars = heat gained by water.

$m_o \times m_o \times \Delta t = m_\omega \times m_\omega \times \Delta t$
3,5 x 461 x (500 - *T*) = 28 x 4,187x (*T* - 285)
806 750 - 1613,5 *T* =117,236 *T* - 33 412,26
1 730,736 *T* = 840 162,26
T = 485,436 K

Worked Example 2.6

Oil with a density of 0,8 kg/l and a specific heat capacity of 3,14 kJ /kg. °C is used to temper 4 kg steel at a temperature of 667 °C. The temperature of the steel decreases to 27 °C. The rise in temperature of the oil may not exceed 25 °C.

Calculate:
(a) the heat released by the steel if the specific heat capacity of steel is 460 J /kg. °C
(b) the amount of oil required if it absorbs all the heat released by the steel.

Given:	Steel	Oil
	m = 4 kg	*m* =?
	T_2 = 667 °C	Δt = 25 °C
	t_1 = 27 °C	*c* = 31,14 kJ/kg. °C
	c = 0,460 kJ/kg. °C	

(a) Heat released by steel
= $m \times c \times (t_2 - t_1)$
= 4 x 460 x (667- 27)
= 1177,6 kJ

(b) 1177,6 = $m \times c \times (t_2 - t_1)$
= *m* x 3,14 x 25
m = 15 kg
but density = $\frac{mass}{volume}$
volume = $\frac{15}{0{,}8}$
= 18, 75 l

2.7.5 Experiment to determine the specific heat capacity or a copper calorimeter

In order to determine the specific heat capacity of a substance, a calorimeter is used. The experiment is based on the law of conservation of energy.

Experiment 2.1

- Determine the mass of a clean, dry calorimeter.
- Fill it approximately one third full with cold tap water and determine the mass again.
- Wrap up the calorimeter with cotton wool and place it in a larger calorimeter.
- Heat a quantity of water, enough to fill the calorimeter completely.
- Take the temperature of the cold water in the calorimeter as well as the temperature of the hot water.
- Quickly but carefully pour the heated water into the cold water in the calorimeter while stirring it with a thermometer.
- Take the final temperature of the water in the calorimeter, which will also be the temperature of the calorimeter.
- Determine the mass again.

According to the law of conservation of energy, the heat emitted by the hot water must be equal to the heat absorbed by the calorimeter with cold water.

$$Heat\ released\ by\ hot\ water = mass\ of\ hot\ water \times c_{\omega} \times \Delta t$$
$$Heat\ absorbed\ by\ cold\ water = mass\ of\ cold\ water \times c_{\omega}\Delta t$$
$$Heat\ absorbed\ by\ copptr\ calorimeter = mass\ of\ copper \times c_{\omega} \times \Delta t$$

Now equate $heat\ absorbed = heat\ released$ and calculate the specific heat capacity c_k of the copper.

2.7.6 Water equivalent

The water equivalent (water value) of an object is the mass of water that has the same heat capacity as the object. Say a copper calorimeter has a mass of 100 g and the specific heat capacity of copper is 0,386 J fg.K.

If the temperature rises by 1 K, the copper absorbs heat energy equal to:

Q = 100 0, 386 x 1
= 38,6 J

The heat capacity of the calorimeter is therefore 38,6 J/K.

But 9,22 g water also absorbs heat energy that is equal to:

Q = 9,22 x 4,187
= 38,6 J

Therefore the water equivalent of the copper calorimeter is 9,22 g, as the heat capacity of 9,22 g of water is equal to the heat capacity of 100 g copper.

From the above, it follows that:

water equivalent = mass of substance x specific heat capacity of substance + specific heat capacity of water.

or: m_{water} x c_{water} = $m_{subtance}$ x $c_{substance}$ where m_{water} = water equivalent.

Worked Example 2.7

45 g water at a temperature of 50 °C is poured into a calorimeter containing 42 g of water at 20 °C. The final temperature of the mixture is 23 °C.

Calculate:
(a) the water equivalent of the calorimeter
(b) the mass of the calorimeter if it is made of brass having a specific heat capacity of 0,363 kJ/kg. °C.

Solution:
Given: 45 g water at 50 °C; 42 g water at 20 °C final temperature = 23 °C
(a) Heat released by 45 g water
= m x c x (t_1 - t_3)
= 0,045 x 4,187 x (50 - 23)
= 5,087 kJ

Heat absorbed by 43 g water
= m x c x (t_1 - t_3)
= 0,042 x 4,187 x (23 - 20)
= 0,528 kJ

Heat absorbed by water equivalent of calorimeter
= m x 4,187 x (23 - 20) = 12,561 x m kJ

Heat released = heat absorbed
5,087 = 0,528 + 12,561 x m
m = 0,363 kg

(b) Water equivalent = mass of body x specific heat capacity
0,363 = m x 0,363
∴ m = 1 kg

Worked Example 2.8

A steel block that has a mass of 0,16 kg is placed in an oven until it has the same temperature as the oven. It is then quickly transferred to a container that has a water equivalent of 50 g containing 1 kg of water. The temperature of the container rises from 20 °C to 24 °C and it is assumed that no heat is lost.

Calculate:
(a) the amount of heat transferred to the container and the water
(b) the temperature of the oven. The specific heat capacity of the steel is 500 J/kg. °C.

Solution:
Given: m_o = 0,16 kg; heat equivalent of container = m_c = 50 g; m_w = 1 kg; t_2 = 24 °C; t_1 = 20 °C; c_o = 500 J/kg.°C; Q = ?; *toven* =?

(a) heat absorbed by container and 1 kg water
= $(m_w + m_c)$ x c_w, x $(t_2 – t_2)$
= (1 + 0,05) x 4,187 x (24 - 20)
=17,585 kJ

(b) heat released by steel = heat · absorbed by water and container
m_o x c_o x (t_{oven} - 24) = 17,585
0,16 x 0,5 x (t_{oven} - 24) = 17,585
t_{oven} - 24 = 219,8
t_{oven} = 243,8 °C

2.8 Important formulae for conservation of energy

- $Q = m \times c \times \Delta t$
- Heat released = heat absorbed
- Heat capacity = mass x specific heat capacity
  $C = m \times c$
- Water equivalent = mass of substance x specific heat capacity of substance ÷ c of water.

2.9 Kinetic molecular theory

You will need to use kinetic-molecular theory to explain what happens when you study gases and develop the gas laws.

Definition: Kinetic molecular theory
Explains the properties of solids, liquids and gases in terms of the behaviour of the microscopic particles molecules and atoms) that make up the solids, liquids and gases.

Remember the following:

- All matter is made up of particles. These particles are atoms in the case of the noble gases and molecules in all other cases.
- These particles have no kinetic energy at 0 K, but are in continuous motion at temperatures above 0 K.
- The temperature of a substance or body is directly proportional to the average kinetic energy of the particles of which it is made.

Definition: Kinetic energy
Kinetic energy is the energy that objects or particles have as a result of their motion.

For a substance in the gas phase this means that:

- at room temperature, the particles occupy only about one thousandth of the volume of the gas
- the particles are far apart so the gas can be easily compressed
- the intermolecular forces between particles are the weakest because the particles are so far apart

Did you know?
Particles of gases typically move at speeds of about 500 $m.s^{-1}$.

- the particles only exert significant forces on each other when they collide with each other
- the particles have high kinetic energy compared with the particles of the same substance in the liquid or solid phase
- when the particles collide with solid surfaces , such as the sides of their container, they exert a force on the surface. This explains the pressure that gases exert

Note:
In the same substance, the average kinetic energy of the particles in the solid is less than the average kinetic energy of the gas. For example, water molecules in ice have a lower average kinetic energy than molecules of water in running water or steam. But, remember that ice is also at a lower temperature.

2.10 The concept of an ideal gas

An ideal gas is a model of a gas that is used to explain how real gases behave. In the ideal gas model, the particles of the gas have no volume and they do not exert forces on each other except when they collide.

Note:
The ideal gas model is useful because it allows us to explain how real gases behave and predict how they will behave under different conditions.

Real gases are everyday substances in a gaseous state. At room temperature and pressure, a real gas behaves like an ideal gas. For this reason the ideal gas model is very useful for describing the behaviour of real gases.

2.11 Investigating the gas laws

You need to know how to use the investigative method to establish the relationships between:

- the volume and temperature of trapped gas (Charles's law)
- the volume and pressure of trapped gas (Boyle's law)
- the pressure and temperature of trapped gas (Amontons's law)

2.11.1 The Kelvin scale

The SI unit of temperature is the kelvin (K). When you investigate the relationship between the volume and temperature of a gas you need to use the Kelvin or absolute temperature scale.

On the Kelvin scale temperature is given in kelvin (K). One kelvin is the same size as 1 °C, but the Kelvin scale starts 273 °C below 0 °C.

So: 0 K = -273 °C. This is the temperature known as absolute zero.
0 °C = 273 K

Think about it!
To convert between Celsius and Kelvin, you need to add or subtract 273.
If T = Kelvin temperature; t =Celsius temperature then $T = t + 273$ or $t = T - 273$.

Worked Example 2.9: Converting temperatures

A. fixed sample of gas has a volume of 38,0 cm^3 at a temperature of -5 °C. The volume of the gas sample increases 1 cm^3 with a 7 degree increase in temperature. Calculate the absolute temperature when the gas has a volume of 39,0 cm^3.

Solution:
Celsius temperature at volume of 39,0 cm^3 = -5 + 7 = 2 °C
Kelvin temperature = Celsius temperature + 273 = 2 + 273 = 275 K

2.11.2 Direct and inverse proportion

To investigate the gas laws you need to collect data and organise it into tables that you can use to draw graphs. Once you have drawn a graph, you need to be able to interpret the graph to deduce relationships and equations.

This means that you have to recognise when a graph shows a directly proportional relationship and when it shows an inversely proportional relationship.

2.11.2.1 Direct proportion

When an increase in one variable, x, causes a corresponding increase in another variable, y, the relationship between the variables is directly proportional if the graph of x against y is a straight line passing through the origin.

Think about a situation in which you get paid R40 per hour to do a job. If you work for one hour, you get paid R40, if you work for two hours (double the time) you get paid R80 (double the money). If you do no work you get no money.

The relationship between the amounts you are paid and the hours you work is directly proportional, as shown in **Figure 2.4**.

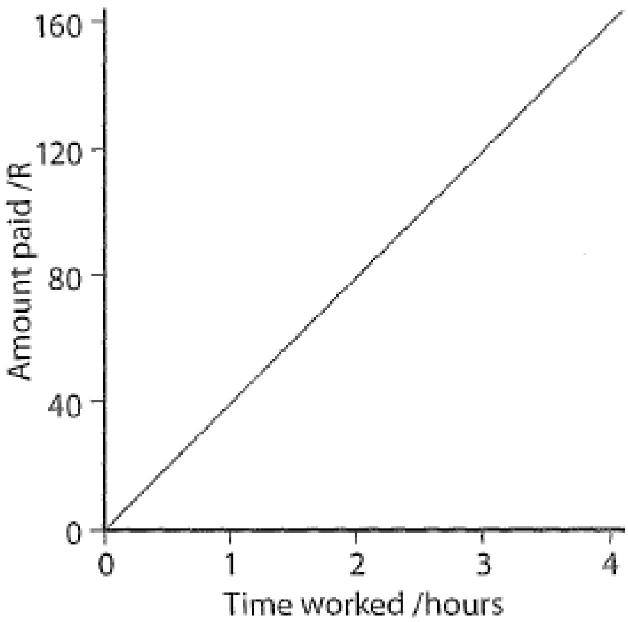


Figure 2.4

The ratio of the quantities is constant (it stays the same). In other words:
$\frac{y}{x} = k$ or $y = kx$, the equation of a straight line passing through the origin where k is the constant of proportionality.

We say y is directly proportional to x and write $y \propto x$.

2.11.2.2 Inverse proportion

The relationship between two variables is inversely proportional when an increase in one variable (x) by a factor results in a decrease in the other variable (y) by the same factor.

For example,
if you drive at a speed of 60 km.h^{-1} you will take one hour to cover a distance of 60 km. If you double your speed to 120 km.h^{-1} you will halve the time it takes to cover the distance.

If you graph this relationship you will get a curved line or hyperbola.

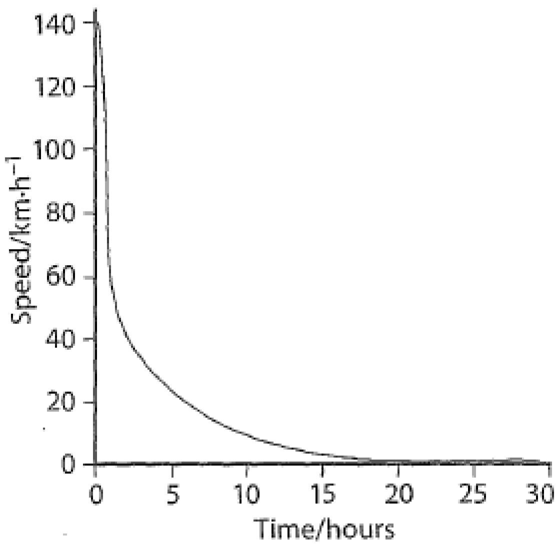


Figure 2.5

The product of the variables is constant, $xy = k$, the equation of a hyperbola where k is the constant of proportionality. We say y is inversely proportional to x and write $y \frac{1}{\propto} x$ or say y is directly proportional to the inverse of x and write $y \propto \frac{1}{x}$.

2.11.3 Investigating the relationship between volume and temperature

The relationship between the volume and temperature of trapped gas can be investigated using the apparatus shown in **Figure 2.6**. In this investigation the pressure of the gas must be kept constant.

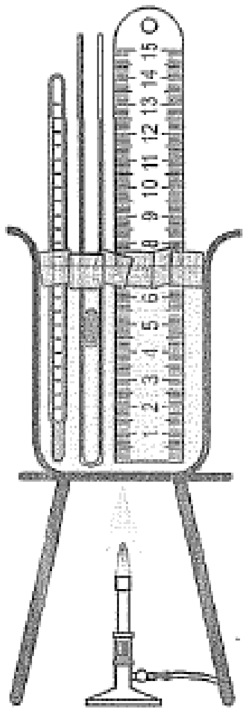


Figure 2.6

Steps in the investigation:

1. Keep the external pressure on a fixed mass of gas constant by trapping the sample of gas (air) using a bead of mercury that moves freely up and down the sealed glass tube under constant air pressure.
2. Attach the tube of trapped air to a ruler with elastic bands.
3. Change the temperature of the gas in the tube by heating the water and then measure the temperature using the thermometer.
4. Measure the length of the trapped air column on the ruler.
5. Assume that the tube trapping the gas is uniform. Therefore, the volume of the gas is directly proportional to the length of the air column that we measure on the ruler.

Table 2.1 shows the results that you might expect using the apparatus.

Result	**Volume (cm of tube)**	**Volume (cm^3 x 10^{-2})**	**Temperature (°C)**
1	5,5	17,3	2
2	6,0	18,9	27
3	6,5	20,4	52
4	7,0	22,0	77

Table 2.1 Relationship between temperature and volume of trapped gas

Note:
To generate the actual volume of the gas that we give in the third column, we assume a radius of 1 mm for the glass tube.

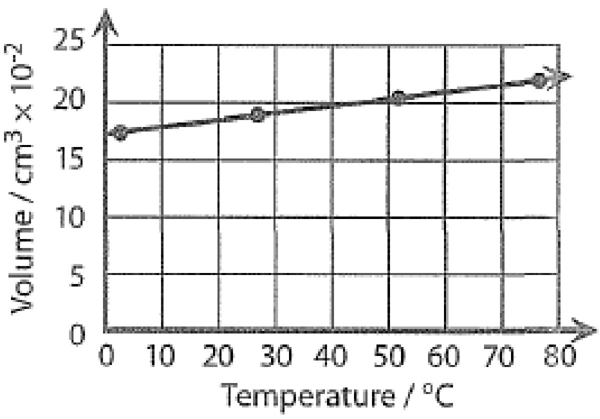


Figure 2.7

2.11.4 Investigating the relationship between volume and pressure

The relationship between the pressure exerted on a fixed mass of gas and the volume of the gas at constant temperature can be investigated using the apparatus shown in **Figure 2.8**.

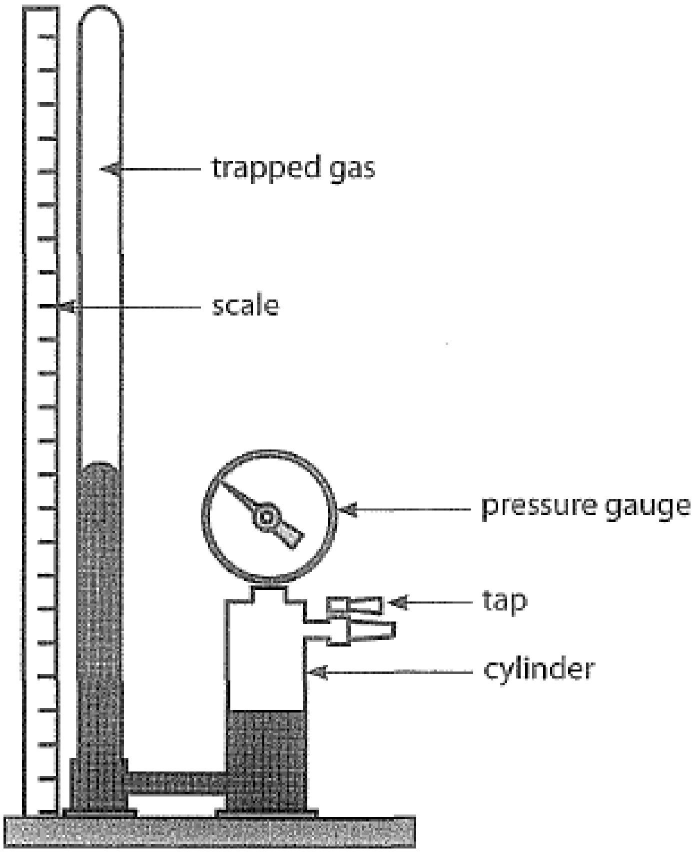


Figure 2.8

Steps in the investigation:

1. Vary the pressure by pumping air into the cylinder, or by removing air from the cylinder by using a vacuum pump. The oil in the cylinder transmits the pressure that the air exerts on the surface of the oil to the gas trapped in the glass tube. We want to investigate the behaviour of the air in the glass tube.
2. Measure the pressure using the pressure gauge and the volume using the scale.

Table 2.2 contains an ideal set of results that we might expect using this apparatus.

Result	Volume(V)/ cm^3	Pressure(p)/ kPa	$\frac{1}{pressure}$/ $kPa^{-1} \times 10^{-3}$	pV/ $J \times 10^3$
1	80	60	16,7	4800
2	60	80	12,5	4800
3	48	100	10,0	4800
4	40	120	8,3	4800
5	30	160	6,25	4800

Table 2.2

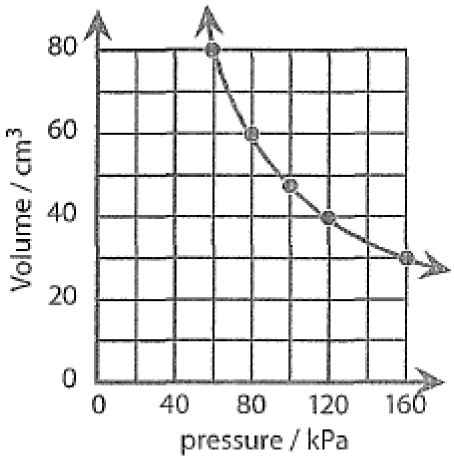


Figure 2.9

2.12 Deducing relationships from graphs experimental results

The process of collecting and analysing results to produce mathematical equations that describe relationships is very important in science.

To describe the relationships between volume, pressure and temperature for a fixed amount of gas you need to apply what you already know about direct and inverse proportion.

2.12.1 The relationship volume and temperature constant

Look at the graph in **Figure 2.7**. They-axis represents the volume of the gas (V).

The x-axis represents the temperature (t) in °C. If k_1 represents the slope of the straight line, we can express the relationship between volume and the temperature using the following equation representing a straight line that cuts the y-axis at (0;c).

$V = k_1 t + c$ ……………………… (1)

However, this graph does not pass through the origin (0,0). In other words, when the volume is 0, the temperature is not zero on the Celsius scale. So, you cannot tell that this is a directly proportional relationship using the figures plotted. To see the relationship you have to use the Kelvin scale for temperature.

$V = k_1 t + c$

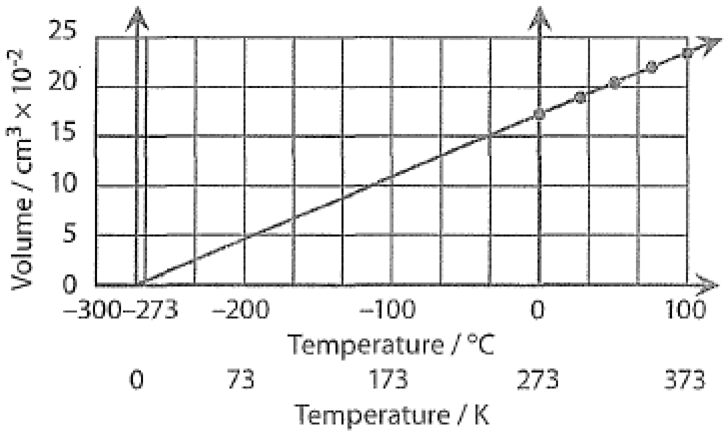


Figure 2.10

The graph in **Figure 2.10** shows the volume of a fixed mass of gas versus temperature with both centigrade and Kelvin scales.

Using this graph we can say that the volume is directly proportional to the Kelvin temperature. We use a T to represent temperature on the Kelvin scale.

If we use t far the Celsius temperature scale, we can describe the relationship between the two scales with the following equation:
$T = t + 273$ ………………………. (2)

Using the following equation we can say V is directly proportional to T, which we write as $V \propto T$.
$V = k_1 T$ ………………………. (3)

Equation (3) shows that volume is directly proportional to Kelvin temperature. That means that if we increase the Kelvin temperature by a factor of 2, the volume increases by a factor of 2.

Think about it!
Remember, whenever you use any of the gas law equations, you must use the Kelvin scale.

2.12.2 The relationship between volume and pressure of a trapped gas
The relationship between volume and pressure of a trapped gas is an example of inverse proportion.

If we plot the volume V against $\frac{1}{pressure}$ (or p^{-1}) we do get a straight line graph, as shown in **Figure 2.11**.

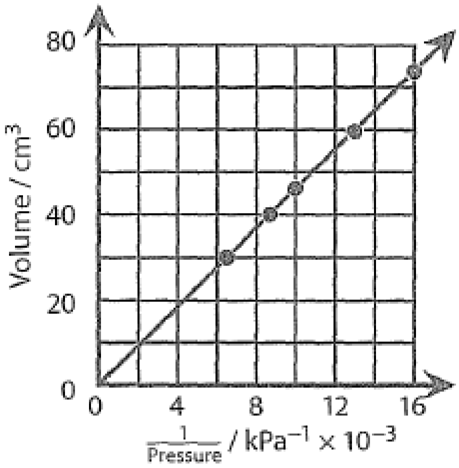


Figure 2.11

So, if k_2 is the slope or gradient of the straight line, we can represent the relationship between V and p with the equation below.

$V = k\frac{1}{2p}$ .... (4)

Equation (4) means that V is directly proportional to $\frac{1}{p}$. This means that V is inversely proportional to p.

Note:

- We use the symbol $\frac{1}{\propto}$ for inverse proportion. So, we write $V \propto \frac{1}{p}$ or $V\frac{1}{\propto}p$.
- If we increase or decrease the independent variable p by a factor, the dependent variable V changes by the inverse of the same factor.
- The original curve in **Figure 2.5** is a hyperbola.

When we change the subject of equation (4) to k_2 we get:
$k_2 = pV$ .... (5)

Warning!
Be careful in your calculations. Increasing the Kelvin temperature by a factor of 2 does not mean that you double the temperature from 25 °C to 50 °C. We are using Kelvin temperature, so it would mean doubling the temperature to 596 K, which means the temperature increases from 25 °C to 323 °C.

2.12.3 Relationships between several variables in one equation
We can express the relationships between several variables by combining the equations that you learnt above.

⚠	**Note:** If we increase the pressure by a factor of 3 (triple the pressure) the volume will decrease by a factor of 3 (the volume will be a third of the original volume). Similarly, if we decrease the pressure by a factor of 2 (halve it), the volume will double.

The following equation gives the relationship between the volume, the pressure and the temperature (Kelvin) of a constant mass of gas:

$pV = kT$ .... (6)

- If the pressure (p) is constant, $k = pk_1$ and equation (6) simplifies to equation (3), above.
- If the temperature (T) remains constant, $k = pk_1$ and equation (6) simplifies to equation (5).

We can also rearrange equation (6) to $\frac{pV}{T} = k$

Then, for particular sets of conditions of temperature and pressure (condition 1 and condition 2), we can write the following:

$pV = kT$ .... (7)

⚠	**Note:** Both equations are equal to k, so we can put the left-hand side. of the equations equal to each other.

We can simplify equation (7) as follows:
If the temperature is constant:

$pV = kT$ .... (8)

This is Boyle's Law and we can state the conclusion given by this equation as follows:
The volume of a constant amount of gas, at constant temperature, is inversely proportional to the pressure exerted by the gas.
If the pressure is constant:

$pV = kT$ .... (9)

This is Charles's Law. We can state the conclusion given by this equation as follows:
The volume of a constant amount of gas, at constant pressure, is directly proportional to the temperature of the gas measured on the Kelvin scale.

P1 P2 If the volume is constant:

$pV = kT$ ……………………… (10)

Worked Example 2.10: Relationship between pressure and temperature

The pressure inside a car tyre is 200 kPa. On a cold morning when the temperature is 7 °C. After driving on the highway for an hour, the pressure in the tyre is measured to be 220 kPa . What is the temperature of the air in the tyre in °C? Assume that the volume of the tyre remains unchanged.

Solution:
The volume is unchanged, so we put V = c. Then, we have the following information:

Condition	Pressure	Temperature	Volume
1	$\rho_1 = 200\,kPa$	$T_1 = 7 + 273 = 280\,K$	$V_1 = c$
2	$\rho_2 = 220\,kPa$	T_2	$V_2 = c$

Table 2.3

We want to find T_2 (the temperature in the tyre after an hour). The volume is constant, so we can use equation (10).

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$T_2 = \frac{P_2}{P_1} \times T_1$$

$$= \frac{220}{200} \times 280$$

$$= 308\,K$$

But, we want the temperature in Celsius, so we use equation (2).

$$t = 308 - 273$$

$$= 35\,°C$$

2.12.4 The relationship between the volume and amount of a gas

Up until now, we have worked with a fixed mass or number of particles of gas. But, the volume of a gas (V) is directly proportional to the number of particles of gas (n), measured in moles. We write this as $V \propto n$.

If k_3 is the constant representing the gradient, then we can express this relationship as follows:

$\mathrm{pV} = \mathrm{kT}$ ……………………… (11)

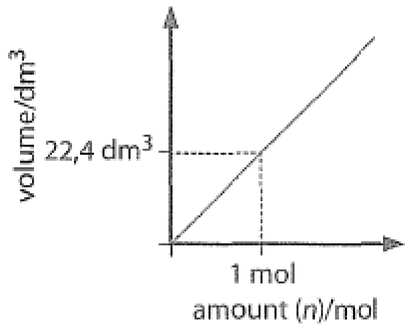


Figure 2.12

At STP (101 kPa and 0 °C), k_3 = 22,4 $dm^3 .mol^{-1}$.

2.12.5 The ideal gas equation

The ideal gas equation describes the relationship between pressure, volume, temperature and amount of gas .

$pV = kT$ ……………………… (12)

⚠	**Note:** R is the universal gas constant with a value of 8,3 $J.K^{-1}$-mol^{-1}.

If the amount of gas is constant, then $nR = k$, which simplifies the equation to equation (6), $pV = kT$.

You should notice that equation (12), $pV = nRT$, incorporates equation (11) and equation (6) and therefore describes all the relationships involving ideal gases that you learnt about above.

2.12.5.1 Units for the ideal gas equation

We give the gas constant in $J.K^{-1}.mol^{-1}$, so we use pascals ($N.m^{-2}$) as the unit for pressure and cubic metres (m^3) as the unit for volume.

⚠	**Note:** We can use units of kPa for pressure and dm^3 for volume and get the right answer. This is because Pa equals $l0^{-3}$ kPa and 1 m^3 equals 1000 dm^3 so you have multiplied and divided *pV* by a thousand.

Table 2.4 shows the units of measurement that we use for the variables in the ideal gas equation.

p	V	n	R	T
$Pa = n.m^{-2}$	m^3	mol	$J.K^{-1}mol^{-1}$	K

Table 2.4 Units of measurement used in the ideal gas equation

Worked Example 2.11

Introduce 0,016 g of an unknown gas into a gas syringe. The volume of the gas is 24,9 cm^3 at 100 kPa and 27 °C.
Calculate the following:
1. The number of moles of gas in the sample
2. The molecular mass of the gas

Solution:
1. We have enough information to solve equation (12) for. the number of moles (n).
$$pV = nRT \quad \text{............... (12)}$$
$$n = \frac{pV}{RT}$$
$$= \frac{100 \times 1000 N.m^2 \times 24{,}9 \times 10^{-6} m^3}{8{,}3\ J.K^{-1} mol^{-1} \times (27+273)K}$$

2. We find the molar mass by using the equation $n = \frac{m}{M}$ and changing the subject to M.
$$M = \frac{m}{n}$$
$$= \frac{0{,}016\ g}{0{,}001\ mol}$$
$$= 16 g \cdot mol^{-1}$$

2.12.6 Molar gas volume and gas type

You should remember that the volume of a gas is independent of the type of gas. This means that you can use the ideal gas equation, to determine the volume of one mole of any of gas at STP. The molar gas volume is 22,4 x 10^{-3} m^3 or 22,4 dm^3.

Note:
STP here is standard pressure, 101,3 kPa, and standard temperature, 0 °C or 273 K.

Worked Example 2.12

Using molar gas volume, find the amount of oxygen gas (O_2) that has a volume of 4,48 dm^3 at STP?

Solution:
We need to divide the volume by the molar gas volume (22,4 dm^3.mol^{-1}) to get the amount n.
$$n = \frac{4{,}48\ dm^3}{22{,}4\ dm^3.mol^{-1}}$$
$$= 0{,}2\ mol$$

2.13 Ideal gas laws and real gases

At room temperatures and pressures, real gases behave like ideal gases. In other words, the laws for ideal gases apply to real gases as well.

Note:
Standard pressure is sometimes taken as 100 kPa. If we use 100 kPa for standard pressure, the molar gas volume is 22,7 dm^3.

When the temperature of a real gas is decreased, or the pressure on a real gas is increased, the gas behaves differently from an ideal gas.

The graphs that show the relationships for each gas law change at very low temperature and very high pressure from the ideal. At these extremes, the ideal gas law equations are not true for a real gas.

Note:
Remember that at absolute zero an ideal gas:

- has no volume
- its particles have no kinetic energy
- the gas exerts no pressure

Two important reasons why the ideal gas law equations do not apply to gases under extreme conditions are as follows:

- The particles of a real gas have volume, but the particles of an ideal gas do not have volume.
- Intermolecular forces of attraction exist between particles of a real gas. No such forces exist between the particles of an ideal gas.

2.14 Heat transfer

Heat moves from one object to another in three ways:

- conduction
- convection
- radiation

2.14.1 Conduction

Conduction happens when two materials touch each other. The transfer of heat always happens from the hotter object to the colder object. For example, if you hold a hot cup of coffee in your hand, the heat from the coffee will transfer to your hand and your hand will feel hotter.

Definition: Conduction
The way energy moves through a solid substance.

If you hold an ice cube in your hand, the heat will transfer from your hand to the ice cube and it will melt.

Conduction can also happen with just one solid object. If you heat one end of a spoon, the heat spreads from the hot end of the spoon to the cold end.

Think about it!

If we touch a good conductor when it is hot, a lot of heat will transfer to us quickly and we might be. burnt.

Metal is a good conductor. This means that if it is hot, it will burn you, should you touch it. People living in the cold parts of South Africa know that if you pick up a piece of metal in winter, such as a spade, your hand could freeze to the metal, because metal is such an excellent conductor of heat.

Coal, on the other hand, is not a good conductor of heat. It is an insulator. This is why some people are able to walk over hot coal with no shoes. The heat does not transfer very easily from the coal to the person's feet and so the person's feet don't burn if the distance is covered quickly enough.

Some objects transfer heat better than others do. Walking on tiles feels colder than walking on a carpet because the tiles conduct the heat from your feet better than the carpet.

Definition: Conductor
A material that transfers heat easily and quickly is called a thermal conductor.

Definition: Insulator
A material that does not transfer heat quickly is called a thermal insulator.

2.14.2 Convection

When we heat water on a stove, the hot water from the bottom of the pot will rise and heat the water at the top of the pot. We call this type of heat transfer convection.

Definition: Convection
The way heat moves through a liquid or gas.

Convection is a useful form of heat transfer in liquids and gases.

Hot air rising is another example of the hot particles moving up into the colder areas. Convection ovens heat food up by circulating warm air around the oven, heating up the food as the hot air flows around it.

Definition: Circulate
To move around within a system, or to cause something to do this.

In most heating, there is some conduction and some convection. In our example of heating water on a stove, the hot water from the bottom moves to the top of the pot by convection.

Definition: Collide
To hit something that is moving in a different direction.

However, the hot particles also heat up the cold particles by colliding into them when they move past. This is conduction.

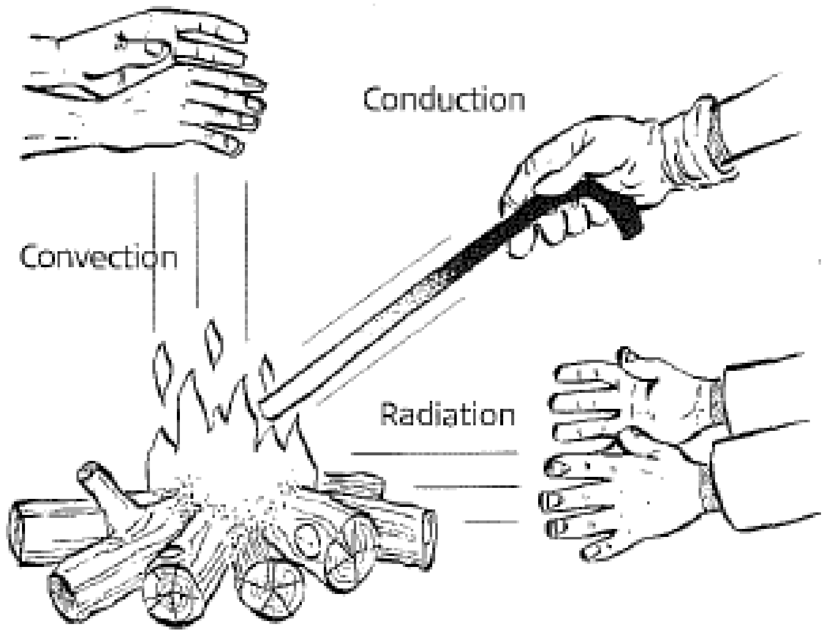


Figure 2.13 Conduction, convection and radiation

2.14.3 Radiation
Remember that electromagnetic waves have energy. Radiation is the transfer of heat through electromagnetic waves. Objects with higher temperatures will transfer more radiation heat than objects at lower temperatures.

Definition: Radiation
The heat energy given out in waves by substances.

A microwave oven uses electromagnetic waves to cook or heat food. **Figure 2.14** illustrates conduction, convection and radiation.

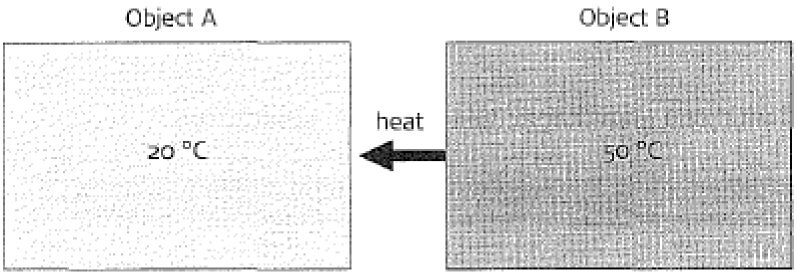


Figure 2.14 Two objects of different temperatures

2.15 Calculating heat

If we can calculate the amount of heat that is transferred, we know what will happen to the thermometric properties. In the example of train tracks, engineers must know how much the steel will expand in hot weather so they can calculate the size of the gaps between the tracks.

It is also useful to predict the temperature of substances, for example, how hot food will be after it has been left in 2 kg ice for five hours when the air temperature is 30 °C.

First, let us examine an important law about the transfer of heat energy.

2.15.1 The first law of thermodynamics

Thermodynamics is the study of how heat is transferred and how it affects different areas of science and technology. The first law of thermodynamics comes from our first definition of heat: to make something become warmer or hotter. We use it to solve many problems when working with heat.

Definition: The First Law of Thermodynamics
This law states that when energy moves from one substance to another, the amount of internal energy lost by the one substance or substances is the same as the amount of internal energy gained by the other substance or substances.

The first law of thermodynamics is an example of conservation of energy. You can move energy from one place to another but you cannot make it or destroy it, so it is conserved.

Look at the two objects in **Figure 2.14**. They are close to each other but B is warmer than A. What will happen? Object B will get colder and A will get warmer. This is because objects always transfer internal energy until they are both at the same temperature. This is the transfer of heat, also called the exchange of heat.

To work out the amount of heat transferred in the diagram, we use the first law of thermodynamics. If we know how much thermal energy Object B lost, we know how much thermal energy Object A gained. So if Object B lost 300 J of internal energy, then Object A gained 300].

Now we can calculate heat more accurately.

The equation for calculating heat
The equation for calculating heat transfer is:

Q = $mc\Delta T$, where:

Q = heat *(J)*
m = mass (kg)
c = specific heat capacity, this is different for different materials$(\frac{1}{kgK})$
ΔT = difference in temperature between the two objects.

According to this equation, two things affect the amount of heat transferred:

- A large mass or a large difference in temperature will increase the amount of heat transferred.
- The specific heat capacity (C) of the material involved . Good conductors have a large specific heat capacity and poor conductors have a small specific heat capacity.

Substance	Specific heat capacity (J/kgK
AIr	715
Aluminium	911
Copper	390
Glass	756
Human *tissue*	3 470
Ice	2 053
Iron/steel	470
Water	4 200
Wood	1 700

Table 2.5 Heat capacity of various substances

The following worked examples show how this equation is used.

Worked Example 2.13

How much energy is needed to heat 60 g of glass from 20ºC to 140 ºC?

Solution:
The amount of energy needed to raise the temperature is Q.

Q = $mc\Delta t$ (1)

m = 60 g = 0,06 kg
c = 756 J/kgK, this value taken from **Table 2.5**.
ΔT = 120 K

Δt was calculated by taking the final temperature 140ºC and subtracting the initial temperature, 20ºC.

So $\Delta T = T_{final} - T_{initial}$ = 140 °C - 20 °C = 120 °C = 120 K.

If you are calculating ΔT it does not matter if you use ºC or K. This is because ΔT is the same in ºC as it is in K.

Converting 140ºC and 20ºC to Kelvin is 317 K and 197 K. 317 K -197 K = 120 K. This works only for ΔT, not with normal temperatures, T.

Substituting into (1) gets:

Q = (0,06)(756)(120)
= 5 443 J

In words, the answer is: 5 443 joules of energy are needed to heat 60 g of glass from 20°C to 140 °C.

In the following example, we will use the first law of thermodynamics and the equation for heat transfer.

Worked Example 2.14

1 kg of hot copper is placed in some water. They are left together until they both have the same final temperature of 30 ºC. If the initial temperature of the copper was 200ºC and the original temperature of the water was 15 ºC, how much water, in kg, was used to cool the copper?

Solution:
We can use the first law of thermodynamics. The heat lost by the copper is equal to the heat gained by the water.

$\text{heat lost}_{copper} = \text{heat gained}_{water}$ (1)
$\text{heat lost}_{copper}$:

Q = $mc\Delta T$ (2)
m = 1kg
c = 390 (from the **Table 2.5**, copper)
$\Delta T = T_{final} - T_{initial}$ = 30°C - 200°C = -170°C = -170K

Substitute into (2):

Q = 1(390)(-170)
= -66 300 J (the minus sign shows that it is heat lost, not gained, so

we can drop it now)

substitute heat loss = 66 300 *J* into (1)

66 300 *J* = heat gained by water, which = $mc\Delta T$

m = ? (this is what we must find)

c = 4 200 (from **Table 2.5**, see water)

ΔT = $T_{final} - T_{initial}$ = 30°C - 15ºC = 15 K

$\therefore 66\ 300 = m(4\ 200)(15)$

$\therefore \frac{66\ 300}{(4\ 200 \times 15)} = m$

$\therefore m = 1{,}05$ kg

So 1,05 kg of water was used to cool the copper.

If you take the specific heat capacity of an object (c) and multiply it by the mass of the object (m), then you get *cm*.

This is the same as heat capacity (C). So,
$C = cm$

This is sometimes used in experiments such as the question above. It can be confusing because they are very similar and they are called by almost the same name.

Note: Make sure you use the correct one!
c = specific heat capacity (measured in J/kgK)
C = heat capacity (measured in J/K)

Worked Example 2.15

A 700 g piece of substance has heat capacity of 329 J/K. What substance is it?

Solution:

C = 329J/K

m = 700 g = 0,7 kg

C = cm

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

$\therefore c = \frac{329}{0{,}7}$

$\therefore c = 470$

From **Table 2.5** we can see that *c* = 470 for iron or steel. So the substance is iron or steel.

The questions with the first law of thermodynamics are very similar to the examples with conservation of energy.

2.16 Radiation

Radiation is another by which heat energy can be transferred from one place to another. Heat energy from the Sun reaches us by radiation. The Sun emits electromagnetic waves which travel through space at high speed. Light is such a wave, but the Sun also emits a lot of infra-red waves (or infra-red radiation).

Did you know?
Infra-red waves have longer wavelengths than light waves. It is the infra-red radiation that makes you feel warm when you lie down in the sun. Infrared radiation travels at the same speed as light; as soon as you see the Sun go behind a cloud you feel cooler.

2.16.1 Good and bad absorbers

Infra-red radiation behaves in the same way as light. It can be reflected and focussed using a mirror. **Figure 2.15** shows the idea behind a solar furnace. The shiny surface of the mirror is a poor absorber of radiation, but a good reflector.

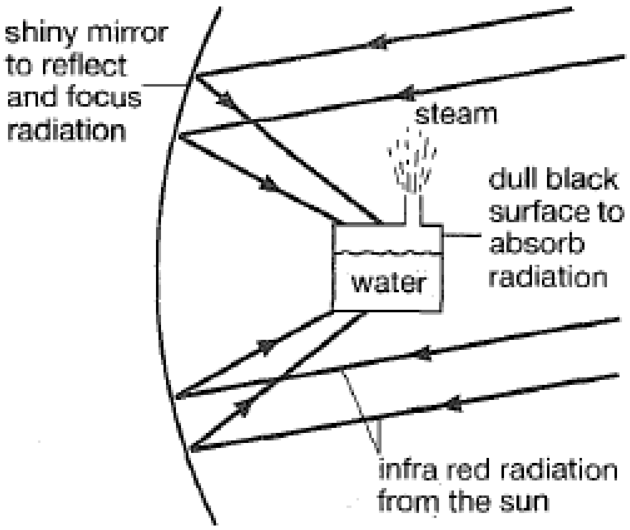


Figure 2.15 A solar furnace

Radiation is absorbed well by dull black surfaces. So the boiler at the focus of the solar furnace is of a dull black colour.

2.16.2 Good and bad emitters

Figure 2.16 shows an experiment to investigate which type of teapot will keep your tea warm for a longer time. One pot has a dull black surface, the other is made out of shiny stainless steel.

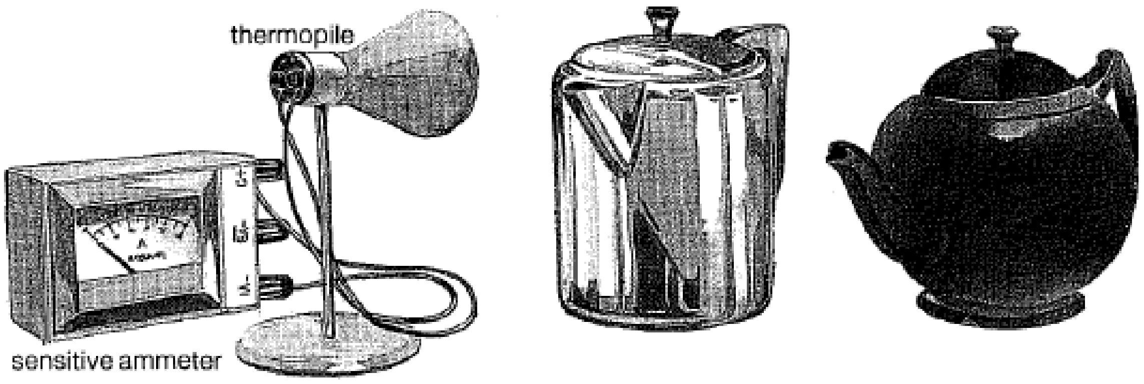


Figure 2.16

Radiation that is emitted from the hot teapots can be detected using a thermopile and a sensitive ammeter. When you do the experiment you will find that the black teapot emits more radiation than the shiny surface. So a shiny teapot will keep your tea warmer than a black teapot.

