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H. J. P. Keighley

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First published 1986
Reprinted with corrections 1986

Published by
MACMILLAN EDUCATION LTD
Houndmills, Basingstoke, Hampshire RG21 2XS
and London
Companies and representatives
throughout the world

Typeset by TecSet Ltd,
Sutton, Surrey

British Library Cataloguing in Publication Data
Keighley, H. J. P.
Work out physics.—(Macmillan work out series)—(Macmillan master series)
1. Physics—Examinations, questions, etc.
I. Title
530′.076 QC32

ISBN 978-0-333-36788-9 ISBN 978-1-349-07213-2 (eBook)
DOI 10.1007/978-1-349-07213-2

To Biz, for her patience, kindness and help

Contents

Preface

The book is designed to help students revise for the 'O' level examination in physics. It has been written with an eye on the proposed GCSE syllabuses so that it can be used by those preparing for this examination when it replaces 'O' level. Each chapter contains complete answers to examination questions. These answers, together with the summaries at the beginning of each chapter, cover the work needed for the examinations of the different boards. Most students find it helpful to see and study worked examples, but it is, of course, essential that they understand them! To aid understanding, additional explanations have sometimes been added. Square brackets have been used for these explanations so that they are easily distinguished from the answer to the question. Cross-references are also given where it is felt that this will lead to a better understanding of the work.

In each chapter there is a section entitled 'Have you mastered the basics?'. This is designed to enable students to ensure that they have mastered the essentials. The answers to these questions are given, in most cases, by reference to the appropriate section in the chapter.

Wherever possible, actual examination questions have been included, but as some boards will not give permission for their questions to be used as worked examples, the rest of the questions are recast questions based on those set by the various boards. Since many of the questions are actual examination questions, they sometimes include more than one topic. No attempt has been made to limit questions to ones on a single theme, as this would be unrealistic, but cross-references are given when it is felt that this would be helpful.

At the end of each chapter there is a selection of examination questions for the student to answer. Answers and considerable help with the solutions are provided. It is hoped that these will be an aid to students who do not have access to a tutor.

The number of straight descriptive questions in examinations has decreased over the years, but many boards still set them and no doubt will continue to do so. For this reason, and for completeness, many of the main descriptive parts of the various syllabuses have been included.

There is an index at the end of the book which may be used to revise a particular topic or a part of a topic.

Finally I must express my thanks to friends who have kindly read parts of the manuscript and given valuable advice.

Marlborough College, 1985 H. J. P. K.

Acknowledgements

The author and publishers wish to thank the Associated Examining Board, the University of London School Examinations Department, the University of Oxford Delegacy of Local Examinations, the Scottish Examination Board, the Southern Universities' Joint Board and the Welsh Joint Education Committee for permission to use questions from past examination papers.

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Introduction

How to Use this Book

This book is intended to help you prepare for your GCSE examination in Physics. It is not intended to replace a textbook but to supplement it. It is written to help you revise and prepare for an examination and assumes that you have completed a GCSE course. If there are topics that you have never studied, refer to a good textbook and carefully read and make notes on the relevant chapter. One good, concise and easy-to-read text for this purpose is *Mastering Physics* published by Macmillan Education.

At the beginning of each chapter there is a pithy summary of the essential physics that you need to know. Spend time in becoming thoroughly familiar with the material in these summaries.

Each chapter contains GCSE-type questions with worked examples. Carefully studying these will help you to revise as well as showing you how to set out your answers in an examination. At the end of the worked examples there is a section entitled 'Have you mastered the basics?'. Do these questions without looking at the solutions provided. Make sure you really grasp the principles and the basic physics contained in these questions. Finally there are questions for you to answer. Answers and fairly extended hints on solutions are provided for you if you get stuck.

Revision

When revising, many people find it helpful to write as they work. Writing as you revise will help you to concentrate and also help you to remember what you have been revising. You are much more likely to remember something you have written than something that you just looked at in a book. In particular, make sure that when you have revised a section of the work you can (i) state the laws, (ii) quote any relevant formula and (iii) draw diagrams of apparatus. It is important that you learn to draw simple clear diagrams of apparatus fairly quickly, and a little practice will be needed.

You will probably find you can concentrate better and learn faster if you revise hard for a number of fairly short sessions rather than for one long one. Most people find that they get more revision done in four half-hour sessions, with breaks between them, rather than in one two-hour session.

Your memory recall of the work you have revised will be improved immensely if you look through it at regular intervals. Suppose you do an hour's revision. If you spend just five minutes revising the same work again the next day and another five minutes a few days later, your memory recall at some future date will be very greatly improved. The important point to remember about revision is that it should occur regularly for short periods rather than for one long period; also that work should be reviewed briefly shortly after you have done it and again a few days later.

A quick revision may be carried out by:

(i) learning thoroughly the summaries at the beginning of each chapter, and
(ii) answering the questions in 'Have you mastered the basics?', which are in each chapter at the end of the Examples. *Do them without looking at the solutions*!

A quick way of revising many of the basic principles is to go through the book answering the multiple choice questions.

To enable you to revise a particular topic there is an index at the end of the book.

The questions at the end of each chapter are to give you practice at answering examination questions.

Check your own syllabus carefully. Topics which only occur in some syllabuses have, wherever possible, been placed towards the end of the worked examples, so that they may be omitted easily. Syllabuses and past papers may be obtained from the addresses shown in the Acknowledgements.

When you are revising using the worked examples, any question which begins with a table such as

A	B	C	D	E
1, 2, 3 all correct	1, 2 only correct	2, 3 only correct	1 only correct	3 only correct

it is a multiple completion type question. The way to answer such a question is explained on page 4.

How to Tackle Different Types of Examination Questions

(a) Calculations

You will not obtain full marks for a calculation unless you start by stating the physical principles involved and show the steps by which you arrive at the answer. You will lose marks in an examination if your answers to calculations consist of numbers without any indication of the reasoning by which you arrive at them. Remember it is a physics examination and not an arithmetic examination! The physics of the question must be clearly stated. Unless the answer is a ratio it will have a unit, so you *must always remember to state the unit*.

You may find it helpful before starting a calculation to ask yourself:

1. What am I being asked to calculate?
2. Which principle, law or formula needs to be used?
3. What units am I going to use?

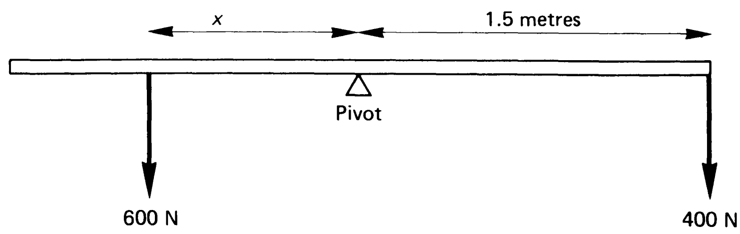
A further hint worth remembering is that an apparently complex problem involving many items of data may often be clarified using a simple diagram. When the question asks for a diagram a description will not do for the answer.

A numerical answer must not have more significant figures than any number used in the calculation (see section 1.3).

Example of a Calculation

A *uniform plank of wood 3 m long is pivoted at its mid-point and used as a seesaw. Jean who weighs 400 N sits on one end. Where must John, who weighs 600 N, sit if the seesaw is to balance?*

To answer this question first draw a diagram showing the plank and the forces acting on it.



All the relevant information is shown on the diagram. We need to calculate the distance x metre so that the seesaw is balanced. The physical principle must first be stated, i.e. for a body in equilibrium:

Anticlockwise moment about a point = Clockwise moment about the same point

We now substitute in this equation, taking moments about the pivot

$(600 \times x) = (400 \times 1.5)$

$\therefore x = \dfrac{400 \times 1.5}{600}$ m

$\therefore x = 1$ m

John must sit 1 m from the mid-point on the opposite side to Jean.

Always check your answer at the end to ensure that it is physically reasonable. Had you got an answer to the above question of 3 m, then you should at once realise that this is unreasonable (John would be off the end of the seesaw!), and look back to discover where you have made a mistake. *And don't forget to put a unit after the answer.*

(b) Multiple Choice Questions

If all the questions have to be attempted, do not waste valuable time reading through the paper before you start. Start at Question 1 and work steadily through the paper. If you come to a difficult question which you can't answer, miss it out and come back to it at the end. If you spend a lot of time thinking about questions which you don't find particularly easy, you may find yourself short of time to do some easier questions which are at the end of the paper.

When possible it is helpful to try and answer the question without first looking at the responses. This can reduce the chance of 'jumping to the wrong conclusions'. When you have found the response you think is correct, if time allows, check the other responses to see why they are incorrect.

When you have worked through the paper in this way, return to the questions you found difficult the first time through, but leave until the very end any questions about which you have little or no idea.

As examination boards do not deduct marks for wrong answers it is essential that you answer every question. If you are not sure which of the choices is the correct answer try and eliminate two or three of the alternative answers, and, if necessary, guess which of the remaining alternatives is correct.

If you have to alter an answer, ensure that the previous one has been completely rubbed out. Only one answer for each question must appear on the answer sheet.

Examples of Multiple Choice Questions

(i) Two resistors of values 2 ohms and 3 ohms are connected together in parallel. The resistance of the combination is

A $\frac{1}{5}\,\Omega$ **B** $\frac{5}{6}\,\Omega$ **C** $1\,\Omega$ **D** $1\frac{1}{5}\,\Omega$ **E** $5\,\Omega$

Since we are told the resistors are connected in parallel we must use the equation in section 12.1d

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\therefore \frac{1}{R} = \frac{1}{2} + \frac{1}{3}$$

$$\therefore \frac{1}{R} = \frac{3}{6} + \frac{2}{6} = \frac{5}{6}$$

$$\therefore R = \frac{6}{5} = 1\tfrac{1}{5}\,\Omega$$

The correct answer is **D**

(You may find it easier to remember that for two resistors in parallel the combined resistance R is given by $R = \frac{\text{product}}{\text{sum}} = \frac{2 \times 3}{2 + 3} = \frac{6}{5} = 1\frac{1}{5}$ ohm.)

(ii)

Summarised directions for recording responses to multiple completion questions				
A	B	C	D	E
1, 2, 3 all correct	1, 2 only correct	2, 3 only correct	1 only correct	3 only correct

Sound is:

(1) A series of moving compressions and rarefactions.
(2) Propagated as a transverse wave.
(3) Able to travel through a vacuum.

To answer this type of question read each answer in turn and put a tick by it if the statement is correct and a cross by it if it is wrong. Sound is a series of moving compressions and rarefactions (see section 11.1(d)), it is a longitudinal wave and it is not able to travel through a vacuum.

The only correct answer is (1). Now look at the table above. The answer is
A if (1), (2) and (3) are all correct
B if (1) and (2) only are correct

C if (2) and (3) only are correct
D if (1) alone is correct
E if (3) alone is correct
The answer is therefore **D**

(c) Short Answer or Structured Questions

In this type of question most examining boards leave space for the answer to be written on the question paper. The amount of space left will be a guide to the length of answer that is required as will the number of marks indicated by the question. It doesn't follow that if you don't fill all the space up you haven't answered the question correctly. But if five lines are left for the answer, and you have only written on one line, or if you can't possibly get your answer on five lines, then you certainly ought to have another think about the answer.

Example of a Short Answer Question

A system of pulleys is used to raise a load of 9 N through 2 m. The effort of 2 N moves through 12 m. What is
(i) the potential energy gained by the load,
(ii) the work done by the effort,
(iii) the efficiency of the system?

Answer

(i) Work done on load = Force × distance = 9 N × 2 m = 18 J
Potential energy gained by load = 18 J
(ii) Work done by effort = Force × distance = 2 N × 12 m = 24 J
(iii) Efficiency = $\frac{\text{Work out}}{\text{Work in}} = \frac{18}{24} = \frac{3}{4}$ = 0.75 or 75%

(d) Long Answer (Free Response) Type Questions

Make sure you attempt the full number of questions you have to answer.

If you are asked to describe an experiment you must normally draw a diagram of the apparatus or the relevant circuit diagram. A labelled diagram saves time, as information shown on the diagram need not be repeated in words. You should state clearly exactly what readings are taken, remembering that readings should be repeated as a check whenever possible. Finally mention any precautions necessary to obtain an accurate result.

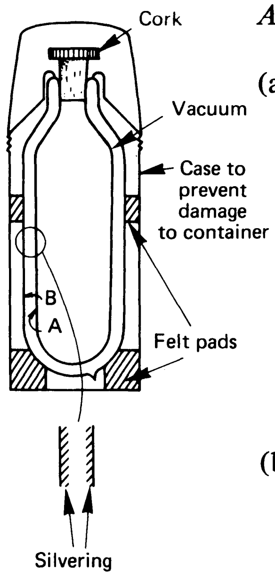
Avoid saying vaguely at the end 'the result is calculated from the readings'. You must state exactly how it is calculated.

If the answer involves drawing a graph, be sure to label the axes and choose a scale so that the graph covers most of the paper.

Example of a Long Answer Question

(a) Draw a labelled diagram of a vacuum (Dewar) flask. Explain how the features of its design make it a suitable container in which to keep cooked food hot. **(10 marks)**
(b) Calculate the quantity of heat required to change 5.00 kg of ice at 0°C into steam at 100°C. **(10 marks)**

(Specific heat capacity of water = 4.20×10^3 J/(kg K); specific latent heat of fusion of ice = 3.36×10^5 J/kg and specific latent heat of vaporisation of water = 2.27×10^6 J/kg.) (AEB)



Answer

(a) To reduce heat escaping from the food we have to reduce heat loss by convection, conduction and radiation. Both conduction and convection need a medium to travel through, so the vacuum prevents heat loss by conduction and convection. Silvered surfaces are poor radiators and the silvered surface indicated by the arrow A reduces the radiation from this surface. The small amount of heat energy which is radiated from this surface will be reflected at the silvered surface indicated by the arrow B. Very little heat is therefore lost by radiation. The main loss of heat is by conduction up the sides of the glass and through the cork at the top. In the absence of the cork, heat would be lost resulting from convection currents in the region of the opening (and also by evaporation if the contents is a liquid).