- Black surfaces are good absorbers and good emitters of radiation
- Shiny surfaces are bad absorbers and bad emitters of radiation

2.16.3 The greenhouse effect

In Italy, where the average temperature in summer is about 5º higher than in Britain, tomatoes grow very well. It is a great help to a tomato grower in Britain if he uses a greenhouse. On a warm day the temperature inside a greenhouse can be 10°C or 15°C higher than outside (**Figure 2.17**).

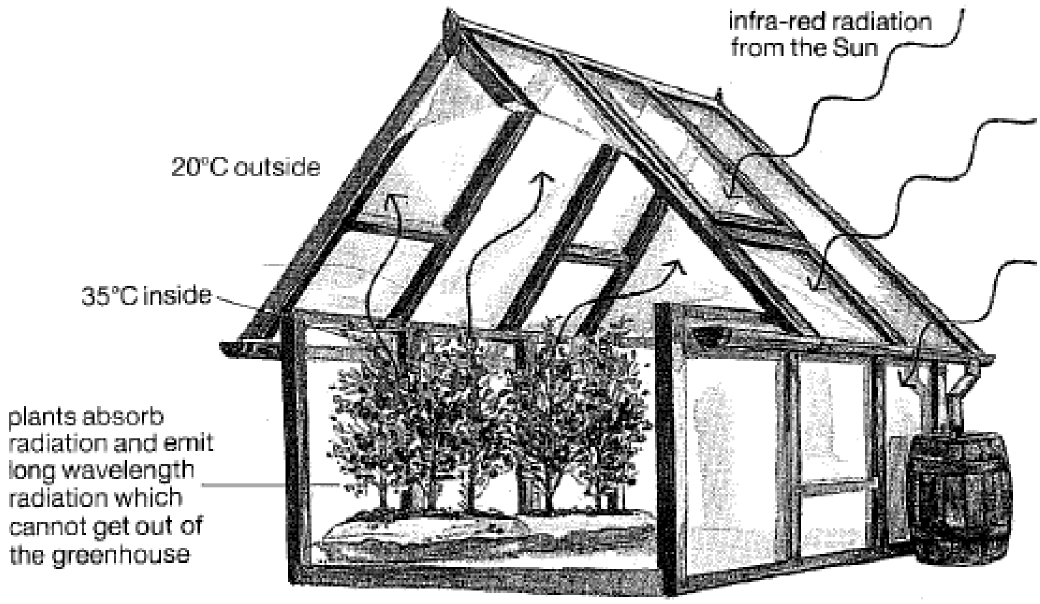


Figure 2.17

Infra-red radiation from the sun passes through the glass of the greenhouse, and is absorbed by the plants and soil inside. The plants radiate energy, but the wavelength of the emitted radiation is much longer.

The longer wavelengths of radiation do not pass through the glass and so heat is trapped inside the greenhouse. The temperature rises until the loss of heat through the glass by conduction balances the energy absorbed from the Sun.

Some people worry that a similar greenhouse effect could be happening in our atmosphere. As we continue to burn fossil fuels we are filling our atmosphere with carbon dioxide and other chemicals.

As these chemicals absorb long wavelength radiation emitted from the Earth's surface, the average temperature of the Earth increases.

Did you know?
The planet Venus shows the greenhouse effect in a big way. Its atmosphere is mostly carbon dioxide, and its average surface temperature is about 460°C, hot enough to melt some metals.

2.16.4 Thermos flask
A thermos flask keeps things warm by reducing heat losses in all possible ways.

The flask is made with a double wall of glass and there is a vacuum between the two walls. Conduction and convection cannot take place through a vacuum. The glass walls are thin, so that little heat is conducted through the glass to the top.

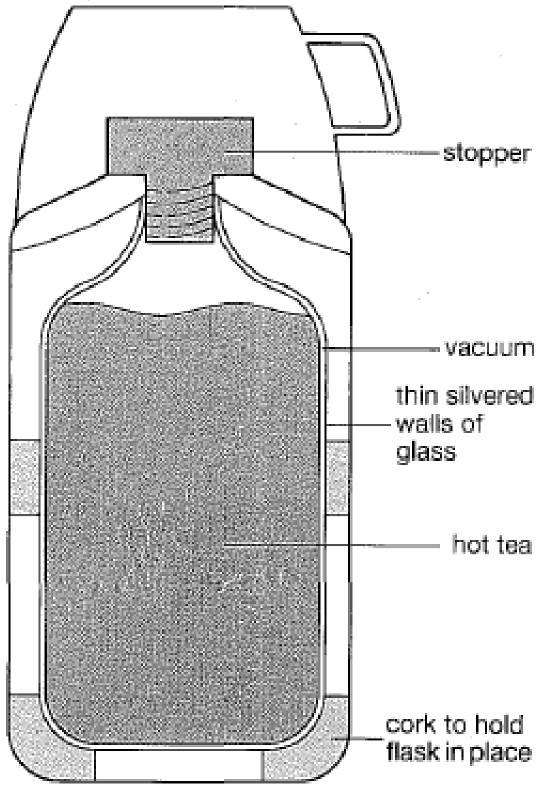


Figure 2.18 A thermos flask

Heat can be radiated through a vacuum, but the glass walls are silvered like a mirror so that they are poor emitters of radiation. The stopper at the top prevents heat loss by evaporation or convection currents (**Figure 2.18**).

2.17 Adiabatic processes

An adiabatic process is one that occurs without transfer of heat between a thermodynamic system and its surroundings.

Definition: Adiabatic process
One that occurs without transfer of heat between a thermodynamic system and its surroundings. During an adiabatic process, energy is transferred only as work.

Some chemical and physical processes occur so rapidly that they may be conveniently described by the "adiabatic approximation", meaning that there is not enough time for the transfer of energy as heat to take place to or from the system.

In way of example, the adiabatic flame temperature is an idealization that uses the "adiabatic approximation" so as to provide an upper limit calculation of temperatures produced by combustion of a fuel.

The adiabatic flame temperature is the temperature that would be achieved by a flame if the process of combustion took place in the absence of heat loss to the surroundings.

Activity 2.1

1.
   (a) What do you understand by the term "thermodynamic temperature"?
   (b) Convert 196 K to degrees Celsius and -10 °C to kelvin. [-77 °C; 263 K]
   (c) A steel vessel contains carbon dioxide at 273 K and an absolute pressure of 1 200 kPa. Calculate the internal gas pressure if the vessel is heated to 373 K. [1640 kPa]
2.
   (a) Is the coefficient of expansion the same for all gases? Explain.
   (b) Nitrogen having a volume of 3,6 m³ at a pressure of 130 kPa is compressed to a pressure of 600 kPa while the temperature is increased from 18 °C to 178 °C. Calculate the final volume of the nitrogen. [1,209 m³]
   (c) State Boyle's gas law.
3.
   (a) Air is compressed in a cylinder from a pressure of 100 kPa and temperature of 20 °C so that t he volume occupies one quarter of the original volume while the temperature remains constant.

Calculate:
(i) the final pressure of the air [400 kPa]
(ii) the final temperature if the air is now heated to the original volume at the new pressure. [1 172 K]

(b) Compressed air at a pressure of 350 kPa and a temperature of 290 K flows through a heater. The temperature rises to 348 K and the pressure drops to 270 kPa. Calculate the percentage change in volume. [64,3 %]

4.
(a) State Charles's gas law.
(b) Oxygen at a pressure of 300 kPa and a temperature of 11 °C increases in volume from 0 , 025 m³ while the temperature drops to 2 °C.
Calculate:
(i) the final pressure of the oxygen [16,138 kPa]
(ii) the volume that the oxygen would occupy at this final pressure if the temperature were kept constant at 11 °C. [0,465 m³]

5.
(a) A gas at 273 K expands by 0,1 m³ if it is heated through 50 K. Calculate the original volume at constant pressure. [0,546 m³]
(b) Name the relation between volume, pressure, and thermodynamic temperature when the following are applied :
(i) Boyle's law
(ii) Charles's law
(iii) the pressure law.
(c) A quantity of hydrogen is confined in a platinum chamber of constant volume. When the chamber is immersed in a container of melting ice, the pressure of the gas in the chamber is 100 kPa.
Calculate:
(i) the temperature if the pressure gauge registered exactly 10 kPa (27,3 K]
(ii) the pressure registered if the temperature of the chamber is increased to 100 °C. (137 kPa]

6. A cylinder contains 0,11 m³ nitrogen at a pressure of 1 700 kPa and a temperature of 284 K. The temperature decreases to 275 K while the volume remains constant.
Calculate:
(a) the pressure at this new temperature [1 464 kPa]
(b) the pressure if the volume changes to 0,095 m³ while the temperature changes to 275 K. [1 906 kPa]

7. A container has a capacity of 0,08 m³ and is filled with oxygen at a pressure of 400 kPa. The temperature is 47 °C. Later it is found that, owing to a leak, the pressure has dropped to 320 kPa while the temperature has fallen to 27 °C.
Calculate:
(a) the mass of oxygen that was initially in the container. Take R for oxygen as 260 J/kg.K [0,385 kg]
(b) the amount of oxygen that leaked out. [0,057 kg]

8. An air bubble at the bottom of a lake occupies 1 m^3 at a temperature of 7 °C and a pressure of 450 kPa. The bubble rises to the surface, where the pressure is 101,3 kPa and the temperature is 27 °C. Calculate the size of the air bubble in m^3 when it reaches the surface. [4,76 m^3]
9. Gas with a volume of 2,8 m^3 at a pressure of 150 kPa is compressed to a pressure of 500 kPa.
   Calculate:
   (a) the final volume if the temperature increases from 20 °C to 170 °C [1,27m^3]
   (b) the final volume if the temperature is kept constant at 20 °C. [0,84 m^3]
10. Helium at a pressure of 300 kPa and a temperature of 27 °C occupies 0,001 m^3. It is heated until both the pressure and the volume double. The gas constant for helium is 2,08 kJ/kg.K.
   Calculate:
   (a) the final temperature [1 200 K]
   (b) the mass of helium in grams. [0,481 grams]
11. A room measures 9 x 4 x 3, 2 m high and has a temperature of 20 °C at an atmospheric pressure of 96 kPa. The mass of 1 m 3 dry air at STP is 1,29 kg. Take R = 287,5 J/kg.K.
   Calculate:
   (a) the volume of 1 kg dry air in the room [0,877 m^3]
   (b) the mass of dry air in the room. [131,36 kg]
12. The stroke length of a single-cylinder air compressor is 150 mm and the cylinder diameter is 100 mm. The free volume of the cylinder when the piston is at top dead centre is $\frac{1}{7}$ of the volume when the piston is at bottom dead centre. The pressure during the inlet stroke is 101,3 kPa, and the temperature of the inlet air is 27 °C. Calculate the final pressure during the compression stroke if the temperature rises to 75 °C. [822,556 kPa]
13. Two grams of nitrogen at 27 °C occupies a volume of 0,002 m^3.
   Calculate:
   (a) the pressure if the gas constant for nitrogen is 297 J /kg.K [89,1 kPa]
   (b) the final volume if the pressure doubles and the temperature increases to 125 °C. [1, 327 x 10^{-3} m^3]

Activity 2.2

1. Some casserole dishes that are used in ovens are black, but the outside of an electric kettle is shiny. Can you explain why?
2. The greenhouse (**Figure 2.19**) can lose heat by radiation and conduction when its windows and doors are closed. Heat can also be lost by convection when a window is opened. Information about heat losses on a particular day is shown in the graph. On this day the greenhouse is absorbing 10 kW of power from the Sun.
   (a) Explain why the graph (opposite) shows that the air temperature outside the greenhouse is 20°C.

(b) At what rate must the greenhouse be losing heat if the temperature inside it is constant?

(c) At 38°C how much heat is lost by:

(i) radiation,

(ii) conduction? Explain why 38°C is the steady temperature with the door and windows closed.

(d) The window is now opened. Use the graph to work out the new steady temperature of the greenhouse.

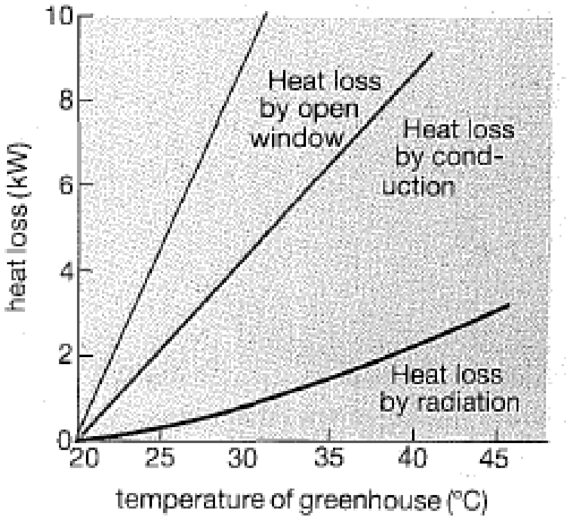


Figure 2. 19

	Self-Check		
I am able to:		**Yes**	**No**
• Describe the gas laws			
• Describe expansion and compression to the law $PV^h = C$			
• Describe elementary kinetic theory			
• Describe van der Waals' equation of state			
• Describe critical constants			
• Describe the first law of thermodynamics			
• Describe conduction			
o Determine conductivities			
• Describe radiation			
o The laws of radiation			
o Emission			
o Absorption			
o Reflection			
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.			

Module 3

Light I

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the sources of light
- Describe reflection from plane and spherical mirrors
  - Formation
  - Position
  - Character and size of images
    - Ray diagrams with formulae
- Describe refraction through glass plates and prisms (constitution of white light)
  - Formation
  - Position
  - Character and size of images in case of convex and concave lenses
  - Minimum deviation
  - Total reflection
  - Critical angle
  - Formation of images by combinations of two thin lenses in contact
    - Convex and concave
- Describe photometry
  - Inverse square law
  - Photometers
- Describe optical instruments
  - Telescope
  - Microscope
  - Human eye
- Describe dispersion and spectrum
  - Simple spectrometer

3.1 Introduction

There are many every day effects that are created by light. The next two modules will cover light, light rays and the properties of light.

There are natural and artificial sources of light. Some natural source of light are the sun and the stars. The discharge of electricity is also a source of light.

Some artificial sources of light include the flame of a candle and electric lights.

There are three things that happen to light:
- It may be allowed to pass through
- It may be totally reflected
- It may be allowed both to pass through and be reflected

3.2 Shadows and eclipses

Shadows are formed when something blocks the path of light. In **Figure 3.1** you can see a piece of card held in front of a small source of light. Some light misses the card and travels on, in a straight line, to the screen.

A sharp shadow is formed on the screen behind the card. Not all shadows are so sharp.

If the source of light is large then the shadows have two parts.
- In the middle of the shadow there is a dark part called the umbra.
- Around the edges of the shadow there is a lighter region called the penumbra.

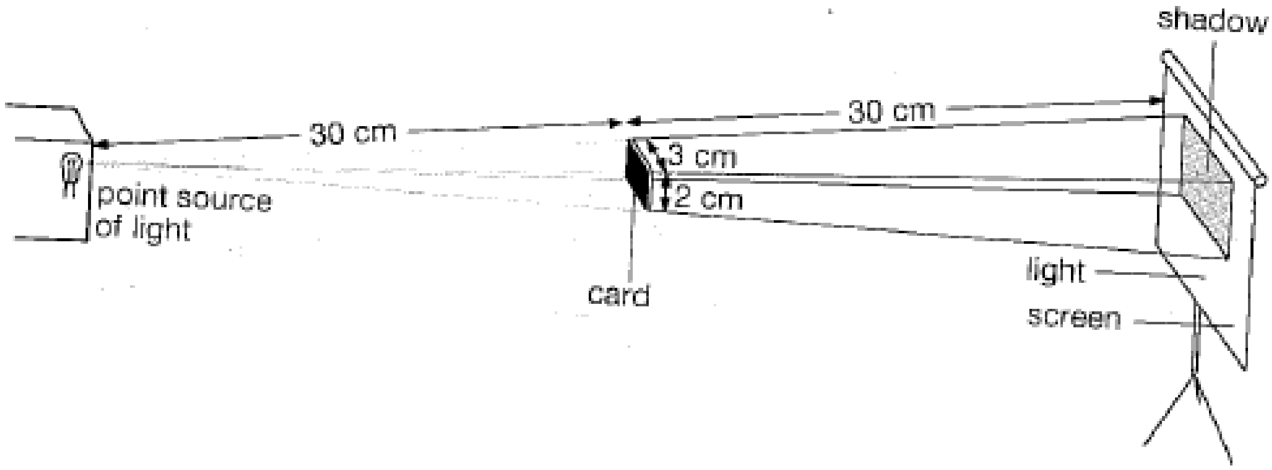


Figure 3.1

> **Note:**
> A good example of shadow formation is provided by eclipses of the Sun and Moon.

An eclipse of the Sun occurs when the Moon passes between the Earth and the Sun. The Moon is a lot smaller than the Sun but it is closer to us. It is just possible for the Moon to cover the Sun completely. When this happens there is a total eclipse of the Sun.

During a total eclipse of the Sun the sky goes black and it is possible to see stars. It is only possible to see a total eclipse of the Sun if you are in the umbra of the shadow (**Figure 3.2**).

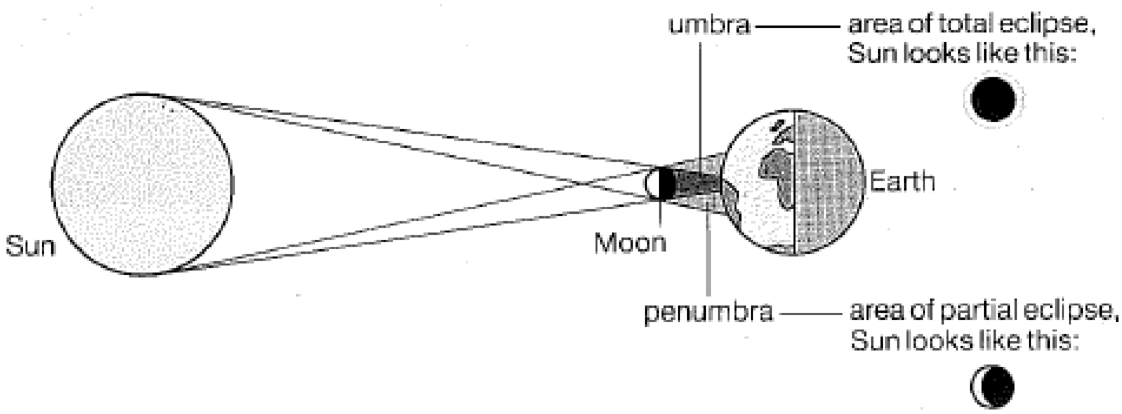


Figure 3.2 An eclipse of the Sun

If you are inside the penumbra of the shadow you will only see a partial eclipse of the Sun. Only part of the Sun is covered during a partial eclipse. An eclipse of the Moon happens when the Moon passes behind the Earth and into the Earth's shadow (**Figure 3.3**).

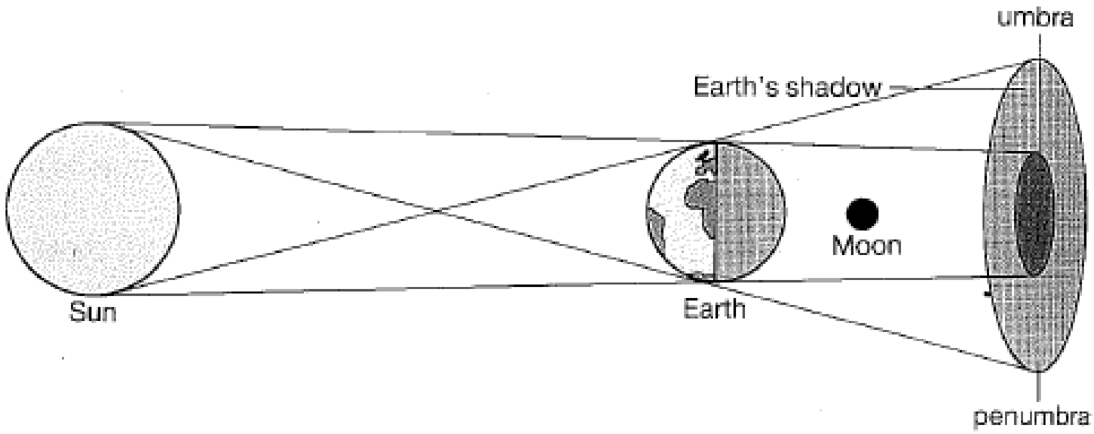


Figure 3.3 An eclipse of the Moon

3.3 The pinhole camera

	Practical 3.1

Make a simple pinhole camera out of a cardboard shoe box.

- Make a small hole in one end.
- Remove the other end of the box and put a piece of tissue paper in its place.
- Take the box outside and point it at some trees and you will see an image of them on the tissue paper.
- If you want to take a photograph of the trees, you must use a light-proof box. The photograph is made by allowing the light to fall on to a piece of photographic paper instead of the tissue paper (**Figure 3.4**).

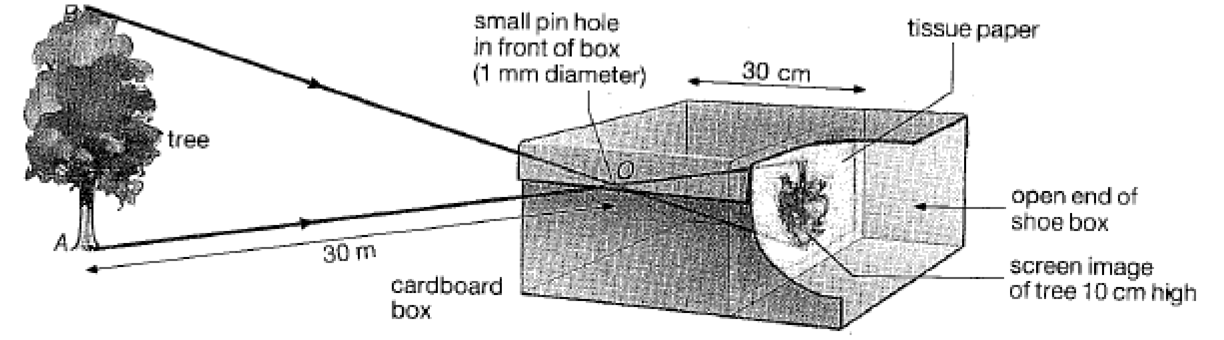


Figure 3.4 The principle of the pinhole camera

The light from the tree travels through the pinhole in a straight line. This causes the image to be upside down. Provided the hole is small the image of the tree will be sharply defined. If the hole is too big the tree will look blurred.

The size of the image lets you work out the height of the tree, which is 30 m from the pinhole.

Safety Warning!
Never look at the Sun through a magnifying glass, binoculars or telescope. You could damage your eyes badly, or even cause blindness.

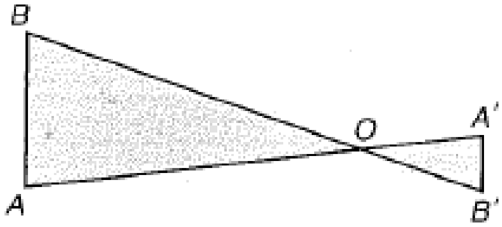


Figure 3.5

In **Figure 3.5** triangles ABO and A' B 'O are similar

So $\frac{AB}{AO} = \frac{A'B'}{A'O}$

$$AB = \frac{A'B'}{A'O} \times AO$$
$$= \frac{10\ cm}{30\ cm} \times 30\ m$$
$$= 10\ m$$

3.4 Reflection of light

You may use a mirror every day for various reason. Mirrors work because they reflect light. In **Figure 3.6** you can see an arrangement for investigating how light is reflected from a mirror.

A ray box is used to produce a thin beam of light. Inside the ray box is a light bulb; light is allowed to escape from the box through a thin slit.

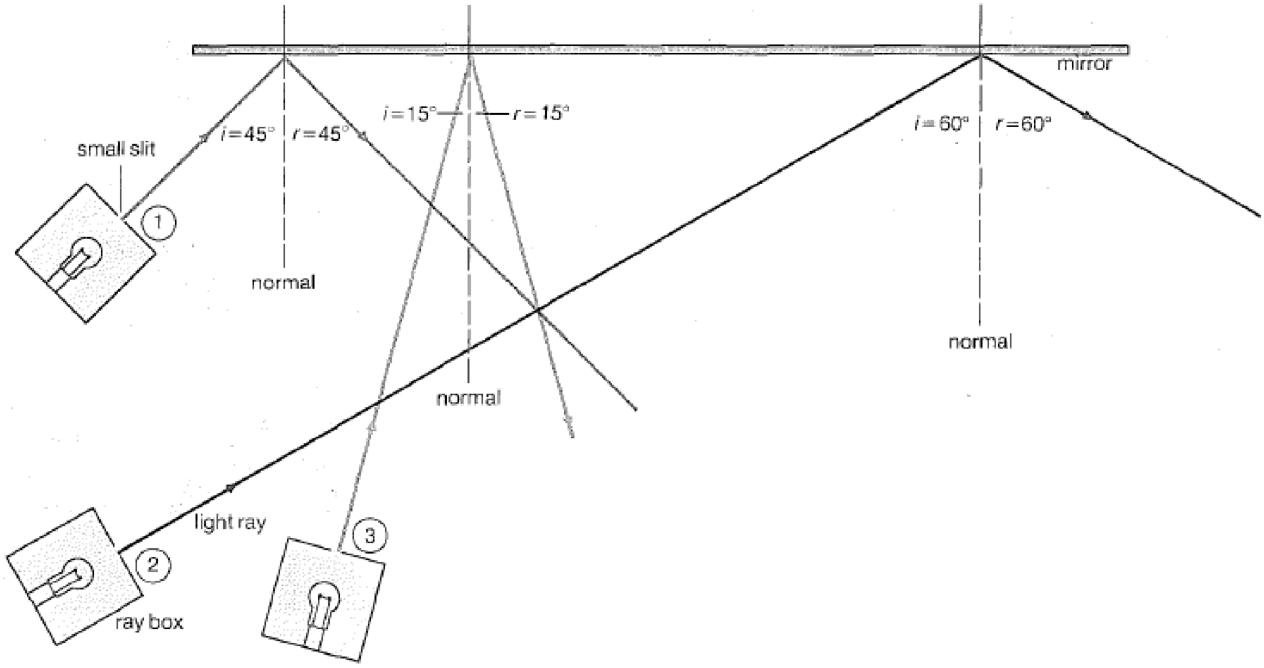


Figure 3.6 Reflection of light rays from a mirror

Before the light ray strikes the mirror it is called the incident ray. The angle of incidence, i, is defined as the angle between the incident ray and the normal.

The normal is a line that passes at right angles through the mirror surface. After the ray has been reflected it is called the reflected ray.

	Definition: Angle of reflection The angle between the normal and the ray that has been reflected is called the angle of reflection, r.

There are two important points about reflection of light rays that can be summarised as follows:

- The angle of incidence always equals the angle of reflection; i = r.
- The incident ray, the reflected ray and the normal always lie in the same plane.

All surfaces can reflect light. Shiny smooth surfaces produce clear images. **Figure 3.7** shows that light is reflected in all directions from a rough surface so that there is no clear image.

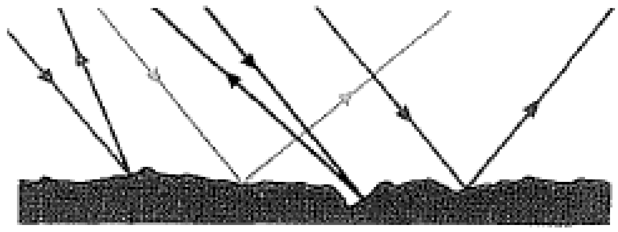


Figure 3.7 Light is reflected from a rough surface in all directions

3.4.1 An image in a plane mirror

We can use the rules about reflection to find the image of an object in a plane (flat) mirror. In **Figure 3.8** the object is a letter L. Rays from the L travel in straight lines to the mirror where they are reflected (i = r).

When the rays enter your eye they appear to have come from behind the mirror. This sort of image is called a virtual image. Your brain thinks that there is an image behind the mirror, but the L is not really there.

You cannot put a virtual image onto a screen. An image that can be put onto a screen (like the one in a pinhole camera) is called a real image.

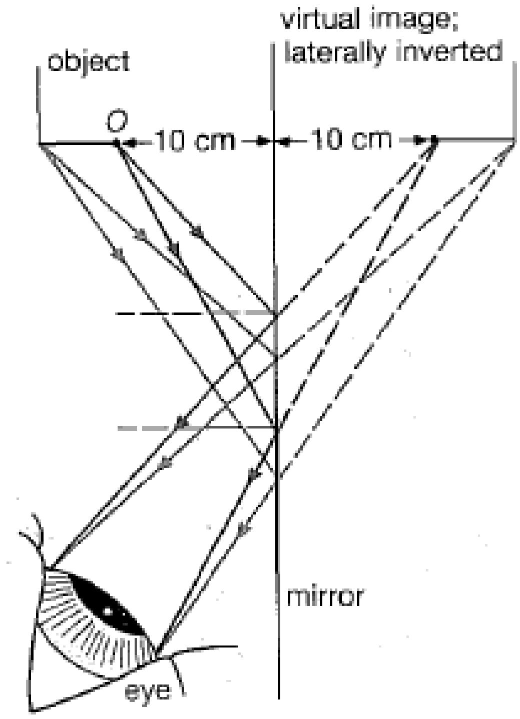


Figure 3.8 Seeing an image in a mirror

You can also see that the image appears to be the same distance behind the mirror as the object is in front of it. The image also appears to be back-to-front.

You will have seen this effect when you look into a mirror. When you lift your right hand, your image lifts its left hand. The image is said to be laterally inverted.

Note:
An image in a plane mirror is virtual, laterally inverted and the same size as the object.

Figure 3.9 shows how it is possible to produce the illusion of an apparition in a play.

The technique is known as 'Pepper's Ghost'. A large sheet of glass is placed diagonally across the stage. The audience can see a wall through the glass on the darkened stage.

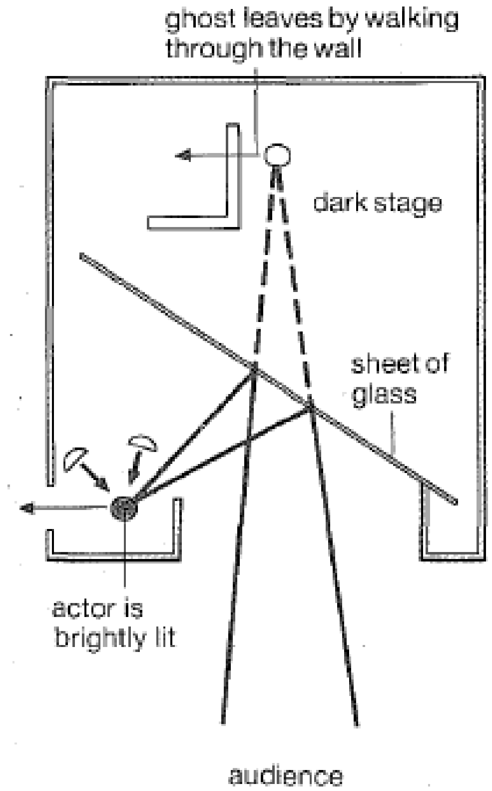


Figure 3.9 Pepper's Ghost

An actor is hidden from the audience in the wings. He is brightly illuminated so that his image is reflected by the glass for the audience to see.

When the actor walks off the stage, his image (the ghost) appears to leave by walking through the wall.

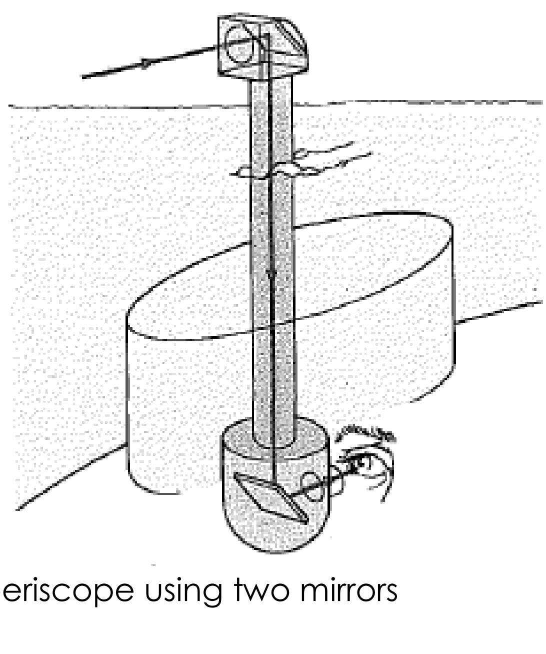


Figure 3.10 A simple periscope using two mirrors

3.5 Refraction of light

When a light ray travels from air into a clear material such as glass or water, you can see the ray change direction. This is called refraction**.** Refraction happens because light travels faster in air than in other substances (**Figure 3.11**).

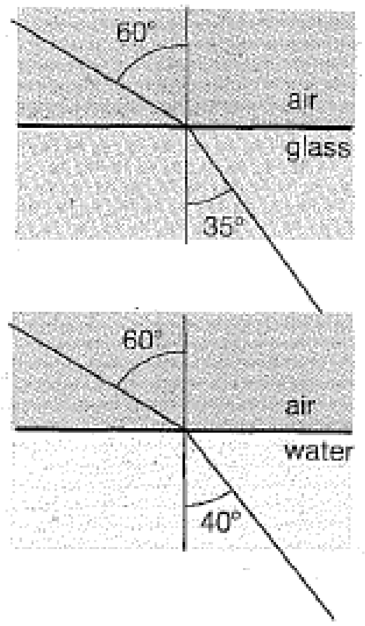


Figure 3.11 Light travels more slowly in glass than it does in water. So a light ray bends more when it goes into glass

The amount by which a light ray bends when it goes from air into another material depends on two things:

- What the material is.
- The angle of incidence

Figure 3.12 shows you how light rays bend when they go into a block of glass. The angle *i* between the normal and the incident ray, *AB,* is the angle of incidence.

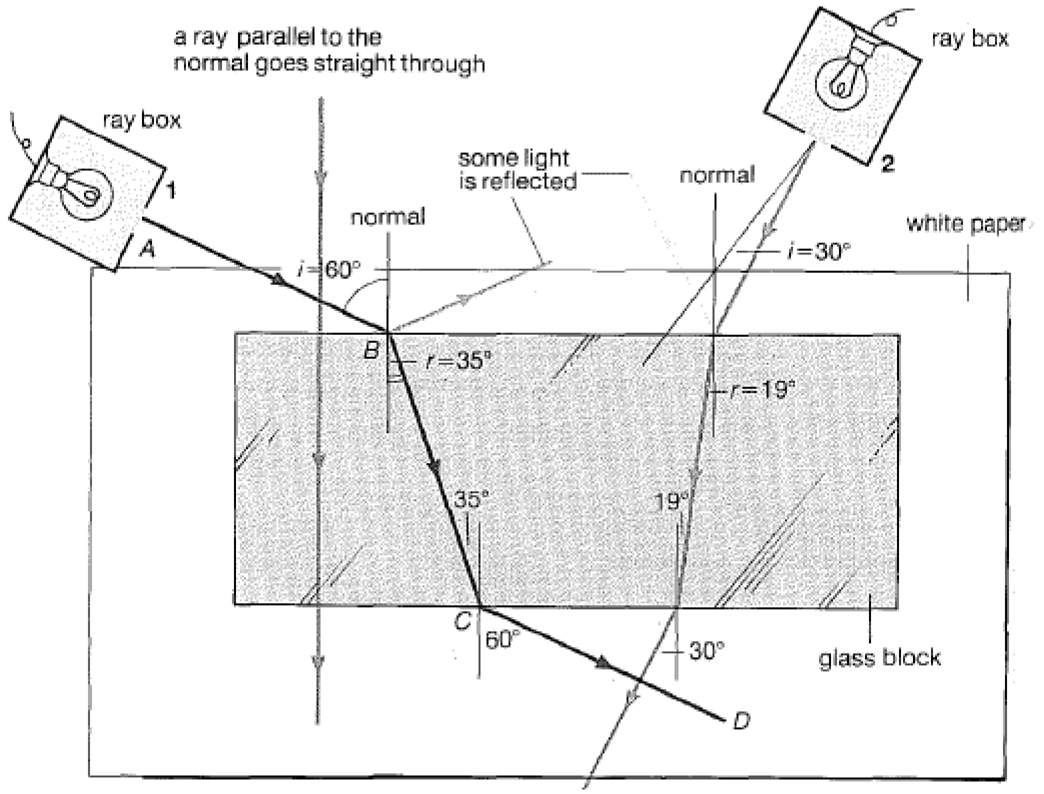


Figure 3.12 Refraction of light rays by a glass prism

The angle between the normal and refracted ray, *BC,* is the angle of refraction.

Figure 3.12 shows these points:

- The light ray is bent towards the normal when it goes into the glass. The angle of incidence is greater than the angle of refraction.
- When the light ray leaves the block of glass it is bent away from the normal.
- If the block has parallel sides, light comes out at the same angle as it goes in.

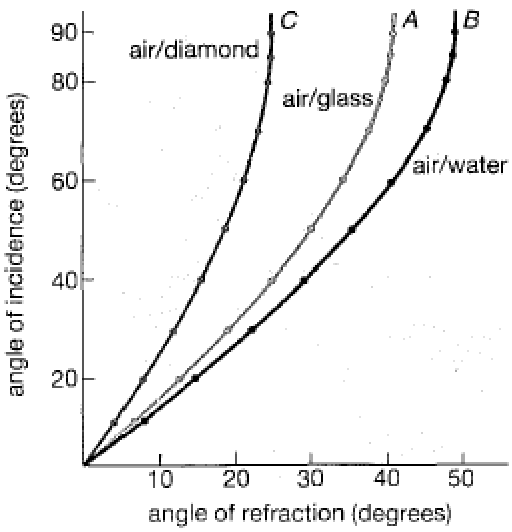


Figure 3.13 These graphs show how r depends on *I* when light travels from air into (a) glass (b) water and (c) diamond

3.5.1 Real and apparent depth

When a light ray leaves water and goes out into air it is refracted. This effect makes a pond look more shallow than it really is.

In **Figure 3.14** Susan is leaning over a pond to look at a fish. Light rays from the fish travel up to the surface water. At the water surface these rays are bent away from the normal.

When rays enter the eye, Susan imagines that these rays come from *I* not 0. What Susan sees is a *virtual image* of the fish. This image is closer to the surface the fish itself.

	Definition: Virtual image An optical image formed from the *apparent* divergence of light rays from a point, as opposed to an image formed from their *actual* divergence.

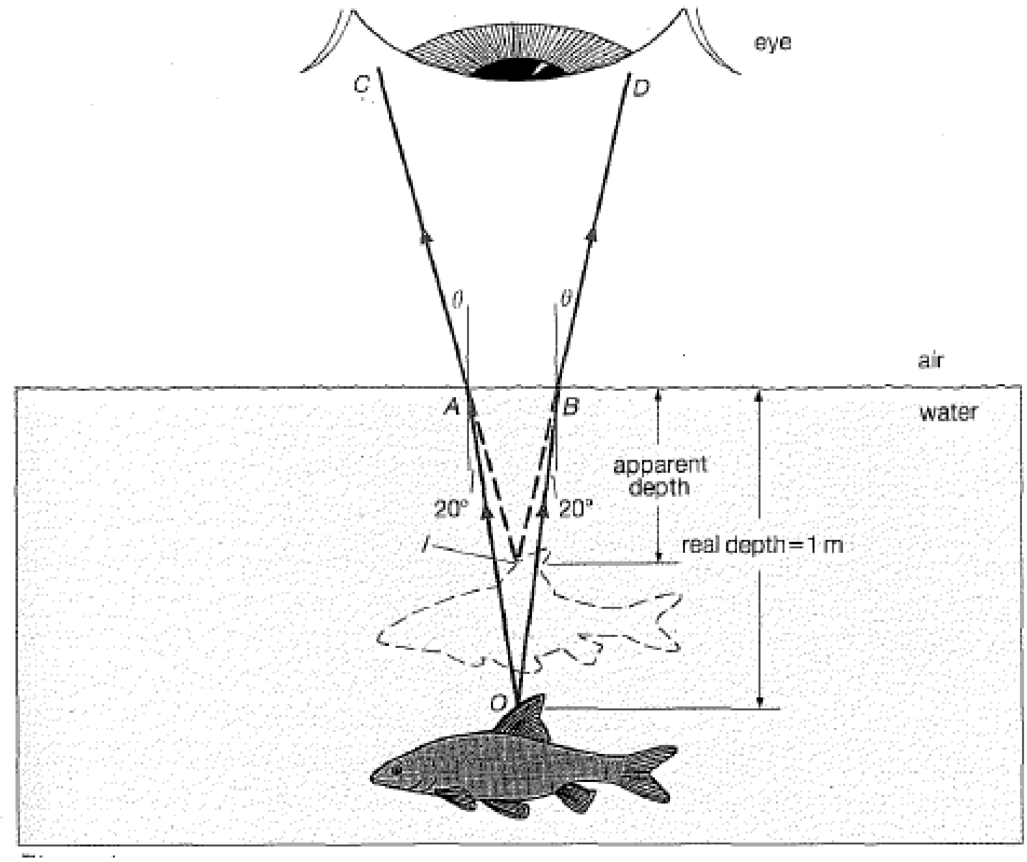


Figure 3.14 Real and apparent depth

3.5.2 Refraction by prisms

Some simple rules about refraction can be learned from **Figure 3.12**. You can apply these rules to predict what will happen to light rays going into any shape of block.

In **Figure 3.15** you can see a light ray passing through a triangular glass prism. Notice that as the ray goes into the prism it is bent towards the normal; as it leaves the prism it is bent away from the normal.

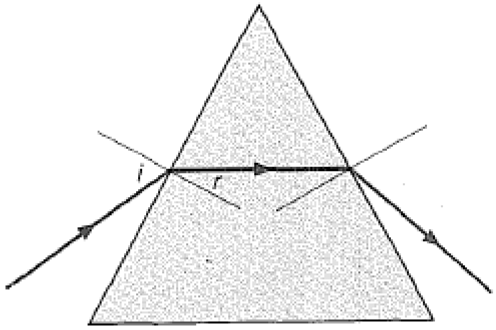


Figure 3.15 Light is refracted by a triangular prism

3.6 Total internal reflection

When a light ray crosses from glass into air, it bends away from the normal. However, this only happens if the angle of incidence is small. If the angle of incidence is too large all of the light is reflected back into the glass. This is called *total internal reflection*.

Figure 3.16 shows how you can see this effect for yourself in the lab. Three rays of light are directed towards the centre of a semicircular glass block.

Each ray crosses the circular part of the block along the normal, so it does not change direction.

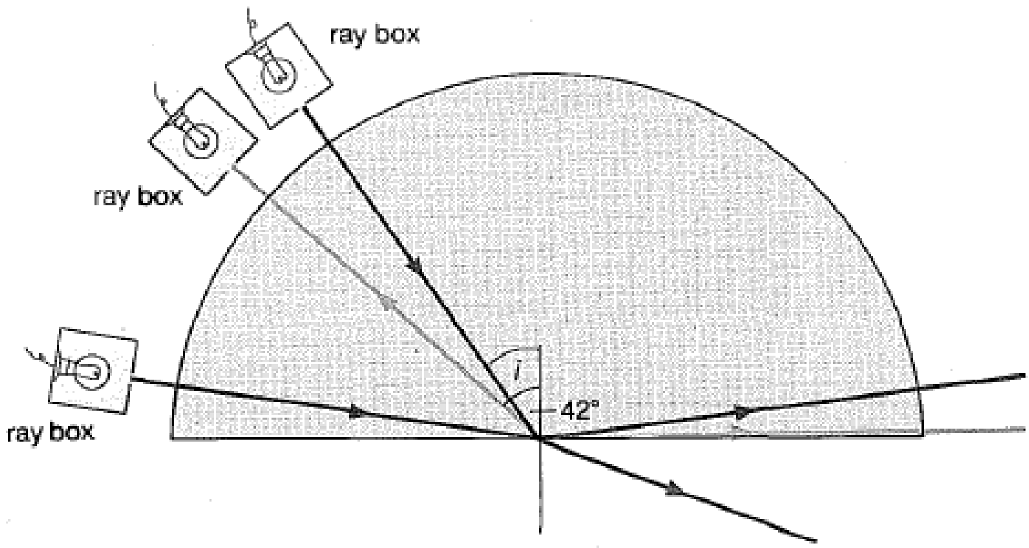


Figure 3.16 Refraction and reflection in a glass block

However, when a ray meets the plane surface there is a direction change. For small angles of incidence, the ray is refracted. Some light is also reflected back into the block.

At an angle of 42° the ray is refracted along the surface of the block. This is called the *critical angle*.

If the angle of incidence is greater than this critical angle then all of the light is reflected back into the glass.

Think about it!
The critical angle varies from material to material. While it is 42° for glass, for water it is about 49°.

3.6.1 Total internal reflection in prisms

An ordinary mirror has one main disadvantage: the silver reflecting surface is at the back of the mirror. So light has to pass through glass before it is reflected by the mirror surface.

This can cause several weaker reflections to be seen in the mirror, because some light is reflected back off from the glass/ air surface (**Figure 3.17**).

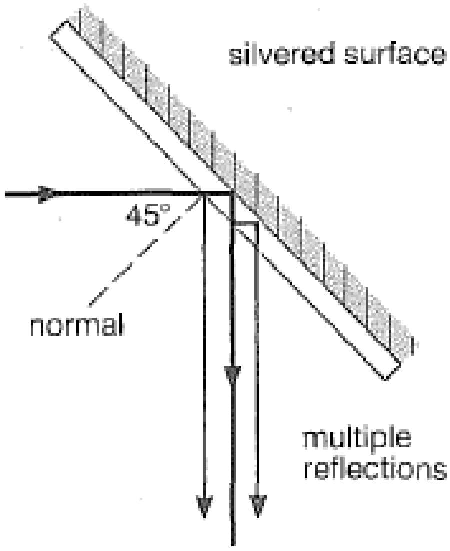


Figure 3.17 Reflection from a mirror

These multiple reflections can be a nuisance, for example in a periscope. We can avoid the extra reflections by using prisms. In **Figure 3.18** the light ray AB meets the back of the glass prism at an angle of incidence of 45°.

This angle is greater than the critical angle for glass, so the light is totally reflected. There is only one reflection because there is one surface. Total internal reflection by prisms is also put to use inside binoculars and cameras.

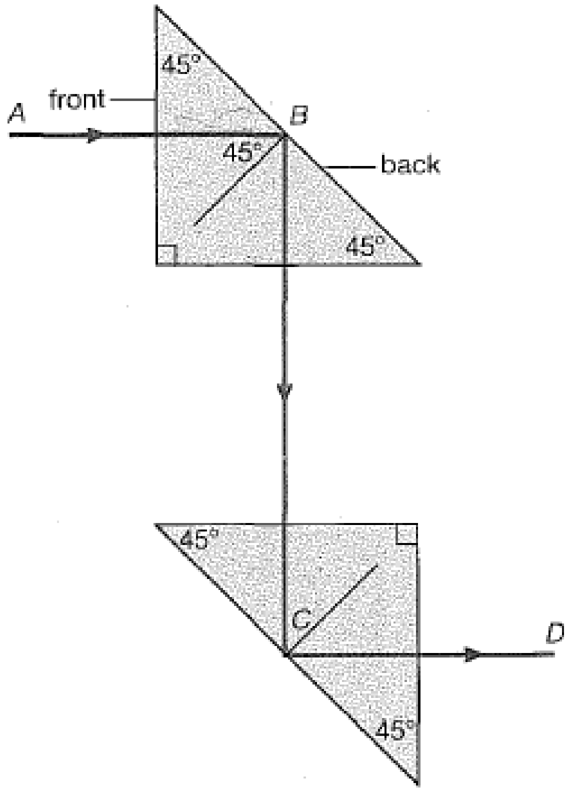


Figure 3.18 Reflection from two prisms to make a periscope

3.6.2 Refraction and cars

Refraction and reflection are put to use in your car. It is important that your rear lights are clearly visible to the car behind you. At the same time they must not dazzle the driver of a following car. **Figure 3.19** shows how this is achieved.

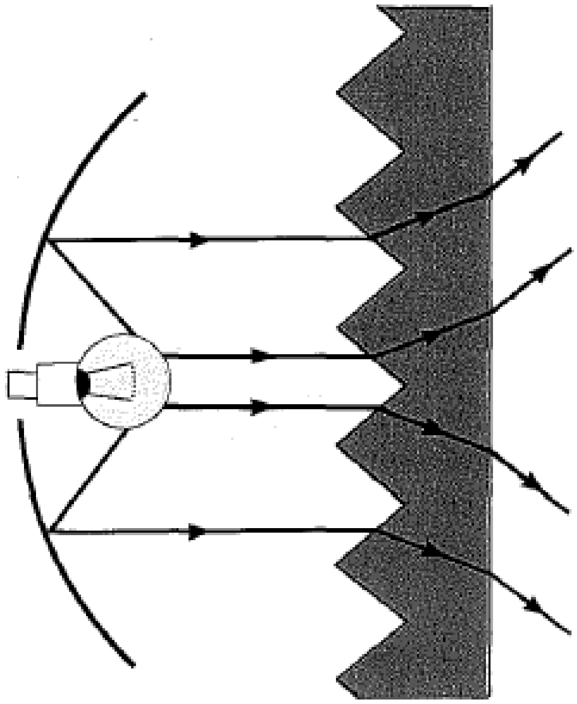


Figure 3.19 A car rear-light cover

The cover of the rear light is made with a series of points. Any light that is travelling directly backwards is refracted to the side. A similar shape of plastic is used in reflectors on the back of the cars and bicycles. This time the light from the headlights of a car passes straight through a plane plastic surface (**Figure 3.20**).

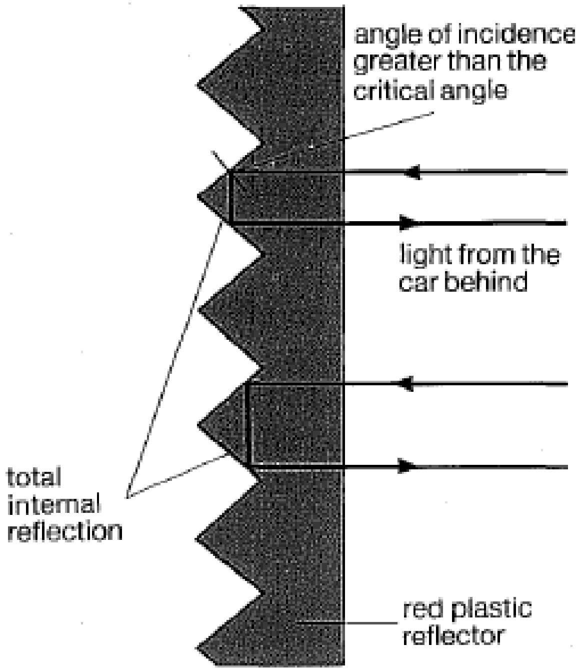


Figure 3.20 A reflector for a car or a bicycle

Then total internal reflection occurs at the inside surfaces of the pointed plastic.

3.6.3 Optical fibres

Glass fibres are used for carrying beams of light (**Figure 3.21**). The fibres usually consist of two parts. The inner part (core) carries the light beam. The outer part provides protection for the inner fibre. It is important that light travels more slowly in the outer part. Then the light inside the core is trapped due to total internal reflection.

Did you know?
Surgeons use a device called an endoscope to examine the inside of patients' bodies. This is made of two hollow light tubes. One carries light down inside the patient, and the other tube allows the surgeon to see what is there.

Optical fibres are also in use Telecommunications companies. A small glass fibre, only about 0,01 mm in diameter, is capable of carrying hundreds of telephone calls at the same time.

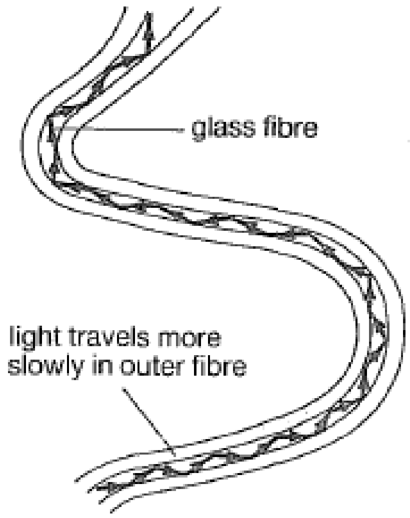


Figure 3.21 Internal reflection traps light inside the glass fibres of an endoscope

3.7 Converging lenses

There are also converging lenses in many optical instruments such as telescopes, cameras and slide projectors.

Did you know?
Every day of your life you use a converging lens; there is one in each of your eyes.

Converging lenses are usually made out of glass and they have two nearly spherical surfaces. When a light ray enters the glass it is refracted towards the normal, and then away from the normal when it leaves (**Figure 3.22**).

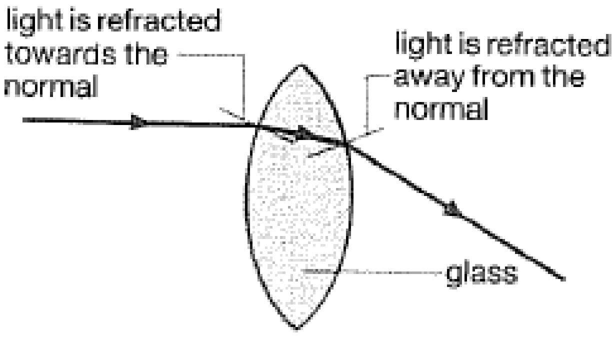
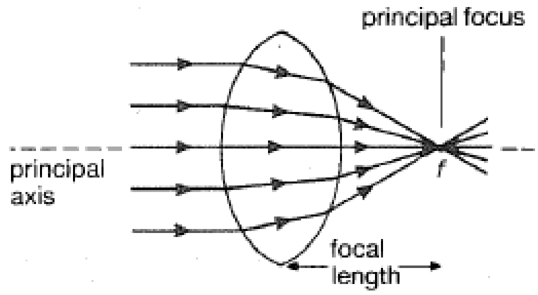


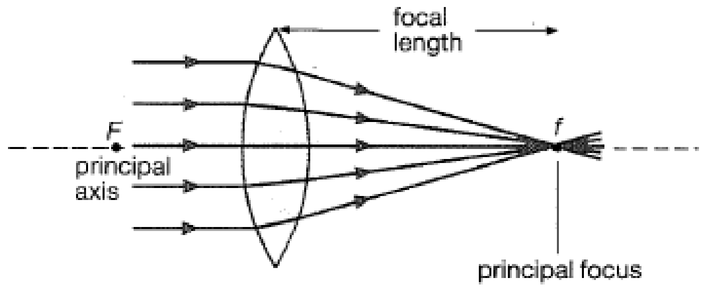
Figure 3.22 Refraction by curved lens surfaces

In **Figure 3.23** you can see what happens to a lot of rays which are parallel to the principal axis. Each ray is refracted by a different amount, depending on where it meets the lens.

After these rays have passed through the lens they converge and meet at a point. This point is called the principal focus of the lens. The focal length, J, of the lens is the distance between the lens and the principal focus.



(a) A fat lens is a strong lens; it has a short focal length. Its curved surface refracts the light through a large angle



(b) A thin lens is a weak lens; it has a longer focal length than the strong lens

Figure 3.23

Each lens has two principal focuses. If the rays were to come from the right in **Figure 3.23a**, they would come to a focus on the left of the lens.

Figure 3.24 shows how a lens can focus rays that are not parallel.

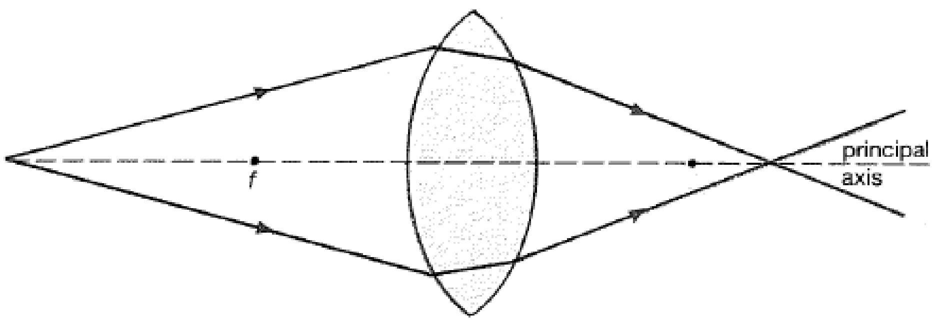


Figure 3.24 A lens can also focus rays that are not parallel; this time the rays meet behind the principal focus

3.7.1 Finding the image

If you know the focal length of a lens and the position of an object, you can work out where the lens will form an image of that object.

You can construct a scale drawing using any two of the three rays shown in **Figure 3.25a**.

- A ray parallel to the principal axis is refracted through the principal focus.
- A ray through the centre of the lens, C, does not change its direction.
- A ray through the principal focus on the first side of the lens is refracted parallel to the principal axis.

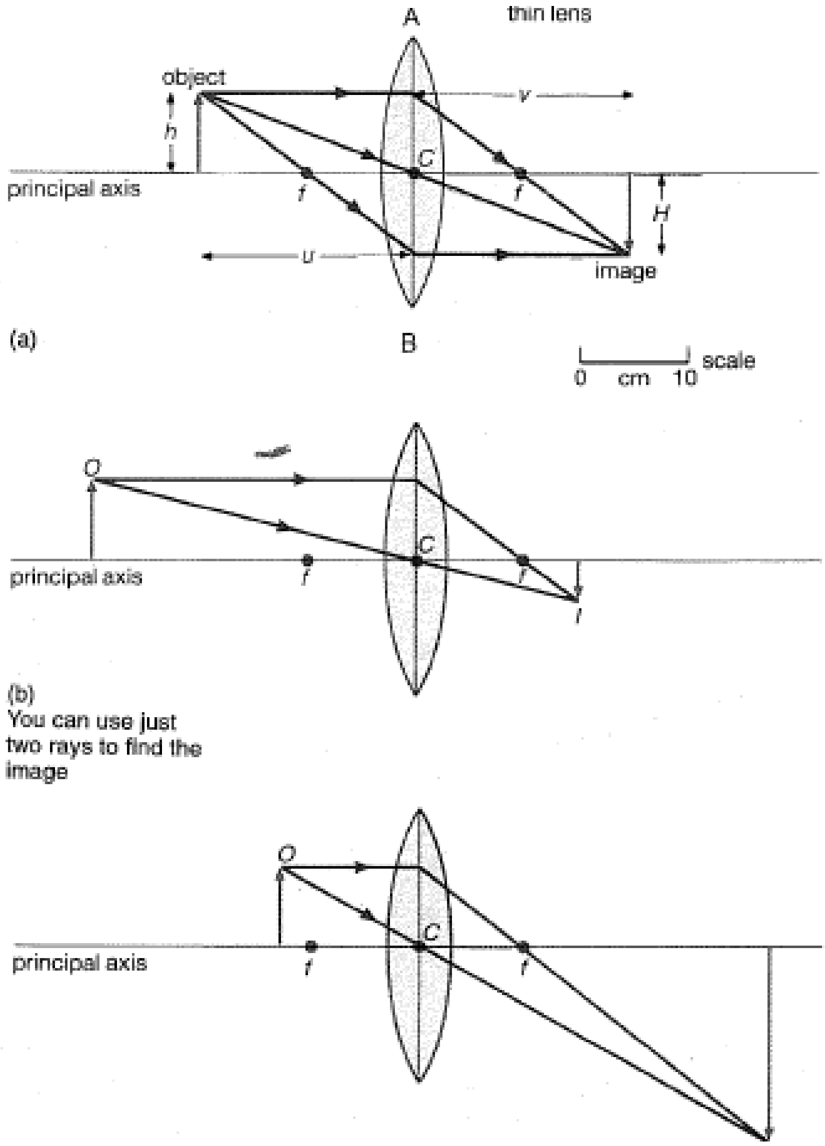


Figure 3.25 In drawing these scale diagrams we show all of the refraction occurring at the centre of the lens along line AB in (a)

3.8 Optical instruments

3.8.1 Camera

A diagram of a simple camera is shown in **Figure 3.26**. The purpose of the lens is to project an image of a distant object (a mountain, for example) on to a film.

When you want to take the photograph, pressing a button opens up the shutter to allow light to fall on to the film.

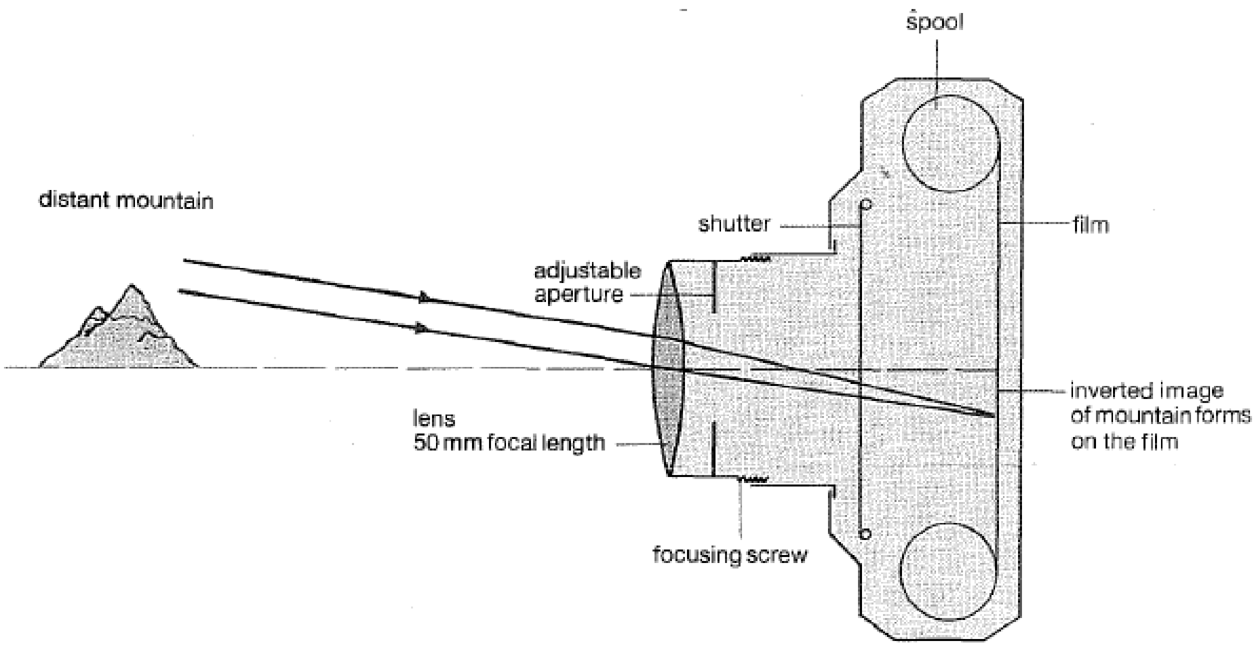


Figure 3.26 A typical camera

However, before you take a photograph you need to consider these points.

- *Choice of film*. A 'fast' film is more sensitive to light than a 'slow' film. The fast film needs less time to take a photograph than a slow film. The advantage of faster film is that you can take a photograph when the light is poor, or when something is moving quickly. The disadvantage of a fast film is that is produces poorer quality pictures than a slow film.
- *Focusing*. Your picture must be in focus. To focus, move the lens backwards and forwards with the focusing screw. For distant objects the lens is moved back towards the film. For closer objects you move the lens forwards.
- The *shutter speed* controls the amount of light coming into the camera. On a dark day you might choose a shutter speed of 1/30 s, while on a bright day you can use a faster speed of 1/60 s.
- *f-nurnber*. This refers to the diameter of the aperture. If you set your aperture at f/8, it means that its diameter is 1/8 of the focal length of the lens. The f-number, like the shutter speed, controls the amount of light coming into the camera. A wide gap allows more light in. The f-number also determines the depth of focus of your photograph (**Figure 3.27**). A small gap (a small f-number, such as f/22) will give a large depth of focus. This means that things both near and far to the camera will be in focus.

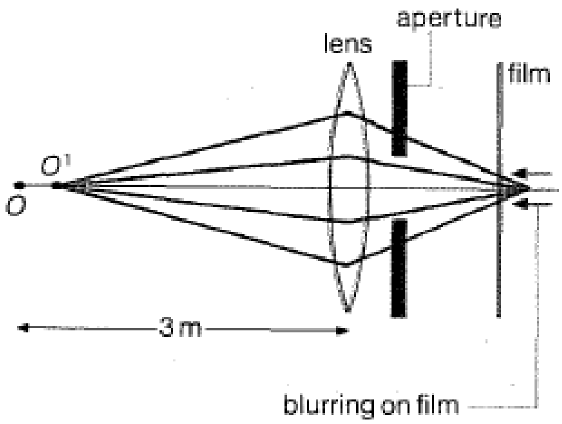


Figure 3.27 The depth of focus is larger if an aperture is used. In this diagram the camera is correctly focused on an object 3 m away. Rays from 0^1 will be more out-of-focus if they pass through all of the lens

3.8.2 The slide projector

Figure 3.28 shows how a slide projector works.

- A brightly illuminated slide (A) is used as an object for the projector lens (B).
- This lens projects an image of your slide on to a screen a few metres away.
- A 500 W light bulb (C) is used to make the slide bright.
- A concave mirror (D) behind the bulb reflects light forwards.

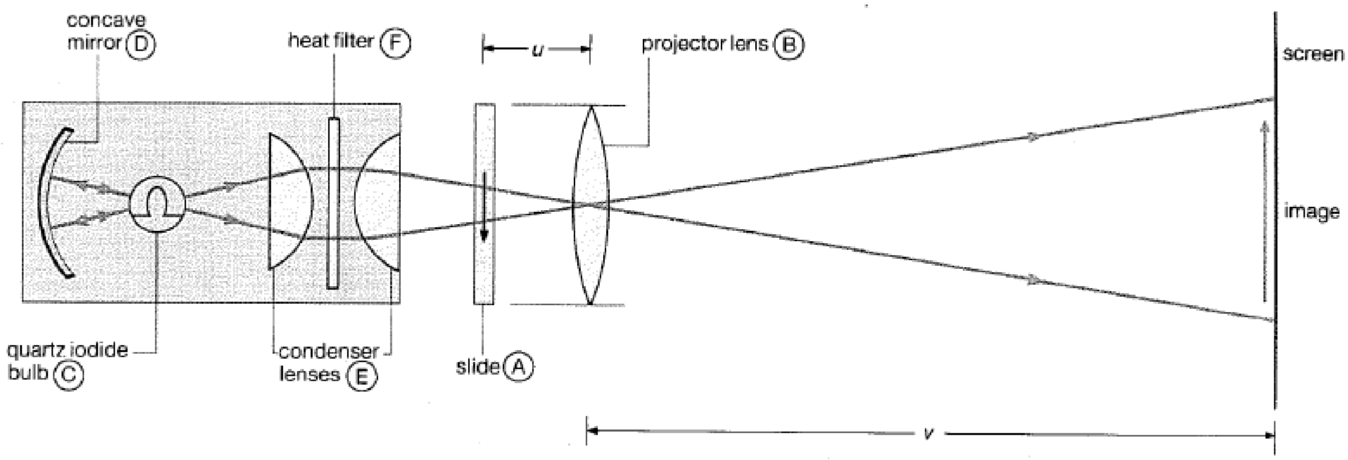


Figure 3.28 The principle of the slide projector

- The two condenser lenses (E) then converge the light towards the slide.
- A heat filter (F) is used to prevent the slide being damaged.
- Light bulbs produce infra-red waves as well as light.
- The heat filter absorbs the infra-red waves, which would heat up the slide. The filter does let light through.
- The slide projector is cooled by a fan which blows air through it.
- Vents on top of the projector allow the warm air to escape.

In this slide projector, the distance, *u*, between the lens and slide can be adjusted between 15 cm and 20 cm.

What lens should you choose for the projector?

	Think about it! It is important that the slide is just outside the focal length of the projector lens. This makes sure that you see a large image on the screen. So a lens with a focal length of about 15 cm will be the best.

Figure 3.29 gives a series of graphs for different lenses, to show how the distance, *u,* affects the distance between the image and lens, *v*.

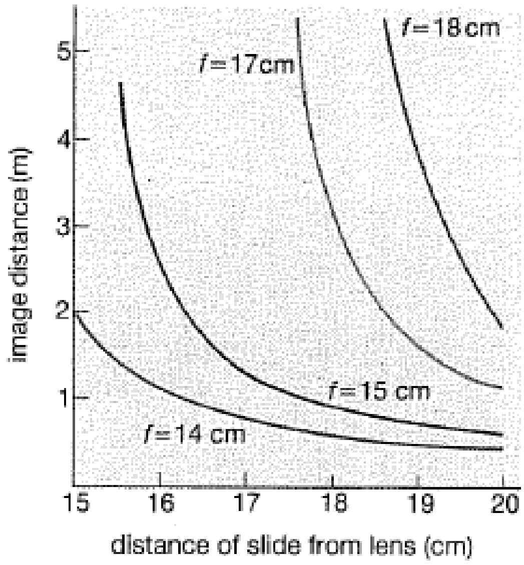


Figure 3.29 Graphs to show how the distance of the slide from the lens affects the image distance. Graphs for four different lenses are shown.

3.9 The human eye

Figure 3.30 shows you what an eyeball would look like if you could see it from the top.

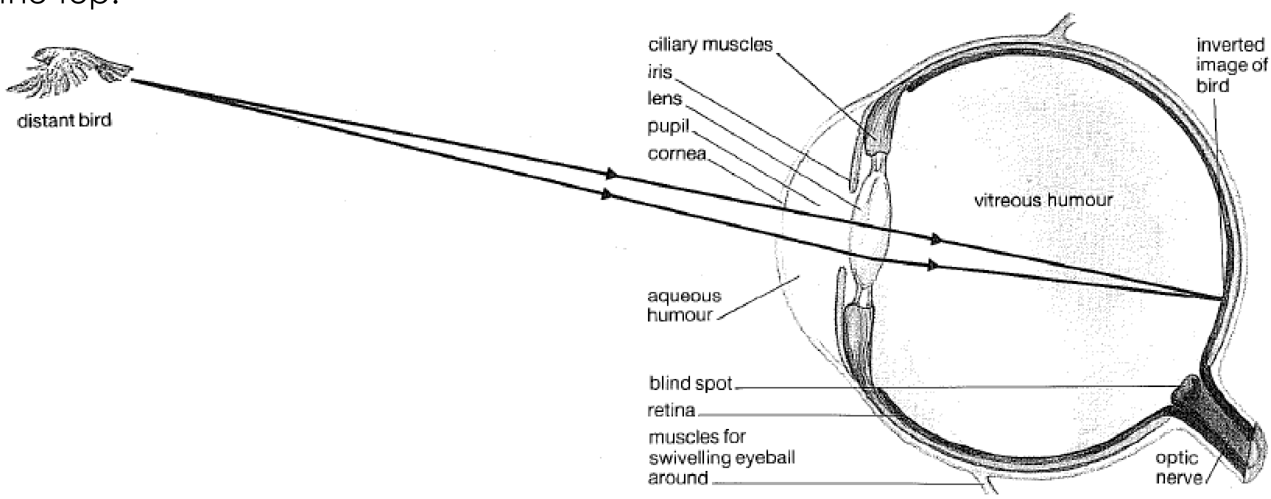


Figure 3.30 The plan view of a human eyeball

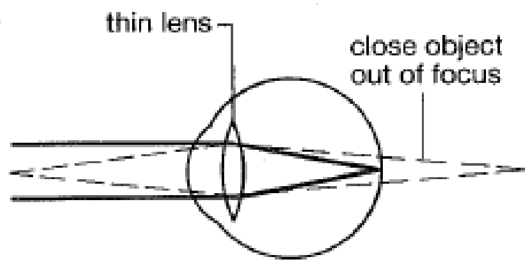
Below are listed the important points about the working of the eye:

- The eyeball is roughly spherical and keeps its shape due to the liquids inside it, the vitreous humour and the aqueous humour.
- The eye lens makes an image of a distant object on the retina.
- The retina contains cells which are sensitive to light. Some cells (cones) detect different colours, and other cells (rods) respond to the brightness of light.
- The optic nerve carries signals from the retina to the brain. Although the image on the retina is upside down, the brain sorts this out for us so we can see things the right way up.
- The amount of light that enters the eye is determined by the size of the pupil. The iris acts like the aperture of a camera. In bright light it closes down to protect the eye. In the dark the iris opens up to allow the eye to gather more light.

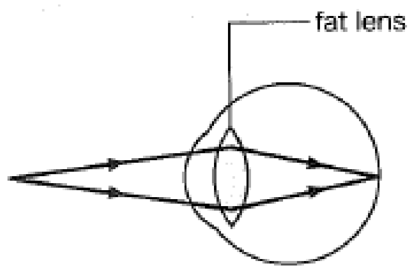
3.9.1 Focusing the eye

Your eye is most relaxed when you are looking at distant objects. The eye then focuses parallel rays onto the retina (**Figure 3.31a**).

> **Did you know?**
> When you are looking at distant objects, your eyes cannot focus on something that is close to you at the same time. The lens is not strong enough to converge rays coming from nearby on to the retina. To look at something close to you, the eye lens has to change shape.



(a) A thin lens focuses parallel rays onto the retina



(b) A fat lens is needed to look at objects close to the eye

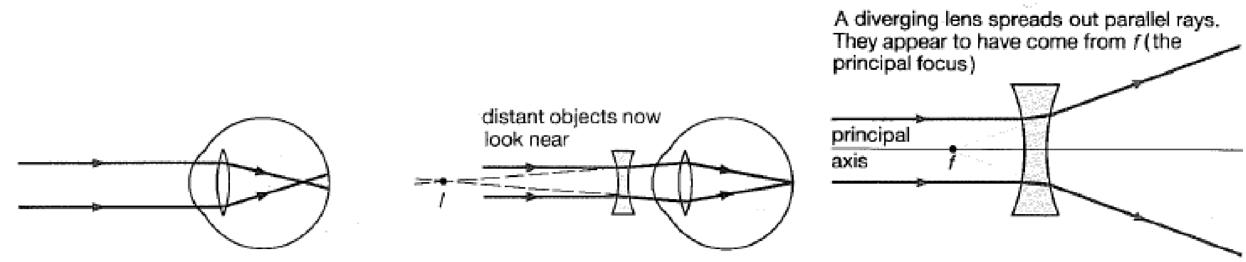
Figure 3.31

Definition: Accommodation
The ciliary muscles in the eye make the lens fatter (**Figure 3.31b**). The light is now bent more when it goes through the lens and can be focused on the retina. This focusing process is called accommodation.

3.9.2 Wearing spectacles

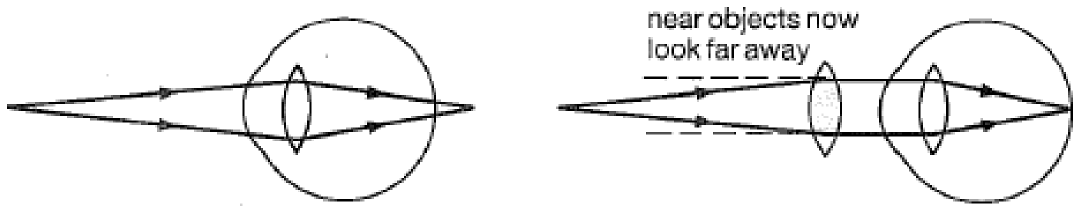
A normal eye is able to see both near and distant objects clearly. However, it is quite common for people to suffer from either short or long sight:

- Someone who is short-sighted can see things nearby, but cannot focus on distant objects. The problem is that the eye lens is too powerful. Parallel rays from distant objects are focused in front of the retina. This can be corrected by using a diverging lens. A diverging lens will spread the rays out, so the eye can now bring them to focus on the retina (**Figure 3.32**).
- People who are long-sighted cannot focus on objects that are close to the eye. However, they may be able to see clearly things far away. This time the problem is that the eye lens is too weak. So rays from objects close to converge at a point behind the retina. This sight defect can be corrected by using spectacles with converging lenses (**Figure 3.33**).



(a) A short-sighted eye cannot see distant objects *(b) A diverging lens corrects short sight* *(c) A diverging lens*

Figure 3.32



(a) A long-sighted eye cannot see objects close to *(b) A converging lens corrects long sight*

Figure 3.33

3.9.3 Binocular vision

With two eyes at the front of the head, the brain gets two slightly different views of everything. This is very helpful when it comes to judging distances.

Think about it!
An animal that has both eyes at the front of the head is usually a hunter. Those animals that have eyes at the side of the head make good meals for the hunters. Having eyes at the side of the head

	gives an animal a wide range of vision. That is important if the animal does not want to get eaten!

When hunting for food like a lioness, the hunter needs to know how far away it is.

Try putting a pencil in each hand and touching the points together; you will find it easy with both eyes open but difficult if you close one eye.

3.10 The spectrometer

The spectrometer is an optical instrument which is mainly used to study the light from different sources. It can be used to measure accurately the refractive index of glass in the form of a prism.

The instrument consists essentially of:

- a *collimator,* C
- a *telescope,* T, and
- a *table,* R, on which a prism B can be placed

The lenses in C, T are achromatic lenses. The collimator is fixed, but the table and the telescope can be rotated round a circular scale graduated in half-degrees (not shown) which has a common vertical axis with the table, **Figure 3.34**.

A vernier is also provided for this scale. The *source of light,* S, used in the experiment is placed in front of a narrow slit at one end of the collimator, so that the prism is illuminated by light from S.

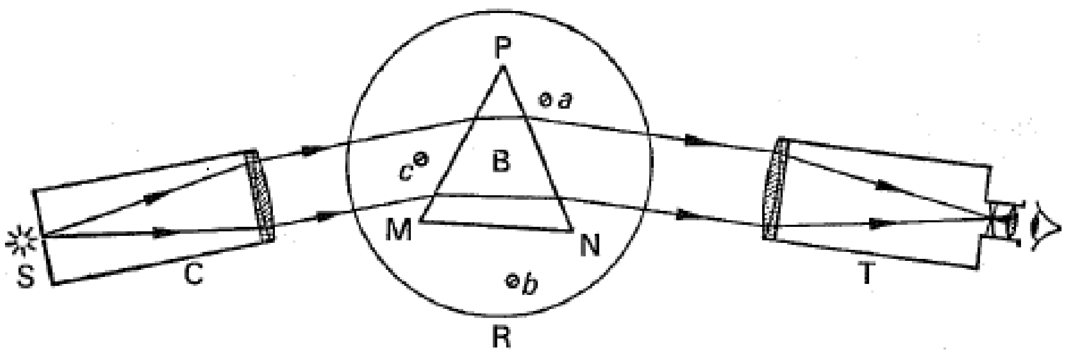


Figure 3.34 Spectrometer

Before the spectrometer can be used, however, three adjustments must be made:

- The collimator C must be adjusted so that parallel light emerges from it;
- the telescope T must be adjusted so that parallel rays entering it are brought to a focus at cross-wires near its eye-piece;
- the refracting edge of the prism must be parallel to the axis of rotation of the telescope, ie, the table must be "levelled".

3.10.1 Adjustments of spectrometer

The telescope adjustment is made by first moving its eye-piece until the cross-wires are distinctly seen, and then sighting the telescope on to a *distant* object through an open window.

The length of the telescope is now altered by a screw arrangement until the object is clearly seen at the same place as the cross-wires, so that parallel rays now entering the telescope are brought to a focus at the cross-wires.

3.10.1.1 The collimator adjustment

With the prism removed from the table, the telescope is now turned to face the collimator, C, and the slit in C is illuminated by a sodium flame which provides yellow light.

The edges of the slit are usually blurred, showing that the light emerging from the lens of C is not a parallel beam.

The position of the slit is now adjusted by moving the tube in C, to which the slit is attached, until the edges of the latter are sharp.

3.10.1.2 "Levelling" the table.

If the rectangular slit is not in the centre of the field of view when the prism is placed on the table, the refracting edge of the prism is not parallel to the axis of rotation of the telescope.

The table must then be adjusted, or "levelled", by means of the screws *a, b, c* beneath it.

One method of procedure consists of:

- placing the prism on the table with one face MN approximately perpendicular to the line joining two screws *a, b,* as shown in **Figure 3.34**.
- The table is turned until MN is illuminated by the light from C, and the telescope T is then moved to receive the light reflected from MN.
- The screw *b* is then adjusted until the slit appears in the centre of the field of view.
- With C and T fixed, the table is now rotated until the slit is seen by reflection at the face NP of the prism, and the screw *c* is then adjusted until the slit is again in the middle of the field of view.
- The screw *c* moves MN in its own plane, and hence the movement of *c* will not upset the adjustment of MN in the perpendicular plane.

3.11 Photometry

3.11.1 Standard candle: the candela

Think about it!
Light is a form of energy which stimulates the sensation of vision.

The sun emits a continuous stream of energy, consisting of ultra-violet, visible, and infra-red radiations, all of which enter the eye; but only the energy in the visible radiations, which is called luminous energy, stimulates the sensation of vision.

Note:
In photometry we are concerned only with the luminous energy emitted by a source of light.

Years ago the luminous energy per second from a candle of specified wax material and wick was used as a standard of luminous energy. This was called the *British Standard Candle*.

The luminous energy per second from any other source of light was reckoned in terms of the standard candle, and its value was given at 10 candle-power (10 cp) for example.

As the standard candle was difficult to reproduce exactly, the standard was altered. It was defined as one-tenth of the intensity of the flame of the *Vernon Harcourt pentane lamp,* which burns a mixture of air and pentane vapour under specified conditions.

Later it was agreed to use as a standard the *international standard candle,* which is defined in terms of the luminous energy per second from a particular electric lamp filament maintained under specified conditions, but the precision of this standard was found to be unsatisfactory.

In 1948, a unit known as the *candela,* symbol "cd", was adopted.

Definition: Candela
The luminous intensity of 1/600 000 metre^2 (1/60 cm^2) of the surface of a black body at the temperature of freezing platinum under 101 325 newtons per metre^2 pressure.

3.11.2 Illumination and its units

If a lamp S of 1 candela is placed 1 metre away from a small area A and directly in front of it, the *illumination* of the surface of A is said to be I *metre-candle* or *lux,* **Figure 3.35**.

If the same lamp is placed 1 centimetre away from A, instead of 1 m, the illumination of the surface is said to be 1 *cm-candle* (or 1 *phot)*.

The SI unit of illumination is the lux.

Figure 3.35 Metre-candle (lux)

	Note: It is recommended that offices should have an intensity of illumination of about 90 lux, and that the intensity of illumination for sewing dark materials in workrooms should be about 200 lux.

3.11.3 Luminous Flux, *F*

In practice a source of light emits a continuous stream of energy, and the name *luminous* flux has been given to the *luminous energy emitted per second.* The unit of luminous flux is the lumen, lm.

Since a lumen is a certain amount of "energy per second", or "power", there must be a relation between the lumen and the watt, the mechanical unit of power; and experiment shows that 621 lumens of a green light of wavelength 5,540, x 10^{-10} m is equivalent to 1 watt.

3.11.4 Solid Angle

A lamp radiates luminous flux in all directions .round it. If we think of a particular small lamp and a certain direction from it, for example that of the corner of a table, we can see that the flux is radiated towards the corner in a cone whose apex is the lamp.

	Note: A thorough study of photometry must include a discussion of the measurement of an angle in three dimensions, such as that of a cone, which is known as a *solid angle*.

An angle in two dimensions, ie, in a plane, is given in radians by the ratio *s*/*r,* where *s* is the length of the arc cut off by the bounding lines of the angle on a circle of radius *r.*

In an analogous manner, the solid angle, *w,* of a cone is defined by the relation

$$\omega = \frac{S}{r^2} \text{...} \quad (1)$$

where S is the area of the surface of a sphere of radius *r* cut off by the bounding (generating) lines of the cone, **Figure 3.36i**.

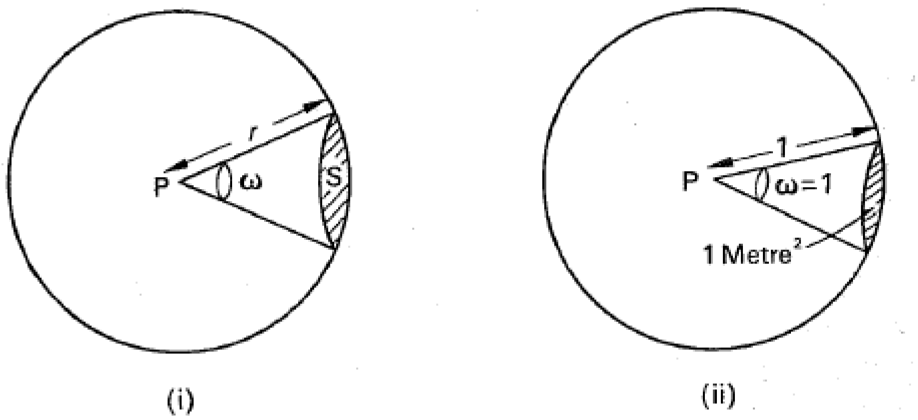


Figure 3.36 (i) Solid angle at P. ii) Unit solid angle at P

Since S and r^2 both have the dimensions of (length)², the solid angle ω is a ratio.

When S = l m², and *r* = 1 m, then ω = 1 from equation (1).

Thus *unit solid angle* is subtended at the centre of a sphere of radius 1 m by a cap of surface area 1 m², **Figure 3.36ii**. It is called" 1 steradian", sr. The solid angle all round a point is given from (1) by

$$\frac{total\ surface\ area\ of\ sphere}{r^2}$$

ie, by $\frac{4\pi r^2}{r^2}$, or 4π

> **Note:**
> Thus the solid angle all round a point is 4π sr. The solid angle all round a point on one side of a plane is thus 2π sr.

3.11.5 Luminous Intensity of Source, I

Experiments show that the luminous flux from a source of light varies in different directions; to be accurate, we must therefore consider the luminous flux emitted in a particular direction.

Suppose that we consider a small lamp P, and describe a cone PCB of small solid angle ω about a particular direction PD as axis. The *luminous intensity, I, of the source in this direction* is then defined by the relation:

$$I = \frac{F}{\omega} \quad \text{...} \quad (2)$$

where F is the luminous flux contained in the small cone. Thus the luminous intensity of the source is the *luminous flux per unit solid angle* in the particular direction.

Note:
It can now be seen that "luminous intensity" is a measure of the "luminous flux density" in the direction concerned.

The unit of luminous intensity of a source is the *candela,* defined on and the luminous intensity was formerly known as the *candlepower* of the source.

When the luminous flux, F, in the cone in **Figure 3.37** is 1 lumen (the unit of luminous flux), and the solid angle, ω, of the cone is 1 unit, it follows from equation (2) that I = 1 candela.

Thus *the lumen can be defined as the luminous flux radiated within-unit solid angle by a uniform source of one candela.*

A small source of I candela radiates $4\pi I$ lumens all round it.

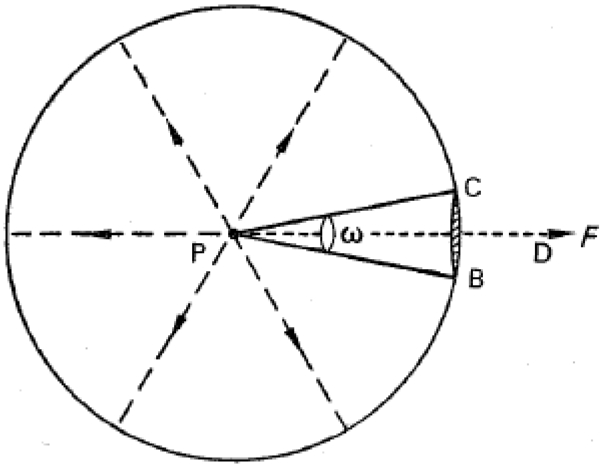


Figure 3.37 Luminous intensity of source

Activity 3.1

1. Work out the area of the shadow in **Figure 3.1**.
2. **Figure 3.38** shows how an annular eclipse of the Sun can happen. During an annular eclipse the Moon is further away from the Earth than in a total eclipse. Sketch how the Sun would appear when viewed from: (i) X and, (ii) Y.

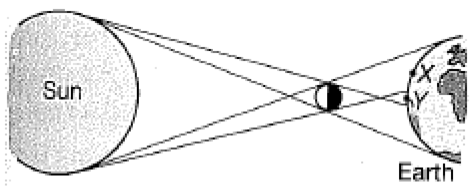


Figure 3.38

3. Venus moves in an orbit closer to the Sun than the Earth's orbit. In the diagram you can see Venus in three positions marked V_1, V_2, V_3. On the right, X, Y and Z show how Venus looked when seen on three occasions through a telescope. Match X, Y and Z to the positions of Venus.

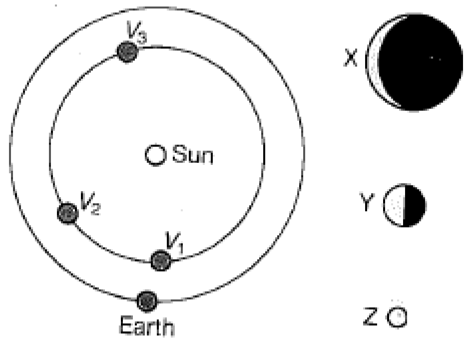


Figure 3.39

4.
   (a) Explain why making the hole larger in a pinhole camera makes the image more blurred. Illustrate your answer with a diagram.
   Sylvie used a pinhole camera to form an image of the Sun. She investigated how the size of the Sun's image depended on the size of the pinhole. **Table 3.1** shows her results.

Diameter of Sun's image (mm)	6,5	8,0	9,5	11,0	12,5
Diameter of hole (mm)	2,0	3,5	4,0	6,5	8,0

Table 3.1

   (b) Plot a graph of image size (y-axis) against hole diameter (x-axis).
   (c) The student has made an incorrect measurement of the diameter of the hole. Which measurement is wrong and what should it have been?
   (d) Use the graph to predict what the diameter of the Sun's image would be for a very small hole.
   (e) Use your answer to part (d) and the extra data provided to calculate the Sun's diameter.
   Distance of Earth to Sun: 150 million km
   Length of pinhole camera: 500 mm

5.
   (a) Describe the image that you will see when you look through the periscope as shown in **Figure 3.10**.
   (b) At what angle must the mirrors be fitted into the periscope?

6. John runs towards a mirror at 5 m/s. At what speed does his image approach him?

7.
   (a) How many 50c coins will the eye see reflected in these mirrors?
   (b) Draw diagrams to show how each of the images are formed.