(b) Total quantity of heat needed = (heat to melt the ice) + (heat to raise the temperature of the water from 0°C to 100°C) + (heat to change water at 100°C to steam)

$= (mL)_{\text{ice}} + (m \times c \times T)_{\text{water}} + (m \times L)_{\text{steam}}$

$= (5 \times 3.36 \times 10^5)\text{ J} + (5 \times 4.20 \times 10^3 \times 100)\text{ J} + (5 \times 2.27 \times 10^6)\text{ J}$

(the equations used above are given in sections 7.1 and 7.2)

$= (16.8 \times 10^5 + 21.0 \times 10^5 + 113.5 \times 10^5)\text{ J}$

$= 151.3 \times 10^5$ J

Heat required = 15.1 MJ

A Few Important Points

(i) Read the question carefully before you write anything. Make sure you know exactly what the question is asking.

(ii) Answer the question precisely as asked. Note carefully the phrase used in the question. For example, 'explain', 'define', 'state', 'derive' and 'describe' all mean different things and are meant to be taken literally. It is a waste of time, for example, to explain a law if the question simply asks you to state it. On the other hand you will not get full marks if you *state* a law when the question asks you to *explain*.

(iii) Always attempt the full number of questions specified even if you cannot answer them fully. It is much easier to obtain the first few marks of a new question than the last few marks of a previous question. The candidate who only answers four questions when he should answer five reduces his maximum mark to 80%. So keep an eye on the clock and make sure you do not spend too much time on any one question.

(iv) Set your work out neatly and clearly. An examiner is human and if he has done many hours of marking, he is likely to be far more sympathetic if your work is well set out and easy to follow.

(v) Make sure you are familiar with the style of question set by your particular examining board and the length of time allowed for each question (syllabuses and past papers may be obtained from the addresses given in the Acknowledgements).

(vi) Don't spend a lot of time on a Multiple Choice Question or a Short Answer Question with which you are having difficulty. Leave that question and come back to it later if you have time.

1 Some Help with Mathematics

1.1 Using Mathematical Equations

Equations help us to relate certain quantities. The usefulness of the equation is extended if it can be rearranged. There are three helpful rules for rearranging an equation.

(a) The Plus/Minus Rule

A symbol or number may be moved from one side of an equation to the other provided the sign in front of the symbol or number is changed. That is, a 'plus' item on one side becomes a 'minus' item on the other side and vice versa. For example:

$X = Y + 30$

$X - Y = 30$ or $X - 30 = Y$

(b) The Diagonal Rule

An item may be moved diagonally across an equals sign. For example if

$$\frac{A}{B} = \frac{C}{D}$$

then the arrows show possible moves, so that

$$\frac{A}{B \times C} = \frac{1}{D} \quad \text{or} \quad \frac{A}{C} = \frac{B}{D} \quad \text{or} \quad \frac{D}{B} = \frac{C}{A}$$

(c) The 'Do unto Others' Rule

Whatever is done on one side of the equation must be done to the other side. For example:

if $A = B$ then $A^2 = B^2$ (both sides have been squared)

if $C = \frac{1}{D}$ then $\frac{1}{C} = D$ (both sides have been inverted)

BUT if $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ then $R \neq R_1 + R_2$ ($\neq$ means 'does not equal')

The WHOLE of each side must be inverted, i.e.

$$R = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2}} = \frac{1}{\dfrac{R_2 + R_1}{R_1 R_2}} = \frac{R_1 R_2}{R_1 + R_2}$$

1.2 Graphs

Choose easy scales, such as one large square to represent 1, 2, or 5 units (or multiples of 10 of these numbers). Avoid scales where one large square is 3, 4, 6, 7, 8 or 9 units. If each large square is say, 3 units, then a small square is 0.3 units and this makes the plotting of the graph much more difficult. Usually the spread of readings along the two axes should be about the same and they should cover most of the page.

It is important to remember to label the axes and to put a title at the top of the page. In Physics most relationships are either straight lines or smooth curves, so it is not correct to join adjacent points together by short straight lines. You must decide whether the relationship is a straight line or a curve, and then either draw the best straight line through the points or a smooth curve.

1.3 Significant Figures

A useful rule to remember is that you must never give more significant figures in the answer than the number of significant figures given in the least precise piece of data. For example, if a cube of side 2.0 cm has a mass of 71.213 g, then we may calculate the density by using the equation

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \text{(see section 2.3)}$$

$$= \frac{71.213\ \text{g}}{8.0\ \text{cm}^3} = 8.901625\ \text{g/cm}^3$$

according to my calculator! But the side was only given to two significant figures and we may not give the answer to more than two significant figures i.e. 8.9 g/cm^3 (we certainly do not know the density to the nearest millionth of a g/cm^3!). The answer should be written 8.9 g/cm^3.

A problem arises when the examiners use whole numbers without a decimal point and expect you to take it as exact. In the above calculation, if the side were given as 2 cm we may only strictly give the answer to one significant figure, i.e. 9 g/cm^3. If you are in doubt in such a calculation, work the calculation to, say, 3 sig. figs. and then give the answer to 1 sig. fig.

1.4 Powers of Ten

100 may be written as 10^2. $1000 = 10^3$

$\frac{1}{10}$ may be written as 10^{-1}.

$$\frac{1}{100} = 10^{-2} \qquad \frac{1}{1000} = 10^{-3} \qquad \frac{1}{100\,000} = 10^{-5}$$

1.5 Conversion of Units

$1 \text{ m}^2 = 100 \text{ cm} \times 100 \text{ cm} = 10^4 \text{ cm}^2$

so $5 \text{ N/cm}^2 = 5 \times 10^4 \text{ N/m}^2 = 50 \text{ kN/m}^2$

$1 \text{ m}^3 = 100 \text{ cm} \times 100 \text{ cm} \times 100 \text{ cm} = 10^6 \text{ cm}^3$

so $1 \text{ g/cm}^3 = 10^6 \text{ g/m}^3 = 1000 \text{ kg/m}^3$

Therefore to convert g/cm^3 to kg/m^3 we multiply by 1000.

1.6 Solidus and Negative Index Notation

Make sure you are familiar with the notation used by your examination board. Most boards use the solidus at O-level, i.e. m/s and kg/m^3 and will probably continue to do so for GCSE examinations. But m/s may be written m s^{-1} and kg/m^3 may be written kg m^{-3}.

2 SI Units, Density, Pressure and Hooke's Law

2.1 SI Units

(a) Some SI Base Units

Some base units of the SI system (Système International) are shown in table 2.1.

Table 2.1

Physical quantity	*Name of unit*	*Symbol for unit*
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Current	Ampère	A
Temperature	Kelvin	K

(b) Prefixes

Some of the more commonly used prefixes are given in table 2.2.

Table 2.2

Prefix	*Sub-multiple*	*Symbol*	*Prefix*	*Multiple*	*Symbol*
Centi-	10^{-2}	c	Kilo-	10^3	k
Milli-	10^{-3}	m	Mega-	10^6	M
Micro-	10^{-6}	μ	Giga-	10^9	G
Nano-	10^{-9}	n			
Pico-	10^{-12}	p			

2.2 Weight and Mass

The mass of a body (measured in kg) is constant wherever the body is situated in the Universe. The weight of a body (measured in N) is the force of gravity on the body and this does depend on where the body is situated in the Universe.

The Earth's gravitational field is 10 N/kg so the weight of a mass of 1 kg is 10 N.

2.3 Density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

If the mass is in kg and the volume in m^3 then the density is in kg/m^3.

Density may be determined by measuring the mass of a measured volume.

2.4 Pressure

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

If the force is measured in newtons and the area in $(\text{metre})^2$ then the pressure is in pascals (Pa). 1 Pa = 1 N/m^2.

The pressure due to a column of liquid (i) acts equally in all directions (ii) depends on the depth and the density of the liquid. It may be calculated using the equation

Pressure (Pa) = 10 (N/kg) x depth (m) x density (kg/m^3)

which may also be written as

Pressure (Pa) = $\rho g h$

where ρ is the density in kg/m^3, g the acceleration due to gravity (10 m/s^2) and h the depth in metres.

Pressure may be measured using a U-tube manometer or a Bourdon gauge. When any part of a confined liquid is subject to a pressure, the pressure is transmitted equally to all parts of the vessel containing the liquid. This principle, and the fact that liquids are virtually incompressible is made use of in hydraulic machines. Such machines are useful force multipliers. Referring to Fig. 2.1 the pressure on the small piston is 20 N/10 cm^2 or 2 N/cm^2. This pressure is transmitted to the large piston and the force on it is 2 N/cm^2 x 100 cm^2 = 200 N.

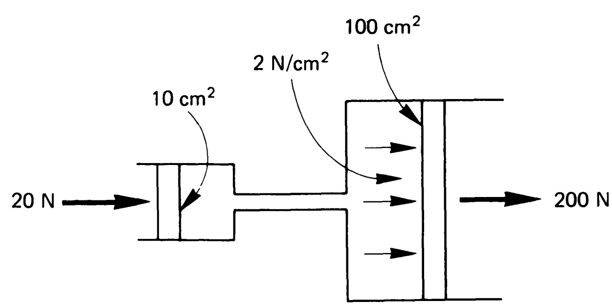


Figure 2.1 The principle of hydraulic machines.

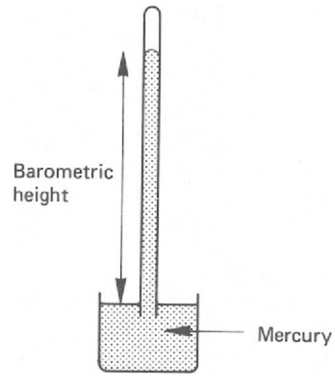


Figure 2.2 A mercury barometer.

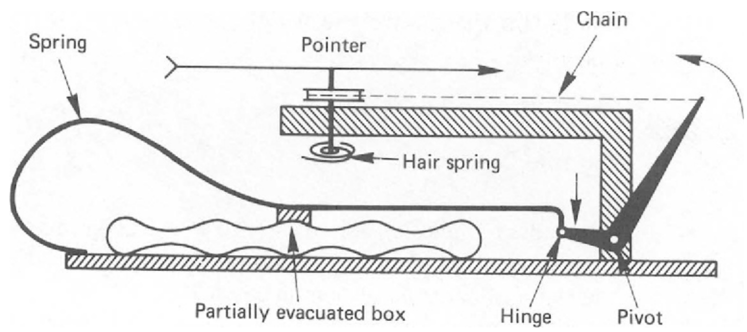


Figure 2.3 An aneroid barometer. When the atmospheric pressure increases, the centre of the partially evacuated box moves inwards and this small movement is magnified by a system of levers. The chain attached to the end lever moves the pointer. The large spring prevents the box from collapsing.

The atmosphere above us exerts a pressure known as the atmospheric pressure. The atmospheric pressure may be measured using a mercury barometer (Fig. 2.2) or an aneroid barometer (Fig. 2.3).

2.5 Hooke's Law

Hooke's law states that provided loads are not used which would cause a spring or wire to approach its *elastic limit*, the extension is proportional to the applied load.

Until the elastic limit is reached a spring (or wire) returns to its original length if the load is removed.

2.6 Worked Examples

Example 2.1

A mass of 1 kg is secured to the hook of a spring balance calibrated on the Earth. The spring balance reading is observed when it is freely suspended at rest just above the Earth's surface, secondly inside a spaceship orbiting round the Earth, and finally at rest on the Moon's surface.

If the acceleration due to free fall on the Earth is 10 m/s^2 and acceleration due to free fall on the Moon is 1.6 m/s^2, the spring balance readings, in N, would be (table 2.3).

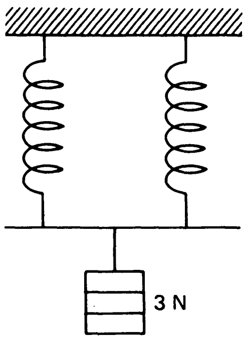
Table 2.3

	Point above Earth's surface	*Inside a spaceship*	*On the Moon*
A	1.0	0	0.16
B	1.0	0.84	0.16
C	10.0	0	1.6
D	10.0	0.84	0.16
E	10.0	11.6	1.6

(AEB)

Solution 2.1

[Weight on Earth = 1 x 10 = 10 N.
Weight on Moon = 1 x 1.6 = 1.6 N.
Inside the space ship the weight is zero.]
Answer **C**



Example 2.2

A student applies a force of 6 N to a helical spring and it extends by 12 cm. He then hangs the spring in parallel with an identical spring and attaches a load of 3 N as shown. The resulting extension of the system, in cm, will be

A 3 **B** 4 **C** 6 **D** 12 **E** 24

(AEB)

Solution 2.2

[Force acting on end of each spring = 1.5 N (the total upward force must equal the total downward force)

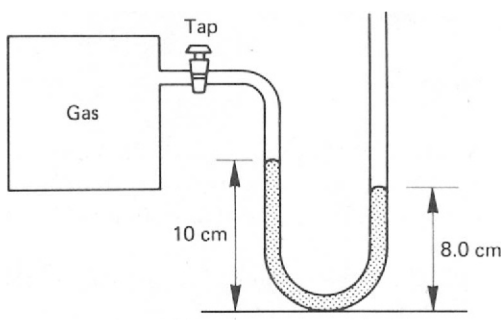
6 N extends the spring by 12 cm. Assuming Hooke's law applies (section 2.5)

1.5 N extends the spring by $\frac{12}{6} \times 1.5 = 3$ cm.]

Answer **A**

Example 2.3

A U-tube containing mercury is used as a manometer to measure the pressure of gas in a container. When the manometer has been connected, and the tap opened, the mercury in the U-tube settles as shown in the diagram.



The pressure of the atmosphere is equal to that exerted by a column of mercury of length 76 cm. The pressure of the gas in the container is equal to that exerted by a column of mercury of length

A 2.0 cm **B** 58 cm **C** 74 cm **D** 78 cm **E** 94 cm

Solution 2.3

[The atmospheric pressure exerted on the open limb of the U-tube is greater than the gas pressure by 2 cm of mercury. The gas pressure is therefore 76 – 2 = 74 cm.]