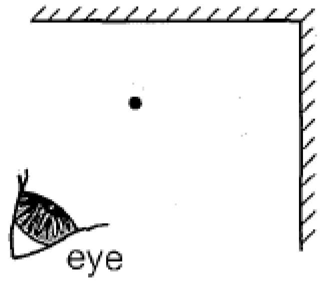


Figure 3.40

8. Show how the word CALCULATOR would look when reflected in a mirror.
9. The diagram on the right shows a split image range finder that fits into a camera.
   (a) Explain why you see two images.
   (b) How do you adjust the range finder to focus the camera?

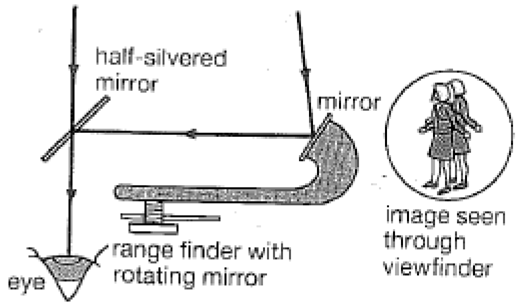


Figure 3.41

10. When a light ray goes into glass it bends towards the normal; when it comes out it bends away from the normal. Use this rule to sketch the path of the rays through the blocks in these cases.

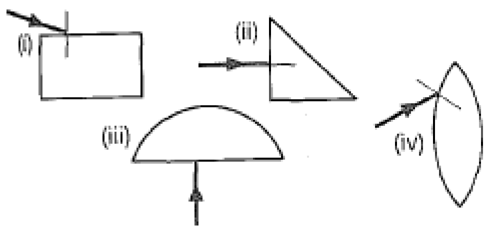


Figure 3.42

11.
   (a) Make a copy of **Figure 3.14**. Mark in only the rays OB and OA. Use a protractor to measure the angle zoo as shown.
   (b) Use the information in **Figure 3.13** to work out what the angle e should be.
   (c) Now draw in the rays BD and AC.
   (d) Use your scale diagram to calculate the apparent depth of the fish.
12. Draw diagrams to explain why a swimming pool of a constant depth looks shallower at the far end.
13. When a light ray goes from air into a clear material you see the ray bend. How much the ray bends is determined by the refractive index of the material.

(a) Look at the date in **Table 3.2**. How is the refractive index of a material related to the speed of light in it?
(b) A light ray strikes three materials with angle of incidence of 60°. These materials are: (i) glass, (ii) water, (iii) diamond. Use **Figure 3.13** to calculate the angle of refraction in each case.
(c) Which bends light more, glass or perspex? Perspex refractive index = 1,4.

Material	Speed of Light ($\times 10^8$ m/s)	Refractive Index
Air	3,0	1
Glass	2,0	3/2
Water	2,25	4/3
Diamond	1,25	2,4

Table 3.2

Activity 3.2

1. Explain how the graphs in **Figure 3.13** can help you to work out critical angles. What are the critical angles of glass, water and diamond?
2. Explain, with the help of a diagram, what the fish in **Figure 3.43** will see as he looks upwards.

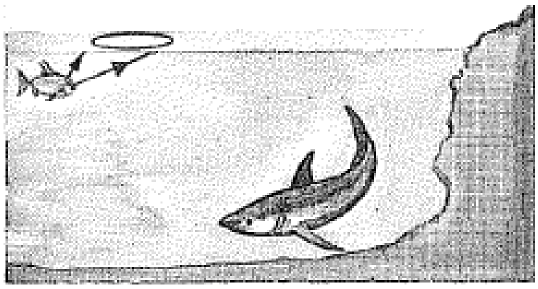


Figure 3.43

3. Below, you can see a ray of light entering a five-sided prism. Copy **Figure 3.44** and draw the path of the ray through the prism.

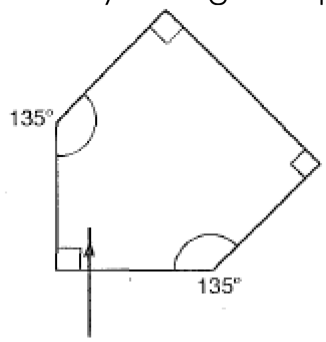


Figure 3.44

4. **Figure 3.45** shows sunlight passing through a prismatic window, that is used to light an underground public convenience.

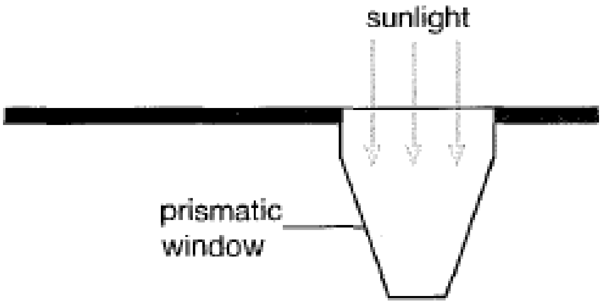


Figure 3.45

(a) Copy the diagram and show the path of the rays through the window.

(b) Explain why the window is shaped this way.

5. The diagram below shows light rays from a small object 0, passing through a lens and forming an image at *I*.

   (a) Copy the diagram. Add to the diagram the position of the image, for each of the object positions, A, B, C, D. Mark your images A', B', C', D to correspond to each object position.

   (b) What would happen to the image if a piece of card covered the bottom half of the lens?

6. In **Figure 3.25** you can see that the image is magnified if the object is close to the lens. We define the magnification as:

$$M = \frac{height\ of\ image}{height\ of\ object}$$

   (a) Work out the magnification for each of the images in **Figure 3.25**.

   (b) Take careful measurements to prove that this formula is also true:

$$\frac{image\ height}{object\ height} = \frac{distance: lens - image}{distance: lens - object}$$

7. A lens of focal length 15 cm is used in the slide projector in **Figure 3.28**.

   (a) Use **Figure 3.29** to work out how far the slide is from the lens to project an image: (i) 3 m from the lens, (ii) 5 m from the lens.

   (b) A slide measures 35 mm x 23 mm. What is the size of the picture on the screen, when the distance between the projector and the screen is 3 m? This formula may help:
   Image height _ Image distance *(v)*
   Object height - Object distance *(u)*

   (c) The lens in the projector breaks. The shop only has lenses of focal length 14 cm, 16 cm and 19 cm. Which one would you choose? Why?

8.

   (a) Suggest three ways in which the eye and the camera are similar.

   (b) What is different about the way a camera and an eye focus light?

9. Instead of spectacles some people wear contact lenses to solve their eyesight problems. Contact lenses are curved pieces of plastic that fit directly on to the cornea. Below you can see three shapes of contact lens.

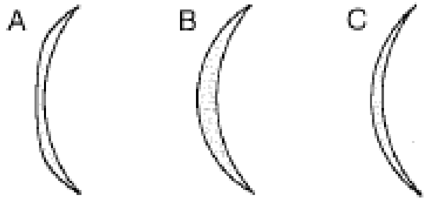


Figure 3.46

(a) Which side of each lens sticks on the eye? (the left or the right side)
(b) Which lens(es) could be used to correct for: (i) long sight, (ii) short sight?

10.
(a) (a) The eye in **Figure 3.33** is longsighted. How can you tell from **Figure 3.33b** that the eye can see distant objects normally?
(b) Peggy wears bifocal spectacles. Without her bifocals Peggy can only see things about 4 m away from her eyes clearly. Explain how her bifocals help.

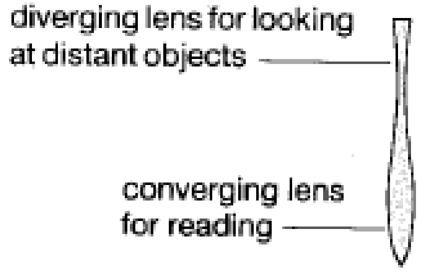


Figure 3.47

11. A surgeon in Russia suggested that it is possible to cure short sight with an operation. His idea is to cut the muscles that control the shape of the eye lens. What are the advantages and disadvantages of this idea?
12. A 30 candelas (cd) lamp X is 40 cm in front of a photometer screen. What is the illumination directly in front of X on the screen? Calculate the cd of a lamp Y which provides the same illumination when placed 60 cm from the screen.
13. A lamp of 800 cd is suspended 16 m above a road. Find the illumination on the road (i) at a point A directly below the lamp, (ii) at a point B 12 m from A.
14. Define the terms luminous intensity and illumination. Describe an accurate method of comparing the luminous intensities of two sources of light.
A lamp is fixed 4 m above a horizontal table. At a point on the table, 3 m to one side of the vertical through the lamp, a light-meter is placed flat on the table. It registers 4 m candles. Calculate the intensity of the lamp.
15. What is meant by luminous intensity and illumination? How are they related to each other?
16. A small source of 32 cd giving out light equally in all directions is situated at the centre of a sphere of 8 m diameter, the inner surface of which is painted black. What is the illumination of the surface?

If the inner surface is repainted with a matt white paint which causes it to reflect diffusely 80 per cent of all lighting falling on it, what will the illumination be?

17. Describe an accurate form of photometer for comparing the luminous intensities of lamps.
    A lamp is 100 cm from one side of a photometer and produces the same illumination as a second lamp placed at 120 cm on the opposite side. When a lightly smoked glass plate is placed before the weaker lamp, the brighter one has to be moved 50 cm to restore the equality of illumination. Find what fraction of the incident light is transmitted by the plate.
18. How would you compare the luminous intensities of two small lamps?
    A small 100 cd lamp is placed 10 m above the centre of a horizontal rectangular table measuring 6 m by 4 m. What are the maximum and minimum values of the illumination on the table due to direct light?
    How would your results be changed by the presence of a large horizontal mirror, placed 2 m above the lamp, so as to reflect light down on to the table, assuming that only 80 per cent of the light incident on the mirror is reflected?
19. Describe one form of a photometer, and explain how you would measure the light loss which results from enclosing a light source by a glass globe.

Self-Check

I am able to:	**Yes**	**No**
• Describe the sources of light		
• Describe reflection from plane and spherical mirrors		
o Formation		
o Position		
o Character and size of images		
• Ray diagrams with formulae		
• Describe refraction through glass plates and prisms (constitution of white light)		
o Formation		
o Position		
o Character and size of images in case of convex and concave lenses		
o Minimum deviation		
o Total reflection		
o Critical angle		
o Formation of images by combinations of two thin lenses in contact		
• Convex and concave		
• Describe photometry		
o Inverse square law		

o Photometers		
• Describe optical instruments		
o Telescope		
o Microscope		
o Human eye		
• Describe dispersion and spectrum		
o Simple spectrometer		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 4

Light II

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the wave theory of light
- Describe interference
- Describe diffraction
- Describe diffraction gratings
- Perform measurements of wave length
- Describe polarisation of light
- Describe double refraction
- Describe rotation of plane polarisation
- Describe the polarimeter

4.1 Introduction

Waves do two important things; they carry energy and information. You have seen ocean waves crashing into a sea wall at high tide. Those waves certainly carry energy.

When you watch television you are taking advantage of radio waves. These waves carry energy and information from the transmitting station to your house. Light and sound waves carry energy and information from the television set to your eyes and ears.

4.1.1 Waves on slinkies

One of the best ways for you to learn about waves is to see them moving along on a stretched 'slinky' or spring. **Figure 4.1** shows a slinky lying on the floor.

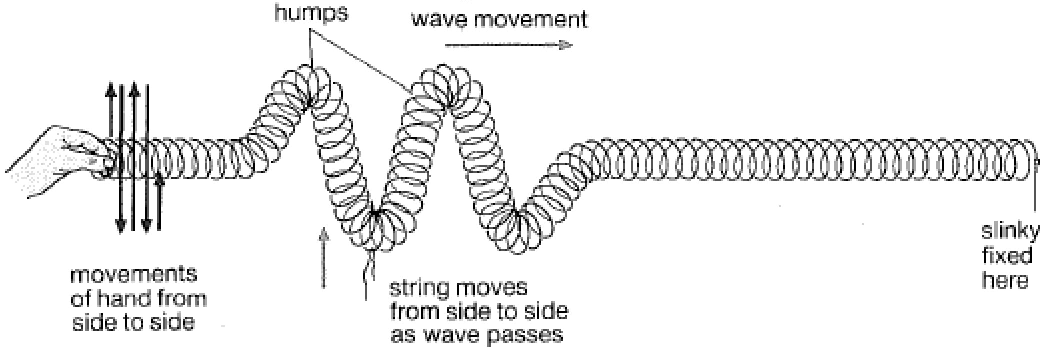


Figure 4.1 A transverse wave moving down a slinky

When you move your hand from side to side some humps move away from you along the slinky. Although the wave moves along the slinky, the movement of the slinky itself is from side to side.

If you tie a piece of string to the slinky, you will see that it moves in exactly the same way as your hand did to produce the waves. This sort of wave is called a transverse wave. The particles carrying the wave in the slinky move at right angles to the direction of wave motion.

Note:
Water ripples on the surface of a pond and light waves are examples of transverse waves.

You produce a different kind of wave when you move your hand backwards and forwards along the slinky (**Figure 4.2**). Your hand compresses and then expands the slinky.

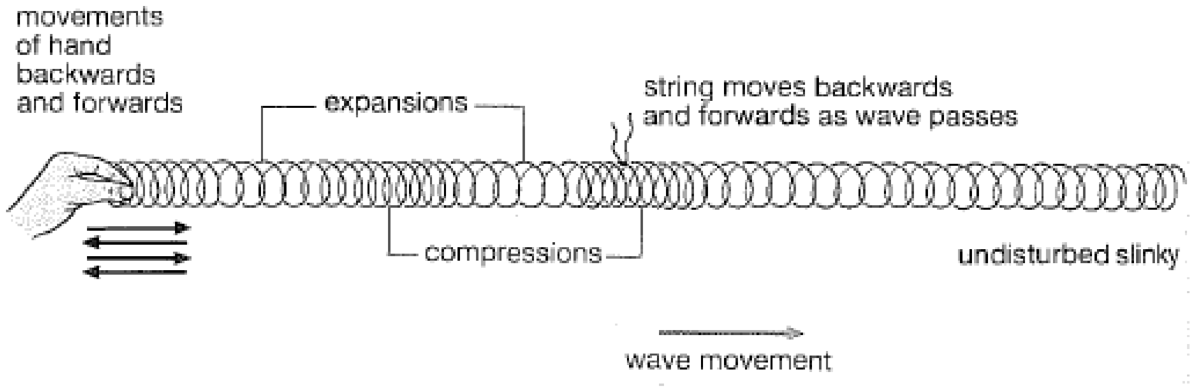


Figure 4.2 A longitudinal wave moving down a slinky

The wave is made up of compressions and expansions which move along the slinky. This time a piece of string tied to the slinky moves backwards and forwards along it. Again, this is how your hand moved to produce the waves.

This sort of wave is called a longitudinal wave. The particles carrying the wave in the slinky move backwards and forwards along the direction of wave motion.

Note:
Sound waves are longitudinal.

4.1.2 Describing waves

Figure 4.3 is a graph showing the displacement of a slinky along its length at one moment. The arrows on the graph show the direction of the motion of the slinky; a larger arrow means a larger speed.

- **Phase.** Points *B* and *J* are moving in phase. They are moving in the same direction, with the same speed. They also have the same displacement away from the undisturbed position of the slinky. *F* has been displaced in the opposite direction to *B* and *J*, and is moving in the opposite direction. *F* is out of phase with *B* and *J*. However, *F* moves in phase with *N*.
- The **wavelength** of a wave motion is the shortest distance between two points that are moving in phase. You can think of a wavelength as the distance between two humps. We use the greek letter *λ (lambda)* for the wavelength.
- The **amplitude** of a wave is the greatest displacement of the wave away from its undisturbed position. You can think of the amplitude as the height of a hump.
- The **frequency,** f, of the wave is the number of complete waves produced per second. There are two complete waves in **Figure 4.3**. The unit of frequency is waves per second or *hertz* (Hz). 1 kHz means 1 000Hz.
- The time **period** of a wave, *T,* is the time taken to produce one complete wave.

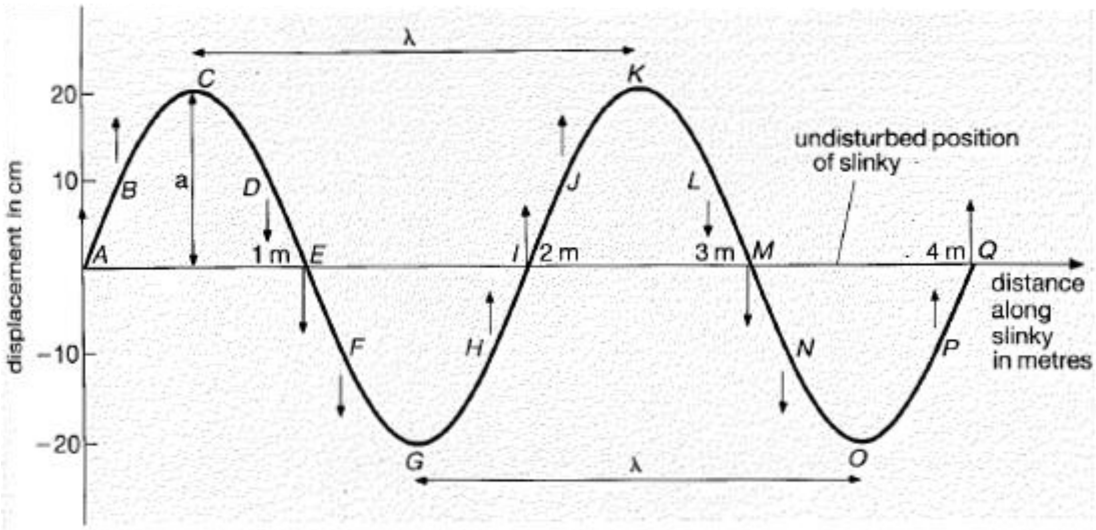


Figure 4.3 The displacement of a slinky along its length. The arrows on the graph show the direction of motion of the slinky

4.1.3 Wave velocities

The **velocity** of a wave, *v,* is the distance travelled by a wave in one second.

The velocity of waves down a particular slinky is the same for all wavelengths.

Figure 4.4a shows waves moving on a slinky with frequency 3 Hz and wavelength 0,4 m. In one second three waves have been produced, so the distance travelled by the first wave is 3 x 0,4 = 1,2 m. The wave velocity is 1,2 m/s.

For any wave (see **Figure 4b**) we can calculate the wave velocity using the formula:

$$Velocity = frequency \times wavelength$$
$$V = f \times \lambda$$

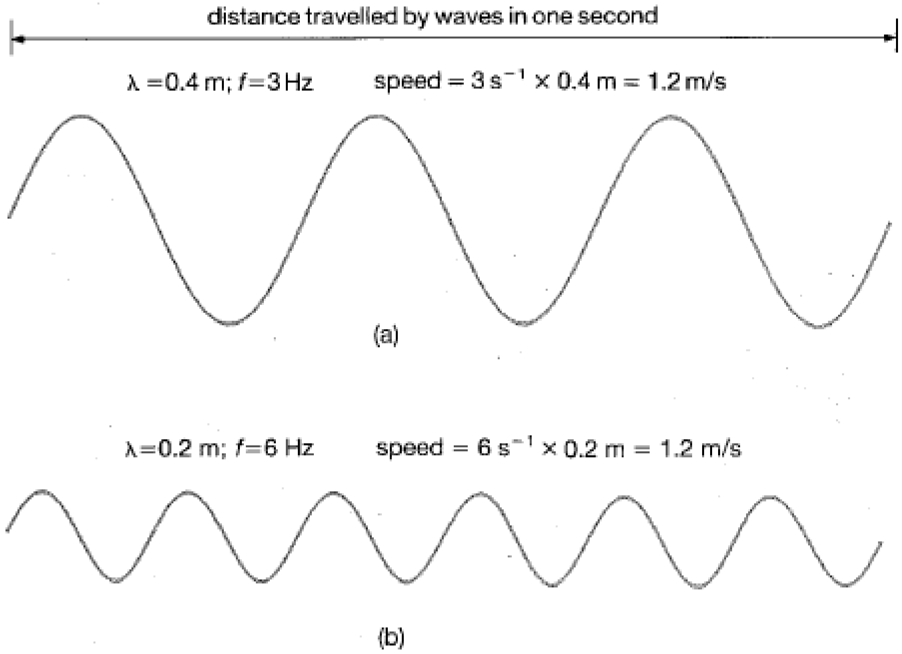


Figure 4.4 The speed of waves along a slinky is the same for all wavelengths

4.2 Light as a wave

4.2.1 Microwave interference

Electromagnetic waves with a wavelength of 3 cm (microwaves) can be used to demonstrate interference effects in a laboratory. **Figure 4.5** shows the sort of arrangement you can use.

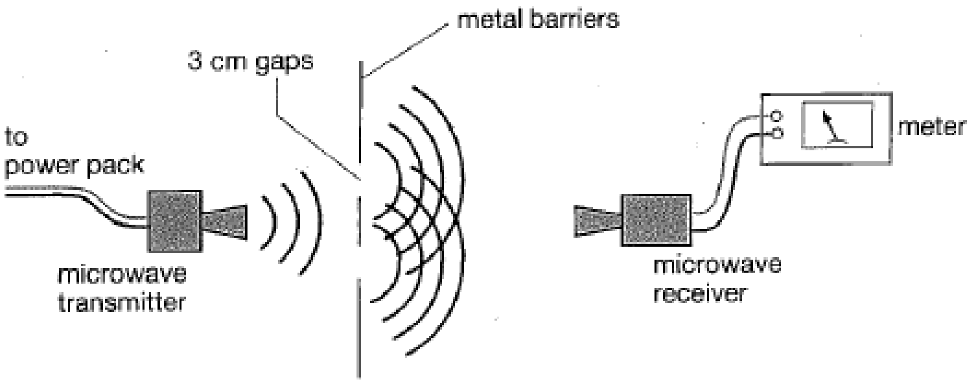


Figure 4.5

	Safety Warning! Microwave transmitters may be a hazard to anyone fitted with a heart pacemaker.

Microwaves from a transmitter are directed towards two small gaps in a metal barrier. The gaps should be about 3 cm wide, then the microwaves diffract out through these gaps.

On the other side of the barrier the microwaves will overlap. This allows them to interfere in the same way that water waves do in a ripple tank. There will be places where the microwave receiver detects *constructive interference*. In other places the receiver detects little energy due to *destructive interference*.

Figure 4.6 shows you how constructive interference can occur in more than one place. Waves travel the same distance to *A*. So they arrive in phase there, and *A* is a point where you detect constructive interference.

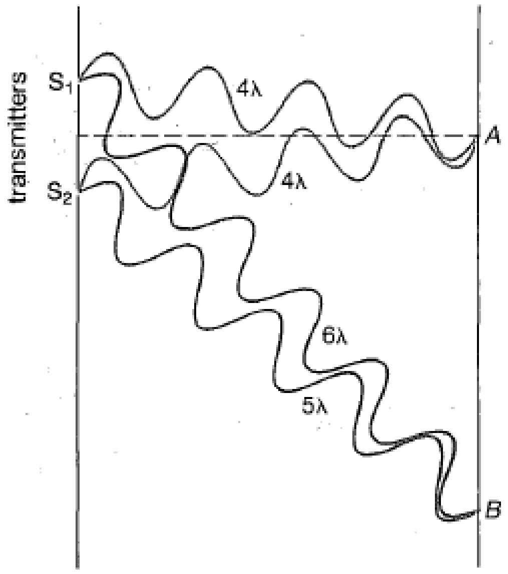


Figure 4.6

You also detect constructive interference at *B*. This time the waves from S_1 travel further than those from S_2 by one extra wavelength. The *path difference* between the two sets of waves is one wavelength. You can use this idea to work out the wavelength of microwaves.

For example you might measure with a ruler that S_1B = 18 cm and S_2B = 15 cm.

$$Path\ difference\ S_1B - S_2B = 1\ wavelength$$
$$\text{So } 1\ wavelength = 18\ cm - 15\ cm$$
$$= 3\ cm$$

In general, constructive interference occurs if path difference = $n\lambda$
destructive interference occurs if path difference $n\lambda + \frac{\lambda}{2}$
(n is a whole number, 0, 1, 2, 3 etc.)

4.2.2 Interference of light
Figure 4.7 shows you how you can study the interference of light. It is the same of idea you used to study microwave interference. To make interference you must produce two beams of light that overlap.

Light has a very small wavelength. So you need to use two very small slits, as shown.

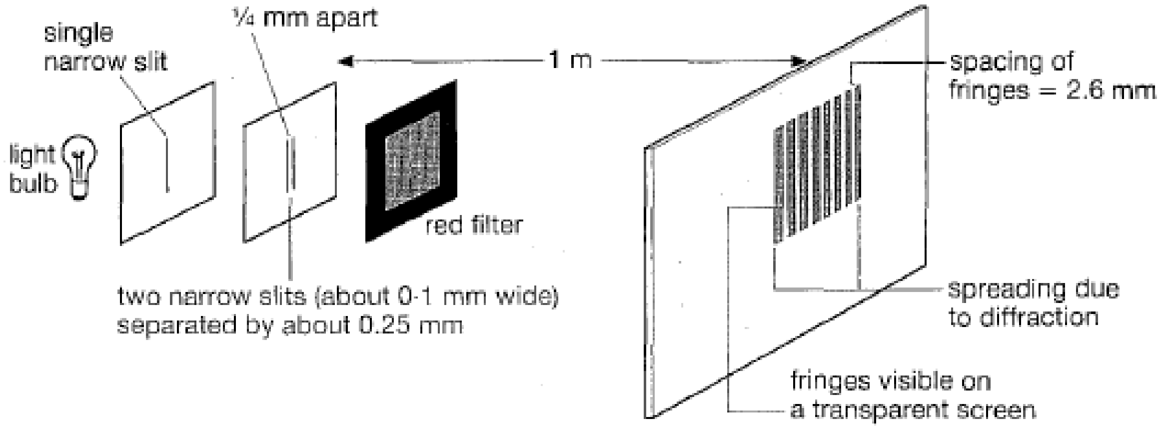


Figure 4.7 An arrangement to see the interference of light

The slits must be very narrow (about 0,1 mm wide) so that light is diffracted by them.

The slits must also be placed close together so that the beams of light from slit overlap.

⚠	**Note:** In a slightly darkened room it is quite easy to see interference fringes.

With a red filter in place, you will see alternate red and dark lines. The red lines correspond to places of constructive interference; here the red light waves arrive in phase. At the dark places the light waves arrive out of phase; this is destructive interference.

⚠	**Note:** The light wavelengths are too small to measure with a ruler as is possible with microwaves.

However, there is a formula which will help you.

$$wavelength = \frac{fringe\ spacing \times slit\ separation}{distance\ from\ slits\ to\ screen}$$

Using the information in **Figure 4.7**, the wavelength for red light is:

$$= \frac{(2{,}6\times10^{-3}\ m)\times(2{,}5\times10^{-4}\ m)}{1\ m}$$
$$= 6{,}5\ \times 10^{-7}\ m$$

Suppose you used the example shown in **Figure 4.7** to create fringes using red, green and blue light. From the formula above you would see that the wavelength is proportional to the fringe spacing. So red light has the longest wavelength and blue light the shortest.

When white light is used, you see a whole series of colours. This is because white light is made up of all colours. Each colour has a different wavelength. At some angles red light interferes constructively, while at other angles blue light does, and so on.

4.3 Geometrical optics

The study of the effects created by the nature and properties of light is called the study of optics.

Think about it!
Why can you see your face in a mirror but not on the pages of this book? Why do you sometimes see what looks like water on the road when the surface is hot and dry? Why are diamonds so shiny? Why can you start a fire with a magnifying glass?

4.3.1 Light as a transversal wave

Think about how you feel when your house has a power failure or the candle in your room suddenly goes out. You feel lost until you can light the candle again or find a torch.

Without light, your eyes can't make out anything in the world around you. Light is a transversal (transverse) wave, which means that the particles move at 90° to the direction of motion.

Light is made up of electromagnetic waves. Electromagnetic waves all have a place in the electromagnetic spectrum. Visible light is just one small part of this spectrum.

Definition: Electromagnetic waves
Electrical field waves and magnetic field waves travelling together.

These waves include the seven colours of the rainbow: red, orange, yellow, green, blue, indigo and violet. The electromagnetic spectrum is illustrated in **Figure 4.8**.

Definition: Electromagnetic spectrum
The range of electromagnetic wavelengths from small to big.

You can see that visible light makes up a very small part of the electromagnetic spectrum.

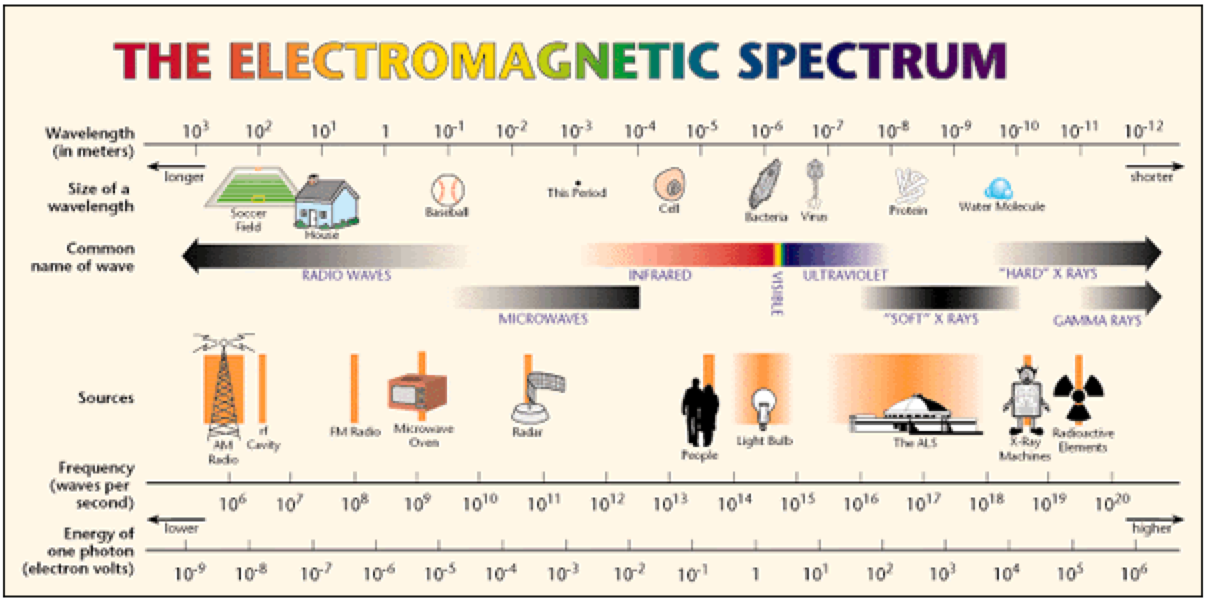


Figure 4.8 The electromagnetic spectrum

4.3.2 Wave properties of light

Light waves travels at a speed of 3×10^{8} $m.s^{-1}$ and it travels much faster than sound. Light waves carry energy. You can feel this energy in the heat of the sun. You can also feel it when you touch a light bulb.

Did you know?
Snakes can detect infrared radiation, and that some insects can see ultraviolet light?

But what is light, then? Is it a wave or a particle? Well, it is actually both a wave and particle.

Did you know?
The sun is our nearest star and it takes eight minutes for sunlight to reach the Earth.

Light is a transversal electromagnetic wave, but it is also a moving particle with energy. Light consists of electrical and magnetic fields that oscillate at very high speeds.

Definition: Oscillate
To vary between two amounts or limits.

We cannot see unless there is light and that light must enter our eyes. Light rays can pass through empty space, air and *transparent* objects. Substances that allow light to pass through them are called optical media. Substances that do not allow light to pass through are called *opaque* media.

Light rays travel in straight lines. When an object is lit up from a light source, such as a book on a desk, we say that it is illuminated. When an object is a light source, such as the lamp on the desk, we say that it is luminous.

Light rays can only change direction when they are reflected or refracted.

4.3.3 Reflection

One of the most beautiful sights that you can see is a motionless lake in the early morning. Then the lake acts like a mirror and reflects the sky, trees and mountains around it.

Think about it!

A light year is the speed of light (3×10^8 m.s^{-1}) x the number of seconds in a year (60 x 60 x 24 x 365 = 31 536 000). This is 9,46 x 10^{12} km.

Think about how far the stars in our night sky are from Earth. If a light year is this long, the stars that we see tonight might already have been destroyed a very long time ago. We simply see light that started travelling towards the Earth millions of years ago.

The stars actually look completely different from how we see them in the sky at night. Our knowledge of the stars comes from some very expensive scientific research and equipment.

If something reflects light, the light waves bounce off its surface and away in a different direction again. Some of those light waves reach our eyes, and we can see reflections.

Reflection happens when light rays bounce off a smooth surface such as a mirror, motionless lake or clean glass.

Reflection cannot happen on rough surfaces such as paper or a white T-shirt. It can only happen on smooth surfaces. Let's look at the effects that the shape of the smooth surface has on the image that you see when you look into mirrors with different shapes.

4.3.3.1 Plane mirrors

An ordinary, flat mirror is called a plane mirror. What happens when light rays shine onto a plane mirror? Look at **Figure 4.9**. It shows a person looking at herself in a plane mirror.

The distance between the person and the mirror is shown as p. The distance between the mirror and the image of the person is shown as i. The solid lines between the person and the mirror are light rays. The dotted line that runs *perpendicular* to the mirror is called the normal.

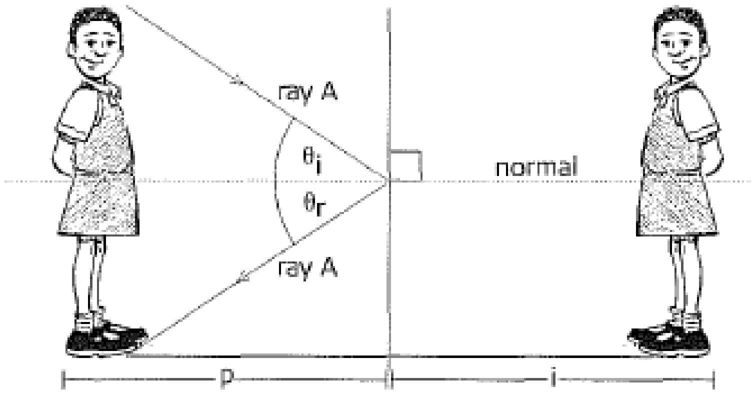


Figure 4.9 A plane mirror

Say that someone is shining a light from the person's head in the illustration to the middle of the plane mirror, or the normal (ray A). This part of ray A is called the incident ray. The light ray reflects back from the mirror at a specific angle.

This second part of ray A, the reflected part, is called the reflected ray. The angle between the incident ray and the normal is called the angle of incidence.

Definition: Incident ray
The ray that is going towards the mirror.

Definition: Reflected ray
The ray after the light has reflected off the mirror.

The symbol for the angle of incidence is θ_1. The angle between the normal and the reflected ray is called the angle of reflection. The size of the angle of incidence is the same as the size of the angle of reflection. The symbol for the angle of reflection is θ_r. $\theta_r = \theta_c$.

What would you see in the mirror if you looked at the light ray being shone from the person's head to the normal? You wouldn't see a real person or an actual ray of light, but a virtual image of a person and a light ray.

The dotted lines in **Figure 4.10** show that if you continue to draw the reflected ray at the same angle back into the image side of the mirror, it traces itself back to the top of the reflected image's head.

So you get an image in the mirror of a person with a light shining from his head, just as the real person is doing. In this diagram, there is no light on the virtual image side because the light and the image are not real.

There is light on the real image side of the mirror, as the person and the light ray are real. This is why the image on an overhead projector screen or a film screen is real and not virtual -because those images contain actual light.

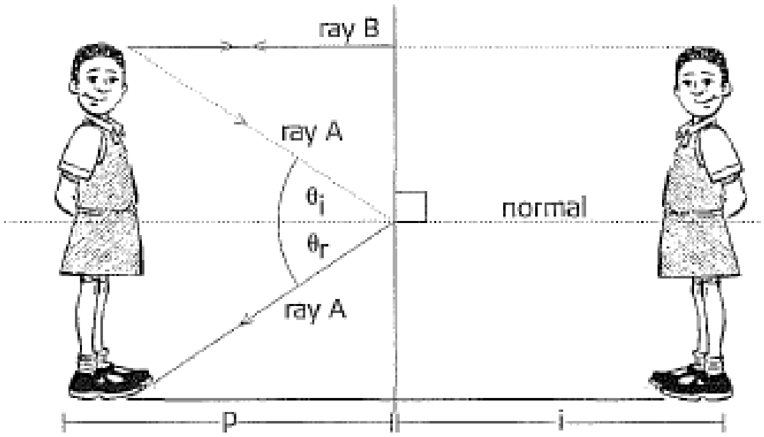


Figure 4.10 A virtual image

⚠	**Note:** A virtual image is a picture of an object in a mirror or the lens of a camera that is not real, but created by reflected light. Whereas a real image is a picture on a screen created by real light, and not reflected light.

What would you see in the mirror when a light ray is travelling from the person's head, parallel to the ground? When a light ray (ray B, in this case) is shone perpendicular to the plane mirror, as shown in **Figure 4.11**, it reflects straight back along itself with no angles of incidence or reflection.

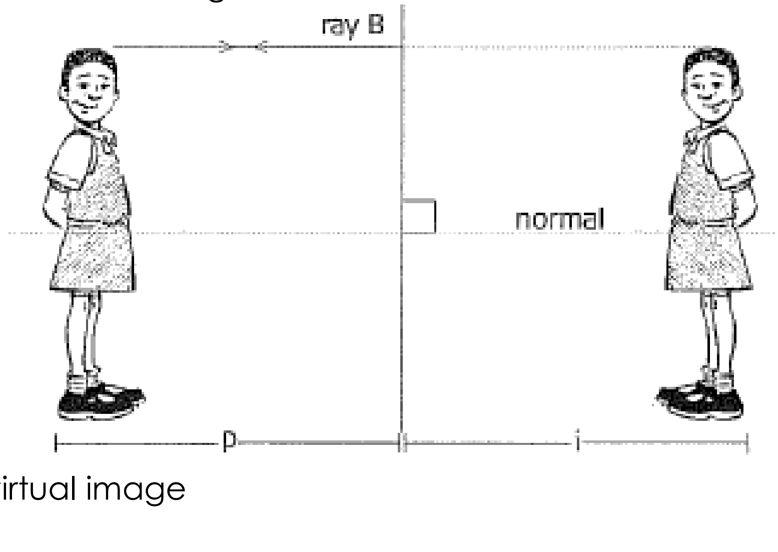


Figure 4.11 A virtual image

Think about it!

Have you ever wondered why it says AMBULANCE on the front of ambulances? This is because of something called lateral inversion.

In plane mirrors, light rays switch from right to left and left to right. So, when you are driving in a car and an ambulance rushes up behind you, you can read the word AMBULANCE when you look at
the ambulance in your rear view mirror.

You can identify the ambulance straight away and immediately get out of its way, allowing it to get to the person needing medical help much faster.

4.3.3.2 Concave mirrors

A concave mirror is a different kind of reflective surface. Hold a spoon in front of your face with the hollow side facing you. What do you see? You are upside down. How does this happen? The spoon's curved shape makes it a concave mirror.

The image reflected in the concave mirror changes its size and type depending on how close it is to the mirror.

Try this: take a pencil and bring it closer to the spoon. The pencil's reflection is upside down until it reaches a certain distance away from the spoon. Then it suddenly turns the right way around. How can we use physics to explain this? Look at **Figure 4.12** for an explanation of how this works.

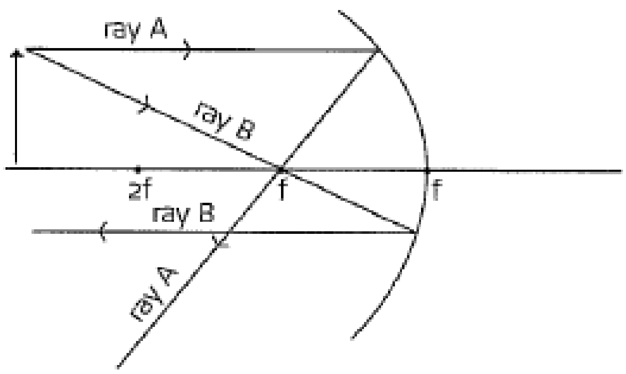


Figure 4.12 A concave mirror

In this figure, the curved line represents the concave mirror. The principal axis is the line that passes through the middle of the concave mirror. The point at which the principle axis intersects the concave mirror is called the pole.

The point on the principal axis marked f is the focal length of the mirror. And the point marked $2f$ is twice the focal length of the mirror. Point $2f$ is also called the radius of curvature.

Definition: Focal length
The distance between the mirror's focus and its centre point.

If the concave mirror made a full circle instead of only part of a circle, the radius of curvature would form the radius of the circle. Say you shone a light ray at the concave mirror at a parallel angle to the mirror's principal axis, as shown in **Figure 4.13**.

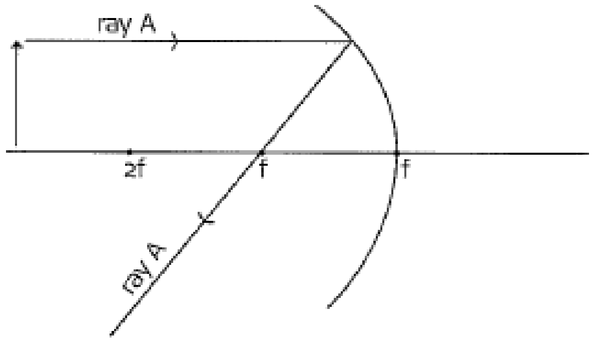


Figure 4.13 Reflections in a concave mirror

Ray A is a light ray travelling parallel to the principal axis, towards the concave mirror. As you can see from the figure, the light ray reflects in the concave mirror and shines back straight through the focal point, f.

In the same way, if you shine a light ray, such as Ray B in **Figure 4.14**, through the focal point at a concave mirror, the ray will reflect back at an angle that is parallel to the principal axis.

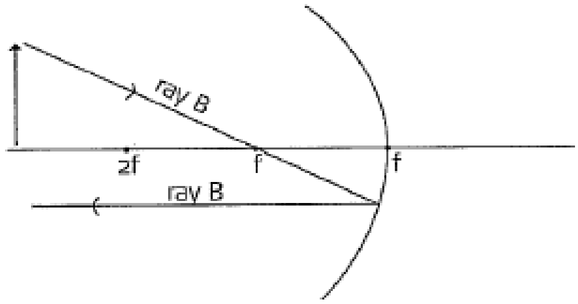


Figure 4.14 Reflections in a concave mirror

Position of object	Distance to image	Type and size of image
Beyond $2f$	Between f and $2f$	Diminished, real, inverted
At $2f$	At $2f$	Same size as the object, real, inverted
Betweenfand $2f$	Beyond $2f$	Larger than object, real, inverted
At f	No image	No image
Before f	Further than object	Larger than object, virtual, upright

Table 4.1 Properties of concave mirrors

4.3.3.3 Convex mirrors

Have you noticed that if you try on a pair of jeans in the fitting room of a shop, the jeans usually look great on you, but when you take them home and look at yourself in the mirror, you don't look quite as thin as you did in the fitting room?

This is because mirrors that have different shapes can make you look bigger or smaller, or even upside down, as we saw previously. When you looked at the concave mirror of the hollow side of the spoon, you were upside down.

Now turn the spoon around and look at the back of the spoon. The back of the spoon curves outwards. This reflective surface is called a convex mirror.

Have you ever seen one of those convex mirrors that the traffic department erects at intersections of roads where it is difficult for drivers to see what is coming around the corner? This is another example of how a convex mirror can be used.

Look at **Figure 4.15** of a convex mirror.

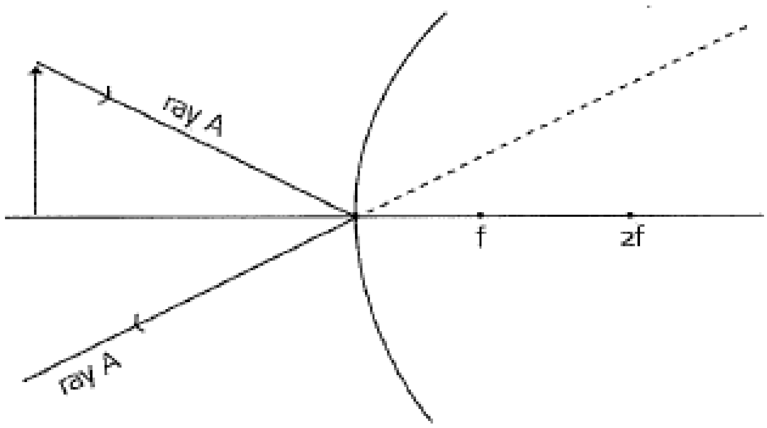


Figure 4.15 A convex mirror

Just like the concave mirror diagram, this figure shows a person shining light rays from different angles. The mirror in this diagram is convex. Once again, the focal point is f and the radius of curvature is $2f$.

Now let's look at how Ray A behaves. Ray A shows the person shining an incident ray at the centre of the convex mirror. Ray A reflects and bounces back at angle θr.

How does a ray of light behave when you shine it at a convex mirror at an angle that is parallel to the ground? As you can see from **Figure 4.15**, the person shines incident Ray B at the convex mirror parallel to the ground.