Answer C

Example 2.4

(a) A block of stone measures 2 m x 2 m x 1 m. It has a mass of 8000 kg.
   (i) What is its density?
   (ii) When it is standing on a bench what is the maximum pressure it can exert on the bench?

(b) A bath has some water in it and the depth of the water at the shallow end is 0.2 m. At the plug hole end it is 0.3 m. What pressure does the water exert on the plug?
(The Earth's gravitational field is 10 N/kg and the density of water is 1000 kg/m³.)

(10 marks)

Solution 2.4

(a) (i) $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$ [section 2.3] $= \frac{8000 \text{ kg}}{4 \text{ m}^3} = \underline{2000 \text{ kg/m}^3}$

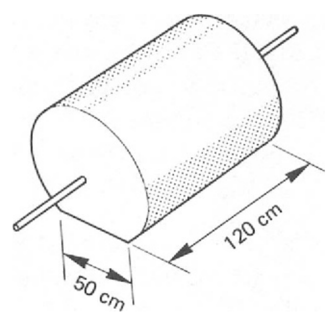
(ii) Maximum pressure occurs when the area of contact is a minimum.
Minimum area in contact with bench = 2 m²

$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ [section 2.4] $= \frac{80\,000 \text{ N}}{2 \text{ m}^2} = 40\,000 \text{ Pa} = \underline{40 \text{ kPa}}$

(b) Pressure = 10 x depth x density [section 2.4] = 10 x 0.3 x 1000 = $\underline{3000 \text{ Pa}}$

Example 2.5

A vehicle designed for carrying heavy loads across mud has four wide low-pressure tyres, each of which is 120 cm wide. When the vehicle and its load have a combined mass of 12 000 kg each tyre flattens so that 50 cm of tyre is in contact with the mud as shown in the diagram.



(a) Calculate
   (i) the total area of contact of the vehicle tyres with the mud,
   (ii) the pressure exerted on the mud.

(b) A car of mass 1000 kg is unable to travel across the mud although it is much lighter than the load-carrying vehicle. Why is this?

(6 marks)
(L)

Solution 2.5

(a) Area = 4 x (120 x 50) cm² = 24 000 cm²

(b) Pressure = $\frac{\text{Force}}{\text{Area}} = \frac{(12\,000 \times 10)\ \text{N}}{24\,000\ \text{cm}^2} = 5\ \text{N/cm}^2$ or $\underline{50\ \text{kN/m}^2}$

(c) The area of car tyre in contact with the road is much less than that of the vehicle. The pressure exerted by the car tyre on the mud is therefore greater than that exerted by the vehicle, and the tyre sinks into the mud.

Example 2.6

Describe how you would obtain, as accurately as possible, a series of readings for the load and corresponding extension of a spiral spring. **(6 marks)**

A student obtained the following readings:

Load/N	0	1	2	3	4	5	6
Length of spring/cm	10.0	11.5	13.0	14.5	16.0	18.5	24.0

Using these results, plot a graph of load against extension and estimate the load beyond which Hooke's law is no longer obeyed. **(7 marks)**

The spring is at rest with a mass of 0.2 kg on its lower end. It is then further extended by a finger exerting a vertical force of 0.5 N. Draw a diagram showing the forces acting on the mass in this position, giving the values of the forces. **(3 marks)**

Describe the motion of the mass when the finger is removed. Make your description as precise as possible, by giving distances. State the position where the kinetic energy of the mass will be greatest. **(4 marks)**

(L)

Solution 2.6

Clamp the top of the spring firmly to a support making sure that the support is also firm and cannot move. Clamp a ruler alongside the spring and attach a horizontal pointer to the bottom of the spring in such a way that the pointer is close to the surface of the ruler (this will help to avoid a parallax error when taking the readings). Record the pointer reading. Hang a known load on the end of the spring and again record the pointer reading. Increase the load and record the new pointer reading. Continue in this way thus obtaining a series of readings. The extension is calculated for each load by subtracting the unloaded pointer reading from the loaded pointer reading. A check may be made by again recording the pointer readings as the loads are removed one at a time (this is also a means of checking that the elastic limit has not been reached).

[Graph (Fig. 2.4). Remember to label axes, choose suitable scales, and when the line is no longer straight, draw a smooth curve. You are asked to plot extension against load so the original length of the spring 10 cm, must be subtracted from each reading.]

Hooke's law is obeyed for loads up to 4 N but very soon after this the graph begins to curve and Hooke's law is no longer obeyed.

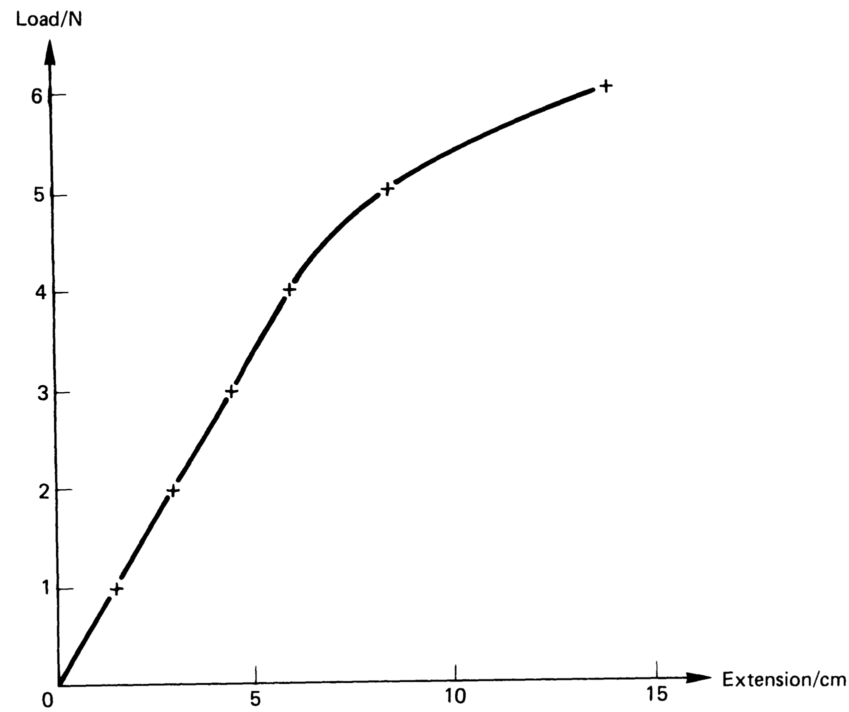
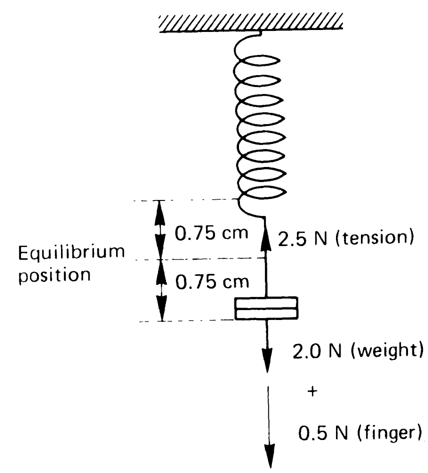


Figure 2.4 Load against extension.

The 0.2 kg mass (force 2 N) extends the spring 3 cm to a position of equilibrium. A further force of 0.5 N extends the spring 0.75 cm beyond this position. When the 0.5 N force is removed the spring oscillates about the original position



of equilibrium. The oscillations will gradually decrease from an amplitude of 0.75 cm to zero. The spring will then be at rest with an extension of 3 cm. The maximum kinetic energy is when the spring passes through the equilibrium position (extension 3 cm).

2.7 Have You Mastered the Basics?

1. Can you define density, pressure and elastic limit?
2. Can you state Hooke's law?
3. Can you describe a mercury barometer, an aneroid barometer, and an hydraulic machine?

4. What is the weight of a mass of 5 kg which is on the Earth?
5. A force of 12 N acts on an area of 3 m x 2 m. What is the pressure?
6. What is the hydrostatic pressure 20 m below the surface of a lake of water of density 1000 kg/m^3?

2.8 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See sections 2.3, 2.4 and 2.5.
2. See section 2.5.
3. See section 2.4.
4. The Earth's gravitational field is 10 N/kg. This means that the pull of gravity on a mass of 1 kg is 10 N. Therefore the pull of gravity on a mass of 5 kg is 5 x 10 = 50 N. Weight = 50 N.
5. Use the equation in section 2.4. The area is (3 x 2) m^2.
   Answer = 2 N/m^2.
6. Use the equation in section 2.4. Pressure = 2×10^5 N/m^2.

2.9 Questions

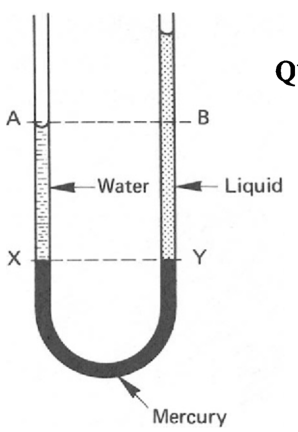
Question 2.1
(Answers and hints on solutions will be found in Section 2.10.)

The gravitational field strength on the surface of the Moon is 1.6 N/kg. Which of the pairs of values shown below applies to a mass taken to the Moon?

	Mass (in kg)	*Weight (in N)*
A	10	0.16
B	10	1.6
C	10	16
D	1.6	1.0
E	1.6	16

Question 2.2

(a) Define density. State a consistent set of units in which the quantities could be measured.
(b) An empty box has a mass of 2 kg and is made from material which has a density of 8000 kg/m^3. What is the volume of material which is needed to make the box?
(c) The density of a liquid is 1200 kg/m^3. What is the liquid pressure 8 m below the surface of the liquid. Take the acceleration of free fall as 10 m/s^2. **(10 marks)**



Question 2.3

Directions summarised				
A	**B**	**C**	**D**	**E**
1, 2, 3 all correct	**1, 2** only correct	**2, 3** only correct	**1** only correct	**3** only correct

The U-tube shown in the diagram contains a liquid and water separated by mercury. Which of the following statements concerning the arrangement is/are correct?

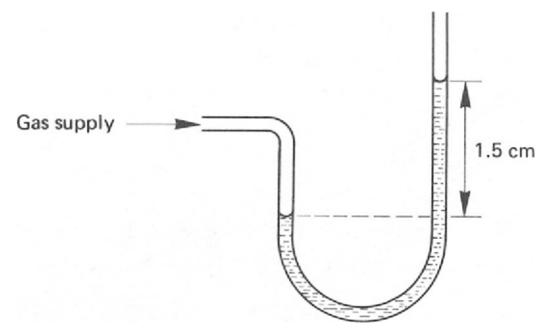
1 The pressure at Y is greater than the pressure at X
2 The pressure at A is less than the pressure at B
3 The density of water is greater than the density of the liquid

Question 2.4

Directions summarised				
A	B	C	D	E
1, 2, 3 all correct	1, 2 only correct	2, 3 only correct	1 only correct	3 only correct

A ballroom floor can withstand a maximum pressure of 3000 kN/m^2 without damage. Which of the following would damage it?
1 A woman weighing 0.7 kN standing on the heel of one shoe of area 10^{-4} m^2
2 An elephant weighing 200 kN standing on one foot of area 0.1 m^2
3 A 1000 kN load standing on an area of 50 m^2 **(AEB)**

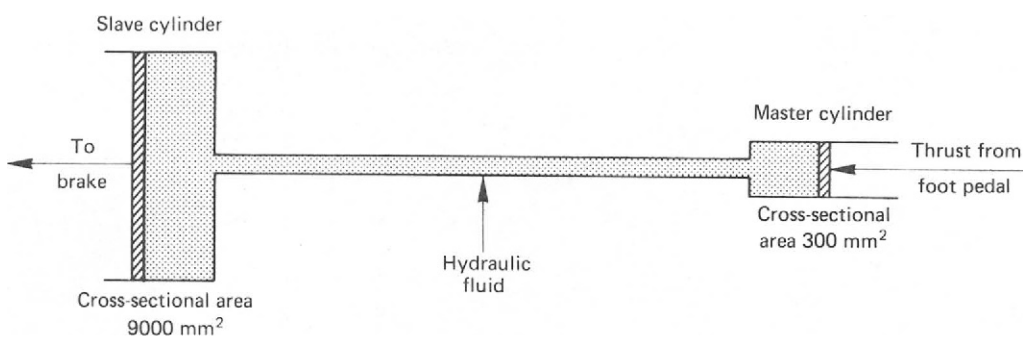
Question 2.5



An manometer containing mercury is connected to a gas supply as shown. If atmospheric pressure is equivalent to 750 mm mercury, the pressure of the gas in mm of mercury is
A 600 **B** 700 **C** 735 **D** 765 **E** 900 **(AEB)**

Question 2.6

(a) What is meant by the pressure at a point in a liquid? **(3 marks)**
(b) The diagram illustrates part of the braking system of a motor car. The master cylinder and its piston are connected hydraulically to a slave cylinder and its piston.



If the thrust on the piston in the master cylinder is 600 N, use the information in the diagram to calculate

(i) the pressure in the hydraulic fluid,

(ii) the thrust on the piston in the slave cylinder. **(6 marks)**

(c) State one property of a liquid that makes it suitable as a hydraulic fluid. **(1 mark)**

Question 2.7

(a) What is meant by 'pressure'? **(2 marks)**

(b) State two factors on which the pressure exerted by a fluid depends. **(2 marks)**

(c) What is the pressure of the atmosphere in pascals on a day when a mercury barometer reads 760 mm Hg? (The density of mercury is 13 600 kg/m^3 and the Earth's gravitational field is 10 N/kg.) **(4 marks)**

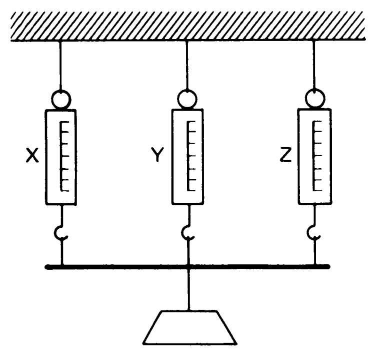
Question 2.8

(a) Describe an experiment you would perform to investigate the relationship between the extension of a spring and the load hung on it. Your answer should include a sketch of the apparatus, a description of all the observations you would make and how you would deduce the relationship from your readings. **(12 marks)**

(b) Distinguish between mass and weight. Which does a spring balance read? Explain why a sensitive spring balance can detect the variation in the Earth's gravitational field as it is taken to different parts of the Earth's surface, but a sensitive beam balance is unable to detect any variation. **(8 marks)**

Question 2.9

The diagram shows three identical spring balances X, Y and Z, supporting a light rod to which is attached a weight of 60 N. X and Z are equidistant from Y.



The table shows possible readings of the spring balances in newtons. Which set of readings is correct?

	X	Y	Z
A	60	60	60
B	20	60	20
C	20	20	20
D	10	40	10
E	0	60	0

(L)

2.10 Answers and Hints on Solutions to Questions

1. The force on 1 kg is 1.6 N, hence the force on 10 kg is 16 N.
   Answer C
2. (a) See section 2.3. (b) Use equation in section 2.3.
   Answer 2.5×10^{-4} m^3
   (c) See section 2.4.
   Answer 9.6×10^4 Pa
3. Answer C
4. Use the definition of pressure in section 2.4. For woman, pressure = 7000 kN/m^2. The elephant and load exert pressures of less than 3000 kN/m^2.
   Answer D
5. Gas pressure = atmospheric pressure + pressure due to 15 mm of mercury.
   Answer D
6. (a) Take a small area round the point and work out the pressure from Pressure = Force/Area.
   (b) (i) 2 N/mm^2 or 2×10^6 Pa. (ii) Remember that the pressure is the same throughout the fluid.
   Answer 18 000 N
   (c) See section 2.4.
7. (a) and (b) see section 2.4. (c) Use equation in section 2.4. What units must the height of the mercury column be in?
   Answer 1.03×10^5 Pa
8. (a) There are 12 marks for this part so full experimental details are needed. Remember to clamp the spring in a support which will not move when the weights are hung from the spring. Check the elastic limit is not exceeded by checking the readings when the weights are removed. Plot load against extension and a straight line through the origin shows that the extension is proportional to the load.
   (b) See section 2.2. A beam balance compares masses and the mass does not change with position on the Earth's surface. The extension of a spring balance depends on the pull of gravity on the mass hung on its end.
9. Answer C

3 Motion, Scalars and Vectors

3.1 Velocity and Acceleration

$$\text{Velocity} = \frac{\text{Distance travelled in a specified direction (i.e. displacement)}}{\text{Time taken}}$$

(Unit m/s)

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken for change}} \qquad (\text{Unit m/s}^2)$$

The gradient of a displacement/time graph is the velocity. The gradient of a velocity/time graph is the acceleration. The area under a velocity/time graph is the distance travelled (N.B. the velocity axis must start from zero).

3.2 Newton's Laws of Motion

1. If a body is at rest it will remain at rest, and if it is in motion it will continue to move in a straight line with a constant velocity unless it is acted on by a resultant external force.
2. The acceleration of a body is directly proportional to the resultant force acting on it and inversely proportional to the mass of the body.
3. If a body A exerts a force on a body B then B exerts an equal and opposite force on body A.

Newton's second law may be verified using a trolley and ticker timer as described in Example 3.5. The second law may be summarised by the equation

$F = ma$

where F is the force in newtons, m the mass in kilograms and a the acceleration in metres per second per second.

3.3 Momentum

Momentum = mass × velocity (Unit kg m/s or N s)

When no external force acts on a system (for example, a collision or an explosion) momentum is conserved. For example, if a body of mass m_1 travelling with a velocity v_1 collides with a stationary body of mass m_2 and sticks to it, both bodies moving on with a velocity v then

$$m_1 v_1 = (m_1 + m_2) v$$

If a body of mass m starts from rest and reaches a velocity v in t seconds as a result of a force F acting on it then the acceleration is v/t and

$$F = ma = \frac{mv}{t} \qquad \text{where } \frac{mv}{t} \text{ is the rate of change of momentum.}$$

3.4 Scalars and Vectors

A *scalar* quantity has magnitude only. A *vector* quantity has magnitude and direction. Examples of scalar quantities are mass, temperature and energy. Force, weight, velocity and momentum are examples of vector quantities.

Vector quantities must be added by the rule for vector addition. Forces of 3 N and 4 N acting at right angles have a resultant of 5 N. This may be verified by drawing a diagram (Fig. 3.1) to scale and measuring the length of the resultant R. Alternatively R may be calculated using the measurements shown in the diagram.

A force of 10 N acting at an angle of $\theta°$ to the horizontal has a horizontal component of 10 cos θ N and a vertical component of 10 sin θ N (Fig. 3.2).

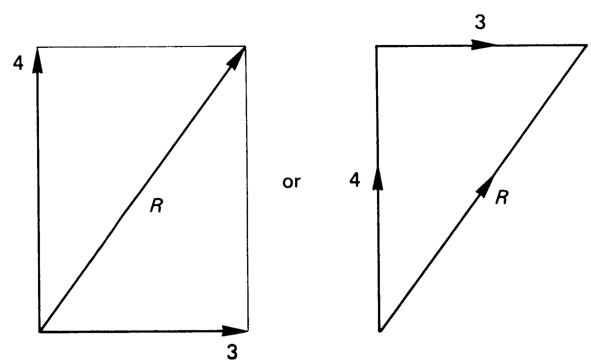


Figure 3.1 Addition of vectors.

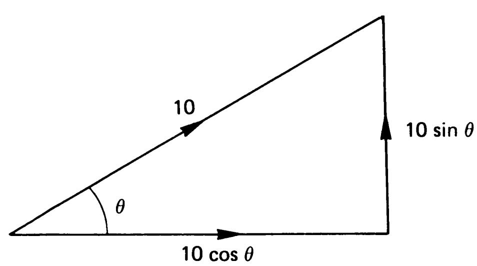


Figure 3.2 The vertical component is 10 sin θ and the horizontal component is 10 cos θ.

3.5 Uniformly Accelerated Motion

If a body starts from rest and accelerates uniformly with an acceleration a for t seconds, acquiring a velocity v and travelling a distance s then

$$v = at \qquad s = \tfrac{1}{2}at^2 \qquad v^2 = 2as$$

(if the body has a velocity u when $t = 0$, the equations become $v = u + at$, $s = ut + \frac{1}{2}at^2$ and $v^2 = u^2 + 2as$).

For a body falling vertically a is replaced by g the acceleration due to gravity. g may be measured using a ticker-timer (see Example 3.5) or by using photodiodes and a centisecond clock (see Example 3.7).

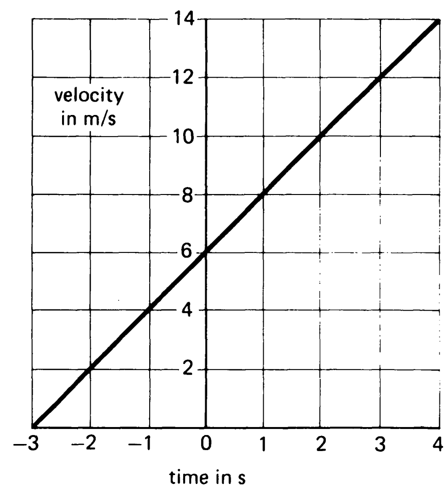
3.6 Independence of Horizontal and Vertical Motion

The horizontal and vertical motions of a body are independent and may be treated separately (see Example 3.10).

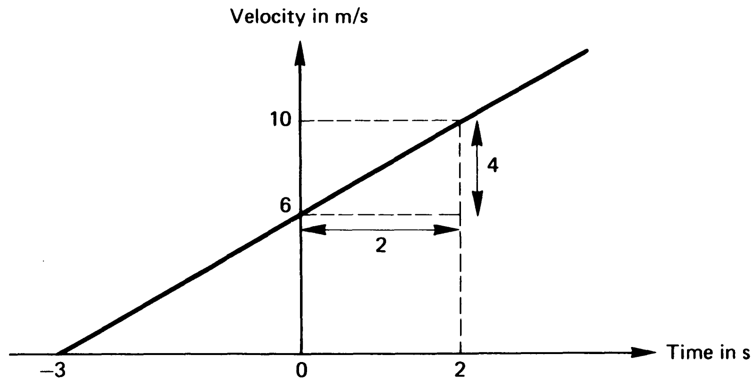
3.7 Worked Examples

Example 3.1

The acceleration, in m/s², of the body whose motion is represented by the graph shown is
A 1.5 **B** 2.0 **C** 3.5 **D** 6.0 **E** 14.0 (AEB)



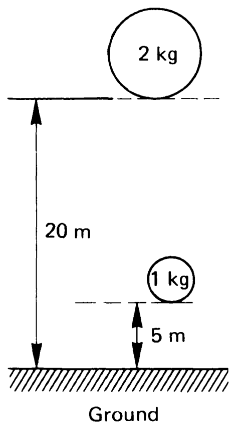
Solution 3.1



$$\left[\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken for change}} = \text{gradient of graph (see section 3.1)}\right.$$

$$\left. = \frac{4\ \text{m/s}}{2\ \text{s}} = 2\ \text{m/s}^2\right]$$

Answer **B**



Example 3.2

The two steel balls shown in the diagram are both released from rest at the same time. What time interval elapses between when the 1 kg ball strikes the ground and when the 2 kg ball strikes the ground? (the acceleration due to gravity is 10 m/s^2).

A 0.25 s **B** 0.50 s **C** 1.0 s **D** 2 s **E** 3 s

Solution 3.2

[Remember that the accelerations and speeds of bodies falling under gravity do not depend on their masses (all masses fall with the same acceleration).

Time for 1 kg mass to fall is given by

$s = \frac{1}{2}gt_1^2$ (see section 3.5)

$5 = \frac{1}{2} \times 10 \times t_1^2$

$t_1^2 = 1$

$t_1 = 1$ seconds

The same formula enables us to calculate the time of fall of the 2 kg mass

$s = \frac{1}{2}gt_2^2$

$20 = \frac{1}{2} \times 10 \times t_2^2$

$t_2 = 2$ seconds

Time interval between hits on ground = $t_2 - t_1 = 1$ second.]

Answer **C**

Example 3.3

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

A force of 10 N gives a mass of 5 kg an acceleration of 2 m/s^2. The same force would produce an acceleration of

1 2 m/s^2 when acting on a mass of 10 kg
2 5 m/s^2 when acting on a mass of 2 kg
3 10 m/s^2 when acting on a mass of 1 kg

Solution 3.3

[The three quantities are related by the equation $F = ma$ (see section 3.2). If $F = 10$ N then the product ma must be 10 N. This is true for responses 2 and 3.]

Answer **D**

Example 3.4

When a mass starts from rest and a constant force acts on it
(1) The acceleration is uniform
(2) The velocity increases by equal amounts in equal times
(3) The distance travelled is directly proportional to the time

Summarised directions for recording responses to multiple completion questions				
A (1) alone	B (3) alone	C (1) and (2) only	D (2) and (3) only	E (1), (2) and (3)

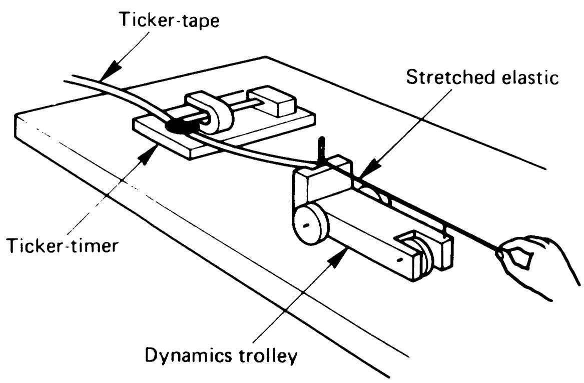
Solution 3.4

[A constant force produces a constant acceleration. Since $s = \frac{1}{2}at^2$ (section 3.5) the distance travelled is proportional to the *square* of the time. Acceleration = $\frac{\text{Change in velocity}}{\text{Time taken}}$ and if the acceleration is constant the velocity must increase by equal amounts in equal times.]

Answer C

Example 3.5

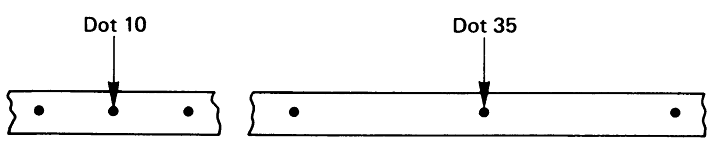
(a) In order to investigate the relationship between force and acceleration, an experiment was carried out using a ticker-tape attached to a trolley as shown in the diagram. The



tape was fed through a ticker-timer which made 50 dots on the tape every second. The trolley was placed on a gently sloping inclined plane. A force was applied by pulling on an elastic band attached to the trolley.

(i) Explain why an inclined plane was used and what experiment would have been con-conducted in order to get the correct inclination of the plane.
(ii) How would the force applied to the trolley have been kept constant?
(iii) How would a force which was twice the magnitude of the original force have been applied?

(b) The diagram below shows two sections of one tape obtained from such an experiment.



The first section shows dots 9, 10 and 11; the second section dots 34, 35 and 36.
(i) Measure the distance between dots 9 and 11 and calculate the average velocity of trolley between dots 9 and 11.

(ii) Calculate the average velocity of the trolley between dots 34 and 36.
(iii) What time interval elapsed between dot 10 and dot 35?
(iv) Calculate the acceleration of the trolley.

(c) The acceleration of the trolley was calculated for five different forces.
(i) Sketch a graph which represents the results of the above experiment.
(ii) State the relationship between force and acceleration.