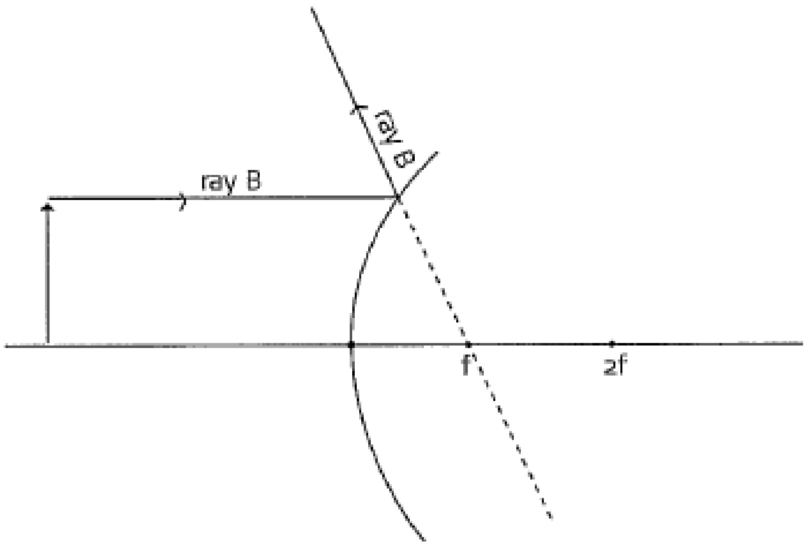


Figure 4.16 Reflections in a convex mirror

The reflected ray reflects back as if someone is inside the mirror shining the ray from the focal point (f).

But what would happen if we shone a ray towards $2f$? In **Figure 4.17**, incident Ray C is shone towards the radius of curvature, $2f$. This ray bounces straight back to where you shone the ray from. So the incident and reflected rays follow the same path.

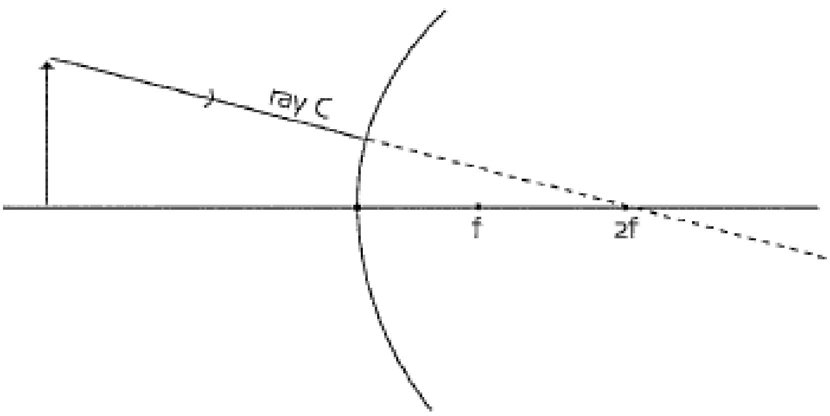


Figure 4.17 More reflections in a convex mirror

In all convex mirrors:

- the image that you see looks smaller than the real object being reflected,
- all images are upright (look at the back of the spoon again to check this), and
- all of the images are virtual as there is no light behind the convex mirror.

4.3.4 Refraction

Light bends when it travels through different media. So, when the sun's rays move from the vacuum of space into the Earth's *atmosphere,* they are bent as shown in **Figure 4.18**. This bending or refraction is what makes the sunrise so colourful.

Did you know?
When you first see the sun in the early morning it has actually not yet risen? This is because the sunrays have been bent so that they reach you earlier than they would have if they were travelling in a straight line.

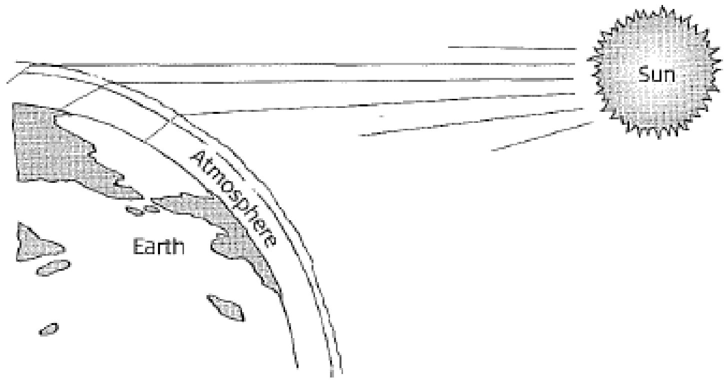


Figure 4.18 Refraction of the sun's rays

Have you ever noticed how on very hot days, when you look into the distance, you sometimes see what looks likes water? This imaginary water is called a mirage.

A mirage is a trick of the light. The hot air is thinner than the cooler air above or below it. As light travels through layers of air that have different densities, it bends. This refraction causes you to see a mirage that looks like water where there is no water.

Did you know?
People lost in the desert without any drinking water often say that they kept moving towards the water that they could see in the distance, thinking that they would arrive at a lake. But the water was just a mirage.

Let's look more closely at what happens to light during refraction. We know that light bends when it changes speed. The change in speed is caused by the light waves moving through media that have different densities.

Say that light travels through the air and reaches a pool of oil lying on the road. The air is less dense than the oil. The light ray changes speed by slowing down when it hits the oil. The way that it bends is illustrated in **Figure 4.19**.

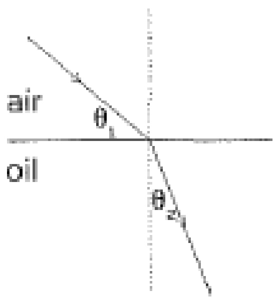


Figure 4.19 Refraction of a light ray

The angle between the light ray travelling through the air and the normal (θ_1) is greater than the angle between the light ray travelling through the oil and the normal θ_2.

When light moves through a less dense medium to a denser medium, it bends towards the normal.

Now suppose that light has been travelling through oil. It reaches the air and refracts like in **Figure 4.20**.

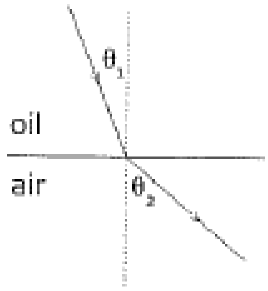


Figure 4.20 Refraction of a light ray

Here you can see how the angle between the light travelling through the oil and the normal θ_1 is smaller than the angle of the light travelling through the air and the normal θ_2.

Note:
The general rule for refractions is that when light travels from a less dense medium to a denser medium, the light bends towards the normal, as shown in **Figure 4.21**.

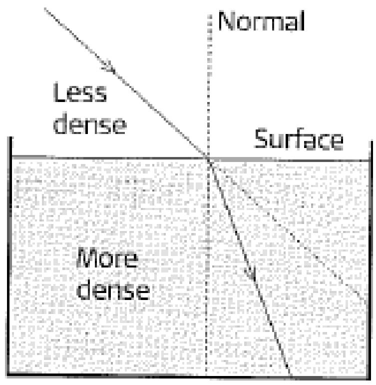


Figure 4.21 Refraction from less dense to more dense medium

Say your bath is full of water, and you have dropped a coin on the bottom of the bath. When you put your hand in to pick it up, the coin is not where you thought it was.

This is because the light refracted as went from the denser water to the less dense air.

When light travels from a denser medium to a less dense medium, it bends away from the normal, as shown in **Figure 4.22**.

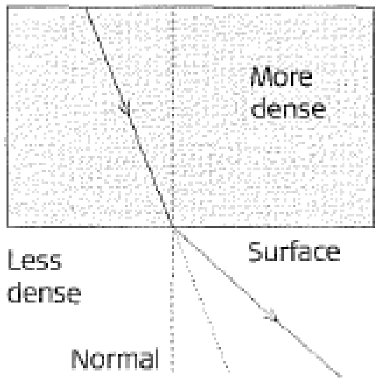


Figure 4.22 Refraction from more dense to less dense medium

4.3.5 Total internal reflection

Why are diamonds so shiny? Why do they glitter? Not all the light that goes into the diamond refracts directly out of it again. The surfaces are cut in such a way that light can only come out at an angle that is almost perpendicular to the surfaces.

All of the other light refracts back into the diamond until it reaches a surface at right angles. All the light coming out together at the same angle is the glitter that we see. And the bending of the other light back into the diamond is called total internal reflection.

This happens when light reflects off a substance instead of refracting out of it. The angle of incidence must be greater than the critical angle and light must be moving from an optically dense medium to a less dense medium. This is what makes it so shiny.

4.3.5.1 How total internal reflection works

If a light shines from an underwater light source, some of the rays will move through the surface without much refraction.

However, as the angle with which rays of light approach the surface between the water and the air, increases it reaches a point where none of the rays pass through to the air.

> **Note:**
> At some stage, the light rays are refracted parallel to the boundary between the water and the air.

Look at **Figure 4.23**. It shows rays of light shining from an underwater light source. The dotted lines show the normal.

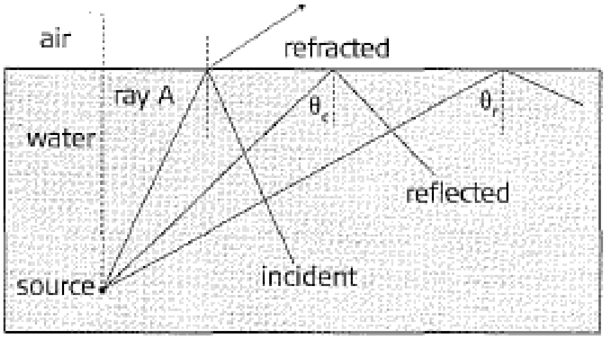


Figure 4.23 Total internal reflection

The critical angle is the angle of incidence that causes a light ray to refract at goo to the normal. When the angle of incidence equals the critical angle, the angle of refraction is therefore goo.

Note:
When the angle of incidence is greater than the critical angle, all the light rays undergo reflection.

4.3.5.2 Internal reflection in glass

The critical angle of glass is about 43°, depending on the type of glass. This means that light that has entered a 45° glass prism at an angle greater than 43° will be totally internally reflected and the prism behaves like a mirror.

This is why prisms instead of mirrors are mostly used in optical instruments such as binoculars. Whereas a mirror only reflects approximately 90% of incident light, a system of glass prisms is more efficient, yielding 100% reflection of the incident light.

Activity 4.1

1. Explain the difference between longitudinal and transverse waves.
2. This question refers to the graph in **Figure 4.3**.
   (a) What is the wavelength of the wave?
   (b) What is the amplitude of the wave motion?
   (c) The frequency of the wave motion is 2 Hz. What is the time period of the wave?
   (d) Calculate the speed of the wave.
   (e) Give a point moving in phase with (i) I, (ii) B, (iii) M.
   (f) Make a sketch of the wave motion in **Figure 4.3.** Use the arrows, showing the direction of movement of the particles in the slinky, to draw in the position of the slinky a short time later.
   (g) In which direction is the wave moving?
3. Make a sketch of a longitudinal wave of a slinky, and mark in a distance

to show one wavelength.

4. A radio station produces waves of frequency 200kHz and wavelength 1500m.
   (a) What is the speed of radio waves?
   (b) Another station produces waves with a frequency 600kHz. What is their
   (c) wavelength?
5. Why do the wave pulses shown below contain some information?

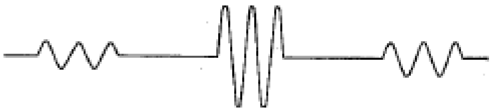


Figure 4.24

6. This question is about the interference fringes shown in **Figure 4.7**.
   (a) The screen is moved further away from the slits. What difference does that make to: (i) the spacing of the fringes, (ii) the brightness of the fringes?
   (b) The slits are moved further apart. What difference does that make to the spacing of the fringes?
   (c) The slits are made slightly narrower. What difference does that make to: (i) the spacing of the fringes, (ii) the brightness of the fringes, (iii) the number of fringes that you can see?
7. **Figure 4.25** shows a thin layer of oil floating on a puddle of water. You can see a ray of light that is partly reflected from the surface of the oil, and then partly reflected from the water surface. Explain why if you look at oil on water you can see patches of colour.

Figure 4.25

8. All waves show interference effects. Design an experiment to show that sound waves interfere. Explain how you are going to observe this interference.

Activity 4.2

1. Jane fills a glass beaker with water and oil. Which liquid will be at the bottom of the beaker? She then drops a marble into the liquid.
   (a) Describe what happens to the speed of the marble as it moves from the air through the two liquids until it reaches the bottom of the beaker.
   (b) How does this correspond with the speed of a wave through these media?
2. Describe the change in the wavelength and speed of waves approaching a beach?
3. When are standing waves formed in a medium? Draw a neat, labelled

sketch to represent a standing wave.

4. What is the difference between a standing wave and a moving wave?
5. When does superposition in waves occur? Give an example to illustrate your answer.
6. When one wave approaches another wave describe what happens when the:
   (a) peaks of both the waves meet,
   (b) troughs of both the waves meet, and
   (c) the peak of one wave meets the trough of another wave.
7. How is light made up?
8. An example of visible light is the rainbow. Name the different colours you can see.
9. The medium through which light travels affects how fast light moves. Explain this statement.
10. Distinguish between reflection and refraction of light.
11. Draw a labelled sketch of a light ray passing through a rectangular Perspex block.
12. Name two examples of total internal reflection.
13. Draw accurate ray diagrams to show the formation of the images if an object is placed at the following points in front of a concave mirror. Describe each image:
    (a) beyond $2f$,
    (b) at $2f$,
    (c) between f and $2f$,
    (d) at f, and
    (e) before f.
14. Would the answers be the same if a convex mirror were used? Explain your answer by drawing accurate ray diagrams.
15. An object at the bottom of a swimming pool appears closer to the surface than it really is. Draw a light ray diagram to explain this.
16. The word PG GLASS is printed backwards on the front of a delivery van. When Sam looked in the rear view mirror of his motor he could read the word. Explain why this is the case.
17. A light beam in air enters a glass block at an angle of 60° from air. Describe what could happen to the light beam after striking the glass block.
18. Draw labelled sketches (ray diagrams) to show:
    (a) total internal reflection, and
    (b) critical angle when a light wave passes through a half circle perspex block.

Self-Check		
I am able to:	**Yes**	**No**
• Describe the wave theory of light		
• Describe interference		
• Describe diffraction		
• Describe diffraction gratings		
• Perform measurements of wave length		
• Describe polarisation of light		
• Describe double refraction		
• Describe rotation of plane polarisation		
• Describe the polarimeter		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 5

Magnetism

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the law of force
- Describe deflection magnetometer
- Describe magnetic effects of current
  - Magnetic field due to a current in a straight conductor
  - Magnetic field due to a current in a circular conductor
- Describe solenoids
  - Storage
- Describe the force on a current carrying conductor in a magnetic field
- Describe electromagnetic induction

5.1 Introduction

Magnets are named after stones found mainly in Magnesia, Asia Minor, which early man noticed had certain properties on small bits of iron. These stones were used in navigation and were given the name loadstone.

5.2 Magnets

A piece of iron or steel may be magnetised by placing in on contact with a loadstone, or by winding a coil of wire around the wires. Hardened steel will retain its magnetism for a considerable length of time.

Note:
Soft iron produces a strong magnetic effect but loses its magnetism rapidly once the current is switched off.

Permanent magnets are made from hardened steel, while soft iron is used as the core for relays and solenoids when a strong magnetic field is required only when the current is switched on.

When a steel bar is magnetised, the magnetic effect concentrates at the ends of the bar and the ends are called poles of the magnet.

Away from the ends and around the bar, an invisible force is present called a magnetic field. When a magnet is placed in iron filings, the iron filings will be attracted to both ends of the magnet, the poles.

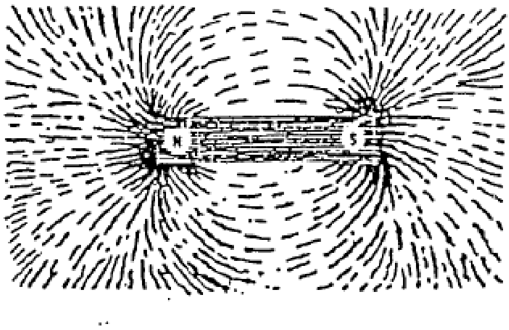


Figure 5.1 Magnetic field pattern around a magnet

Note:
The magnetic field is symmetrical unless disturbed by another magnetic force.

The lines of force have direction and are represented as emanating from the N pole and entering the S pole.

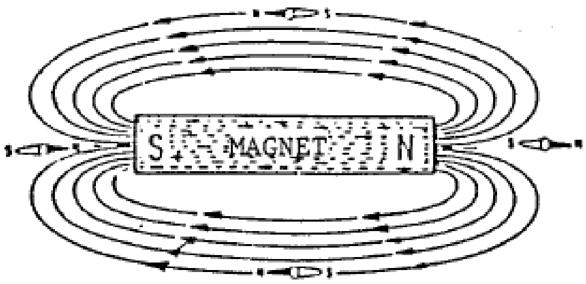


Figure 5.2 Bar magnet

If two magnetised needles, (compass) are suspended near one another it will be seen that an N pole repels an N pole, and an S pole repels an S pole, but an N pole attacts an S pole.

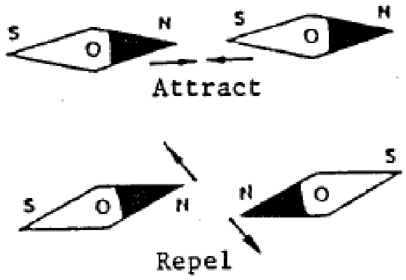


Figure 5.3 Attraction and repulsion of magnets

Similarly if the poles of two magnets are brought together the one N pole repels the other N pole while an S pole will attract an N pole.

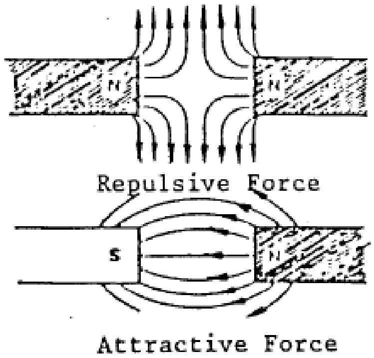


Figure 5.4 Actions of magnets

> **Note:**
> The earth is a large magnet and surrounding the earth is a magnetic field produced by the earth's magnetism.

The earth's north/south geographic poles are not the axis for the magnetic poles and, therefore, the magnetic and geographic poles are not at the same place on the surface of the earth.

The early uses of the compass regarded the end of the compass needle that points in a northerly direction as being a north pole and on maps the pole towards which the north pole of a compass pointed was designated a north magnetic pole.

This magnetic pole was obviously called a north pole because it was near the north geographic pole. The South Pole was treated in a similar manner.

When it was realised that the earth was a magnet itself, it became obvious that the naming of the magnetic poles has to be switched over in order to comply with the rule that opposing poles attract one another. Thus the south magnetic pole is located near the north geographic pole.

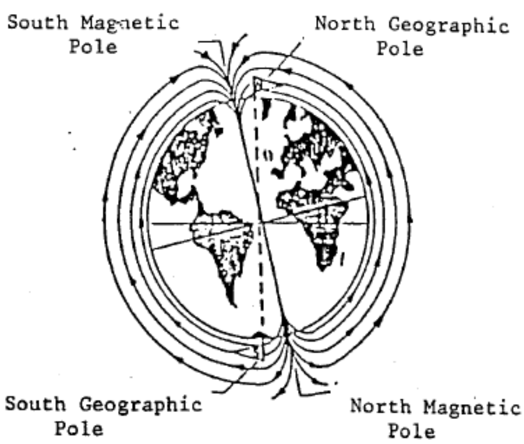


Figure 5.5

A compass will point to the magnetic poles and not to the geographic poles and the angle between the two poles is known as angle of variation. This angle of variation varies from place to place and on a certain longitude can be zero.

There is no known insulator for magnetic flux, as it passes through everything. Instruments which may be affected by the earth's magnetic flux and other magnetic fields are shielded by placing them in a case of soft iron.

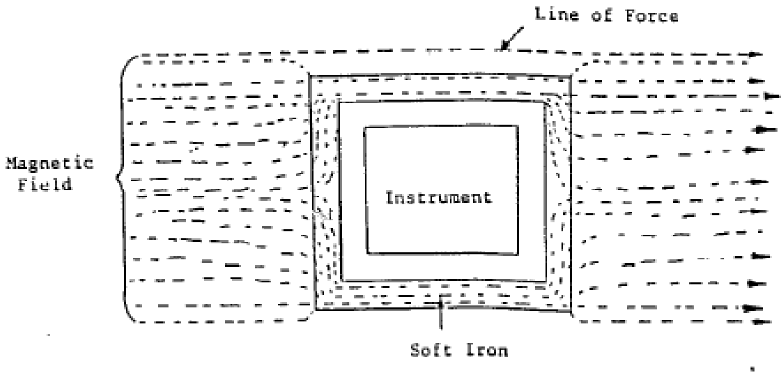


Figure 5.6

Magnets may be either "permanent" or "temporary" depending on the amount of magnetism retained by the magnet after the magnetic force has been removed. Temporary magnets (soft iron) have a high permeability while permanent magnets have a low permeability.

Temporary magnets (soft iron) are used in transformers where the magnetism is constantly changing and in generators and motors where the strength of the fields can be readily charged.

When the magnetic force is removed the magnetism that remains is called residential magnetism which is an important factor in the design of electric motors.

Note:
Permanent magnets are used in meters and telephone receivers.

5.3 Magnetic effect

The next step is to bring together magnetism and the flow of an electric current.

A current flowing through a conductor which passes vertically through a sheet sprinkled with iron filings will cause lines of force to form in a concentric circle around the conductor. This shows that the conductor has been magnetised.

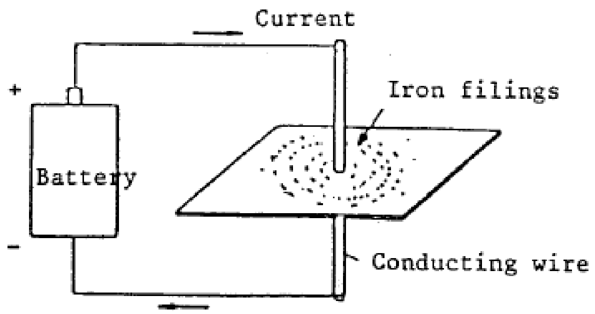


Figure 5.7

The current and the lines of force will have the following relationship:

When the conductor is held with the right hand and the thumb pointed in the direction of current flow, magnetic lines of force will be produced in the direct ion of the four fingers. This is known as right-hand thumb rule.

This could be expressed as if the current flows in the direction in which a right-hand screw is advancing, the lines of force will be in the direction of the turning screw. In this case, this is known as the right-hand screw rule.

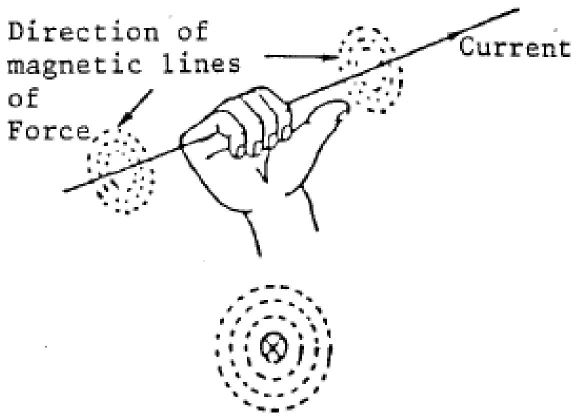


Figure 5.8 Right-hand thumb rule

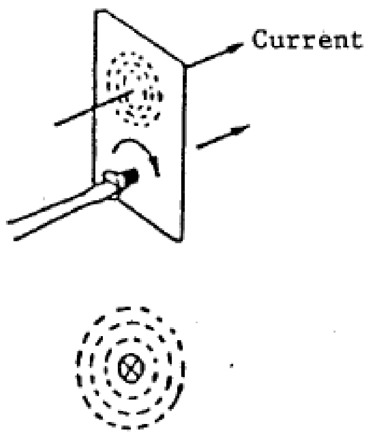


Figure 5.9 Left-hand thumb rule

5.4 Lines of a force when a current is passed through a coil

Passing a current through a single turn coil in the arrow direction will cause lines of force to be produced around the wire as shown by dotted lines, resulting in the overall lines of force shown by the solid lines.

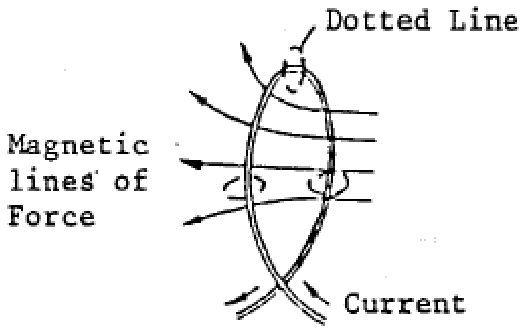


Figure 5.10

In the case of the coil having numerous turns, each turn will produce its own lines of force, and this combining together result in vast numbers of lines of force. These are produced in the direct ion shown in **Figure 5.11**.

The lines of force produced in the coil are concentrated in the inner side so that the coil can be assumed to have N and S poles. A magnet formed in this manner by flow of current is called an electromagnet.

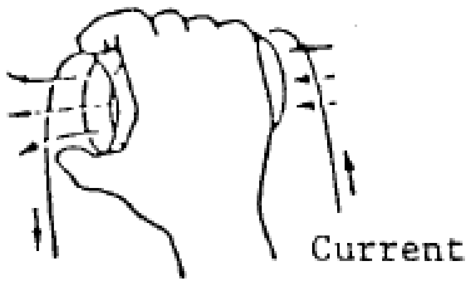


Figure 5.11

5.5 Electromagnetism

Merely by passing a current through a coil it will not produce an electromagnet strong enough to pick up a piece of iron. By inserting an iron core in the coil, it will produce a strong electromagnet capable of picking up a piece of iron.

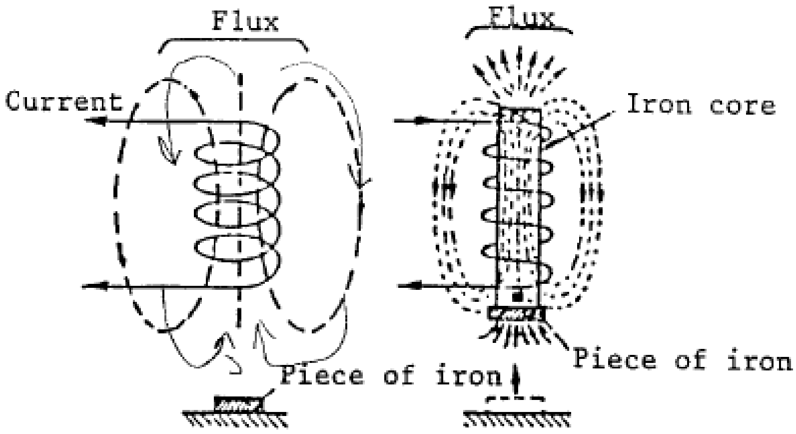


Figure 5.12

This is due to coil magnetism forming an infinite number of lines of magnetism in the iron core into a powerful electromagnet. The sum of the lines of force is lines of magnetism in the coil are generally called flux.

5.6 Electromagnetic force

Electromagnetic force is the force produced between the electric current and magnetism.

As shown in **Figure 5.13**, passing a current through a conductor inserted between two magnetic poles will cause the conductor to move in the direction shown by the heavy arrow.

> **Note:**
> There are already magnetic lines of force existing between the N and S poles.

When the current flows through the conductor, circular lines of force are produced around the conductor in the direction given by the right-hand screw law also known as the Fleming's Left-hand Rule.

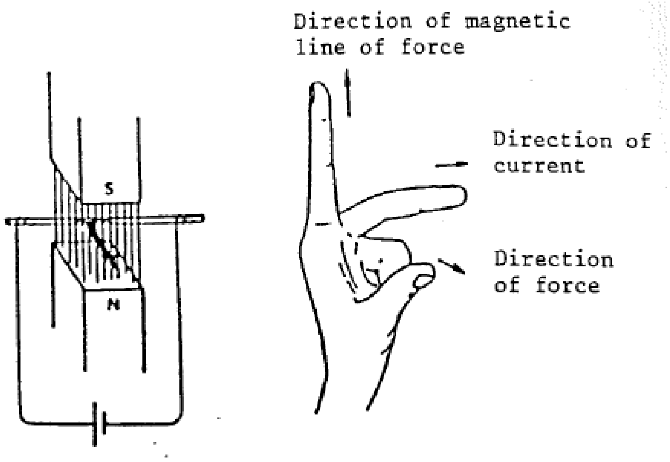


Figure 5.13

The Fleming Left-hand Rule is used to determine the relation between the lines of force, current and force. This is "set the forefinger, the thumb and the middle finger of the left hand at right angles to one another.

If the forefinger points along the line of magnetism and the middle finger towards the direction of current flow, the thumb will point in the direction of force".

⚠	**Note:** This force will be directly proportional to the product of the lines of magnetism and current. The electric motor is an application of this principle.

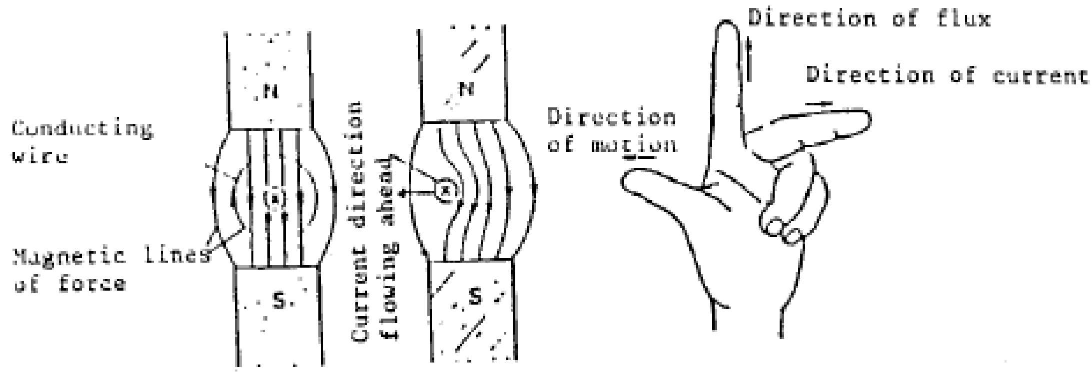


Figure 5.14

5.7 Electromagnetic induction

As shown in **Figure 5.15**, cutting the lines of magnetism between the N and S poles by moving the conductor in the direction shown by the heavy arrow will produce electromotive force in the conductor and cause current to flow.

⚠	**Note:** The size of current produced will be proportional to the speed at which the lines of magnetism are cut and the strength of the magnetic field.

If the conductor is made in coil form, the current produced will increase in proportion to the number of coil turns. This cutting of the lines of magnetism by the conductor which produces electromotive force in the conductor and causes current to flow is called electromagnetic induction.

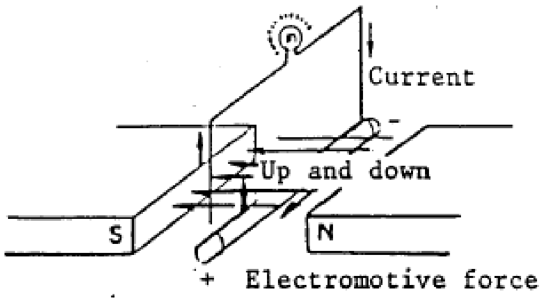


Figure 5.15 Producing electricity (generator principle)

The direction of the electromotive force can be determined by Fleming's Right-hand Rule. This is "Set the forefinger, the thumb and the middle finger of the right hand at right angles to one another.

If the forefinger points along the lines of magnetism and the thumb in the direction of conductor motion, the middle finger will point in the direction of the induced electromotive force".

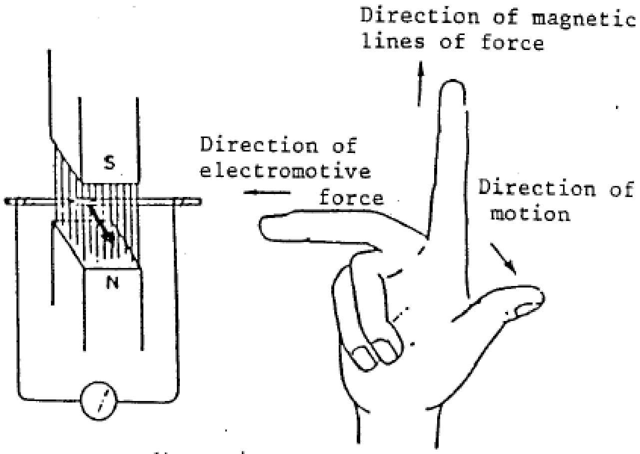


Figure 5.16 Fleming's right-hand rule

5.7.1 Self-inductance

Self-inductance is a form of electrical inertia. If the current flowing through a coil is stopped or increased or decreased, the amount of magnetic flux being produced in the coil will change so that an electromotive force will be induced in the coil.

According to Lenz's Law the electromotive force will always be set up in the direction to oppose the change in flux.

Note:
The electromotive force induced is directly proportional to the rate of change in flux.

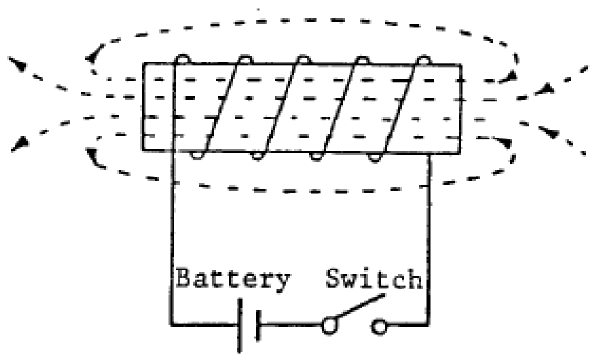


Figure 5.17 Self-inductance

5.7.2 Mutual inductance

Figure 5.18 shows a primary coil and a secondary coil placed near to each other.

If the current flowing through the primary coil is switched on and off (varied), the lines of magnetism vary, causing electromotive force (voltage) to be produced in the secondary coil through magnetic inductance.

The electromotive force induced becomes stronger as the rate of current change in the primary coil becomes larger, and also as the magnetic coupling between the primary and secondary coil becomes stronger. This induction of voltage in one coil due to the effects of varying the current through the other coils is called mutual induction.

⚠	**Note:** The voltage induced In the secondary coil is directly proportional to the number of turns in the primary and secondary coils.

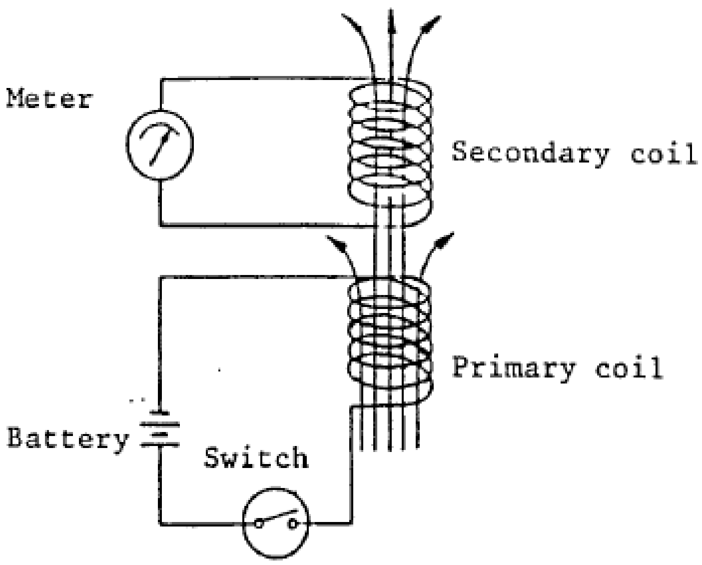


Figure 5.18 Mutual inductance

5.8 Ampere - turns

The magnetising force of a coil is based on the ampere-turns of the coil. The ampere-turns of a coil are equal to the amount of current flowing through the coil multiplied by the number of turns.

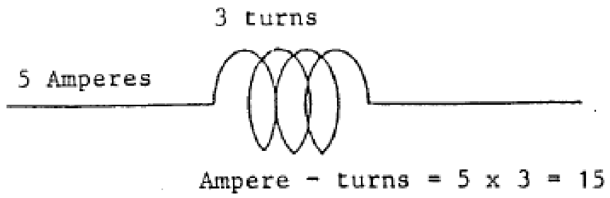


Figure 5.19

5.9 Magnetometers

Magnetometers are measurement instruments used for two general purposes:

- to measure the magnetization of a magnetic material like a ferromagnet, or
- to measure the strength and, in some cases, the direction of the magnetic field at a point in space.

Did you know?
The first magnetometer was invented by Carl Friedrich Gauss in 1833 and notable developments in the 19th century included the Hall Effect which is still widely used.

Magnetometers are widely used for measuring the Earth's magnetic field and in geophysical surveys to detect magnetic anomalies of various types. They are also used militarily to detect submarines.

Consequently, some countries, such as the USA, Canada and Australia classify the more sensitive magnetometers as military technology, and control their distribution.

Magnetometers can be used as metal detectors: they can detect only magnetic (ferrous) metals, but can detect such metals at a much larger depth than conventional metal detectors; they are capable of detecting large objects, such as cars, at tens of metres, while a metal detector's range is rarely more than 2 metres.

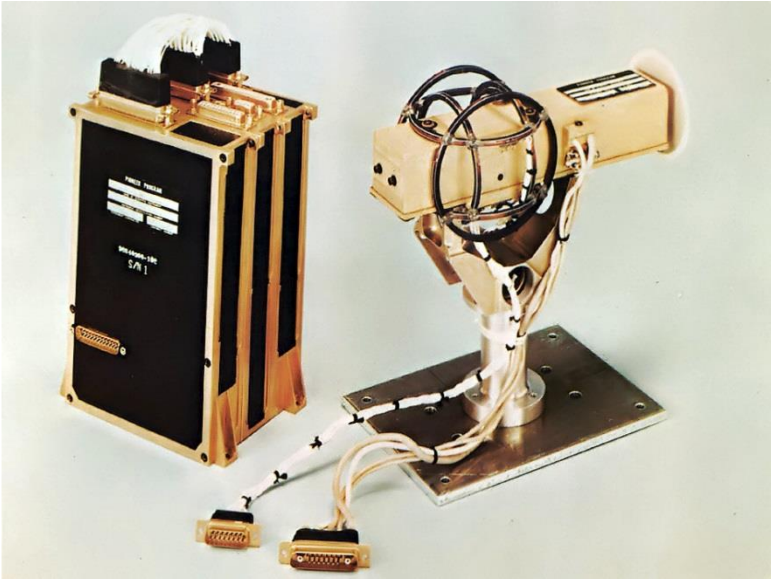


Figure 5.20 Magnetometer

In recent years magnetometers have been miniaturized to the extent that they can be incorporated in integrated circuits at very low cost and are finding increasing use as compasses in consumer devices such as mobile phones and tablet computers.

5.10 Coulomb's Law of Force

Coulomb's law or Coulomb's inverse-square law, is a law of physics describing the electrostatic interaction between electrically charged particles. The law was first published in 1784 by French physicist Charles Augustin de Coulomb and was essential to the development of the theory of electromagnetism.

It is analogous to Isaac Newton's inverse-square law of universal gravitation. Coulomb's law can be used to derive Gauss's law, and vice versa. The law has been tested heavily, and all observations have upheld the law's principle.

It is a follows:

$$F = \frac{k.m_1.m_2}{r^2}$$

Where *k* is the ratio constant.

The force *F* is expressed in Newtons and the distance *r* in metres when using the SI. The size or strength of a magnetic pole was made possible with the discovery of the electrically induced magnetic field.

This is the amount of current I passing through a conductor length *L* which will produce a magnet of strength Im (ampere-meter).

Activity 5.1

1. Describe in your own words what is meant by magnetism.
2. Name three magnetic substances.
3. A piece of white cardboard is placed on top of a permanent bar magnet. Fine iron filings are then sprinkled on the cardboard. What happens to the iron filings? Draw a neat sketch of your observation.
4. Use a sketch show what will happen if:
   a. a north and a south pole are brought close to each other, and
   b. two north poles are brought close to each other.
5. Define a magnetic field.
6. Give another name for the Earth's magnetic field.
7. Define magnetic declination.
8. Is magnetic declination the same all over the Earth? Explain your answer.
9. Say you are standing somewhere in South Africa and have a compass in your hand, which is pointing north. Is the North Pole slightly to the right or to the left of where the compass points?
10. Write down three characteristics of magnetic field lines.
11. Is it possible for the iron and steel in buildings to become magnetised? Explain your answer.
12. On a survival camp, the guide told Sammy to make sure that he is not near another magnet when using his compass. Explain why the guide said this.
13. Use an example to explain magnetic induction.
14. The flight attendant on board an airplane asked the passengers to switch off their cellular phones. Why do you think he did this?
15. Define a shield.
16. Describe where shielding might be useful in everyday life.

Self-Check

I am able to:	Yes	No
• Describe the law of force		
• Describe deflection magnetometer		
• Describe magnetic effects of current		
o Magnetic field due to a current in a straight conductor		
o Magnetic field due to a current in a circular conductor		
• Describe solenoids		
o Storage		
• Describe the force on a current carrying conductor in a magnetic field		
• Describe electromagnetic induction		

If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 6

Electricity

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the principle of operation of moving coil measuring instruments
  - Ammeter
  - Voltmeter
  - Wattmeter
  - Galvanometer
- Describe the basic principle of ac and dc generators
  - The principle of operation of the single phase transformer

6.1 Introduction

We all take electricity for granted. At home you can turn on a light or a fire at the flick of a switch. Without electricity, our lives would be completely different and less comfortable.

6.2 Lenz's law

The direction of an induced emf is always such that it tends to set up a current opposing the motion and the change of magnetic flux responsible for producing that emf.

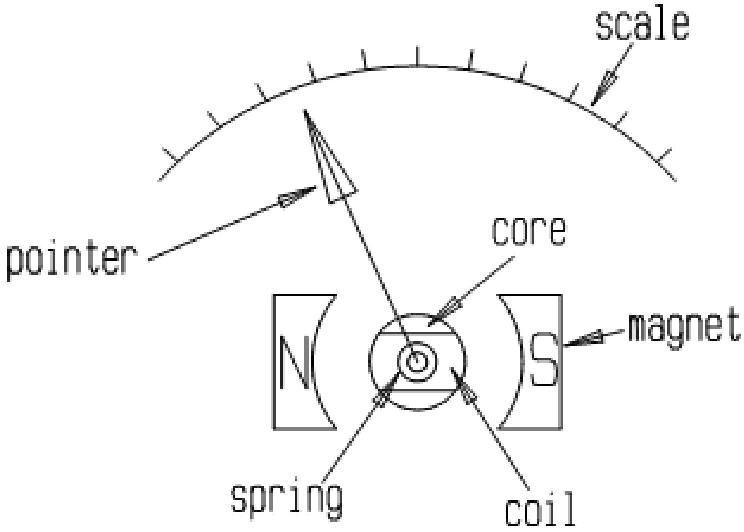


Figure 6.1 Moving coil meter, analogue type

The value under test is passed through the coil which interrupts the magnetic flux of the magnet, which forces the pointer to a different position. The scale is calibrated to read off the correct value.

6.3 Moving coil instruments

6.3.1 The ampere meter

An ampere meter is a meter which is used to measure the amount of current flowing in a circuit. The current that will give a full scale deflection (fsd) will normally be between 1 mA and 20 mA.

A shunt resistor (R_{SH}) will be placed in parallel to the coil winding to prevent damage to the meter if a large current (I_T) is to be measured. The shunt resistor is usually composed of a few resistors placed on parallel and is selectable so as to vary the range of the ampere meter.

The shunt resistor (R_{SH}) value can be calculated as follows:

(1) $R_{SH} = \frac{I_M \times R_M}{I_{SH}}$

R_{SH} = shunt resistor
I_M = Current through the meter
R_M = Internal resistance of the meter

(2) $I_{SH} = I_T - I_M$

(3) $R_{SH} = \frac{I_M \times R_M}{I_T - I_M}$

I_{SH} = current through R_{SH}
I_T = current being measured

6.3.1.1 Internal arrangement of shunt resistor for the ampere meter

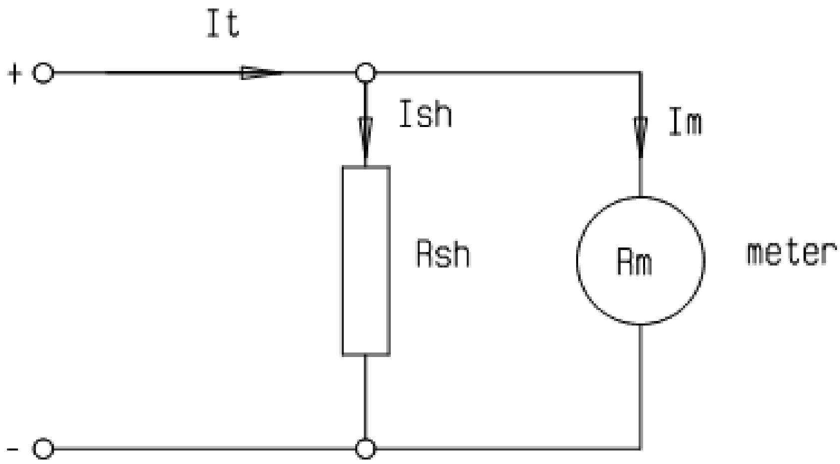


Figure 6.2 An ampere meter is always connected in series with the circuit.

Worked Example 6.1

A current value of 7A is to be measured. The ampere meter has a internal resistance of 2Ω and a full scale deflection of 10mA.

Calculate:
1. the value of the shunt resistor.
2. the value of current through the shunt resistor.

Solution:

$I_T = 7A$
$R_M = 2\Omega$
$I_M = 10\ mA = 10 \times 10^{-3}$

1. the value of the shunt resistor

$$R_{SH} = \frac{I_M \times R_M}{I_T - I_M} = \frac{(10\times10^{-3})\times2}{7-10\times10^{-3}} = \frac{0,02}{6,99} = 2,86\ m\Omega$$

2. the value of current through the shunt resistor

$$I_{SH} = I_T - I_M = 7 - (10 \times 10^{-3}) = 6,99\ mA$$

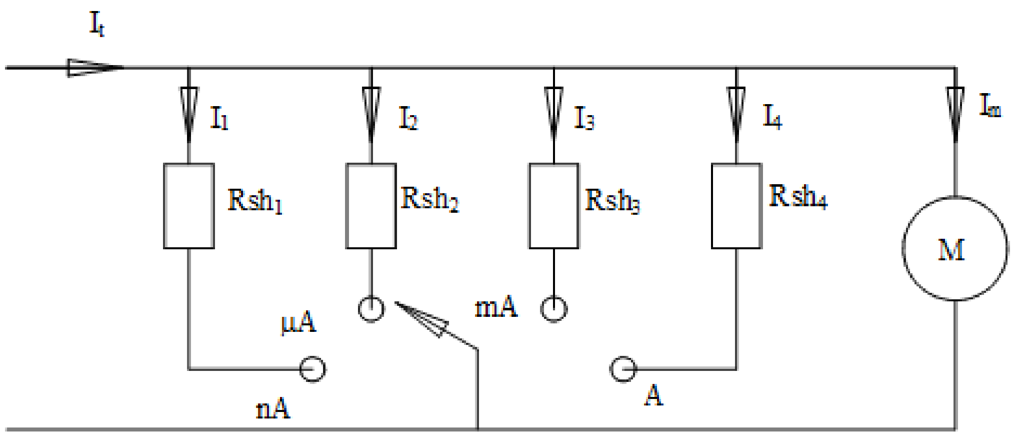


Figure 6.3 Multi range ampere meter

Definition: Galvanometer
a type of sensitive ammeter: an instrument for detecting electric current. It is an analogue electromechanical actuator that produces a rotary deflection of some type of pointer in response to electric current through its coil in a magnetic field.

6.3.2 The volt meter

A volt meter is always connected in parallel with the circuit under test. The same type of moving-coil meter is used as in the ampere meter. A resistor connected in series to the meter is to prevent the current from exceeding the full-scale current rating and damaging the meter.

This resistor is called a multiplier and is used to make the meter multi-range. The multiplier can be calculated as follows.

(1) $R_S = \frac{V_T}{I_M} - R_M$ R_S = multiplier
V_T = voltage under test
R_M = Internal resistance of the meter
I_M = current through coil
(2) $V_T = I_M(R_S + R_M)$ R_M = resistance of coil

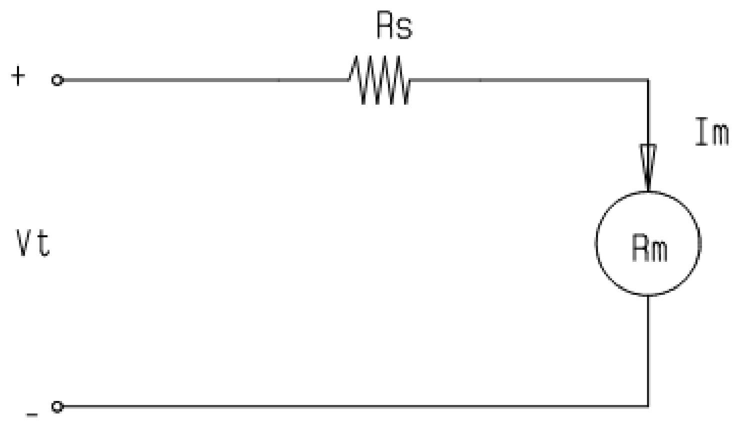


Figure 6.4 Internal arrangement of multiplier for the voltmeter

Worked Example 6.2

A voltmeter has a full scale deflection of 15mA and a internal resistance of 5 Ω.

Calculate the value of the resistor to measure a full scale voltage of 50V.

Solution:

$V_T = 50\ V$, $R_M = 5\Omega$, $I_M = 15\ mA = 15 \times 10^{-3}\ A$

$$R_S = \frac{V_T}{I_M} - R_M$$
$$= \frac{50}{15\times10^{-3}} - 5$$
$$= 3333{,}33 - 5$$
$$= 3328{,}3\ \Omega$$
$$= 3328\ \Omega$$

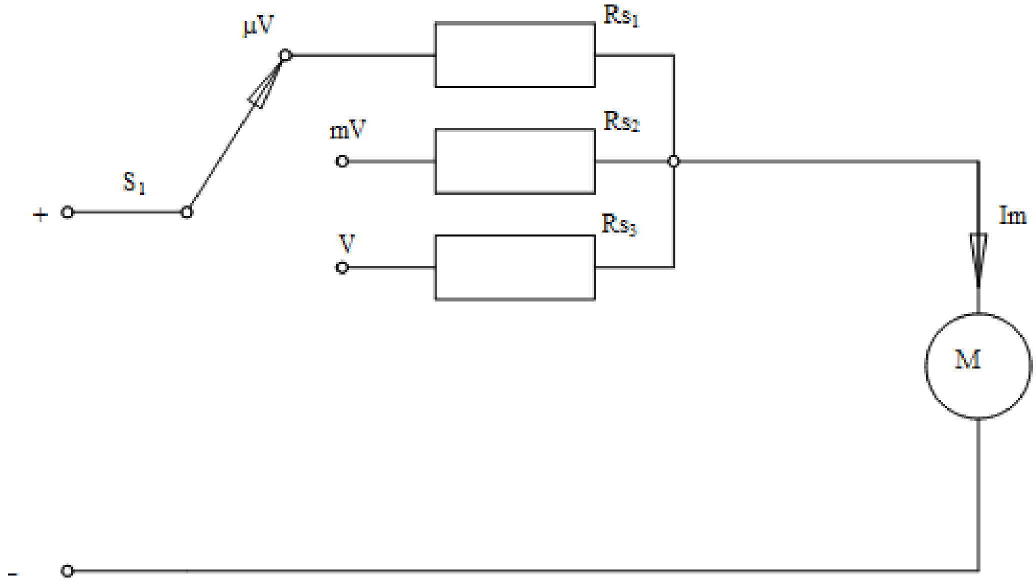


Figure 6.5 Multi range volt meter

6.3.3 The ohmmeter

A moving - coil meter can be used to measure the value of an unknown resistance (R_x).

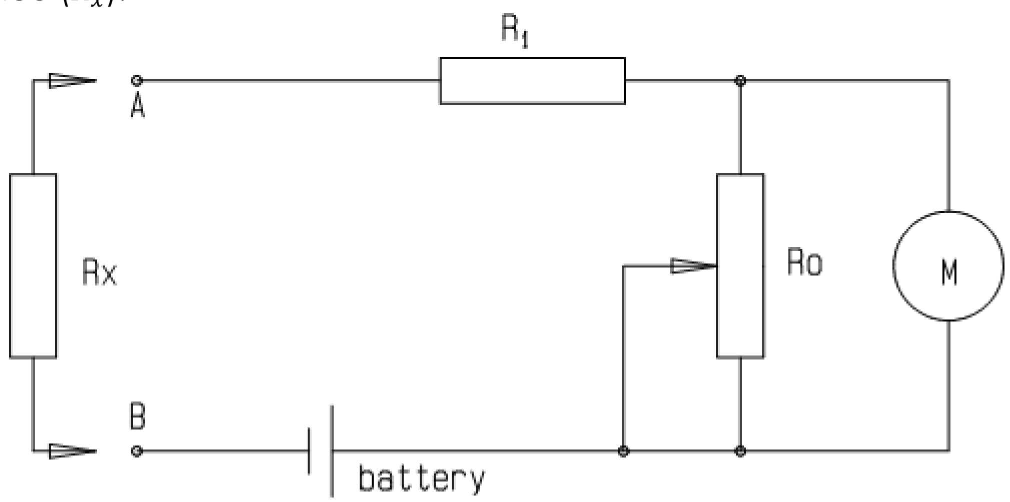


Figure 6.6

R_l = Current limiting resistor
R_o = Variable zero adjustment resistor
R_x = Resistance under test
B = Battery or power source of meter

6.3.4 The analogue multi-meter

This analogue can be used as a multipurpose meter to measure current, voltage and resistance with multi- ranging selectivity. The meter is also known as a (AVO meter).

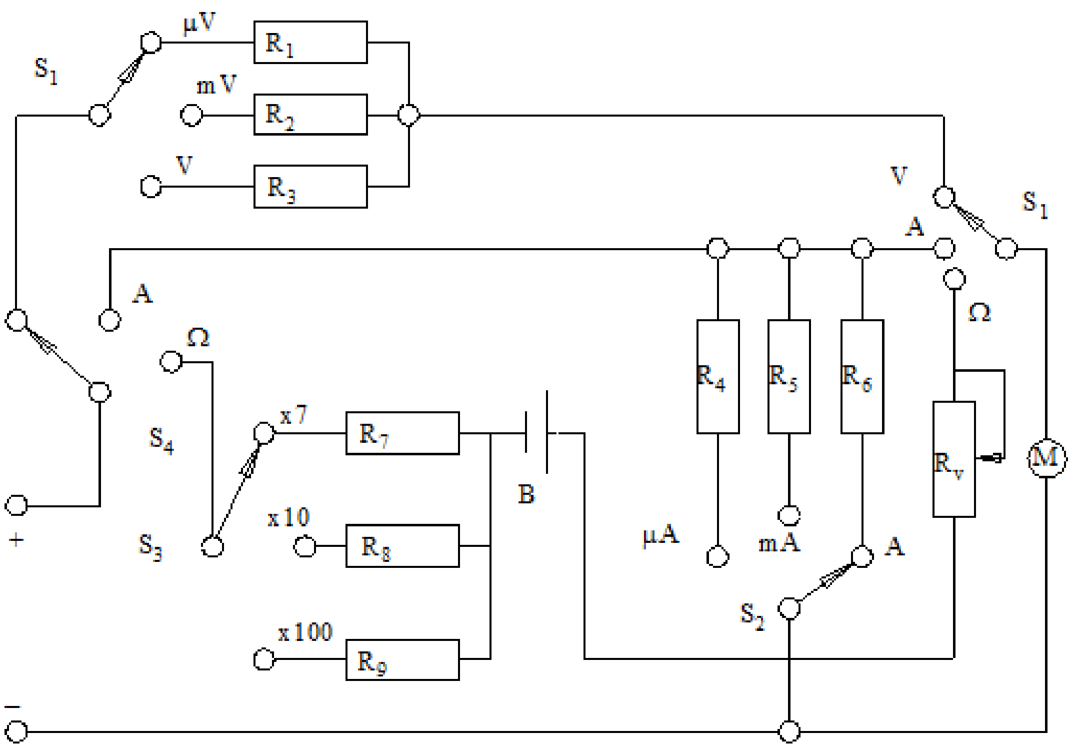


Figure 6.7

⚠	**Note: When using a multi-meter for testing current in a circuit** Multi-meters have a small internal resistance in the circuit for measuring electric current. Therefore, a multi-meter should *never* be connected in parallel to a circuit as a large amount of current will flow and destroy the multi-meter. The multi-meter must be connected in series with the circuit.

Precautions to be taken when using an analogue meter

- Always select the highest scale first and then decrease the scale if necessary.
- Never leave the meter on the ohm scale. This could cause the batteries to run down.
- Before any measurements are made, the meter must be set to zero.
- Prevent polarity reversal.

⚠	**Note: When using a multi-meter for testing voltage in a circuit** Multi-meters, when used to measure voltage, have a high internal resistance, therefore, a multi-meter should never be connected in series to a circuit. The multi-meter must be connected in parallel with the circuit.

⚠	**Note: When using a multi-meter for measuring resistance in a circuit** Multi-meters, when used to measure resistance, can be damaged if the current in the circuit is flowing. Therefore the current must be switched off or the voltage disconnected.

6.3.5 The digital multi-meter
This type of multi-meter uses a numerical readout. The display is usually a LCD (liquid crystal display) or 7 segment LED (Light emitting diodes). This meter has a high level of accuracy, and can automatically select a suitable range.

Uses of the digital multi-meter:

- Current meter
- Volts meter
- Ohms meter
- Continuity tester
- Diode tester
- Test (HFE) current gain of transistors

Auto-ranging scale automatically selects a suitable range.

The advantages of the digital multi-meter over a analogue multi-meter:

- Zero - adjustment is not necessary
- Indicates polarity reversal
- Polarity reversal protection
- Overload protection
- Auto-ranging
- High degree of accuracy
- Response speed is increased
- More robust.

Definition: Wattmeter
An instrument for measuring the electric power (or the supply rate of electrical energy) in watts of any given circuit. Electromagnetic wattmeters are used for measurement of utility frequency and audio frequency power; other types are required for radio frequency measurements.

6.4 The ac generator (alternator)
Figure 6.8 shows the design of a very simple alternating current (ac) generator. By turning the axle you can make a coil of wire move through a magnetic field. This causes a voltage to be induced between the ends of the coil.

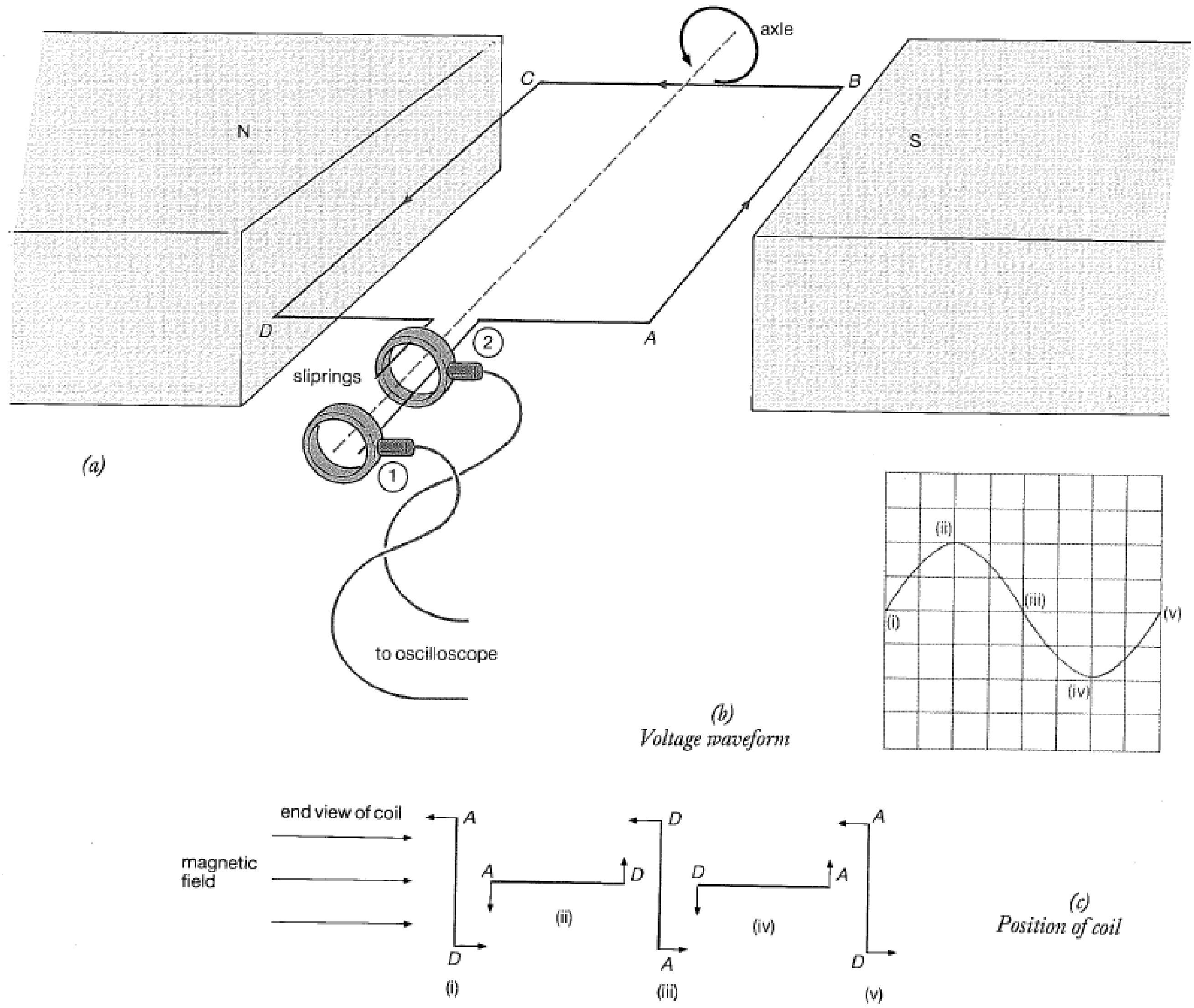


Figure 6.8 The ac generator

You can see how the voltage waveform, produced by this generator, looks on an oscilloscope screen.

In position (i) the coil is vertical with AB above CD. In this position the sides CD and AB are moving parallel to the magnetic field. No voltage is generated since the wires are not cutting across the magnetic field lines.

When the coil has been rotated through a V+ turn to position (ii), the coil produces its greatest voltage. Now the sides CD and AB are cutting through the magnetic field at the greatest rate.

In position (iii), the coil is again vertical and no voltage is produced. In position (iv) a maximum voltage is produced, but in the opposite direction. Side AB is now moving upwards and side CD downwards.

6.5 The dc generator (dynamo)

Figure 6.9 shows how direct current (dc) can be generated. The design of the dynamo is very similar to that of the alternator in **Figure 6.8.** The difference is that the ends of the coil are now fixed to a split-ring commutator rather than two separate slip rings.

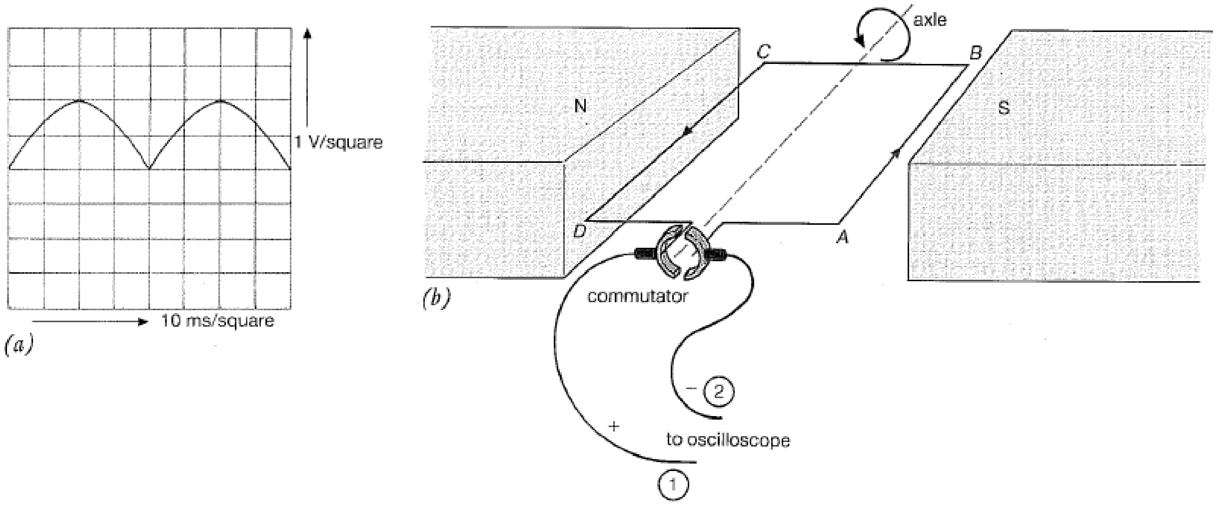


Figure 6.9 The dc generator

Now it does not matter which side, *AB* or *CD,* moves upwards, current will always flow out of one side of the commutator. So direct current is produced.

	Did you know? The dc generator is identical to the dc motor in design. However, a motor is used to turn electrical energy into kinetic energy; whereas the dynamo turns kinetic energy into electrical energy.

6.6 Producing power on a large scale

The electricity that you use in your home is produced by very large generators in power stations. These generators work in a slightly different way from the ones you have seen so far.

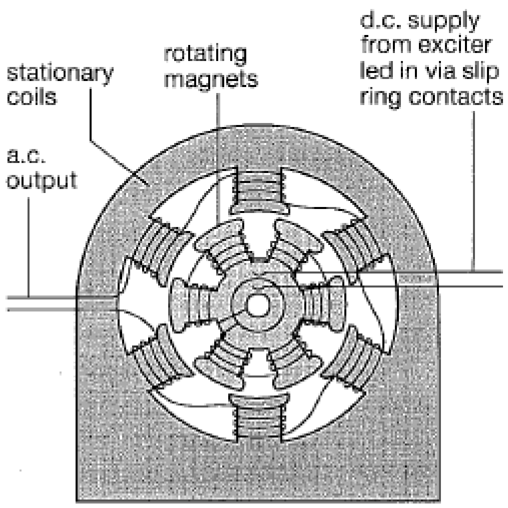


Figure 6.10 A section through a large generator

Instead of having a rotating coil and a stationary magnet, large generators have rotating magnets and stationary coils (see **Figure 6.10**). The advantage of this set-up is that no moving parts are needed to collect the large electrical current that is produced.

The important steps in the generation of electricity in a power station (**Figure 6.11)** are these:

- Coal is burnt to boil water.
- High pressure steam from the boiler is used to tum a turbine.
- The drive shaft from the turbine is connected to the generator magnets, which rotate near to the stationary coils. The output from the coils has a voltage of about 25 000 V.
- The turbine's drive shaft also powers the exciter. The exciter is a direct current generator which produces current for the rotating magnets, which are in fact electromagnets.

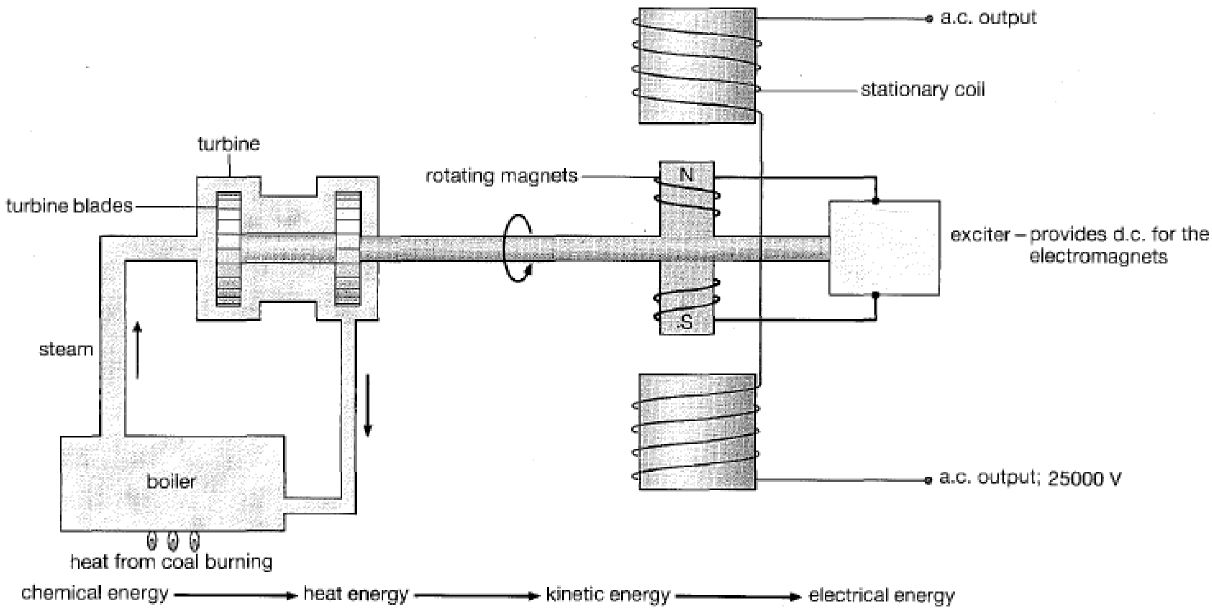


Figure 6.11 Layout of a power station

6.7 Transformers

6.7.1 Mutual inductance

In **Figure 6.12** when the switch is closed in the first circuit, the ammeter in the second circuit kicks to the right. For a moment a current flows through coil 2. When the switch is opened again the ammeter kicks to the left.

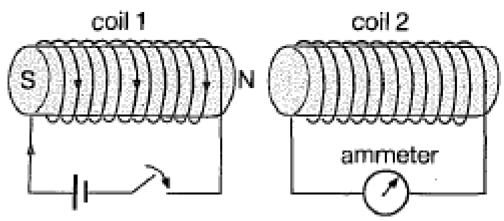


Figure 6.12

Closing the switch makes the current through coil I grow quickly. This makes the coil's magnetic field grow quickly. For coil 2 this is like pushing the north pole of a magnet towards it, so a current is induced in coil 2.

When the switch is opened the magnetic field near coil 2 falls rapidly. This is like pulling a north pole away from coil 2. Now the induced current flows the other way.

The ammeter reads zero when there is a constant current through coil 1. A current is only induced in the second coil by a changing magnetic field. This happens when the switch is opened and closed.

6.7.2 The induction coil

Inside the cylinders of a car's engine, the mixture of air and petrol explodes when it is sparked off by a sparking plug. To make sparks large voltages, about 25 000V, are needed. **Figure 6.13** shows how this is done.

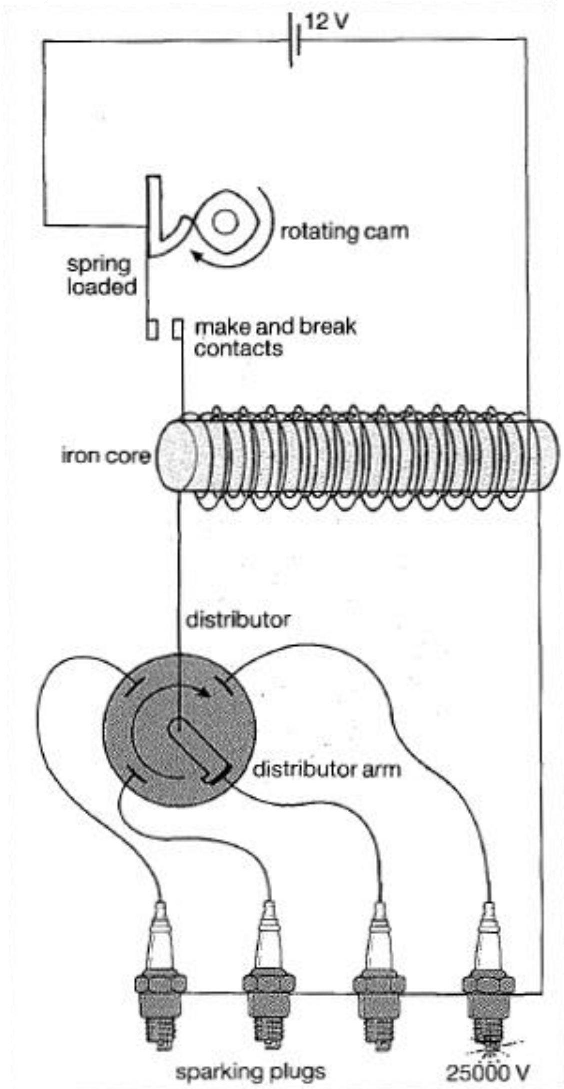


Figure 6.13 An induction coil in a car

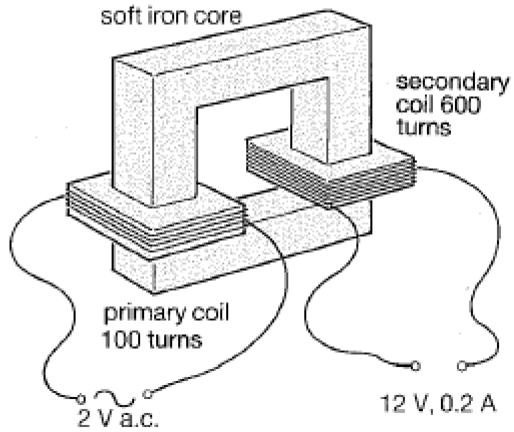
Two solenoids have been wound round an iron core. The red solenoid is connected to the car battery through a pair of make-and-break contacts.

When the circuit is complete there is a current. The iron core becomes magnetised and a strong magnetic field is produced. As the cam rotates the circuit is broken. This causes the magnetic field to fall very rapidly.

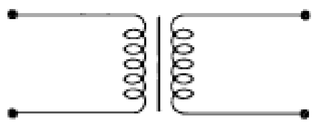
A very large voltage is now induced in the second solenoid, which has a large number of turns. The rotating distributor arm feeds the high voltage to each sparking plug in turn.

6.7.3 The transformer

A transformer is made by putting two coils of wire onto a soft iron core as shown in **Figure 6.14**. The primary coil is connected to a 2 V alternating current supply.



(a) A step-up transformer



(b) The circuit symbol for a transformer

Figure 6.14

The alternating current in the primary coil makes a magnetic field that rises and then falls again. The soft iron core carries this changing magnetic field to the secondary coil.

Now a changing voltage is induced in the secondary coil. In this way, energy can be transferred continuously from the primary circuit to the secondary circuit.

Transformers are useful because they allow you to change the voltage of a supply. For example, model railways have transformers that decrease the mains supply from 240 V to a safe 12 V.

These are step-down transformers. The transformer in **Figure 6.14** steps up the voltage from 2 V to 12 V.

To make a step-up transformer the secondary coil must have more turns of wire in it than the primary. In a step-down transformer the secondary has fewer turns of wire than the primary coil.

The rule for calculating voltages in a transformer is:

$$\frac{V_S}{V_p} = \frac{N_S}{N_p}$$

V_p =primary voltage; V_S = secondary voltage; N_p = number of turns on the primary coil; N_S = number of turns on the secondary.

6.8 Transmitting power

6.8.1 Power in transformers

We use transformers to transfer electrical power from the primary circuit to the secondary circuit. Many transformers do this very efficiently and there is little loss of power in the transformer itself.

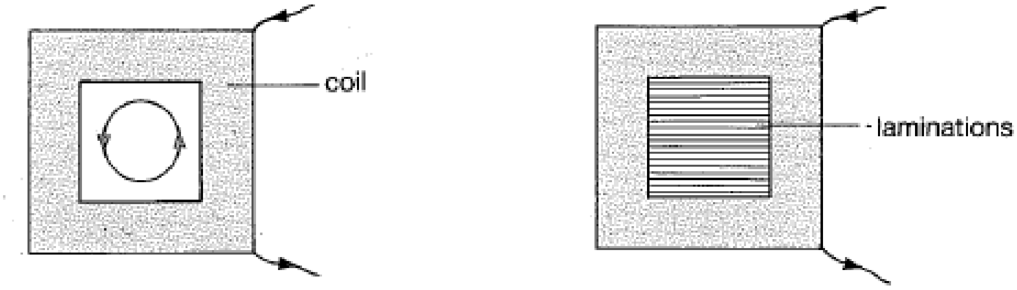
For a transformer that is 100% efficient we can write:

$$\textit{Power supplied by primary circuit} = \textit{Power used in the secondary circuit}$$
$$V_p \times I_p = V_s \times I_s$$

Note:
In practice transformers are not 100% efficient.

These are the most important reasons for transformers losing energy:

- The windings on the coils have a small resistance. So when a current flows through them they heat up a little.
- The iron core conducts electricity. Therefore the changing magnetic field from the coils can induce currents in the iron. These are called eddy currents. To reduce energy lost in this way the core is laminated. This means the core is made out of thin slices of iron with sheets of insulating material between each slice (**Figure 6.15**).
- Energy is lost if some of the magnetic field from the primary coil does not pass through the secondary coil.
- Energy is also used to switch the direction of the domains in the iron core, 50 times each second. This can be done easily in the iron, so energy losses are small.



(a) Eddy currents flow in an unlaminated core   *(b) Laminations help to stop eddy currents flowing*

Figure 6.15

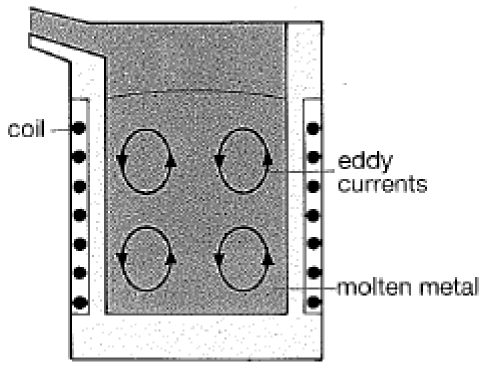


Figure 6.16

An induction furnace, which puts eddy currents to good use. In this furnace, scrap metal is melted down for re-use. The heating is due to eddy currents that are induced in the metal itself These are induced by an alternating current flowing through a coil on the outside of the furnace

6.8.2 The national grid

You may have seen a sign at the bottom of an electricity pylon saying 'Danger high voltage'. Power is transmitted around the country at voltages as high as 400 000 V. There is a very good reason for this - it saves a lot of energy. The calculations shown in **Worked Example 6.3** explain why.

Worked Example 6.3

Figure 6.17 suggests two ways of transmitting 25 MW of power from a power station to the country:

(a) The 25 000 V supply from the power station could be used to send 1000 A down the power cables.

(b) The voltage could be stepped up to 25 0 000 V and 100 A could be sent along the cables.

How much power would be wasted in heating the cables in each case, given that 200 km of cable has a resistance of 10 Ω?

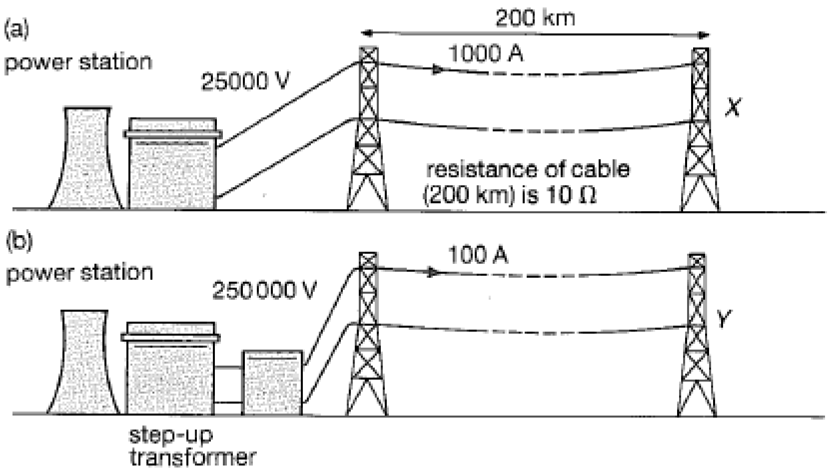


Figure 6.17

Solution:

(a) $Power\ lost = voltage\ drop\ along\ cable \times current$

$= IR \times I$

$= I^2R$

$= (1000)^2 \times 10$

$= 10\ 000\ 000\ W$ or $10\ MW$

(b) $Power\ lost = I^2R$

$= (100)^2 \times 10$

$= 100\ 000\ W$ or $0{,}1\ MW$

A lot less power is wasted in the second case. The power loss is proportional to the square of the current.

Transmitting power at high voltages allows smaller currents to flow along our overhead power lines.

Figure 6.18 shows how electricity is generated at a power station, and how it is distributed around the country through the national grid.

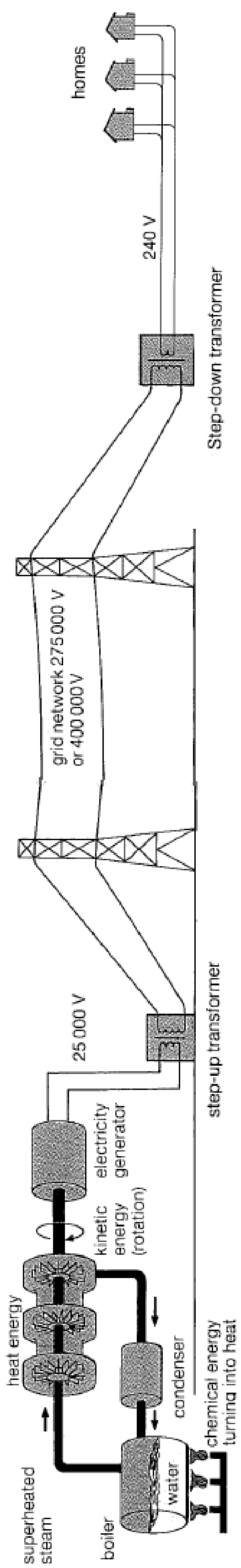


Figure 6.18 How the power gets to your home

Activity 6.1

1. Name two advantages of a digital- multi-meter over an analogue multi-meter and *three* uses thereof.
2. A moving coil meter has a full-scale deflection of 10 mA and an internal resistance of 200 Ω.
   Draw the circuit diagram and calculate the value of the multiplier resistor that would enable the meter to measure 20 V.
3. Mention *three* precautions to be taken when using an ohmmeter.
4. A meter has a full scale deflection of 15mA and an internal resistance of 150Ω. Calculate:
   (a) Value of the multiplier resistor to measure a full scale voltage of 200V.
   (b) Draw and label the circuit.

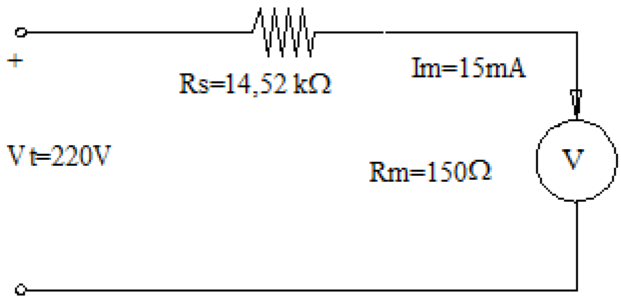


Figure 6.19

5. A current of 45A must be measured. The meter has a internal resistance 150Ω and a scale deflection of 20mA.
   Calculate:
   (a) The value of the shunt resistor.
   (b) The value of the current through the shunt.
   (c) Draw the circuit.

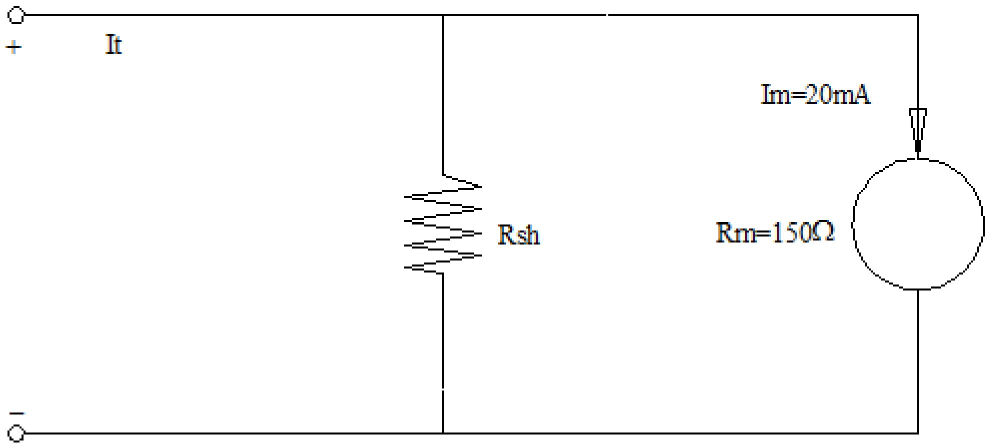


Figure 6.20

6.
   (a) Copy **Figure 6.9b** and mark on the graph the places where the coil is:
   (i) horizontal, (ii) vertical.
   (b) On the same graph show how the voltage appears when the coil is

rotated in the opposite direction: (i) at the same speed, (ii) at twice the speed.

7. In **Figure 6.21** the dynamo is connected to a flywheel by a drive belt. The dynamo is operated by winding the handle. When Surindra turns the handle as fast as she can, the dynamo produces a voltage of 6 V. The graph shows how long the dynamo takes to stop after Surindra stops winding the handle. The time taken to stop depends on how many bulbs are connected to the dynamo.
   (a) Explain the energy changes that occur after Surindra stops winding the handle: (i) when the switches S_1, S_2 and S_3 are open (as shown), (ii) when the switches are closed.
   (b) Why does the flywheel take longer to stop when no light bulbs are being lit by the dynamo?
   (c) Make a copy of the graph. Use your graph to predict how long the flywheel turns when you make it light 4 bulbs.
   (d) The experiment is repeated using the bulbs that use a smaller current. They use 0,15 A rather than 0,3 A. Using the same axes, sketch a graph to show how the running time of the dynamo depends on the number of bulbs, in this second case.

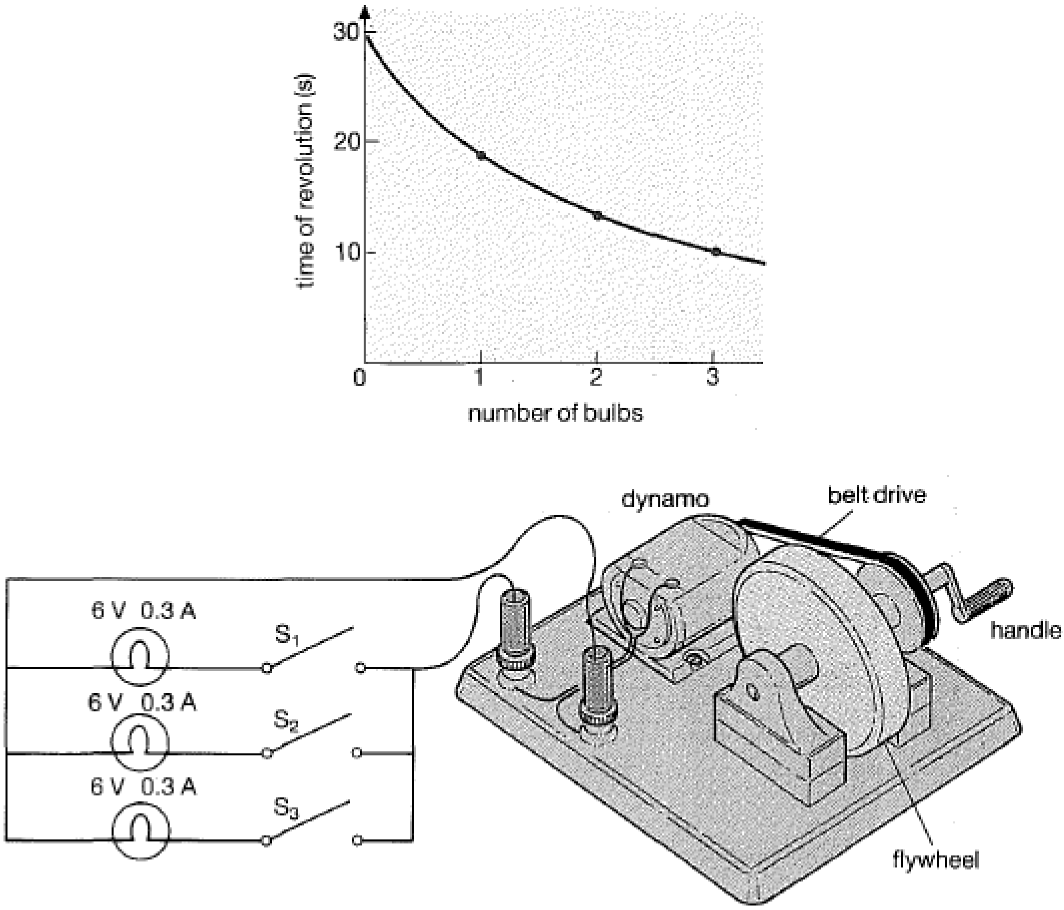


Figure 6.21

Activity 6.2

1.
   (a) In **Figure 6.12** when the switch is opened the ammeter kicks to the left. Describe what happens to the ammeter during each of the following (i) the switch is closed and left closed so that a current flows through coil1, (ii) the coils are now pushed towards each other, (iii) the coils are left close together, (iv) the coils are pulled apart.
   (b) The battery is replaced by an ac voltage supply which has a frequency of 2 Hz. What will the ammeter show when S is closed?
2.
   (a) Explain why the black solenoid in **Figure 6.13** must have such a large number of turns.
   (b) Will the car still work if the black circuit is connected to the battery, and the red solenoid to the distributor?
3. Explain why a transformer does not work when you plug in the primary to a battery.
4. The question refers to **Figure 6.14**.
   (a) What power is used in the secondary circuit?
   (b) Explain why the smallest current that can be flowing in the primary circuit is 1,2 A
   (c) Why is the primary current likely to be a little larger than 1,2 A?
5. **Table 6.1** gives some data about 4 transformers. Copy the table and fill the gaps.

Primary turns	Secondary turns	Primary voltage (V)	Secondary voltage (V)	Step-up or step-down
100	20		3	
400	10 000	10		
	50	240	12	
	5 000	33 000	11 000	

Table 6.1

6. This is about how a transformer could be used to melt a nail. You will need to use the following date: (i) the nail has a resistance of 0,02 Ω; (ii) the melting point of the nail is 1 540 ºC; (iii) the nail needs 10 J to warm it through 1ºC.
   (a) Calculate the voltage across the nail.