Solution 3.5

(a) (i) The inclined plane is to compensate for friction. The plane is tilted until the component of the gravitational force accelerating the trolley is equal to the frictional force. This is done by tilting the plane until the trolley moves with a constant velocity when given a push. When the correct tilt is obtained a ticker-tape attached to the trolley will have dots on it equally spaced.
(ii) The rubber band must be kept stretched by the same amount throughout the run.
(iii) Two identical rubber bands each stretched the same amount as the original rubber band.

(b) (i) Distance between dot 9 and dot 11 = 2 cm
Time between dot 9 and dot 11 = 2/50 = 0.04 s

$$\text{Velocity} = \frac{\text{Distance gone}}{\text{Time taken}} = \frac{2 \text{ cm}}{0.04 \text{ s}} = 50 \text{ cm/s}$$

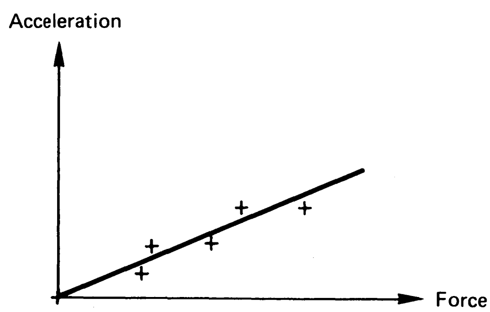
(ii) Distance between dot 34 and dot 36 = 5 cm

$$\text{Velocity} = \frac{5 \text{ cm}}{0.04 \text{ s}} = 125 \text{ cm/s}$$

(iii) 0.5 s [This is the time for 25 dots]

(iv) $$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken for change}} = \frac{(125 - 50) \text{ cm/s}}{0.5 \text{ s}} = 150 \text{ cm/s}^2$$

(c) (i)

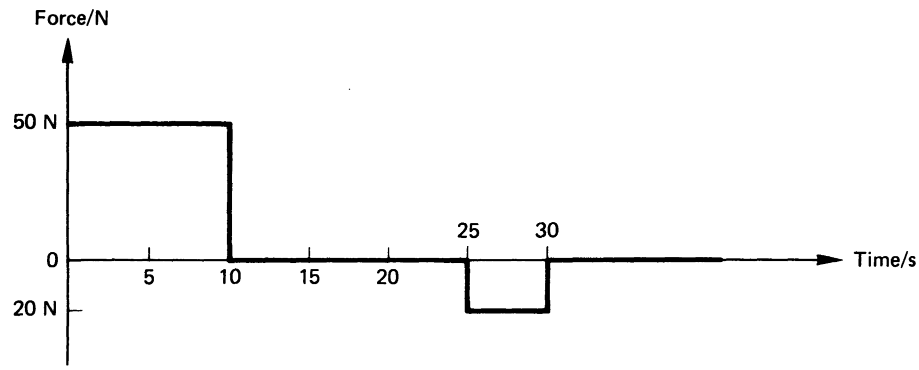


(ii) The acceleration is proportional to the resultant force provided the mass is kept constant.
[or Resultant force = Mass x Acceleration]

[The relationship between mass and acceleration may be investigated by keeping the force constant (band at constant stretch) and varying the mass (add masses to the trolley). The acceleration due to gravity, g, may be measured if the ticker-timer is arranged so that the tape (with a mass on its end) falls vertically.]

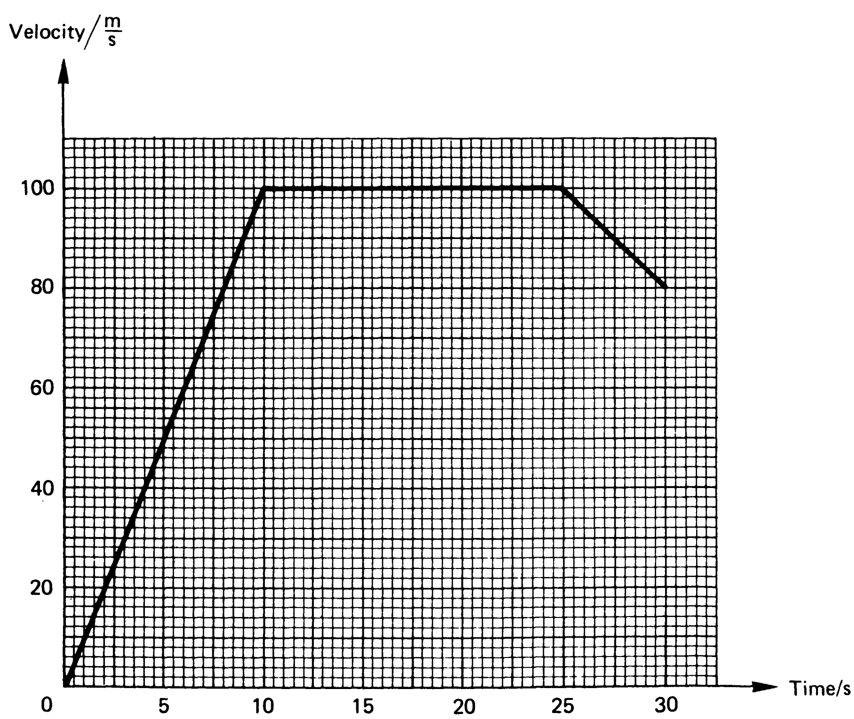
Example 3.6

(a) What do Newton's laws tell us about the effect of a force on a body? **(3 marks)**
(b) Define a newton. **(3 marks)**
(c) A body of mass 5 kg is at rest when a horizontal force is applied to it. The force varies with time as shown on the graph below. Use the figures on the graph to calculate how the velocity varies with time and plot a graph of velocity against time for the first 30 s of its motion. **(11 marks)**
(d) How far does it travel in the first 10 s? **(3 marks)**



Solution 3.6

(a) When a resultant force acts on a body the body accelerates, that is changes its velocity.
(b) A newton is the force which gives a mass of 1 kg an acceleration of 1 m/s^2.
(c) $F = ma$. During the first 10 s, $50 = 5 \times a$ hence $a = 10$ m/s^2.
For the next 15 s no force acts and the body continues with constant velocity.
From 25 s to 30 s the body decelerates and
$-20 = 5 \times a$ hence $a = -4$ m/s^2.
Since $v = at$, after 10 s velocity = $10 \times 10 = 100$ m/s
From 10 s to 25 s the body continues at 100 m/s.
Between 25 s and 30 s the change in velocity is $4 \times 5 = 20$ m/s.
So after 30 s the velocity is $100 - 20 = 80$ m/s.



(d) Distance travelled = Average velocity x time = 50 x 10 = 500 m.
[This is also the area under the graph for the first 10 s.]

Example 3.7

(a) In an experiment to determine g, the acceleration of free fall, it is necessary to make careful measurements both of *length* and *time*. Values for these two quantities are then substituted in an appropriate formula to enable g to be calculated.

(i) Draw a diagram of the arrangement of the apparatus you would use to determine g. Indicate on the diagram the exact length that must be measured for the calculations. **(4 marks)**

(ii) Describe fully how the time interval in the calculation is measured. **(4 marks)**

(iii) In your answer book write a relationship of the form 'g = ' which would enable the acceleration of free fall to be calculated using the measurements of length and time you have described in your answers to (i) and (ii).
How could you improve the reliability of your determination of g? **(3 marks)**

(b) When the manned space station *Skylab* was in operation it orbited the earth above the earth's atmosphere.

(i) One of Newton's laws of motion states: 'An object will continue with constant speed in a straight line unless an external unbalanced force acts on the object'.
Explain why *Skylab* circled the earth rather than continuing with constant speed in a straight line. **(3 marks)**

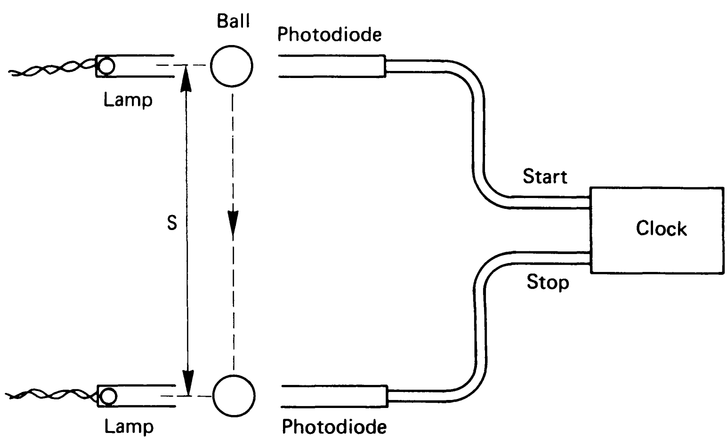
(ii) Experiments conducted by an astronaut in *Skylab* standing on a weighing machine would have shown that he was weightless, i.e. the machine would have read '0'. Explain why the astronaut would have appeared weightless in this situation. **(3 marks)**

(iii) If *Skylab* had been suddenly halted in its orbit, describe and explain its motion in the next few seconds after it had been stopped, assuming that it was now free to move again. **(3 marks)**

(L)

Solution 3.7

(a) (i)



(ii) When the ball breaks the beam from the upper lamp shining on the photodiode, the centisecond clock starts. When the ball prevents light from the lower lamp shining on the other photodiode, the clock is stopped. The time recorded on the clock is the time interval needed (t). The experiment should be repeated and the average value of t calculated.

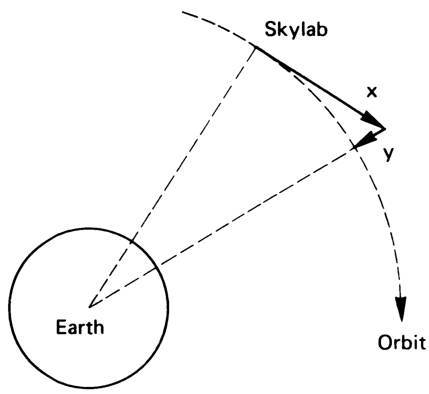
[Don't forget this last sentence is important when describing an experiment.]

(iii) $g = \frac{2s}{t^2}$

Increase the distance s and the corresponding time interval.

[Alternatively, the question could be answered using a simple pendulum.]

(b) (i) Newton's law says that the body continues in a straight line *unless acted on by a resultant external force. Skylab* was acted on by an external (centripetal force), which is the force of gravity acting perpendicular to the direction of motion and pulling it towards the centre of the Earth. Referring to the diagram, in the absence of gravity *Skylab* would travel a distance x in a straight line. While it is travelling x, gravity pulls it a distance y and it travels round a circular path.



(ii) Both *Skylab* and the astronaut are falling freely in space at the *same rate* and the astronaut is therefore weightless. In this situation the centripetal force to keep the astronaut in orbit is exactly equal to the force of gravity.

(iii) *Skylab* would fall vertically towards the Earth, accelerating because of the pull of gravity on it.

Example 3.8

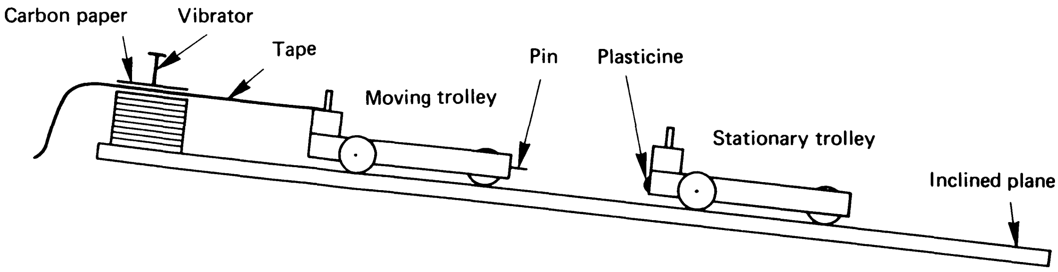
(a) A moving trolley collides with a stationary trolley and sticks to it. Outline an experiment you would do in order to investigate the momentum of the system before and after the collision. **(8 marks)**

(b) A mass of 5 kg is acted on by a constant force. Its initial momentum is 200 N s and after 10 s its momentum is 500 N s. What is the acceleration? **(6 marks)**

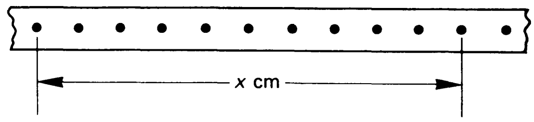
(c) A mobile gun is stationary when a shell of mass 10 kg is fired from it. If the mass of the gun is 2 tonnes and the velocity of the shell is 400 m/s, what is
 (i) the initial velocity of recoil of the gun,
 (ii) the initial kinetic energy of the gun as it recoils?
 (1 tonne = 1000 kg) **(6 marks)**

Solution 3.8

(a) The trolleys are placed on a friction compensating slope and the slope adjusted until the trolleys run with a constant velocity when given a start. A tape passing through a ticker-timer is attached to one of the trolleys. This trolley has a pin attached to it which will stick in some plasticine on the other trolley when they collide. The trolley is given a push, it collides with the stationary trolley and they move on together. The tape will show a set of equally spaced dots before the collision and another set of equally spaced dots after the collision.



The velocity in each case is calculated by measuring the distance travelled in $\frac{1}{5}$ s (i.e. in 10 dots, assuming the ticker-timer makes 50 dots every second). If this is x cm, then the velocity is (x cm)/(1/5 s) = $5x$ cm/s. If the masses of



the trolleys are m_1 and m_2, their initial velocities are u and 0 and their final velocities are v, then

Momentum before collision = $m_1 u$
Momentum after collision = $(m_1 + m_2)\, v$.

(b) [In order to answer this question you need to know the relation between force and momentum (section 3.3).]

$$\text{Force} = \frac{\text{Change of momentum}}{\text{Time}} = \frac{(500 - 200)}{10} = 30\ \text{N}$$

Using $F = ma$ [section 3.2]

$$a = \frac{F}{m} = \frac{30}{5} = 6\ \text{m/s}^2$$

(c) (i) [This is a system on which no external force acts and hence momentum is conserved.]

By the conservation of momentum
Change in momentum of gun = Change in momentum of shell
$2000 \times v = 10 \times 400$ kg m/s
where v is the velocity of recoil of the gun.
$v = 2$ m/s in the opposite direction to the shell motion.