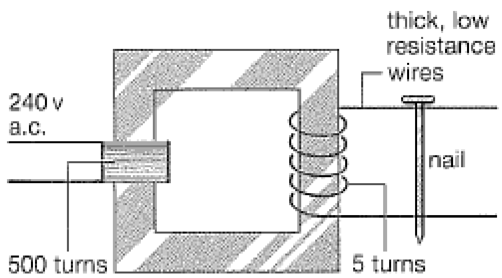


Figure 6.22

(b) Calculate the current flowing in:

(i) the secondary circuit,
(ii) the primary circuit.

(c) Calculate the rate at which power is used in the secondary circuit to heat the nail.
(d) Estimate roughly how long it will take the nail to melt. Mention any assumptions or approximations that you make in this calculation.
(e) Explain how a transformer can be used to produce high currents for welding.

7. Explain why the electricity supply in your home is ac rather than dc.
8. Use the data in **Figure 6.17** to calculate the voltage at each of the points X and Y.
9. The data in the table below was obtained using samples of copper, aluminium and steel wires. Each wire was 100 m long and had a diameter of 2 mm. Use this data to explain why our overhead power cables are made out of aluminium with a steel core.

Material	Resistance (Ω)	Force needed to break wire	Density in kg/m^3	Cost of wire
Copper	2,2 Ω	320 N	8 900	R5 660,00
Aluminium	3,2 Ω	160 N	2 700	R1 600,00
Steel	127 Ω	1 600 N	9 000	R140,00

Table 6.2

Self-Check

I am able to:	**Yes**	**No**
• Describe the principle of operation of moving coil measuring instruments		
o Ammeter		
o Voltmeter		
o Wattmeter		
o Galvanometer		
• Describe the basic principle of ac and dc generators		
o The principle of operation of the single phase transformer		

If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 7

Sound

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the production of sound
  - Simple harmonic motion
  - Transversal and longitudinal waves
  - Reflection
  - Refraction and interference
  - Determination of speed, frequency and period

7.1 Introduction

When you pluck a guitar string the instrument makes a noise. If you put your finger on the string you can feel the string vibrating. Sounds are made when something vibrates. The vibrations of a guitar string pass on kinetic energy to the air. This makes the air vibrate.

Sound is a longitudinal wave. Molecules in air move backwards and forwards along the direction the sound travels in.

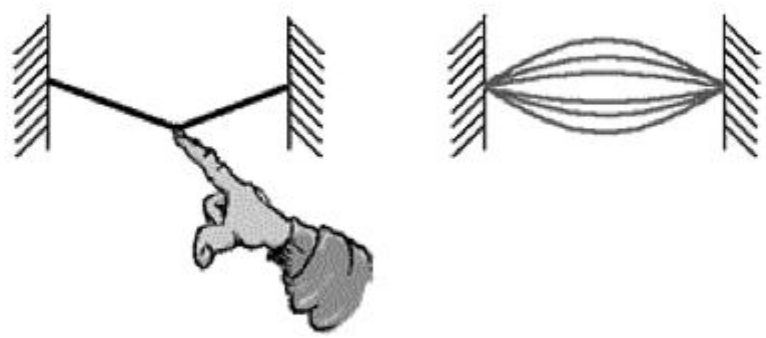


Figure 7.1 Vibrating guitar string

When the guitar string moves to the right it compresses the air on the right hand side of it.

When the string moves to the left the air on the right expands. The string produces a series of compressions and decompressions.

Note:
In a compression the air pressure is greater than normal atmospheric pressure. In a decompression the air pressure is less than normal atmospheric pressure.

Compressions and decompressions travel through air in the same way that compressions will move along a slinky. Your ear detects the changes in pressure caused by sound waves. When a compression reaches the ear it pushes the ear drum inwards.

When a decompression arrives, the ear drum moves out again. The movements of the ear drum are transmitted through the ear by bones. Then nerves transmit electrical pulses to the brain.

Definition: Pulse
A single disturbance in a medium.

7.2 Properties of waves

Waves are disturbances that travel through substances such as water and air. They are periodic movements, and we can describe them as vibrations or oscillations.

Definition: Oscillations
A frequent regular change between two amounts or between two limits.

A wave caused by moving a rope quickly and sharply to the right by 15 cm and then bringing it back to its start position consists of a to-and-fro movement, called a vibration. In this case only one disturbance or pulse travelled through the rope.

We say that a pulse moves through a medium. In this case, the medium is the rope. Pulses and waves can move through many other kinds of media such as air and water.

Definition: Medium
A substance through which something else is carried, or in which some effect is produced. The plural is media.

Note:
A wave travels through a medium, but does not take the medium with it.

An oscillation is also a form of periodic motion. We can describe it by looking at an alternating electrical current. This current travels in one direction, and then the other, changing regularly.

Think about it!
Vibrations are often used in everyday life. For example, soil compacters use vibrations to compact the soil when building roads. Ultrasonic waves are used to break up kidney stones.

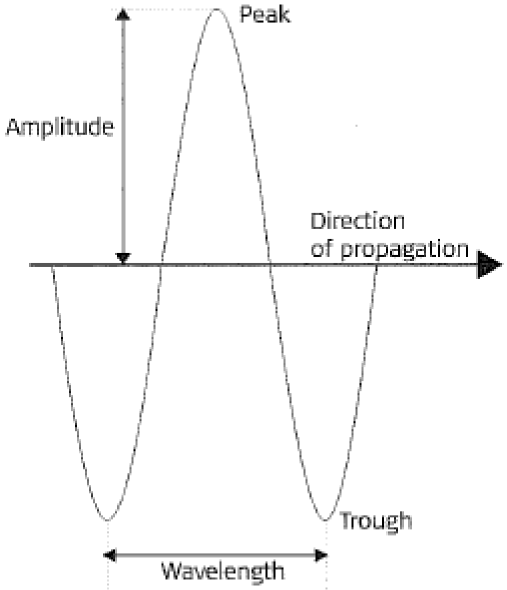


Figure 7.2 Several oscillations of a wave

Table 7.1 lists some of the terms in **Figure 7.2**.

Term	Definition
Equilibrium or rest position	The position of the medium before and after the wave has passed through it. This is a position of rest because it applies when no wave is moving through the medium.
Peak or crest	The highest point that the wave reaches as it moves through the medium.
Trough	The lowest point that the wave reaches as it moves through the medium.
Wavelength	The distance between any two corresponding points on the wave.
Amplitude	The distance from the equilibrium position of the wave to the peak of the wave, or from the equilib1ium position to the trough.

Table 7.1 The properties of waves

7.2.1 Period

We've said that a wave moves through a medium without *permanently* moving the medium itself. The wave moves on, but the medium's particles return to their original position. This is called a periodic movement. So the period of a wave should have something to do with time. The period of a wave is the time for one complete disturbance or cycle. The period of a wave is measured in seconds. The symbol for period is T.

7.2.2 Frequency

The frequency and period of a wave are linked very closely. Frequency is also related to time. Frequency is the number of peaks or troughs of a wave that pass a point in one second. It is measured in Hertz (Hz) The symbol for frequency is f.

	Definition: Frequency The number of waves per second.

If a wave has a frequency of 2 Hz, two full waves pass a point in one second. So 1 Hz is one wave or cycle per second.

If ten waves pass a point in one second, the frequency of each wave is 10 Hz. And if ten waves pass a point in one second, one wave will pass in $\frac{1}{10}$ of a second. So, if the frequency of a wave is 10 Hz, the period of the wave is $\frac{1}{10}s$. This is called an inverse relationship.

	Definition: Inverse relationship One variable gets bigger as the other variable becomes smaller.

We express this inverse relationship as:

$$frequency \ = \frac{1}{period}$$

The symbols for this relationship are:

$$f \ = \frac{1}{T}$$

7.2.3 Amplitude

The amplitude of a wave is the distance between the equilibrium position of the wave to the peak of the wave, or the distance from the equilibrium position of the wave to the trough of the wave.

Look at **Figure 7.2** again to check that you understand what the amplitude is.

	Definition: Amplitude The size of the wave.

7.2.4 Wavelength

You measure the wavelength of a wave by measuring the distance between one peak and the next peak as shown in **Figure 7.3**. You can also use the distance between one trough and the next to measure wavelength. The symbol for wavelength is the Greek letter lambda (λ).

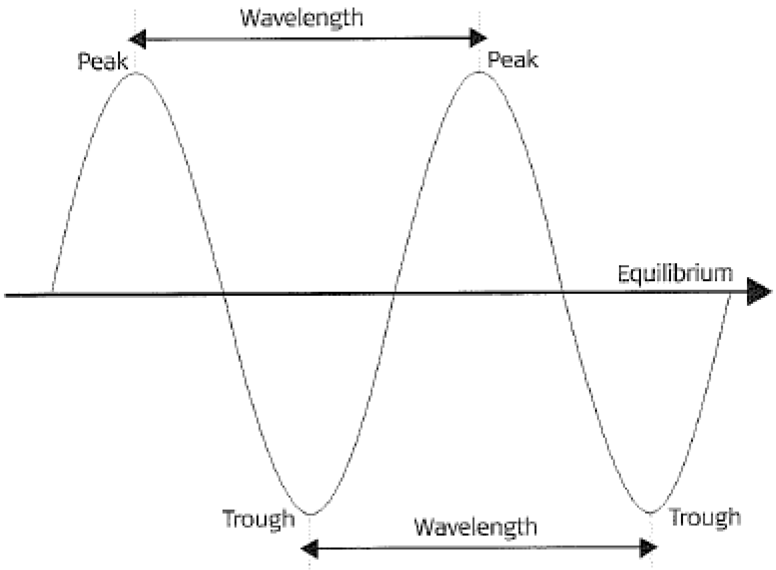


Figure 7.3 How to measure the wavelength

You can see that wavelength and amplitude tell us about the distance that a wave travels, and that period and frequency tell us about the time the wave takes to travel that distance.

7.2.5 Waves in everyday life

There are waves all around us, but we most kinds of waves are invisible to us.

Radio waves have very low frequencies and long wavelengths, while gamma rays have very high frequencies and extremely short wavelengths. Look at the examples of different types of waves in **Table 7.2**.

Type of wave	Example of where these waves are found
Power waves	Electrical currents, electrical circuits
AM radio waves	Radios
FM radio waves	Radios
TV radio waves	TVs
Microwaves	Special vacuum tubes
Infrared light	Warm and hot bodies
Visible light	The sun and lamps
Ultraviolet light	Very hot bodies and special lamps
X-rays	High-speed electron collisions and atomic processes
Gamma rays	Nuclear reactions
Sound waves	Radios and CD players

Table 7.2 Different types of waves

7.3 Nature of waves

We use the shape of the wave created by the pulse to study the properties of waves. The rope mentioned earlier, returned to a straight line after the pulse had moved through it. This kind of wave is a disturbance that travels through a medium without taking the medium with it as it moves.

Definition: Properties
Characteristics or features of something, or all the parts of an object that we can use to describe it.

Think about how a surfer floating on the water beyond the break zone moves up and down as the waves move underneath her. She does not move towards the beach with the wave unless she is surfing the wave.

This is because the motion of the water particles is up and down while the motion (and the energy of the wave) is forward towards the beach. So even though the wave moves towards the beach, the water particles that make up the wave only go up and down until the wave breaks on the beach.

Did you know?

Have you ever heard of a supersonic aircraft, or of something breaking the sound barrier? These concepts have to do with waves, because sound travels in waves.

A sonic boom is the very loud noise that jet aircraft make as they begin to travel faster than the speed of sound. If the sonic boom happens close enough to the ground, the sound it makes is so loud that it can break windows.

When an aircraft goes faster than the speed of sound, we say it breaks the sound barrier, or it flies at supersonic speed. This speed is known as Mach 1 and is approximately 1 225 kilometres per hour.

Perhaps you've seen the way a ship forms a wave in front of it and behind it as it moves through the water. Aircraft do the same thing as they fly.

The forward motion of the aircraft creates pressure waves .in front of the aircraft and also behind it. The faster the aircraft flies, the faster the pressure waves travel ahead of the aircraft's nose.

When an aircraft reaches the speed of sound, the pressure waves cannot move quickly enough to flow past the aircraft.

The plane is crashing into its own sound waves, because it is now travelling faster than they can. They all bunch up and compress in front of the aircraft until they join up to form one single shock wave that travels at the speed of sound.

When the shock wave reaches the speed of sound, we hear a loud noise - the sonic boom. There are actually two booms in a sonic boom. We hear the first boom when the nose of the aircraft passes the shock wave. Then we hear the second boom when the tail of the aircraft passes the shockwave.

7.4 Transversal and longitudinal waves

Earlier, we looked at how a wave travels along a rope. This is a transversal wave. Certain kinds of waves are transversal waves, while others are called longitudinal waves.

Definition: Transversal waves
Where the medium's particles move at right angles to the direction of the wave.

7.4.1 Transversal waves

The wave created when moving the rope caused the wave to move at right angles to the transmission of the pulse.

In other words, each particle in the rope moved at a 90° angle to the direction of the pulse. The pulse travelled from one to the other end of the rope, but the rope itself went up and down. A wave that does this is called a transversal wave. Light waves and radio waves are examples of transverse waves.

7.4.2 Longitudinal waves

A slinky is a long spring made of lots of coils. You can stretch it out so that the coils are wide apart and the spring is very long. Or you can compress it so that the coils are very close together and the spring is very short.

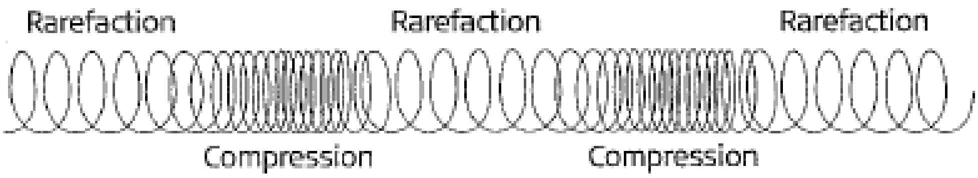


Figure 7.4 Longitudinal waves in a slinky

The areas where the slinky's coils are close together are called compressions, while, the areas where the slinky's coils are far apart are called rarefactions.

Definition: Longitudinal waves
The medium moves back and forth in the same or opposite direction to the wave.

This wave is moving in the same direction as the direction in which the slinky is stretched out. Such waves are called longitudinal waves. Sound waves are longitudinal waves.

7.4.3 Differences between transversal and longitudinal waves

We said that in transversal waves the particles move at 90° to the direction of motion of the wave. However, in longitudinal waves the particles move in the same direction or opposite direction as the direction of motion of the wave.

Transverse waves such as light can travel through outer space, where there is no air or other particles. However, longitudinal waves, such as sound waves, need a medium of a gas, liquid or solid to propagate them. So if you floated in outer space, you would not hear anything.

⚠	**Note:** Outer space is an example of a vacuum, a space that does not contain any matter.

7.5 Displacement position graph

Let's look at how we can use graphs to show the differences between transversal and longitudinal waves.

Look at **Figure 7.5**. The first part of the diagram shows two transversal waves.

When the transversal wave moves through a medium, we can represent the medium as being displaced along the vertical axis of a graph and returning to its original positions, while the wave's motion can be represented as movement along the horizontal axis and along the vertical axis.

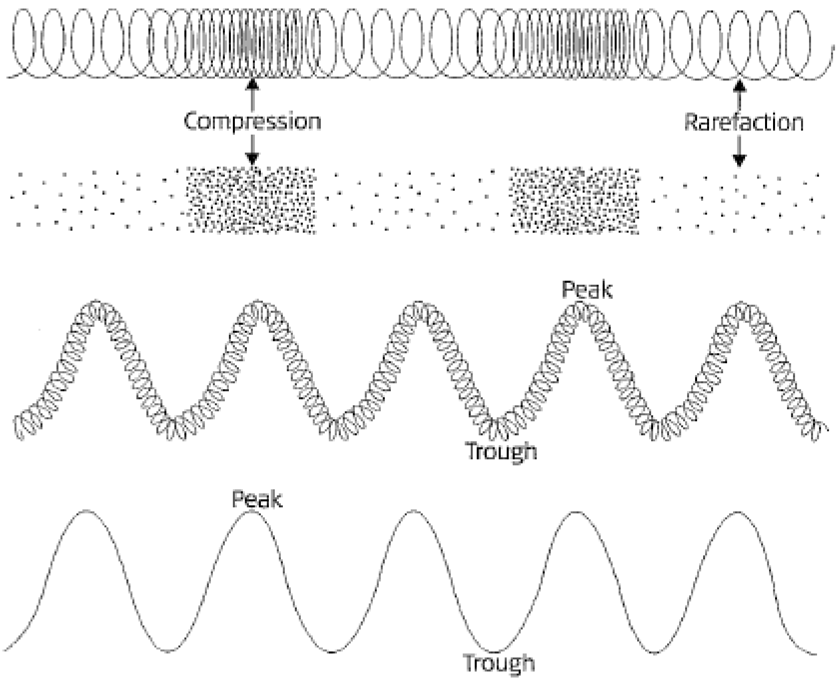


Figure 7.5 Transversal and longitudinal waves

Now look at the second part of the diagram. These two illustrations show what longitudinal waves look like.

The first one shows a longitudinal wave moving through a slinky. This is a picture of what happens when you move your hand forward and back while you hold the slinky stretched out on a desk.

The second illustration shows you the same kind of wave moving through the air. This could be a sound wave, or the particles of gas that move through the air during an explosion.

Look at the labels on the longitudinal wave illustrations. Can you see that the media for both of these waves are moving along the same axis as the wave itself is moving along? And can you see the areas of compression, which are the areas where the coils of the slinky or the particles of the air are very close together?

Note:
When a longitudinal wave travels through a medium, we can represent the motion of the wave as moving along the horizontal axis of a graph. Then the particles of the medium also move along the horizontal axis and back again to their original position.

7.6 Calculations for a transversal wave

Most people have tuned a radio to a certain frequency to listen to a programme. So we know a little about the different frequencies of radio waves. We can use calculations to find how fast the waves travel and also their length.

7.6.1 Wave speed

When we calculate wave speed, we work out what distance in metres each part of the wave travels in 1 second, in other words metres per second.

The equation for calculating wave speed is:

$$v = \frac{distance}{time}$$

where v is the wave speed and the distance is given in metres and the time in seconds.

In waves, distance is the wavelength, and time is the period (or time taken for one wavelength). So,

$$v = \frac{\lambda}{T}$$

where λ is the wavelength and T is the period. Another way of expressing this equation is:

$$v = \lambda f$$

because

$$f = \frac{1}{T}$$

Let's look at an example of how to calculate wave speed using this equation.

Worked Example 7.1

Suppose that the period of a wave is 0,02 s. What is the wave speed if the wavelength is 12 cm?

Remember that you must convert the wavelength into an SI unit before you calculate the wave speed.

Solution:

$v = \lambda f$

$f = \frac{-1}{0{,}02} s$ because $f = \frac{1}{T}$

So f = 50 Hz

This means that

v = 50 Hz x 0,12 m (remember that 12 cm = 0,12 m)

= 6 m.s^{-1}

We could also have used the equation:

$v = \frac{\lambda}{T}$

thus $v = \frac{0{,}12}{0{,}02}$

= 6 m.s^{-1}

7.6.2 Wavelength

To calculate wavelength, you have to change the subject of the equation.

Worked Example 7.2

Suppose in the **Worked Example 7.1** you were asked to calculate the wavelength of a wave with a period of 0,02 s and a wave speed of 6 m.s^{-1}.

For this calculation, you know that f =50 Hz and v = 6 m.s^{-1}. So you can calculate λ as follows:

Solution:

$v = \lambda f$

$\lambda = \frac{v}{f}$

$= \frac{6 m,s^{-1}}{50\ Hz}$

= 0,12 m

7.6.3 Calculating frequency and period

You can also use this method to calculate frequency and period.

Worked Example 7.3

If you were given a wave speed of 6 m.s^{-1} and a wavelength of 0,12 m, how would you calculate the frequency and the period?

Solution:

$v = \lambda f$

$f = \frac{v}{\lambda}$

$= \frac{6}{0,12}$

= 50 Hz

We know that the period is $\frac{1}{f}$, which equals $\frac{1}{50} = 0{,}02.$

So $T = 0{,}02.$

Think about it!

What do you think will make a wave speed up or slow down? The medium the wave is travelling through has an effect on this wave speed.

7.6.4 Density

Think about dropping a stone into clean water. The ripples from the stone spread quickly throughout the water because the wave is travelling fast.

Now think about dropping the stone into thick, muddy water. The ripples will move a lot more slowly. The medium has changed from pure water to muddy water, which means it has become denser.

Therefore, the density of the medium affects wave speed.

Note:

The greater the density of the medium, the slower the wave speed in that medium.

7.6.5 Compressibility

Now look at the data in **Table 7.3**.

Medium	Speed of sound
Steel	$5,1 \times 10^3$ m.s^{-1}
Water	$1,4 \times 10^3$ m.s^{-1}
Air	$3,4 \times 10^2$ m.s^{-1}

Table 6.3 Speed of sound in different media

This shows that sound travels much faster in steel than in air. How much a medium can be compressed, or its particles squashed together, also affects the speed at which sound waves can travel through it.

> **Note:**
> Sound waves can travel faster through solids, which are difficult to compress. Liquids lie in between, while the wave speed is lowest in gases, which are easy to compress.

7.6.6 Depth

Depth is the third factor that affects wave speed. As waves in the sea enter shallow water, the wavelength gets shorter but the frequency remains the same. This means that waves slow down as they enter shallow water.

7.7 Standing and moving waves

A moving wave was created a transverse wave moved along a rope, and a longitudinal wave moved along a slinky.

Standing waves look different. They get their name because it looks as though they are not moving at all, but are standing still. But they are actually constantly moving sets of waves formed when a wave, moving in one direction, is met by another wave moving in the opposite direction.

> **Definition: Standing wave**
> These waves form when a wave is met by another wave going the opposite way.

They can also be formed if the medium they are travelling in is moving in the opposite direction to the wave. Look at **Figure 7.6** where two waves are moving in opposite directions.

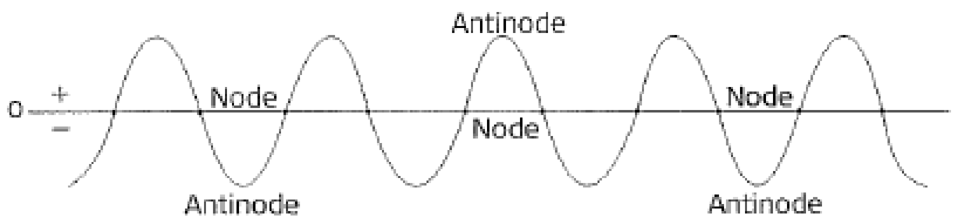


Figure 7.6 A standing wave

The place where the peak of one wave meets the trough of another wave is called a node. You can see **Figure 7.6** that the amplitude at the nodes is 0.

We find antinodes at the points where the amplitude is the greatest. This happens when the peak of one wave meets the peak of another one or when the troughs of two different waves meet. This is called superposition.

Definition: Superposition
When one wave is placed exactly on top of another.

7.7.1 Superposition in standing waves
In real life, waves hardly ever happen on their own, and they often affect each other through superposition.

Think, for example, about water from a tap dripping into a bucket. Each time a drop of water lands in the bucket, ripples or waves move from the place where the drop landed outwards to the edges of the bucket.

When the waves reach the edges of the bucket, they have to change their direction because they cannot go any further.

Some of the waves then bounce back. These waves then hit other waves that are still approaching the side of the bucket. These bounces and crashes cause interference as illustrated in **Figure 7.7**.

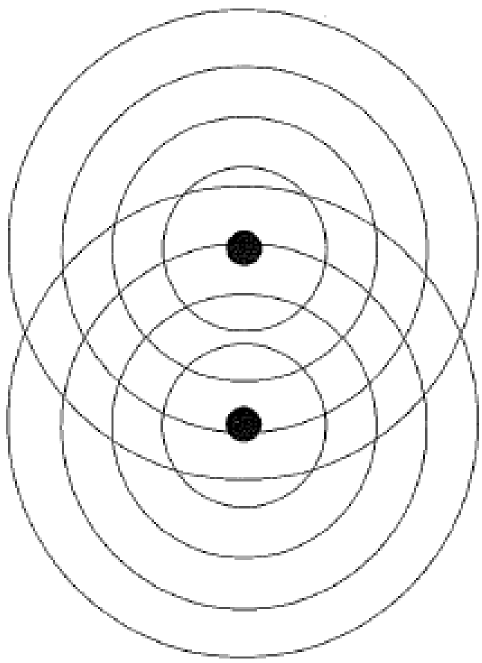


Figure 7.7 Interference

Interference happens because the edge of the bucket reflects the waves towards the centre of the bucket. The original wave is called the incident wave and the wave that bounces back is called the reflected wave.

Definition: Interference
When waves met each other and interact.

Together they can make a standing wave as in **Figure 7.6**.

Have you ever been on the beach when one wave catches up with another wave to form a single very big wave? This is also an example of superposition.

When one wave catches up with another wave, many different things can happen, depending on when they meet.

Three of these cases are shown in **Figure 7.8**:

- The peaks of both of the waves meet.
- The troughs of both of the waves meet.
- The peak of one wave can meet the trough of another wave.

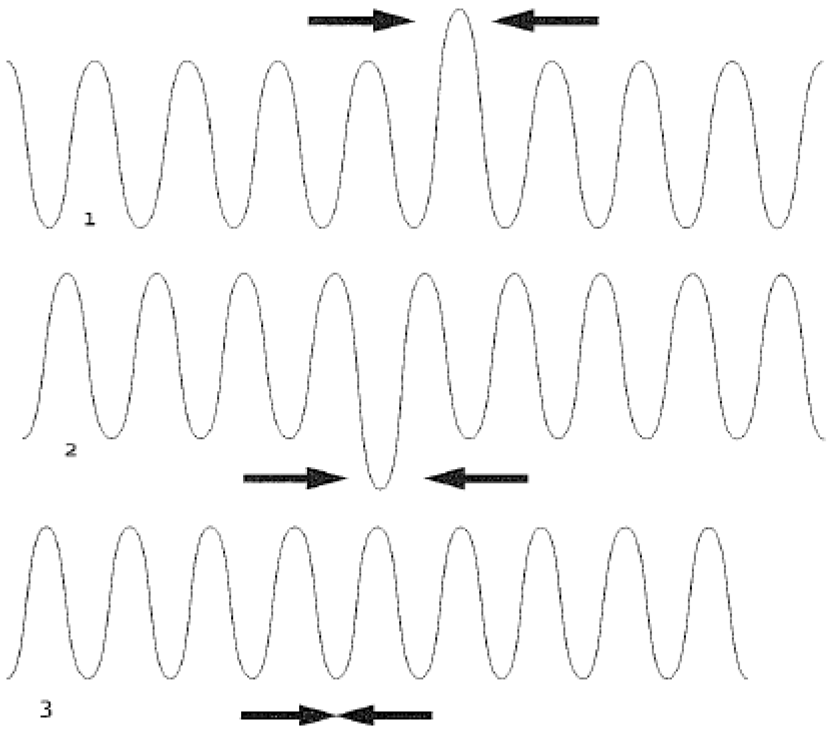


Figure 7.8 Three different types of interference

In Case 1, the peaks will join to increase the amplitude of the wave.

In Case 2, the troughs will join. This will also increase the amplitude of the wave.

In Case 3, a peak and a trough meeting has the same effect as adding a positive number to an equal negative number. The waves will tend to cancel each other out.

In Cases 1 and 2, we say that the interference has been constructive because the amplitude has increased.

In Case 3, the interference is destructive because the amplitude has been reduced.

Activity 7.1

1. What is the relationship between period and frequency?
2. Explain the difference between a pulse and a wave motion.
3. Explain and give a practical example of the term equilibrium position.
4. Which type of waves consists of:
   (a) compressions and rarefactions, and
   (b) wave troughs and wave crests?
   Give an example of each.
5. A red ribbon is tied to one coil of a slinky. Describe how the ribbon will move if:
   (a) a longitudinal wave, and
   (b) a transverse wave is generated in the slinky.
6. Define the following:
   (a) amplitude, and
   (b) wavelength.
7. Draw a simple transverse wave and indicate the following on the wave:
   (a) amplitude,
   (b) wavelength,
   (c) direction of propagation,
   (d) peak, and
   (e) trough.
8. Write down the relationship between wavelength, frequency and wave speed. Say what each symbol represents and in what unit each one would be measured.
9. Waves are produced in the water in a dam at a rate of 25 waves every 10 seconds. Calculate the:
   (a) frequency,
   (b) period, and
   (c) the speed of the waves, if the wavelength is 0,5 m.
10. Waves are generated along a spring with a frequency of 5 Hz, and a speed of 20 m/s. Calculate the wavelength of this wave.
11. The period of a wave is 0,2 s. If the speed of the wave is 8 m/s calculate the:
    (a) frequency, and
    (b) wavelength.

Self-Check

I am able to:	Yes	No
• Describe the production of sound		
o Simple harmonic motion		
o Transversal and longitudinal waves		
o Reflection		
o Refraction and interference		
o Determination of speed, frequency and period		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Past Examination Papers

higher education & training

Department: Higher Education and Training
REPUBLIC OF SOUTH AFRICA

APRIL 2015

NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

(15070115)

7 April 2015 (Y-Paper)
13:00 – 16:00

This question paper consists of 6 pages and a formula sheet of 2 pages

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

QUESTION 1

1.1 Explain and show with a sketch why

1.1.1 some liquids wet their container and others not. (2)

1.1.2 a needle can float on water. (4)

1.1.3 Calculate further the surface tension of a liquid if it is given that the liquid rises 62 mm high in a tube with an inner diameter of 0,25 mm. The density of the liquid is 750 kg/m³ and the liquid has a contact angle of 15° with the glass. (2)

1.2 Define osmosis. Calculate further the density of a liquid that has an osmotic pressure of 1, 76 kPa and rises 140 mm high in a funnel. (4)

1.3 Calculate the height that water will rise at 20ºC between two glass plates due to capillary forces, if the glass plates are 380 mm long and 1,8 mm spaced. (4)

1.4 Calculate the distance a man of 600 N must be from earth to have only a weight of 200 N. (4)

[20]

QUESTION 2

2.1 A partitioned container holding nitrogen contains 60 litres at a pressure of 14 kPa meter pressure. If the capacity is enlarged by removing the partition the pressure drops to 9 kPa meter pressure.

Calculate the increase in the size of the container. (4)

2.2 A cylinder contains 0,3 m³ gas at a pressure of 80 kPa and 30 ºC. The gas is compressed to a pressure of 188 kPa. If Cp = 0,14 kJ/kgºC and Cv = 0,084 kJ/kgºC

Calculate

2.2.1 the mass of gas in the cylinder

2.2.2 the final volume if the gas is compressed adiabatically

2.2.3 the final volume if the gas is compressed according to Boyle's law

2.2.4 the average velocity of one molecule of the gas at the original conditions (4 x 2) (8)

2.3 A solar panel consists of a 400 mm copper tube with an external diameter of 25 mm. It is painted black and inside a glass box at 60 ºC. The solar panel is connected to a 200 L geyser at 10 ºC. If there is circulation between the solar panel and geyser, then calculate the time that the solar panel will take to heat the water of the geyser to 50 ºC. Assume that the sun is shining perpendicular on the water pipes of the solar heater and half of the area of the pipes all the time. (8)

[20]

QUESTION 3

3.1 Draw a sketch of fundamental tones as well as first overtones in an open tube. (4)

Also give the wavelengths of the waves.

3.2 A tuning fork of 200 Hz, a string of 0, 75 m length with a mass of 1 g and a tube open on both ends, is resonating at 0 °C. (7)

Calculate:

3.2.1 the pulling force in the string

3.2.2 the length of the open tube, if the tube is forming fundamental tones

3.3 A copper rod is clamped in its middle and struck, thus producing a sound. The density of copper is 8 200 kg/m³ and Young's modulus for electricity E = 8 x 10^{10}N/m². (9)

Calculate:

3.3.1 the velocity of the sound produced in the rod

3.3.2 the frequency of the waves produced if the rod is 600 mm long

3.3.3 the number of beats that will be heard if a similar rod of 602 mm long is simultaneously hit

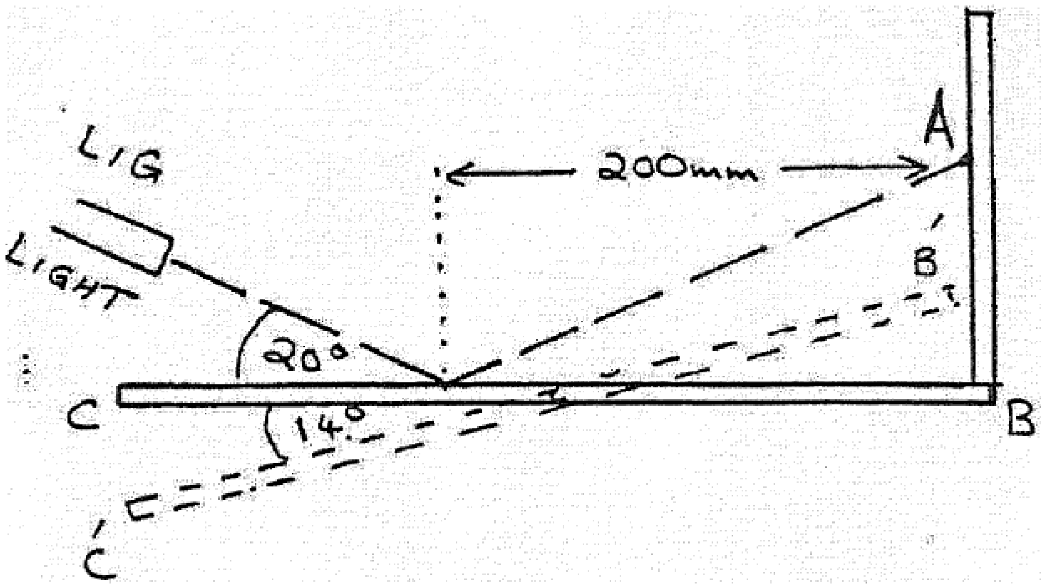
(3 x 3)

[20]

QUESTION 4

4.1 Sketch the THREE images that are formed if an object is placed in front of two rectangular mirrors. (3)

4.2 Calculate the distance from surface BC that the light beam A will be I f the mirror BC is turned through 14º as shown in the sketch below. (3)



4.3 Sketch the images that are formed when an object B is on the following distance from a concave mirror:

4.3.1 further than the radius of curvature C

4.3.2 on the radius of curvature C

4.3.3 between the radius of curvature C and the focal point F

4.3.4 on the focal point F

4.3.5 nearer than the focal point F (5 x 2) (10)

4.4 A concave mirror has a focal point of 40 mm

4.4.1 What will the image distance be if the object is 30 mm from the mirror?

4.4.2 What will the enlargement be if the object is 20 mm from the mirror?

4.4.3 Where must the object be placed to given an enlargement of 5? (3 x 2) (6)

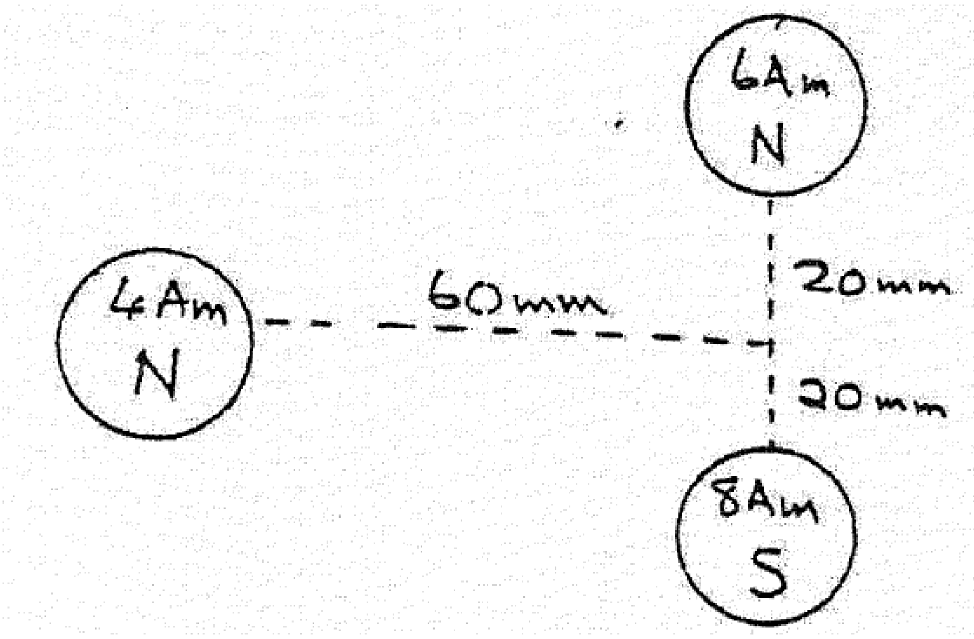
[22]

QUESTION 5

5.1 Describe polarisation of light and give THREE ways to polarise light. (4)

5.2 A floating north pole of 4 Am is in the influence of a fixed north and south pole of 6 Am and 8 Am respectively as shown in the sketch.

Calculate the direction the floating north pole will go initially. (5)



5.3 Draw a sketch of a moving coil ammeter. Also give FOUR methods to make the ammeter more sensitive. (6)

5.4 Calculate the shunt resistance Ro that must be used in a galvanometer of 80 ohm resistance and which can handle a current of 5 mA, to measure up to 220 V and 10 A. (3)

[18]

TOTAL: 100

ENGINEERING PHYSICS N5

FORMULA SHEET

Any applicable formula may be used.

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \frac{\mu_0 I}{2r}$$

$$B = \frac{\mu_0 NI}{2r}$$

$$B = \frac{\mu_0 NI}{L}$$

$$B = \frac{\phi}{A}$$

$$\phi = B\ A \sin\theta$$

$$E = \frac{I\cos\theta}{r^2}$$

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L}$$

$$E = e\sigma T^4 At$$

$$\text{emk/emf} = \frac{N\Delta\phi}{\Delta t}$$

$$\text{emk/emf} = BLv$$

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = BIL\sin\theta$$

$$f = nz$$

$$f = f_1 - f_2$$

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$g = \frac{2\,T\cos\alpha}{r\rho g}$$

$$n = \frac{\sin i}{\sin r}$$

$$n = \frac{\sin(A + Dm)/2}{\sin A/2}$$

$$\sin\theta_c = \frac{1}{n}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$p = \rho gh$$

$$\rho = \frac{m}{V}$$

$$pV = mRT\ (m = nM)$$

$$pV = nR_0T$$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$p_1V_1^\gamma = p_2V_2^\gamma$$

$$Q = u + w$$

$$Q = mc\Delta t$$

$$Q = \frac{ka\Delta T\Delta t}{L}$$

$$R_s = \frac{V_0}{I_g} - R_g$$

$$R_s = \frac{R_gI_g}{I_t - I_g}$$

$$R = c_p - c_v$$

$$\gamma = \frac{c_p}{c_v}$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}} = \sqrt{\frac{M_2}{M_1}} = \frac{t_2}{t_1}$$

$$T = \frac{F}{2\ell} = \frac{F}{4\pi r}$$

$$V = \frac{b}{a}$$

$$V = \frac{0{,}25 \times d}{f_1 \times f_2}$$

$$V = \tfrac{4}{3}\pi r^3$$

$$v = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3R_0T}{M}} \quad \left(n = \frac{m}{M}\right)$$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{\gamma P}{\rho_0}}$$

$$v = f\lambda$$

$$8 = d \sin\theta$$

$$\mu = \frac{m}{L}$$

$$\frac{v}{v_0} = \sqrt{\frac{T}{T_0}}$$

$$W = VI$$

$$W = p\,\Delta V$$

CONSTANT VALUES

Speed of light	$c = 2{,}99 \times 10^8$ ms^{-1}
Speed of sound at 0 °C	$v = 330$ ms^{-1}
Gravitational constant	$G = 6{,}673 \times 10^{-11}$ Nm^2/kg^{-2}
Stefan-Boltzmann's constant	$\sigma = 5{,}67 \times 10^{-8}$ W/m^2.K.^{4}
Universal gas constant	$R = 8{,}314$ J mol^{-1} K^{-1}
Permeability in a vacuum	$\mu_0 = 4\pi \times 10^{-7}$ W A^{-1} m^{-1}
Specific heat capacity of water	$c = 4\ 187$ J kg^{-1}K^{-1}
Standard atmospheric pressure	$p = 1{,}013 \times 10^5$ Pa
Gravitational acceleration	$g = 9{,}8$ ms^{-1}
Refractive index of:	
Water	$n = 1{,}33$
Glycerine	$n = 1{,}47$
Glass	$n = 1{,}5$
Surface tension water	$T = 0{,}0756$ Nm^{-1} (0 °C)
	$T = 0{,}0728$ Nm^{-1} (20 °C)
Mass: Sun	$m = 1{,}99 \times 10^{30}$ kg
Earth	$m = 5{,}98 \times 10^{24}$ kg
Moon	$m = 7{,}36 \times 10^{22}$ kg
Radius: Sun	$r = 6{,}95 \times 10^8$ m
Earth	$r = 6{,}38 \times 10^6$ m
Moon	$r = 1{,}74 \times 10^6$ m
Other: 1 bar = 10^5 Pa	
1 ton = 10^3 kg	

Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

APRIL 2015

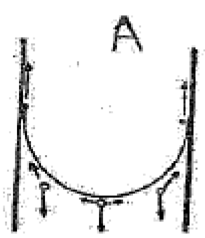
NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

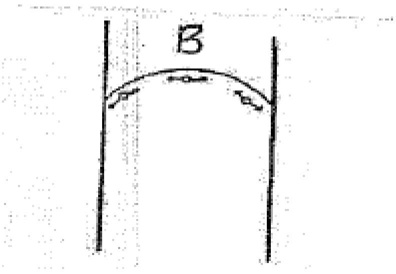
(15070115)

QUESTION 1

1.1.1 (2)



Cohesion greater than adhesion

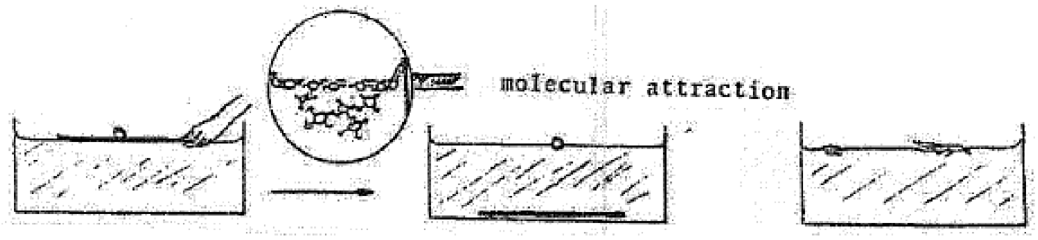


Adhesion greater than cohesion

In A the liquid rather clings to the container as to itself, and will therefore wet the container. In B the liquid will not wet the container.

1.1.2 <u>Surface tension</u> (4)

The lateral forces of attraction between the molecules of a liquid that are on the surface of the liquid cause the liquid to behave as if it were covered with a membrane. This phenomenon is known as the liquid's surface tension. If water had no surface tension, water beetles or wasps would not be able to sit on it, and a needle would not float on it.



1.1.3 (2)

$$h = \frac{2T\ Cos}{rpg} \quad \therefore \quad T = \frac{h \times r \times p \times g}{2 Cos\ \alpha}$$

$$= \frac{0.062 \times 1.25 \times 10^{-4} \times 750 \times 9.8}{2\ Cos\ 15^{0}}$$

$$= 0,0295\ N/m$$

1.2 Osmosis is diffusion that occurs in only one direction. (4)

$$P = pgh$$

$$\therefore p = \frac{P}{gh}$$

$$= \frac{1760\ Pa}{9.8 \times 0.14}$$

$$= 1\ 282,\ 8\ kg1\ m^3$$

1.3 $h = \frac{2T\ Cos\ \alpha}{rpg} = \frac{2 \times 0.0725 \times Cos\alpha}{1.8 \times 10^{-5} \times 1000 \times 9.8}$ (4)

= 0,0082 m

= 8,2 mm

1.4 $F = \frac{Gm_1\ m2}{r^2}$ (4)

$\therefore r^2 = \frac{6{,}673 \times 10^{-11} \times 61{,}2\ kg \times 6 \times 10^{24}}{2.00}$

∴ r = 110 68707, 24 m or 110 68, 7km

∴ from earth = 11 068,7 – 6 380 km = 4 688,7 km

[20]

QUESTION 2

2.1 (4)

60e	V_2

V_1 = 60e V_2 =?