[Remember velocity must have a direction.]

(ii) Kinetic energy = $\frac{1}{2} mv^2 = \frac{1}{2} \times 2000 \times 2^2 = 4000$ J

Example 3.9

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

A moving trolley collides with a stationary trolley of equal mass. The two trolleys stick together and move on with a velocity v. Which of the following statements is/are correct?

1 The total momentum of the trolleys before impact is the same as the total momentum of the trolleys after impact
2 The trolley which was moving before the collision was moving with velocity $2v$

3 The total kinetic energy of the trolleys before impact is the same as the total momentum of the trolleys after impact

Solution 3.9

[See section 3.3.]

Answer C

Example 3.10

(a) Distinguish between scalar quantities and vector quantities. Are the following scalars or vectors? (i) Speed, (ii) velocity, (iii) kinetic energy. Give reasons for your answers. **(6 marks)**

(b) A stone X is catapulted horizontally from the top of a cliff at 30 m/s and it strikes the ground 4 s later. At the same time as X is thrown, a stone Y is dropped from rest vertically.

(i) How long will stone Y take to reach the ground?

(ii) What is the height of the cliff?

(iii) How far from the cliff does the stone X land?

(iv) Explain why the horizontal velocity of stone X is 30 m/s just before it strikes the ground and the vertical velocity of stone X is 40 m/s just before it strikes the ground. State clearly the assumption that is made in making the above statement.

(v) Calculate the velocity of stone X just before it hits the ground. **(14 marks)**

(The Earth's gravitational field is 10 N/kg.)

Solution 3.10

(a) A scalar is a quantity which has magnitude only but a vector quantity has both magnitude and direction. (Vector quantities must be added by the law of vector addition.) Kinetic energy and speed have no direction associated with them and are scalar quantities. Velocity is a vector quantity and has a definite direction.

(b) (i) 4 s

[The vertical component of velocity is the same for both stones and they both hit the ground at the same time. The vertical component of velocity of the stone thrown is totally independent of the horizontal component.]

(ii) $s = \frac{1}{2} gt^2$ where $g = 10$ m/s^2

$s = \frac{1}{2} \times 10 \times 4^2 = 80$ m

(iii) Distance = Velocity x Time = 30 x 4 = 120 m

(iv) The horizontal and vertical components are independent of one another. No horizontal force acts on the stone and it continues at 30 m/s throughout its journey. The force of gravity acts vertically and the vertical acceleration is 10 m/s^2. Hence the velocity after 4 s is given by

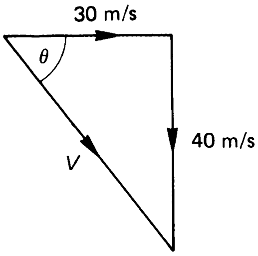
$v = gt = 10 \times 4 = 40$ m/s

The above calculations assume that air resistance is negligible and that gravity is the only force acting on the stone after it is released.

(v) If V is the velocity then

$V^2 = 30^2 + 40^2 = 2500$

$V = 50$ m/s



$$\tan \theta = \frac{40}{30} = 1.33 \qquad \theta = 53.1°$$

Velocity is 50 m/s at an angle of 53.1° to the horizontal.

[Don't forget that when you are finding a vector quantity you must *always* give the direction as well as the magnitude.]

3.8 Have You Mastered the Basics?

1. Can you define velocity, acceleration, momentum, scalar and vector?
2. Do you know what the gradient of a velocity/time graph is and what the area under the graph represents?
3. Can you state the equations of uniformly accelerated motion?
4. Can you describe experiments to (i) show that the acceleration of a body is proportional to the force acting on it and inversely proportional to the mass of the body, (ii) measure the acceleration due to gravity, (iii) show that momentum is conserved in a collision?
5. Do you know the units of the quantities in the equation $F = ma$?
6. Do you know how to add vectors?
7. A force of 10 N acts on a mass of 2 kg. What is the acceleration?
8. A trolley of mass 4 kg is moving at 3 cm/s and collides with a stationary trolley of mass 2 kg. The trolleys join together. What is their velocity immediately after impact?

3.9 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

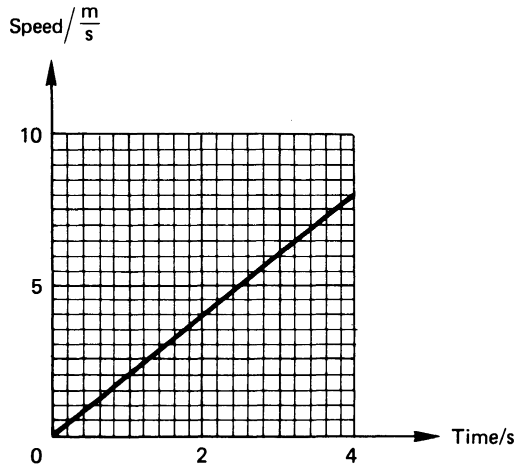
1. See sections 3.1, 3.3 and 3.4.
2. See section 3.1.
3. See section 3.5.
4. See Examples 3.5, 3.7 and 3.8.
5. See section 3.2.
6. See section 3.4.
7. $F = ma \Rightarrow 10 = 2 \times a \Rightarrow a = 5\ \text{m/s}^2$
8. Momentum before impact = Momentum after impact
   $4 \times 3 = (4 + 2) \times v$
   where v is their velocity after impact.
   $v = 2.0$ cm/s in the same direction as the first trolley.

[Don't forget that velocity must have a direction.]

3.10 Questions

(Answers and hints on solutions will be found in section 3.11.)

Question 3.1



The graph shows the speed of a body of mass 5 kg moving in a straight line plotted against the time.

(a) Use the graph to calculate the acceleration of the mass. **(3 marks)**

(b) Use the graph to determine the distance travelled by the mass in the first 4.0 s. **(3 marks)**

(c) What force acts on the body? **(3 marks)**

Question 3.2

Directions summarised				
A	**B**	**C**	**D**	**E**
1, 2, 3 all correct	**1, 2** only correct	**2, 3** only correct	**1** only correct	**3** only correct

An object of mass 5 kg is accelerated uniformly from rest to a velocity of 12 m/s in 4 s.

1 The acceleration of the object is 48 m/s^2

2 The distance travelled is 24 m

3 The force acting is 15 N **(AEB)**

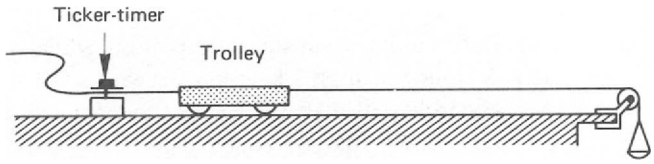
Question 3.3

(a) What does Newton's first law of motion tell us about the effect of a force on a body? **(3 marks)**

(b) Sketch graphs to show the relationship between velocity and time for a trolley moving with (i) zero acceleration, (ii) an acceleration which increases with time. **(4 marks)**

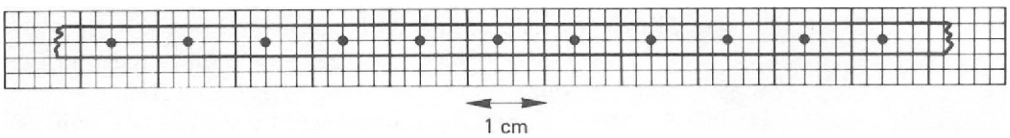
(c) Describe, giving full details, how you would investigate the relationship between force, mass and acceleration. **(13 marks)**

Question 3.4



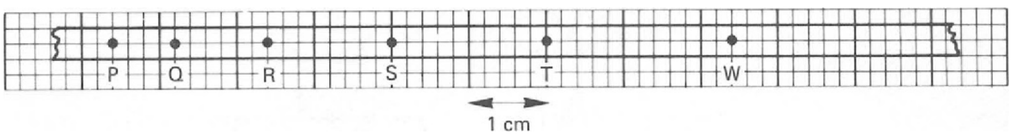
(a) The diagram shows a trolley on a horizontal bench. A scale pan is attached to one end of the trolley by means of a light string which runs over a pulley. A paper tape which runs through a ticker-timer is attached to the other end of the trolley.

(i) When a small mass is put into the pan and the trolley is given a gentle push a series of dots is obtained on the tape as shown below. (Only every tenth dot is shown; the time interval between each dot shown in the diagram is $\frac{1}{5}$ s.)



What conclusions can you draw from the dots? **(2 marks)**

(ii) An extra mass is put into the pan, the trolley is released and a series of dots is obtained as shown below. (Again only every tenth dot is shown.)



From this diagram

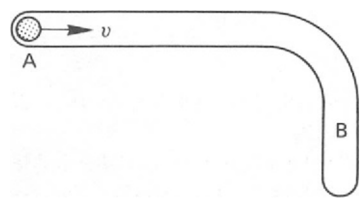
(1) find the average speed, u, between P and Q, **(2 marks)**

(2) find the average speed, v, between T and W, **(2 marks)**

(3) show that the acceleration of the trolley is constant, **(2 marks)**

(4) find the acceleration of the trolley, a. **(4 marks)**

(b)



The diagram shows a horizontal table top, seen from above, with a smooth L-shaped groove in its surface.

A ball is projected from A and travels from A to B along the groove. What differences, if any, do you expect in

(i) the speed of the ball at A and B, **(2 marks)**

(ii) the velocity of the ball at A and B, **(2 marks)**

(iii) the kinetic energy of the ball at A and B, **(2 marks)**

(iv) the momentum of the ball at A and B? **(2 marks)**

(Give a reason for each answer.) **(L)**

Question 3.5

(a) A ticker-timer makes 50 dots every second. A tape moving with constant velocity passes through the ticker-timer. The distance between dot 5 and dot 7 is 1 cm. What is the velocity of the tape?

(b) A body of mass 500 g has a resultant force of 2 N acting on it. What is its acceleration?

(c) A force acts for 3 s on a body and produces an acceleration of 2 m/s^2. Sketch the speed-time graph for the first 5 s of its motion. How far did it travel in the 5 s?

Question 3.6

(a) Define momentum and state a unit in which it can be measured. **(2 marks)**

(b) A trolley of mass 2 kg is moving with a velocity of 5 m/s when it collides with a stationary trolley of mass 0.5 kg. The two trolleys stick to each other and move together after impact. What is

(i) their velocity after impact,

(ii) their total kinetic energy before impact and their total kinetic energy after impact? Explain why the two values are different. **(10 marks)**

Question 3.7

(a) Sketch two graphs, each having distance as the vertical axis and time as the horizontal axis, one for (i) an object moving with uniform (constant) velocity, and one for (ii) an object moving with uniform (constant) acceleration. **(6 marks)**

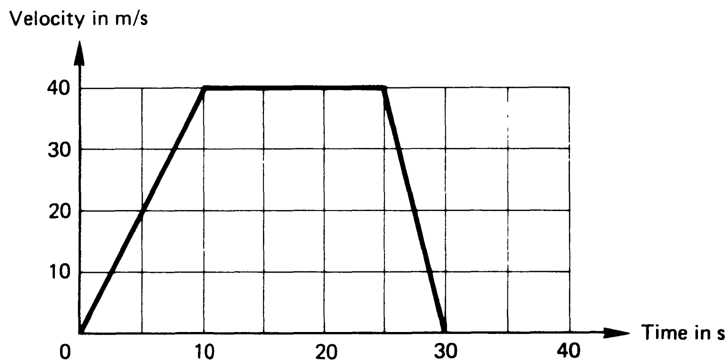
(b) An object of mass 2 kg travelling in a straight line with a velocity of 20 m/s collides with, and sticks to, a stationary object of mass 3 kg. They both move off together in the same straight line with a velocity of v m/s. If no external forces are acting, calculate

(i) the total momentum just before impact,

(ii) the total momentum just after impact,

(iii) the velocity v. **(6 marks)**

(c)



The graph shows the motion of an object of mass 10 kg over a time period of 30 s. Calculate

(i) the deceleration of the object during the last 5 s.

(ii) the kinetic energy of the object when it is moving with constant velocity,

(iii) the distance travelled during the first 25 s. **(12 marks)**

(d) In terms of the physical principles involved, explain how a rocket motor works. **(7 marks)**

(AEB)

Question 3.8

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

A ball is thrown horizontally at 10 m/s from the top of a cliff. It strikes the ground 4 s later. Neglecting air resistance and taking the acceleration due to gravity as 10 m/s^2, which of the following is/are true?

(1) It will strike the ground 20 m from the bottom of the cliff

(2) The height of the cliff is 80 m

(3) The vertical component of the velocity just before it strikes the ground is 40 m/s and the horizontal component of velocity just before it strikes the ground is 10 m/s

Question 3.9

What is meant by (a) a scalar quantity, (b) a vector quantity. **(4 marks)**
What is the magnitude of the resultant vector when two forces each of magnitude 4 N act at an angle of 60° to each other. **(6 marks)**

3.11 Answers and Hints on Solutions to Questions

1. (a) Acceleration = $\frac{8 \text{ m/s}}{4 \text{ s}} = 2 \text{ m/s}^2$.
   (b) Distance travelled = Area under graph = $\frac{1}{2} \times 8 \times 4 = 16$ m.
   (c) $F = ma = 5 \times 2 = 10$ N.
2. (1) Acceleration = 12/4 = 3 m/s^2, (2) distance = Average velocity x Time = 6 x 4 = 24 m, (3) $F = ma = 5 \times 3 = 15$ N.
   Answer C
3. (a) See section 3.2.
   (b) See Fig. 3.3.

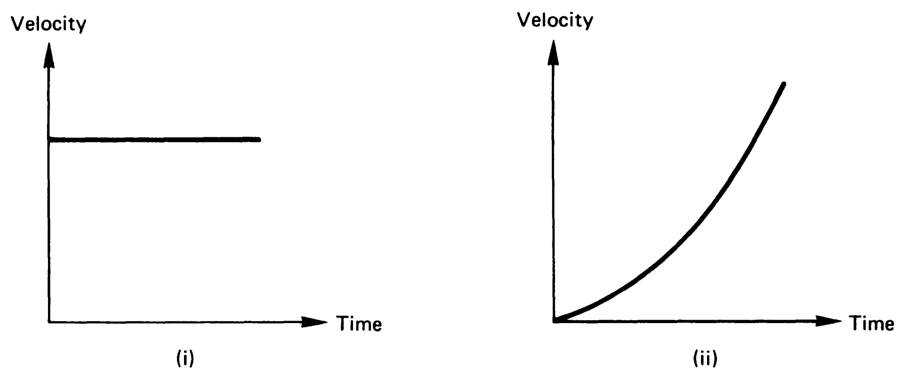


Figure 3.3

   (c) The experiment is described in Example 3.5. The mass is kept constant to investigate the relationship between force and acceleration. The relationship between mass and acceleration is investigated by keeping the force constant (one rubber band at constant stretch) and varying the mass (this can be done by having two trolleys with one piled on the other, then three piled up, then four and five. A graph of acceleration against $1/m$ is a straight line through the origin.
4. (a) (i) The trolley is travelling with a constant velocity. (ii) (1) Average speed (u) = (Distance gone)/(Time taken) = 0.8/0.2 = 4 cm/s. (2) 2.4/0.2 = 12 cm/s. (3) The acceleration is constant because in equal time intervals the distance travelled always increases by the same amount; in this case 0.4 cm (2 squares). (4) Acceleration = $(v - u)$/Time taken (see section 3.1) = (12 – 4)/(4 x 0.2) = 10 cm/s^2.
   (b) (i) No difference (because speed is a scalar quantity). (ii) The velocity has changed because the direction of travel has changed and velocity is a vector quantity (see section 3.4). (iii) Since the groove is smooth we neglect friction so energy is conserved and the kinetic energy at A is equal to the kinetic energy at B. (iv) Momentum is a vector quantity (mass x velocity) and the momentum has changed because the direction of travel has changed.

5. (a) Tape travels 1 cm in 1/25th of a second. Velocity = 25 cm/s.
   (b) Use $F = ma \Rightarrow a = 4$ m/s^2.
   (c) For the first 3 s the graph is a straight line reaching 6 m/s after 3 s. It is then horizontal. Distance = area under graph (see section 3.1) = 9 + 12 = 21 m.
6. (a) Momentum is defined as mass x velocity. Its unit is kg m/s or N s.
   (b) (i) Use the conservation of momentum (momentum is always conserved in a collision). $2 \times 5 = (2 + 0.5)\, v$, where v is the common velocity after impact. $v = 4$ m/s in the same direction as the 2 kg trolley was moving.

      [Don't forget to give the velocity a direction.]

      (ii) $KE_{before} = \frac{1}{2} mv^2$ (section 4.2) $= \frac{1}{2} \times 2 \times 5^2 = 25$ J; $KE_{after} = \frac{1}{2} mv^2 = \frac{1}{2} \times 2.5 \times 4^2 = 20$ J. The kinetic energy is less after the collision because of energy which becomes heat and sound when the trolleys collide.
7. (a) (i) A straight line through the origin. (ii) The speed is increasing so the gradient of the graph is increasing and it is a curve of increasing gradient. Your answer must include sketches of the graphs.
   (b) (i) $2 \times 20 = 40$ kg m/s. (ii) 40 kg m/s since momentum is always conserved in a collision. (ii) $40 = 5 \times v$, hence $v = 8$ m/s.
   (c) (i) -8 m/s^2. (ii) 8000 J. (iii) 800 m.
   (d) The chemical reaction inside the rocket propels gases at a high velocity out through the tail of the rocket. The reaction to this force (Newton's Third Law) propels the rocket forwards. The high velocity of the expelled gases means that there is a large change of momentum. An equal momentum is imparted to the rocket in the opposite direction and the rocket moves forward.
8. See section 3.6.
   Answer **D**
9. See section 3.4. Draw the vector diagram and measure the magnitude and direction of the resultant.
   Answer 6.9(3) N at 30° to each force

4 Moments, Equilibrium, Work, Energy, Power and Machines

4.1 Moments and Equilibrium

(a) Principle of Moments

When a body is in equilibrium, the sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about the same point. In Fig. 4.1 a beam is balanced at its centre point. Using the measurements shown in the diagram

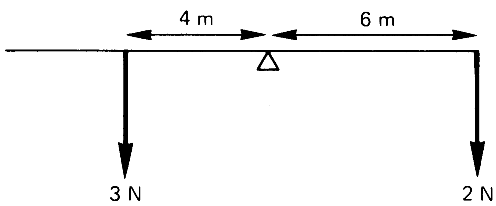


Figure 4.1 Clockwise moment = Anticlockwise moment = 12 N m.

Clockwise moment = 2 N × 6 m = 12 N m   Anticlockwise moment = 3 N × 4 m = 12 N m

The clockwise moment equals the anticlockwise moment and the beam is in equilibrium.

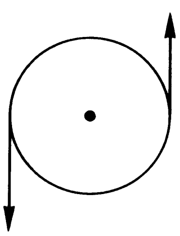


Figure 4.2 A couple.

(b) Couple

A couple is any system of forces which tends to cause rotation only. The simplest kind of couple is a pair of equal and opposite parallel forces which do not act through the same point (see Fig. 4.2).

(c) Centre of Gravity (Centre of Mass)

The centre of gravity of a body is the point through which its whole weight may be considered to act. (Determination of this is described in Example 4.7.)

(d) Types of Equilibrium

A body is said to be in stable equilibrium if when given a small displacement and then released it returns to its original position.

A body is said to be in unstable equilibrium if when given a small displacement and then released it moves further from its original position.

A body is said to be in neutral equilibrium if when given a small displacement and then released it stays in its new position.

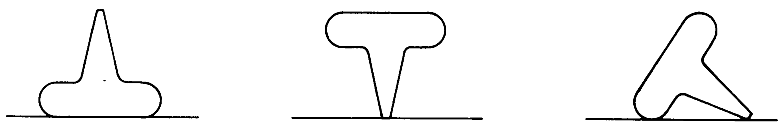


Figure 4.3 (a) Stable equilibrium, (b) unstable equilibrium, (c) neutral equilibrium.

Referring to Fig. 4.3, the equilibrium is stable in (a), unstable in (b) and neutral in (c).

4.2 Work, Energy and Power

(a) *Work* = Force × Distance moved in the direction of the force. Unit J
1 *joule* (J) of work is done when a force of 1 N moves its point of application through a distance of 1 m.

(b) *Energy* is the capacity to do work. It is measured in joules. *The principle of conservation of energy* states that energy cannot be created or destroyed, although it can be changed from one form to another.

(i) *Potential energy* is energy possessed by a body by virtue of its position or the state the body is in.

(ii) *Kinetic energy* is energy possessed by a moving body; for a body of mass m moving with velocity v, the kinetic energy is $\frac{1}{2}mv^2$. If a body of mass m is lifted through a height h then the work done is the force (mg) multiplied by the distance moved (h) which is mgh. The body has potential energy mgh. If the mass is now released and it falls, then its potential energy changes into kinetic energy. When it has fallen the distance h and has a velocity v then $mgh = \frac{1}{2}mv^2$.

(iii) *Sources of energy*. Some of the available sources of energy are (i) oil, diesel fuel, and petroleum (the known sources of these portable fuels are being gradually exhausted). (ii) sea waves, solar, tidal, wind, nuclear and geothermal energy.

(c) *Power* is the rate of doing work, or Power = $\dfrac{\text{Work done}}{\text{Time taken}}$ Unit, watt (W).

1 *watt (W)* is a rate of working of 1 joule per second (J/s).

4.3 Friction

Friction is the force tending to prevent one body sliding over another. When two bodies are in contact and at rest the maximum frictional force between them is known as the limiting static friction. When sliding occurs the force is known as the sliding friction. Friction may be reduced by the use of lubricants and ball bearings.

4.4 Machines

(a) Some Definitions

$$\text{Mechanical advantage} = \frac{\text{Load}}{\text{Effort}} \qquad \text{Velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$$

$$\text{Efficiency} = \frac{\text{Work got out of a machine}}{\text{Work put into a machine}}$$

A useful relationship is $\quad \text{Efficiency} = \dfrac{\text{Mechanical advantage}}{\text{Velocity ratio}}$

but this must not be used as a definition of efficiency. Notice that for a machine which is 100% efficient the mechanical advantage is equal to the velocity ratio.

(b) Pulleys

For the machine shown in Fig. 4.4, the work got out of the machine is equal to the potential energy gained by the load and the work put into the machine is the work done by the effort. If the load rises 1 m then each of the strings A, B and C must each shorten by 1 m and the effort moves 3 m. The velocity ratio is therefore 3.

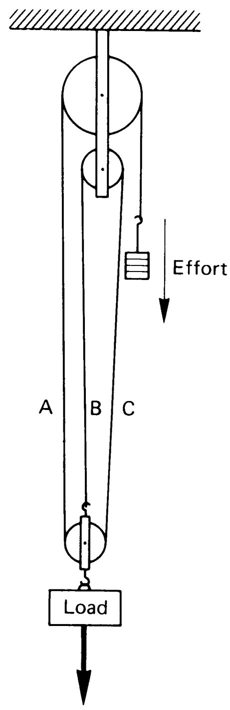


Figure 4.4 A simple pulley system.

(c) The Inclined Plane

When the load is lifted a height h (Fig. 4.5) the effort moves d and the velocity ratio is d/h.

$$\text{Mechanical advantage} = \frac{\text{Weight of object}}{\text{Force needed to move the object up the plane}}$$

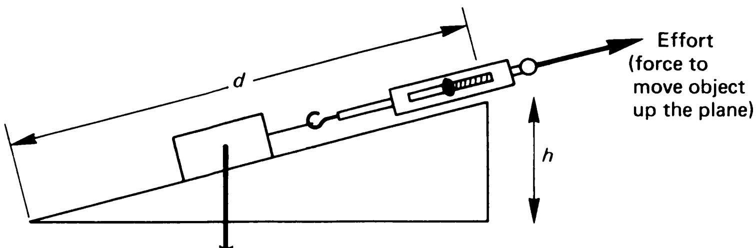


Figure 4.5 An inclined plane.

$$\text{Efficiency} = \frac{\text{Work got out}}{\text{Work put in}} = \frac{\text{Energy gained by load}}{\text{Work done on load}} = \frac{mgh}{\text{Effort} \times d}$$

(d) Gears

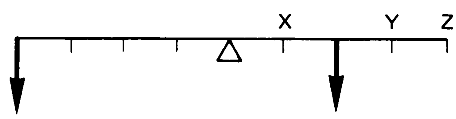
The velocity ratio of two intermeshed gears is given by

$$\frac{\text{Number of rotations of driving gear}}{\text{Number of rotations of driven gear}} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driving gear}}$$

4.5 Worked Examples

Example 4.1

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only



The diagram illustrates a uniform beam pivoted at its centre. The marks on the beam show equal distances each of 1 m in length. Loads of 6 N and 2 N are hung from the positions shown. Which of the following additional loads would keep the beam in equilibrium?

1 20 N at X **2** 6 N at Y **3** 4 N at Z

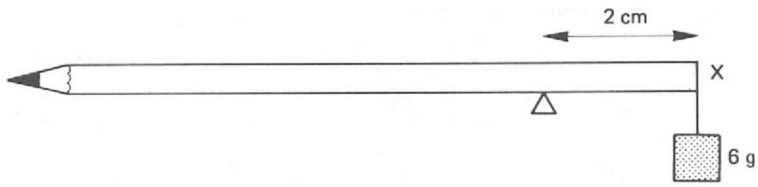
Solution 4.1

Total anticlockwise moment about pivot = 6 x 4 = 24 N m
So total clockwise moment must be 24 N m.
The 2 N force provides a clockwise moment of 2 x 2 = 4 N m, so the additional load must provide a moment of 24 – 4 = 20 N m
The additional moments are
1 20 x 1 = 20 N m 2 6 x 3 = 18 N m 3 4 x 4 = 16 N m

Answer = **D**

Example 4.2

A pencil of mass 4 g can be balanced horizontally about a knife edge 2 cm from the end X when a mass of 6 g is hung from this end, as shown below.

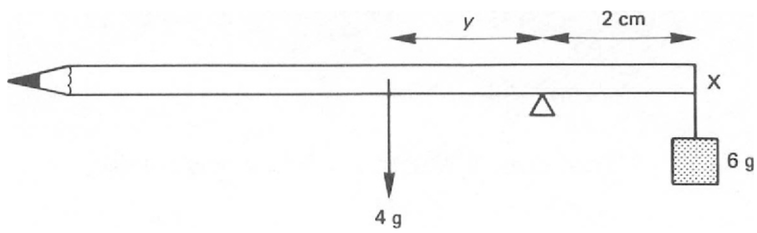


The distance of the centre of mass of the pencil from X is

A 1.3 cm **B** 2.0 cm **C** 3.0 cm **D** 3.3 cm **E** 5.0 cm (L)

Solution 4.2

[The centre of mass is the point where the whole mass may be considered to act. This is shown at distance y from the fulcrum. Taking moments about the fulcrum



Anticlockwise moments = Clockwise moments

$4 \times y = 6 \times 2$

$y = 3$ cm

Strictly speaking the moment of a force is the force multiplied by the distance, but we can use mass in such an equation since force is proportional to mass and the same conversion factor has been omitted on both sides of the equation.

The centre of mass is 3 cm from the fulcrum and is therefore 5 cm from X.]

Answer E

Example 4.3

(a) What power is produced by a machine which lifts a mass of 2 kg through a vertical height of 10 m in 2 s?