P_1 = 14 кpa P_2 = 9 кpa

$P_1 V_1 = P_2 V_2$

$\therefore V_2 = \frac{14 \times 60}{9}$ = **93, 3 ℓ**

Thus the increase is 93, 3e – 60e

= *33, 3 ℓ*

2.2.1 ***PV = mRT*** (8)

R $= C_P - C_V$
= 140 – 84
= 56 J

$\therefore m = \frac{Pv}{RT}$

$= \frac{80 \times 10^3 \times 0.3}{56 \times 303}$

= *1, 414 kg* ⟶

2.2.2 $P_1V_1^{\,2} = P_2\ V_2^{\,2}$ and $\alpha = \frac{c_p}{c_v} = \frac{140}{84}$

$= 1.67$

$\therefore V_2^{\,1,67} = \frac{80\times10^3\times0.3^{1,67}}{56\times10^3}$

$V_2^{\,1,67} = 0.\ 057$

$\therefore V_2 = \sqrt[1,67]{0,057}$

$= 0,\ 18\ \text{m}^3$

2.2.3 $P_1V_1 = P_2V_2$

$\therefore V_2 = \frac{80\times10^3\times0,3}{188\times10^3}$

$= 0,\ 12\ \text{m}^3$

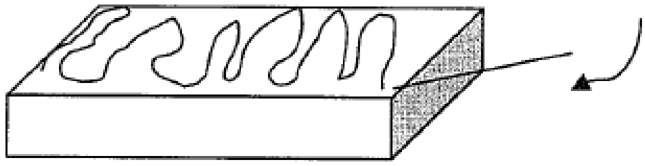
2.2.4 $\overline{V} = \sqrt{\frac{3p}{p}}$ and $p = \frac{m}{V} = \frac{1,414\ kg}{0,3m^3}$

$= 4,\ 713\ \text{kg/m}^3$

$\therefore \overline{V} = \sqrt{\frac{3\times80\times10^3}{4,713}}$

$= 225,\ 6\ m/s$ ⟶

2.3 (8)



Required heat energy : $E = mc\Delta t$

$E = 200kg \times 4187 \times (50 - 10)$

$= 33{,}496 \times 10^6 J$ →

Area of pipe :

$2\pi r$

$\pi \times 0.025$

$A = \pi D \times 400$

$= \pi \times 0.025 \times 400m$

$= 31.416\ m^2$

Only one half is exposed, therefore:

$A = \frac{31.416}{2}$

$= 15{,}71\ m^2$ →

Energy emitted $E = e\,\alpha\, T^4 A\, t$

$\therefore t = \frac{33.496 \times 10^6}{1 \times 5.67 \times 10^{-8} \times (60 + 273)^4 \times 15.71}$

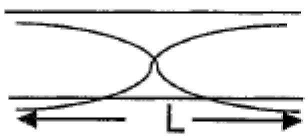
$= 3058\ s$

$= 50\ min\ 58\ sec$ →

[20]

QUESTION 3

3.1 Fundamental tone (4)



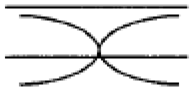
$\frac{1}{2}\lambda = L$

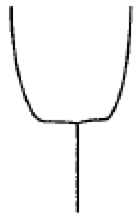
$\lambda = 2L$

First overtones

$\lambda = L$

3.2.1 First overtone: 200 Hz





SnQ2r: $\lambda = 2L = 2 \times 0,75 = 1,5$ m

$V = f \cdot \lambda = 200 \text{ Hz} \times 1,5 \text{ m} = 300$ m/s

$\therefore V = \sqrt{\frac{T}{\mu}}$ but $\mu = \frac{0,001\ kg}{0.75m}$

$= 0,00133$ kg/m

$\therefore T = v^2 \times \mu$

$= 300^2 \times 0,00133 = 120$ N

3.2.2 Open tube: (7)

$\lambda = 2L$ or $L = \frac{\lambda}{2}$

At 0°C is v = 330 m/s

$\therefore \lambda = \frac{v}{f} = \frac{330m/s}{200Hz} = 1,65$ m

$\therefore L = \frac{\lambda}{2} = \frac{1,65}{2} = 0,825$ m

OR 825 mm

3.3.1 $V = \sqrt{\frac{E}{p}} = \sqrt{\frac{8 X 10}{8200}} = 3\ 123,5$ ms

3.3.2 $F = \frac{v}{\lambda}$ and $\lambda = 2L$

$= 2 \times 600$

$= 1\ 200$ of 1,2 m

$\therefore f = \frac{v}{\lambda} = \frac{3123,5m/s}{1,2m}$

$= 2\ 602,9$ Hz

3.3.3 $\lambda = 2 \times 602 = 1,204$ m

En $f = \frac{3123,5}{1,204} = 2\ 594,3$ Hz

Beats $= f_2 - f_1 = 2602,9 - 2594,3$

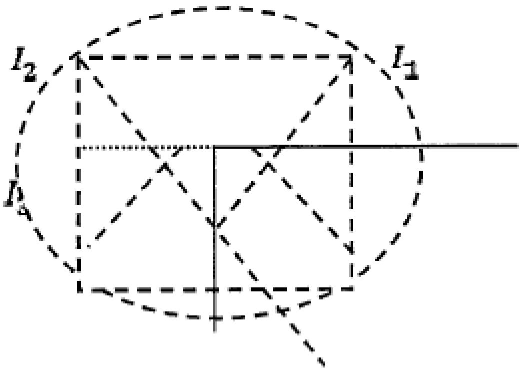
$= 8,6$ Hz

(3 x 3) (9)

[20]

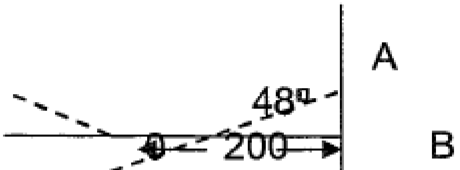
QUESTION 4

4.1 Images and I_3 result from the object before the mirrors, and I_2 is virtual image of I_1 (3)



4.2 Reflection Angle (3)

$$\alpha = (2 \times \beta) + \theta$$
$$= (2 \times 14) + 20°$$
$$= 48°$$



$$\text{Tan}48° = \sqrt{\frac{AB}{200}}$$

$$\therefore AB = 200 \cdot \text{Tan } 48°$$
$$= 222{,}12 \text{ mm}$$

4.3.1

4.3.2

4.3.3

4.3.4

4.3.5 (10)

4.4.1

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$
$$\frac{1}{40} = \frac{1}{30} + \frac{1}{b}$$
$$b = -120 \ mm$$

4.4.2 $\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

$\frac{1}{40} = \frac{1}{20} + \frac{1}{b}$

$b = -40\ mm$

$v = \frac{b}{a} = \frac{40}{20} =$ 2 times

4.4.3 $v = \frac{b}{a}$

$5 = \frac{b}{a}$

$5a = b$ ..

$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

$\frac{1}{40} = \frac{1}{a} + \frac{1}{5a}$

$\frac{1}{40} = \frac{5+1}{5a}$

$5a = 6 \times 40$

$a = 48\ mm$

OR

$\frac{1}{40} = \frac{5-1}{5a}$

$5a = 4 \times 40$

$a = 32\ mm$

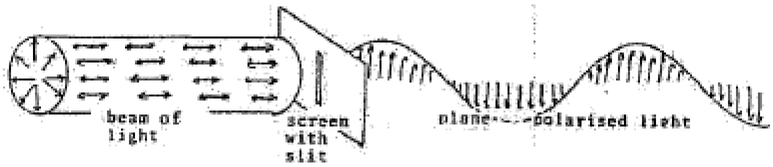
(3 x 2) (6)

[22]

QUESTION 5

5.1 (a) Polarisation by reflexion. (4)
(b) Polarisation by double refraction.
(c) Polarisation through Polaroid iodine crystals.
(d) Tourmaline crystals

if we want a beam of light that oscillates only on a specific vertical plane, we must take the main wave and polarise it, i.e. we must make a valve that will permit light waves to pass through only on that specific vertical plane, as illustrated below.



$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$

$$\frac{1}{40} = \frac{1}{a} + \frac{1}{5a}$$

$$\frac{1}{40} = \frac{5+1}{5a}$$

$$5a = 6 \times 40$$

$$a = 48\ mm$$

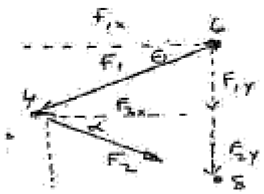
OR

$$\frac{1}{40} = \frac{5-1}{5a}$$

$$5a = 4 \times 40$$

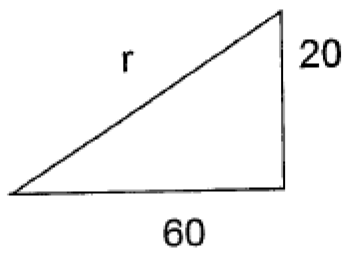
$$a = 32\ mm$$

5.2 (5)



$$\theta = \tan^{-1}\frac{20}{60}$$

$=18{,}43^{o}$



r= $\sqrt{60^2 + 20^2}$

= 63,25

Force between 4 and 6 Am

$$f_1 = \frac{4\pi x\, 10^{-7} x 4 x 6}{4\pi x\, 63{,}25^2}$$

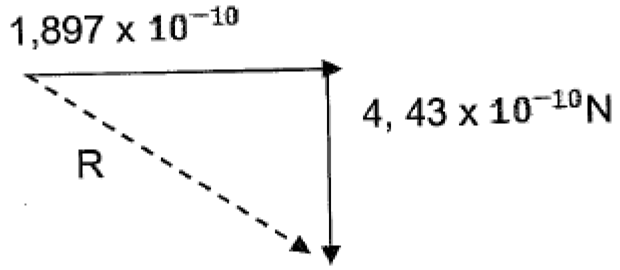
$=6x10^{-10}$N

$$f_2 = \frac{4\pi x\, 10^{-7} x 4 x 8}{4\pi x\, 63{,}25^2}$$

$= 8x10^{-10}$N

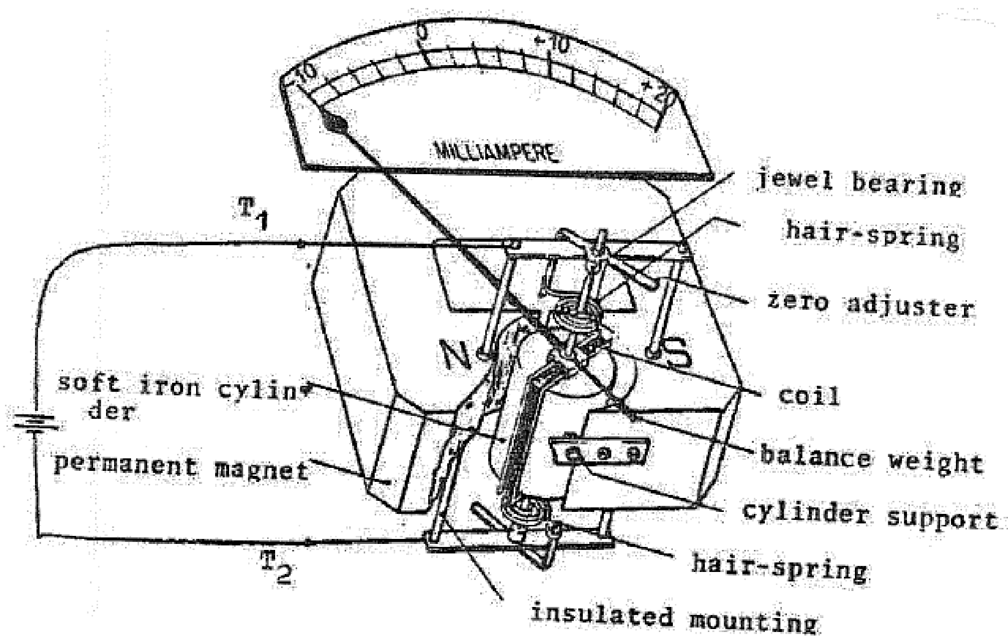
$f_{1x} = 6x\ 10^{-10}$ Cos 18, 43
$=5{,}69\ x\ 10^{-10}N$
$f_{2x} = 8\ x\ 10^{-10}$Cos 18, 43
$= 7,\ 59\ x\ 10^{-10}N$
$\sum fx = f_2 - f_1 = 7,\ 59 - 5,\ 69$
$= 1{,}897\ x\ 10^{-10}$

$f_{1y} = 6x10^{-10}$ sin 18, 43
$= 1{,}89710^{-10}N$
$f_{2y} = 8x10^{-10}$ sin 18, 43
$= 2,\ 53\ x\ 10^{-10}\ N$
$\sum fy = f_{1y} + f_{2y} = 1,\ 89 - 2,\ 53$
$= 4,\ 43\ x\ 10^{-10}N$



$\theta = \tan^{-1}\frac{4{,}43}{1{,}89} = 66{,}8°$

5.3 (6)



5.4 Parallel resistance needed for 10 A (3)

$Ro = \frac{Rg\ Ig}{It - Ig} = \frac{80\Omega \times 0{,}005}{(10 - 0{,}005)} = 0{,}04$ □

Series resistance needed for 250 V.

$Rs = \frac{Vo}{Ig} - Rg$

$= \frac{250V}{0{,}005} - 80$ □ $= 49{,}92$ k □

[18]

TOTAL: 100

Past Examination Papers

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2014

NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

(15070115)

19 November 2014 (Y-Paper)
13:00 – 16:00

This question paper consists of 6 pages and a formula sheet of 2 pages

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

QUESTION 1

Indicate whether the following statements are TRUE or FALSE. Choose the answer and *write* only 'true' or 'false' next to the question number (1.1-1.1 0) in the ANSWER BOOK.

1.1 It is possible that a liquid in a container shows no capillary curve (90° contact angle).

1.2 Gases diffuse more rapidly than liquids.

1.3 The focal distance of a lens is twice the radius of curvature.

1.4 A shortsighted eye needs a curvature lens to see far.

1.5 Interference of light can be seen with the naked eye.

1.6 Polarised light vibrates transversally.

1.7 Short radio waves are shorter than long light rays.

1.8 A ball of 1 m² and a plate of 1 m² at the same temperature, emit the same quantity of heat.

1.9 Exponent of expansion of gases (gamma) does not have a unit in which it is Measured

1.10 A closed tube produces longer sound waves than an open tube of equal length.

(10 x 1) **[10]**

QUESTION 2

2.1 Calculate the force F with which TWO masses of 12 kg and 80 g respectively attract one another if they are 120 mm apart.

2.2 If a cutting wire is 3,22 m long during the cutting process and 3,04 m long if the wire is not under tension, calculate the strain in the wire.

2.3 Calculate the density of a liquid that rises 93 mm in a tube, after it goes through a semi-permeable membrane and thus has an osmotic pressure of 3,108 kPa.

2.4 A partitioned container holds nitrogen gas of 60 fat a pressure of 24 kPa. If the capacity is enlarged by removing a partition, the pressure drops to 9 kPa.

Calculate the increase in the size of the container.

2.5 A screen of a projector is 1 m from a projector which has a convex lens with a focal point of 0,20 m.

Find the position of an image that is projected on the screen.

2.6 Calculate the magnetic flux density B induced inside a solenoid of 100 mm long, which has a diameter of 50 mm, if the wire of the solenoid has a thickness of 0,5 mm and draws a current of 4 A.

2.7 Calculate the angle of incidence the following substance must have to be plane polarised: A glass plate with an index of refraction of 1,5

2.8 Calculate the velocity with which sound is propagated in a copper rod if E = 8 x 10^{10} N/m² and the copper has a density of 8 500 kg/m³.

2.9 Calculate the velocity of sound at 70 °C if sound travels 331 m/s at 0ºC.

2.10 An aeroplane with a wingspan of 12 m flies at 600 km/h rectangular to the magnetic field of the earth.

Calculate the EMF induced in the wings of the aeroplane if the earth's magnetic field is 10^{-6} Wb/m².

(10 x 3) **[30]**

QUESTION 3

Make neatly labelled sketches of:

3.1 The human eye (4)

3.2 Dispersion of light at a triangular prism. Also name the colours of light obtained. (6)

3.3 Galvanometer (4)

[14]

QUESTION 4

Name the places where the following physical phenomena can be used in practice:

4.1 Grease spot photometer

4.2 Total internal reflection of light

4.3 Concave mirror(s)

(3 x 2) **[6]**

QUESTION 5

Choose an item from COLUMN B that matches a word(s) in COLUMN A. Write only the letter (A-J) next to the question number (5.1-5.10) in the ANSWER BOOK.

COLUMN A		COLUMN B	
5.1	Newton	A	total reflection
5.2	Glass	B	one direction
5.3	Plastic	C	torsion wire
5.4	Ring metals	D	kelvin
5.5	Cohesion	E	brittle
5.6	Osmosis	F	liquification
5.7	Boyle	G	malleable
5.8	Critical constants	H	surface tension
5.9	Radiation	I	meniscus
5.10	Periscope	J	temperature

(10 x 1) **[10]**

QUESTION 6

6.1 A siren is resonating with a tube that is closed on one end. If the frequency of the siren is 400 Hz and it has 40 holes in it.

Calculate the following:

6.1.1 Velocity in revolutions per minute that the siren must e turned (4)

6.1.2 Length of the tube at 0º (3)

6.1.3 Length of the tube at 35º (4)

6.2 A galvanometer has a resistance of 150 Ω and can carry 5 rnA current. The galvanometer must be converted to a voltmeter to read 500 V and an ammeter to read 5 A. (6)

Make a sketch of how the resistance is used to convert this galvanometer and calculate the value of each resistance.

6.3 Calculate the distance an object must be placed in front of a convex mirror to give an image distance of 90 mm if the mirror has a radius of curvature of (4)

400 mm.

6.4 A short-sighted person cannot focus further than 500 mm. (4)

What type of lens will be required to see very far?

6.5 Calculate the quantity of energy that is radiated from the roof of a house in 6 hours' time if the roof is 60 ºC and the radiation constant e = 0,75. The area of the roof is $200 m^2$. (5)

What power can be delivered from the roof?

[30]

TOTAL: 100

ENGINEERING PHYSICS N5

FORMULA SHEET

Any applicable formula may be used.

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \frac{\mu_0 I}{2r}$$

$$B = \frac{\mu_0 NI}{2r}$$

$$B = \frac{\mu_0 NI}{L}$$

$$B = \frac{\phi}{A}$$

$$\phi = B\ A \sin\theta$$

$$E = \frac{I\cos\theta}{r^2}$$

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L}$$

$$E = e\sigma T^4 At$$

$$\text{emk/emf} = \frac{N\Delta\phi}{\Delta t}$$

$$\text{emk/emf} = BLv$$

$$F = \frac{Gm_1 m_2}{r^2}$$

$$F = BIL\sin\theta$$

$$f = nz$$

$$f = f_1 - f_2$$

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$g = \frac{2\,T\cos\alpha}{r\rho g}$$

$$n = \frac{\sin i}{\sin r}$$

$$n = \frac{\sin(A + Dm)/2}{\sin A/2}$$

$$\sin\theta_c = \frac{1}{n}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$p = \rho gh$$

$$\rho = \frac{m}{V}$$

$$pV = mRT\ (m = nM)$$

$$pV = nR_0 T$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$p_1 V_1^\gamma = p_2 V_2^\gamma$$

$$Q = u + w$$

$$Q = mc\Delta t$$

$$Q = \frac{ka\Delta T\Delta t}{L}$$

$$R_s = \frac{V_0}{I_g} - R_g$$

$$R_s = \frac{R_g I_g}{I_t - I_g}$$

$$R = c_p - c_v$$

$$\gamma = \frac{c_p}{c_v}$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}} = \sqrt{\frac{M_2}{M_1}} = \frac{t_2}{t_1}$$

$$T = \frac{F}{2\ell} = \frac{F}{4\pi r}$$

$$V = \frac{b}{a}$$

$$V = \frac{0{,}25 \times d}{f_1 \times f_2}$$

$$V = \tfrac{4}{3}\pi r^3$$

$$v = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3R_0T}{M}} \quad \left(n = \frac{m}{M}\right)$$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{\gamma P}{\rho_0}}$$

$$v = f\lambda$$

$$8 = d\sin\theta$$

$$\mu = \frac{m}{L}$$

$$\frac{v}{v_0} = \sqrt{\frac{T}{T_0}}$$

$$W = VI$$

$$W = p\,\Delta V$$

CONSTANT VALUES

Speed of light	$c = 2{,}99 \times 10^8\ \text{ms}^{-1}$
Speed of sound at 0 °C	$v = 330\ \text{ms}^{-1}$
Gravitational constant	$G = 6{,}673 \times 10^{-11}\ \text{Nm}^2/\text{kg}^{-2}$
Stefan-Boltzmann's constant	$\sigma = 5{,}67 \times 10^{-8}\ \text{W/m}^2.\text{K.}^4$
Universal gas constant	$R = 8{,}314\ \text{J mol}^{-1}\ \text{K}^{-1}$
Permeability in a vacuum	$\mu_0 = 4\pi \times 10^{-7}\ \text{W A}^{-1}\ \text{m}^{-1}$
Specific heat capacity of water	$c = 4\ 187\ \text{J kg}^{-1}\text{K}^{-1}$
Standard atmospheric pressure	$p = 1{,}013 \times 10^5\ \text{Pa}$
Gravitational acceleration	$g = 9{,}8\ \text{ms}^{-1}$
Refractive index of:	
Water	$n = 1{,}33$
Glycerine	$n = 1{,}47$
Glass	$n = 1{,}5$
Surface tension water	$T = 0{,}0756\ \text{Nm}^{-1}$ (0 °C)
	$T = 0{,}0728\ \text{Nm}^{-1}$ (20 °C)
Mass: Sun	$m = 1{,}99 \times 10^{30}\ \text{kg}$
Earth	$m = 5{,}98 \times 10^{24}\ \text{kg}$
Moon	$m = 7{,}36 \times 10^{22}\ \text{kg}$
Radius: Sun	$r = 6{,}95 \times 10^8\ \text{m}$
Earth	$r = 6{,}38 \times 10^6\ \text{m}$
Moon	$r = 1{,}74 \times 10^6\ \text{m}$

Other: 1 bar = 10^5 Pa
1 ton = 10^3 kg

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higher education & training

Department: Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2014

NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

(15070115)

QUESTION 1

1.1 True

1.2 True

1.3 False

1.4 False

1.5 False

1.6 True

1.7 False

1.8 True

1.9 True

1.10 True

(10 x 1) **[10]**

QUESTION 2

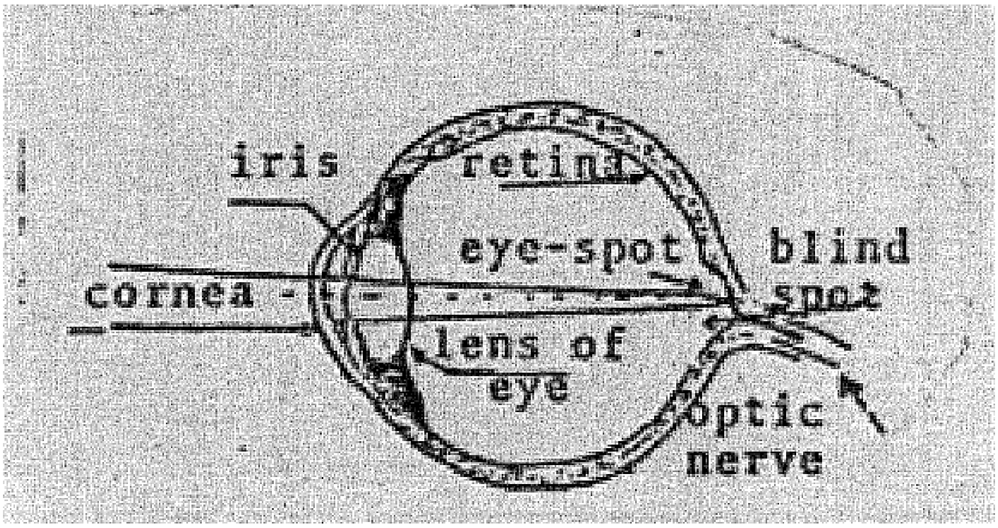
	FORMULA	ANSWER	UNIT
2.1	$F=\frac{M_1M_2}{r^2}$√	4,449 x 10^{-9}√	N√
2.2	$\epsilon = \frac{\Delta \ell}{\Delta \ell}$√	0,0592√	√
2.3	P = ρgh√	3410√	Kg/m^3√
2.4	$P_1V_1= P_2V_2$√	100√	ℓ √
2.5	$\frac{1}{f}=\frac{1}{a}+\frac{1}{b}$ √	a= 0,25√	m√
2.6	B = $\frac{\mu NI}{L}$ √	0,01005√	Wb/m^2√

2.7	$\square = \tan^{-1} n$ √	56,3√	0√
2.8	$V = \sqrt{\frac{E}{P}}$ √	3067,86√	m/s√
2.9	$\frac{V}{V_0} = \sqrt{\frac{T}{T_0}}$ √	371√	m/s√
2.10	Emf = BLV √	0,002√	V√

(10 x 3) **[30]**

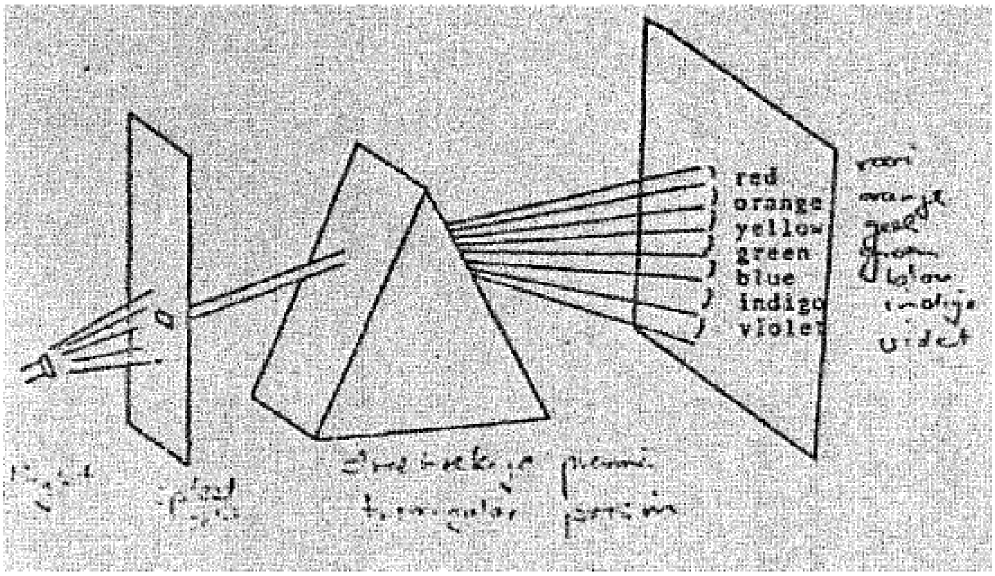
QUESTION 3

3.1



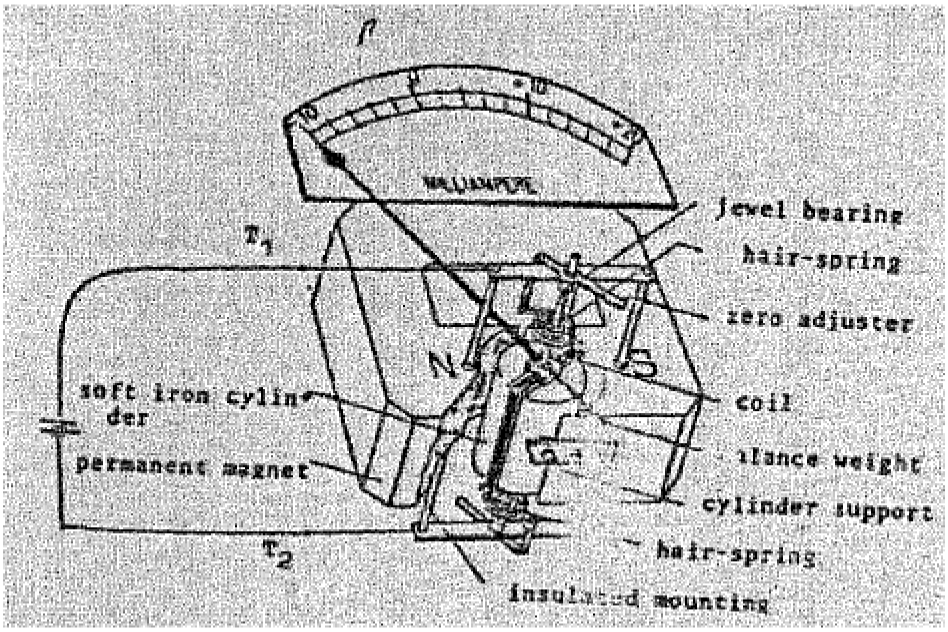
(4)

3.2



(6)

3.3



(4)

[14]

QUESTION 4

4.1 To determine the strength of an unknown light

4.2 Periscope binocular

4.3 Telescope

(3 x 2) **[6]**

QUESTION 5

5.1 C
5.2 E
5.3 G
5.4 H
5.5 I
5.6 B
5.7 J
5.8 F
5.9 D
5.10 A

(10 x 1) **[10]**

QUESTION 6

6.1 (a) $f = nz$

$400 = n.\ 40$

$n = 10\ r/s$

$= 10 \times 60$

$= 600\ rpm$ (4)

(b) $v = f\lambda$

$330 = 400 \times \lambda$

$\lambda = \frac{330}{400} = 0{,}825m$

$\therefore L = \frac{\lambda}{4} = \frac{0{,}825}{4} = 206mm$ (3)

(c) by 35°C is $V = Vo\sqrt{\frac{T}{}} = 330\sqrt{\frac{308}{273}} = 250{,}5\ m/s$ (4)

6.2 Voltmeter $Rs = \frac{Vo}{Ig} - Rg$

$= \frac{500}{0{,}005} - 150$

$= 99850\ \Omega$

$= 99{,}85\ k\Omega$ (6)

6.3 C = 400 mm $\therefore$ f = 200 mm

$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

$-\frac{1}{200} = \frac{1}{a} + \frac{1}{90}$

a = 163 mm (4)

6.4 $\frac{1}{f} = \frac{1}{\infty} + \frac{1}{500}$

f = - 2 Diopter (4)

6.5 $E = e\delta T^4 At$

$= 0{,}75 \times 5{,}67\times10^{-8} \times 333^4 \times 200 \times 60 \times 60 \times 60$

$= 3{,}0119 \times 10^9\ J$

$= 2{,}259 \times 10^9\ J$

$\therefore 0{,}75 \times 5{,}67 \times 10^{-8} \times 333 \times 200$

$= 104580{,}6\ J/s$

$= 104{,}6\ kW$ (5)

[30]

TOTAL: 100

Past Examination Papers

higher education
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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

APRIL 2014

NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

(15070115)

1 April 2014 (Y-Paper)
13:00 – 16:00

This question paper consists of 7 pages and a formula sheet of 2 pages

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

QUESTION 1

Indicate whether the following statements are TRUE or FALSE. Choose the answer
and write only 'true' or 'false' next to the question number (1.1-1 .15) in the ANSWER
BOOK.

1.1 Sound travels faster in air than in steel.

1.2 The higher the pulling force on a string the higher is the frequency of the sound

1.3 In transformers the winding ratio is the same as the current ratio

1.4 A galvanometer contains a permanent magnet.

1.5 The more windings on a loop, the stronger the electromagnetic field inside the
loop if the loop carries a current.

1.6 A sugar solution will turn a ray of light.

1.7 Light does not need a medium of propagation.

1.8 The smaller a slit, the more is the diffraction of light at the slit.

1.9 A far-sighted person needs a concave lens to see close by.

1.10 A lens with a focal point of 0,5 m has a power of 2 diopters.

1.11 An image that lies in front of a mirror is an imaginary.

1.12 If two similar bodies A and B are at the temperatures of 50 ºC and 100 ºC respectively, then B will radiate twice as much energy as A.

1.13 If the pressure of a gas increases, the molecular velocity of the gas will decrease.

1.14 If the molecular mass of a substance increases, then the substances rate of diffusion will decrease.

1.15 Capillary rise in hair tubes can be reduced by increasing the surface tension of the liquid in it.

(15 x 1) **[15]**

QUESTION 2

Give the SI-unit of the following quantities:

2.1 Light strength

2.2 Electrical energy consumption

2.3 Electrical tension

2.4 Velocity of sound

2.5 Force between two magnetic poles

(5 x 1) **[5]**

QUESTION 3

Make neat, labelled sketches of the following:

3.1 Interference with light.

3.2 Diffraction with light

3.3 The eye of a human

(2 x 3) **[6]**

QUESTION 4

Name where the following physics phenomena can be used in practice:

4.1 Convex lenses

4.2 Kundt's tube

4.3 Tourmaline crystals

4.4 Diffraction grating

(3 x 4) **[12]**

QUESTION 5

Calculate the following distances:

5.1 Two similar masses of six tons each must be apart to attract one another with a force of 2 mN

5.2 Must be between the two ends of a rod to carry over 2 J/s of energy from one end to the other end if the rod has a diameter of 15 mm and the one end is at 10 ºC and the other end at 300 ºC. The conductivity constant K of the rod is 80 W/m.K.

5.3 A man must be in front of a convex mirror to see his own face twice as small. The focal point of the mirror is -100 mm.

5.4 There must be between two magnetic poles of 6 A.m to repel each other with a force of 1 N in a vacuum

(4 x 4) **[16]**

QUESTION 6

An observer notices that milk rises 20 mm in a glass tube and that it has a density of 1 100 kg/m³ and a surface tension of 0,03 N/m. The contact angle of the milk in the glass is 5°.

Calculate the following:

6.1 The diameter of the glass tube.

6.2 The height to which the water will rise in the same tube.

(4 x 2) **[8]**

QUESTION 7

A 40 W neon tube has a length of 1,2 m and an external diameter of 35 mm. The working temperature of the neon tube is 82 ºC and it has a radiation constant 3 = 0,1.

Calculate the following:

7.1 The area of the neon tube

7.2 The heat radiated by the neon tube per second

7.3 The light energy radiated by the neon tube per second

7.4 The effectiveness of the neon tube (in percentage)

[10]

QUESTION 8

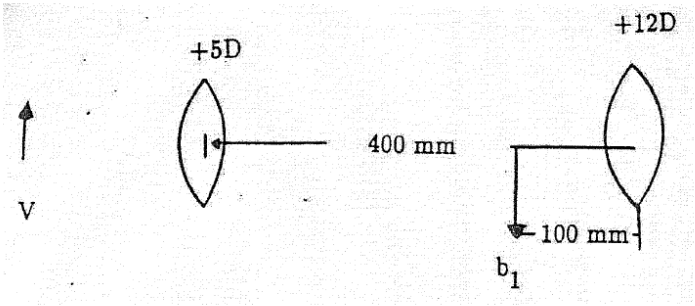

Figure 1

Calculate the following:

8.1 Where the object V must be placed to give an image b_1 100 mm from the second lens

8.2 The position of the second image b_2

8.3 The final enlargement of the lens combination

8.4 The nature of the final image

(3 x 4) **[12]**

QUESTION 9

A cylinder contains 250 ml gas at a pressure of 180 kPa and 20 ºC. The gas is adiabatically compressed to a pressure of 400 kPa.

If Cp = 0,14 kJ/kg/ºK and Cv = 0,084 kJ/kg/ºK, calculate the following:

9.1 The mass of gas in the cylinder

9.2 The final volume

9.3 The final temperature

9.4 The average velocity of the gas molecules at the original conditions.

(3 x 4) **[12]**

QUESTION 10

Calculate the force T with which a string must be pulled to vibrate with a frequency of 240Hz at fundamental tones if the string is 0,75 m long and has a mass of 1 g.

[4]

TOTAL: 100

ENGINEERING PHYSICS N5

FORMULA SHEET

Any applicable formula may be used.

$$B = \frac{\mu_0 I}{2\pi r}$$

$$B = \frac{\mu_0 I}{2r}$$

$$B = \frac{\mu_0 NI}{2r}$$

$$B = \frac{\mu_0 NI}{L}$$

$$B = \frac{\phi}{A}$$

$$\phi = B\ A \sin\theta$$

$$E = \frac{I\cos\theta}{r^2}$$

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A}{\Delta L/L}$$

$$E = e\sigma T^4 At$$

$$\text{emk/emf} = \frac{N\Delta\phi}{\Delta t}$$

$$\text{emk/emf} = BLv$$

$$F = \frac{Gm_1m_2}{r^2}$$

$$F = BIL\sin\theta$$

$$f = nz$$

$$f = f_1 - f_2$$

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$g = \frac{2\,T\cos\alpha}{r\rho g}$$

$$n = \frac{\sin i}{\sin r}$$

$$n = \frac{\sin\left(A + Dm\right)/2}{\sin A/2}$$

$$\sin\theta_c = \frac{1}{n}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$p = \rho g h$$

$$\rho = \frac{m}{V}$$

$$pV = mRT\ (m = nM)$$

$$pV = nR_0T$$

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$p_1V_1^\gamma = p_2V_2^\gamma$$

$$Q = u + w$$

$$Q = mc\Delta t$$

$$Q = \frac{ka\Delta T\Delta t}{L}$$

$$R_s = \frac{V_0}{I_g} - R_g$$

$$R_s = \frac{R_gI_g}{I_t - I_g}$$

$$R = c_p - c_v$$

$$\gamma = \frac{c_p}{c_v}$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\rho_2}{\rho_1}} = \sqrt{\frac{M_2}{M_1}} = \frac{t_2}{t_1}$$

$$T = \frac{F}{2\ell} = \frac{F}{4\pi r}$$

$$V = \frac{b}{a}$$

$$V = \frac{0{,}25 \times d}{f_1 \times f_2}$$

$$V = \tfrac{4}{3}\pi r^3$$

$$v = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3R_0T}{M}} \quad \left(n = \frac{m}{M}\right)$$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{\gamma P}{\rho_0}}$$

$$v = f\lambda$$

$$8 = d \sin\theta$$

$$\mu = \frac{m}{L}$$

$$\frac{v}{v_0} = \sqrt{\frac{T}{T_0}}$$

$$W = VI$$

$$W = p\,\Delta V$$

CONSTANT VALUES

Speed of light	$c = 2{,}99 \times 10^8$ ms^{-1}
Speed of sound at 0 °C	$v = 330$ ms^{-1}
Gravitational constant	$G = 6{,}673 \times 10^{-11}$ Nm^2/kg^{-2}
Stefan-Boltzmann's constant	$\sigma = 5{,}67 \times 10^{-8}$ W/m^2.K.^{4}
Universal gas constant	$R = 8{,}314$ J mol^{-1} K^{-1}
Permeability in a vacuum	$\mu_0 = 4\pi \times 10^{-7}$ W A^{-1} m^{-1}
Specific heat capacity of water	$c = 4\ 187$ J kg^{-1}K^{-1}
Standard atmospheric pressure	$p = 1{,}013 \times 10^5$ Pa
Gravitational acceleration	$g = 9{,}8$ ms^{-1}
Refractive index of:	
Water	$n = 1{,}33$
Glycerine	$n = 1{,}47$
Glass	$n = 1{,}5$
Surface tension water	$T = 0{,}0756$ Nm^{-1} (0 °C) $T = 0{,}0728$ Nm^{-1} (20 °C)
Mass: Sun	$m = 1{,}99 \times 10^{30}$ kg
Earth	$m = 5{,}98 \times 10^{24}$ kg
Moon	$m = 7{,}36 \times 10^{22}$ kg
Radius: Sun	$r = 6{,}95 \times 10^8$ m
Earth	$r = 6{,}38 \times 10^6$ m
Moon	$r = 1{,}74 \times 10^6$ m

Other: 1 bar = 10^5 Pa
1 ton = 10^3 kg

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REPUBLIC OF SOUTH AFRICA

APRIL 2014

NATIONAL CERTIFICATE

ENGINEERING PHYSICS N5

(15070115)

QUESTION 1

1.1 False

1.2 True

1.3 False

1.4 True

1.5 False

1.6 True

1.7 True

1.8 True

1.9 False

1.10 True

1.11 False

1.12 False

1.13 False

1.14 True

1.15 True

(15 X 1) **[15]**

QUESTION 2

2.1 Cd

2.2 Watt

2.3 Volt

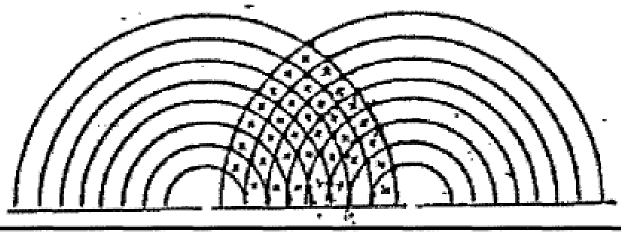
2.4 m/s

2.5 N

(5 X 1) **[5]**

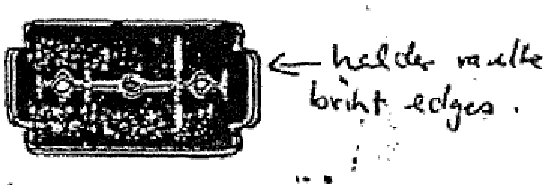
QUESTION 3

3.1 Interference



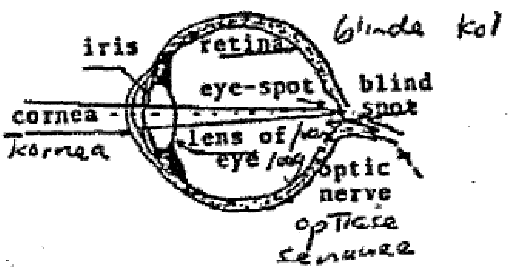
- x shows where waves weaken one another
- . shows where waves reinforce one another
- At the x positions it will appear dark, and at the. position the light will be bright. We see a series of dark and light strips. (2)

3.2 Diffraction



(2)

3.3 The eye



(2)

[6]

QUESTION 4

4.1
- Photocopy machine
- Velocity of sound determined in the gas
- To polarise light
- To determine the wavelength of the light

(3 x 4) **[12]**

QUESTION 5

5.1 $F = G\frac{m_1 m_2}{r^2}$

$r^2 = \frac{6{,}673 \times 10^{-11} \times 6 \times 1000 \times 6 \times 1000}{0{,}002}$

$r^2 = 1{,}2$

$r = 1{,}095$ m (4)

5.2 $Q = \frac{k\,A\,\Delta T\,\Delta t}{L}$

$L = \frac{k.A\,\Delta T\,\Delta t}{Q}$

$= \frac{80 \times \pi \times \frac{0{,}015^2}{4} \times 290}{2}$

$= 2{,}05$ m (4)

5.3 $\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

$-\frac{1}{100} = \frac{1}{a} + \frac{1}{0.5a}$

$-\frac{1}{100} = \frac{1+2}{2a}$

$\frac{1}{f} = \frac{3}{2a}$

$-2a = 300$

$a = 150$ (4)

5.4 $F = \frac{\mu F\,F_2}{4\pi r^2}$

$r^2 = \frac{10^{-7}.6 \times 6}{1}$

$r = 0{,}00189$ m

$r = 1{,}9$ mm (4)

[16]

QUESTION 6

6.1 $h = \frac{2\,T\,Cos\alpha}{r\rho g}$

$r = \frac{2 \times 0{,}03 \times Cos5}{0.02 \times 1100 \times 9.8}$

$r = 0.2773$ mm

$d = 0{,}2773 \times 2$

$= 0{,}554$ mm (4)

6.2 $h = \frac{2\,T\,Cos\alpha}{rpg}$

$= \frac{2 \, x \, 0{,}0725 \, x \, 1}{0{,}277 \, x \, 10^{-5} \, x \, 1000 \, x \, 9{,}8}$

$\lambda = 0{,}0536$ m

$= 53{,}37\ mm$ (4)

[8]

QUESTION 7

7.1 A = $\pi \, x \, D \, x \, h$

$= \pi \, x \, 0{,}035 \, x \, 1{,}2$

= 0,1319 m² (3)

7.2 Q = $e\delta T^4 A$

= 0,1 x 5,67 x10^{-8} x 305⁴ x A

= 49,067 x 0,1319

= 6,47 J/s (3)

7.3 light energy = electrical energy – heat energy

= 40 – 6,47

= 33,53 J/s (3)

7.4 effec = $\frac{output}{inut}$

$= \frac{33{,}53}{40}$

= 83,8% (1)

[10]

QUESTION 8

8.1 $\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

$5 = \frac{1}{a} + \frac{1}{0{,}3}$

a = 0,6 m (3)

8.2 $12 = \frac{1}{0{,}1} + \frac{1}{b}$

= 0,5 m (3)

8.3 $v = \frac{b}{a}$

$V = \frac{0,3}{0,1} = ½$

$V2 = \frac{0,5}{0,1} = 5$

$V = V \times V2 = ½ \times 5 = 2,5$ (3)

8.4 ????? (3)

[12]

QUESTION 9

9.1 $PV = mRT$

$180 \times 10^3 \times 250 \times 10^{-6} = m \times 56 \times 293$

$m = \frac{45}{16400}$

$= 0,002$ kg (3)

9.2 $\gamma = \frac{Cp}{Cv}$

$= 1,667$

$P_1V_1^{\gamma} = P_2V_2^{\gamma}$

$180 \times 10^{-3} \times (250)^{1,67} = 400 \times 10^4 \times V_2^{1,67}$

$V_2 = \sqrt[1,67]{\frac{180}{400} \times 250^{1,67}}$

$V_2 = 154,8$ mL (3)

9.3 $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$T_2 = \frac{400 \times 154,8}{180 \times 250} \times 293$

$= 403,25$ K (3)

9.4 $P = \frac{m}{V}$

$= \frac{0{,}0027}{250 \times 10^{-6}}$

$= 10{,}97\ kg/m^3$

$V = \sqrt{\frac{3p}{P}}$

$= \sqrt{\frac{3 \times 180 \times 10^3}{10{,}97}}$

$= 221{,}8\ m/s$ (3)

[12]

QUESTION 10

10.1 $\lambda = 2L$

$= 2 \times 0{,}75$

$= 1{,}5\ m$

$V = F \times \lambda$

$= 240 \times 1{,}5$

$= 360\ m/s$

$\mu = \frac{0{,}0011}{0{,}75}$

$= 0{,}00133\ kg/m$

$V = \sqrt{\frac{T}{\mu}}$

$T = 360^2 \times 0{,}00133$

$= 1\ 728\ N$

[4]

TOTAL: 100

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