(b) A mass of 3 kg is thrown vertically upwards with a kinetic energy of 600 J. To what height will it rise?
(The acceleration of free fall is 10 m/s^2.) **(6 marks)**

Solution 4.3

(a) Force needed to lift 2 kg = 20 N

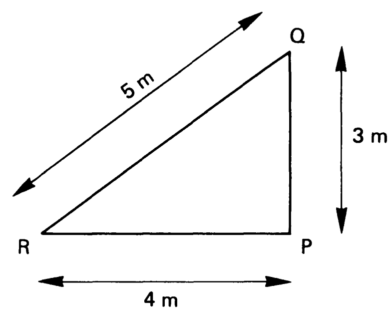
$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{20 \times 10}{2} \text{ J/s} = 100 \text{ W}$$

(b) 600 J = mgh [see section 4.2]

$\therefore 600 = 3 \times 10 \times h$

$\therefore h = 20$ m
Height = 20 m

Example 4.4



A weight of 5 N is moved up a frictionless inclined plane from R to Q as shown. What is the work done in joules?

A 15 **B** 20 **C** 25 **D** 35 **E** 60

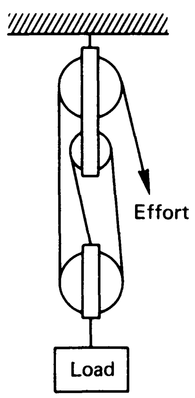
(AEB)

Solution 4.4

[Work done = Weight x Vertical height raised
= (5 x 3) J
= 15 J]

Answer A

Example 4.5



Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only

Referring to the pulley system shown in the diagram, a load of 4.5 N is raised through 1 m by an effort of 2.0 N.

1 The effort moves 3 m to raise the load 1 m
2 The efficiency is 75%
3 The lower pulley weighs more than 1.8 N

Solution 4.5

[If the load rises 1 m, the effort must move 3 m (each of the three strings supporting the load must each shorten by 1 m)

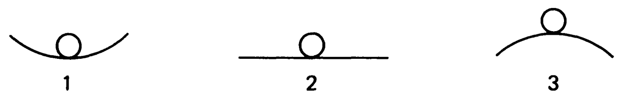
$$\text{Efficiency} = \frac{\text{Work out}}{\text{Work in}} = \frac{\text{Load} \times \text{Distance load moves}}{\text{Effort} \times \text{Distance effort moves}}$$

$$= \frac{4.5 \times 1}{2.0 \times 3} = \frac{4.5}{6.0} = \frac{3}{4} = 75\%$$

If the lower pulley weighs 1.8 N, the total load lifted is 4.5 + 1.8 = 6.3 N. If the system is 100% efficient, the effort needed is 6.3/3 = 2.1 N. So an effort of 2.0 N couldn't possibly raise the load and the pulley. The pulley must weigh less than 1.8 N.]

Answer B

Example 4.6



The diagrams show a ball resting on different shaped surfaces. They represent three different types of equilibrium which are

	1	2	3
A	Stable	Unstable	Neutral
B	Unstable	Neutral	Stable
C	Stable	Neutral	Unstable
D	Neutral	Stable	Unstable
E	Unstable	Stable	Neutral

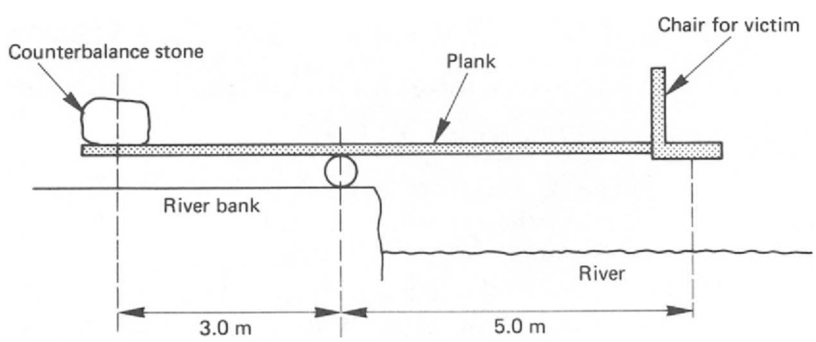
Solution 4.6

[Use the summary in section 4.1d.]

Answer C

Example 4.7

(a)



The 'ducking stool' shown in the diagram was used in mediæval Britain as an instrument of punishment by lowering the victim, strapped to the chair, into the cold water of a river. The total mass of the chair and plank is 150 kg and this can be counterbalanced, when no victim is present, by a flat stone of mass 100 kg placed at the end of the plank, 3.0 m from the pivot.

(i) Sketch the arrangement of the ducking stool and mark on it all the forces that act on the plank. **(3 marks)**

(ii) Calculate the position of the centre of mass of the chair and plank. **(5 marks)**

(iii) If a victim of mass 75 kg is strapped into the chair, calculate the additional force that will need to be applied by the ducking stool operators who push down on the counterbalance stone to operate the instrument slowly. **(3 marks)**

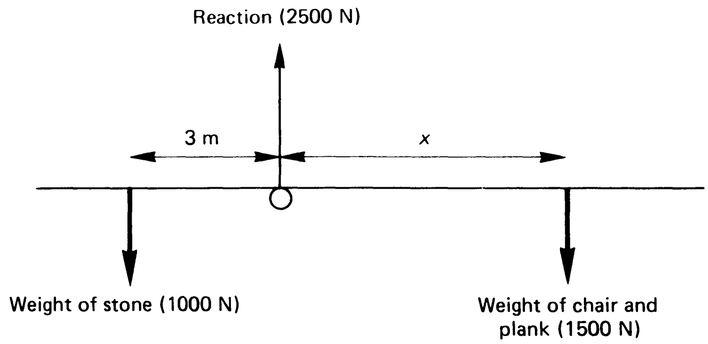
(iv) To make it easier for the operators it was suggested that another stone whose weight was equal to the force calculated in (iii) could be placed on top of the counter-balance stone. Explain why, when this suggestion was tried, the victim failed to be fully immersed in the water. **(4 marks)**

(b) Describe how you would experimentally determine the position of the centre of mass of a semicircular sheet of plastic (e.g. a mathematical protractor). **(5 marks)**

(L)

Solution 4.7

(a) (i)



(ii) Taking moments about the point of pivot

Clockwise moments = Anticlockwise moments [see section 4.1]
1500 N x x = 1000 N x 3 m

where x is the distance from the pivot to the centre of mass of the chair and plank

$x = 2$ m

The centre of mass of the chair and plank is 2 m to the right of the point of pivot.

(iii) Extra moment needed = 750 N x 5 m = 3750 N m

(Additional force on counterbalance stone) x 3 m = 3750 N m

Additional force = 1250 N

This is the force needed to balance the plank horizontally. To lower the victim the force would need to be slightly less than 1250 N and in order to raise him it would have to be slightly greater than 1250 N.

(iv) As the victim is lowered into the water there is an upthrust on him equal to the weight of water displaced. The total force causing a clockwise moment is therefore reduced and so the clockwise moment is reduced. The operators have to reduce the anticlockwise moment by the same amount by pulling upwards. The further the victim is immersed the greater is the upward force that the operators have to apply, and if the victim failed to be fully immersed they were not able to supply the required force.

(b) Make holes at three points near the perimeter and well spaced out round it. Suspend the sheet by a fixed horizontal pin passing through one of the holes. Make sure the sheet can swing freely in a vertical plane. Hang a plumb line from the pin and when the sheet is stationary mark on it the position of the plumb line. Repeat this for each of the other holes in turn. The centre of mass is where the three lines showing the positions of the plumb line cross.

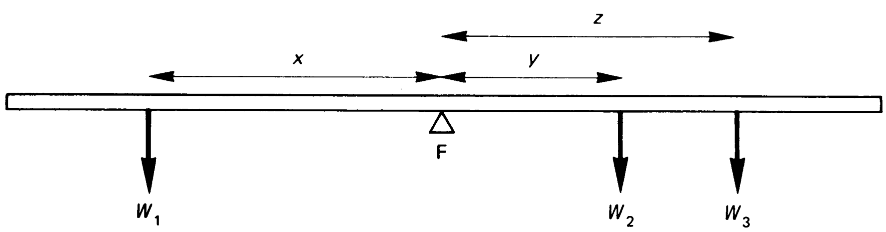
Example 4.8

(a) Describe an experiment you would do in the laboratory in order to show that for a body in equilibrium the sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about the same point.

(b) A painter stands on a horizontal platform which has a mass of 20 kg and is 5.0 m long. The platform is suspended by two vertical ropes, one attached to each end of the platform. The mass of the painter is 70 kg. If he is standing 2.0 m from the centre of the platform, calculate the tension in each of the ropes.

Solution 4.8

(a) Get a metre rule and move it along the knife-edge F until it balances horizontally. Clamp the knife-edge F so that it is high enough to allow known weights W_1, W_2 and W_3 to be hung from the ruler by pieces of cotton. Adjust the



weights until the ruler is again balancing horizontally. Record the distances x, y and z cm. If the experiment is repeated with different weights and different distances it is always found that

The clockwise moment ($W_2 \times y + W_3 \times z$) = The anticlockwise moment ($W_1 \times x$)

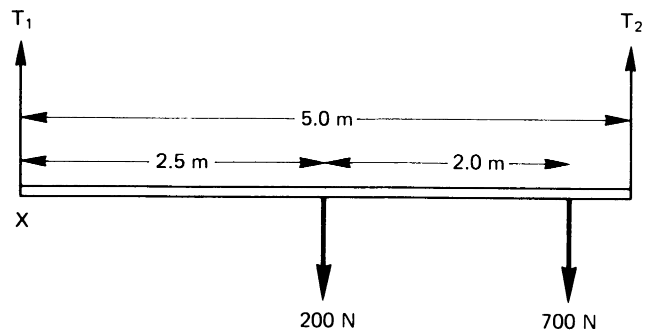


Figure 4.6

(b) Figure 4.6 shows the forces acting on the platform. The platform is in equilibrium, so taking moments about X

Anticlockwise moments = Clockwise moments

$T_2 \times 5 = (200 \times 2.5) + (700 \times 4.5)$

$5T_2 = 500 + 3150$

$$T_2 = \frac{3650}{5}$$

$T_2 = 730$ N

Since the platform is in equilibrium the total force upwards must equal the total force downwards, hence

$200 + 700 = 730 + T_1$
$T_1 = 170$ N

The tensions are 730 N in the rope nearest the painter, and 170 N in the rope furthest from the painter.

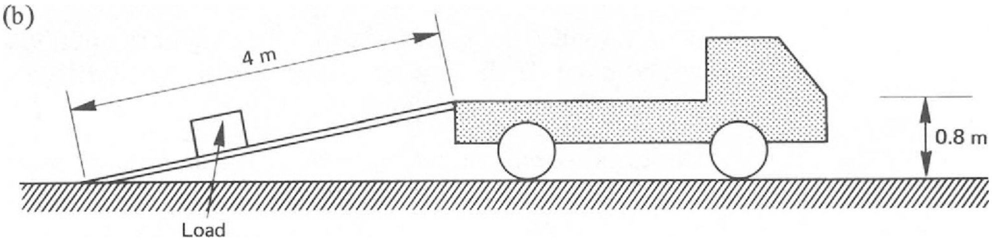
[There are two unknowns in this problem, namely T_1 and T_2. To obtain an equation with only one unknown, choose a point about which to take moments so that the moment of one of the forces is zero. In this case the moment of T_1 about X is zero. T_2 could have been calculated by taking moments about the other end of the platform.]

Example 4.9

PART I

(a) Write down a formula for each of the following:
  (i) the potential energy of an object of mass m at a height h above sea level,
  (ii) the kinetic energy of an object of mass m moving with a speed of v,
  (iii) the electrical energy used by an immersion heater of resistance R carrying a current of I for a time t,
  (iv) the heat given out when a solid of mass m and specific heat capacity s cools through a temperature drop of θ. **(4 marks)**

(b)

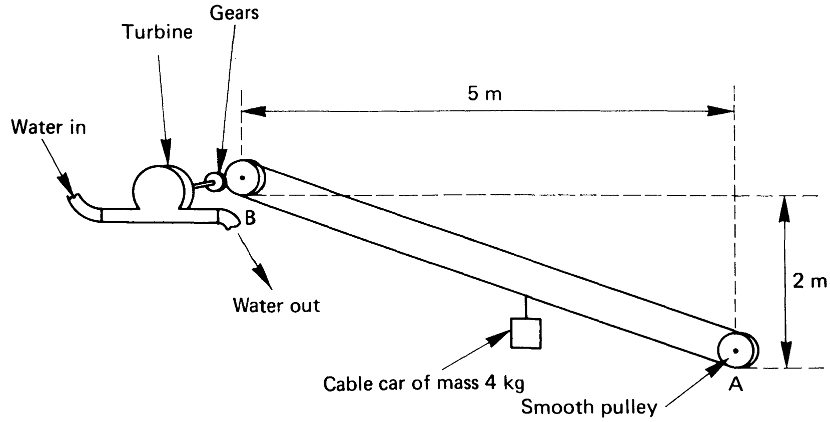


The diagram shows a loading ramp being used to raise a load of weight 2000 N on to a lorry.
  (i) How much work is done against gravity in raising the load?
  (ii) Explain why the force required to move the load up the ramp is less than 2000 N.
  (iii) Explain why the work done in moving the load up the ramp is greater than the work done against gravity. **(4 marks)**

PART II

(c) A catapult is used to fire a stone of mass 50 g vertically to a height of 4.05 m. Calculate
  (i) the potential energy gained by the stone,
  (ii) the speed of the stone as it leaves the catapult. **(6 marks)**

(d)



The diagram shows a driving mechanism consisting of a water turbine and a set of gears. It is being used to lift a model cable car from A to B in 20 s. Calculate

(i) the potential energy gained by the cable car in going from A to B,

(ii) the *output* power of the driving mechanism,

(iii) the *input* power to the turbine, if the driving mechanism is 80% efficient. **(7 marks)**

Data for this question:

Acceleration due to gravity = 10 m/s^2 **(AEB)**

Solution 4.9

(a) (i) Potential energy = mgh.

(ii) Kinetic energy = $\frac{1}{2}mv^2$.

(iii) Electrical energy = I^2Rt.

(iv) Heat energy = $ms\theta$.

(b) (i) Work done = 2000 x 0.8 = 1600 J.

(ii) In the absence of friction the force needed is the component of the weight along the plane and this is less than the weight.

(iii) In the absence of friction the work done in each case would be the same, but extra work must be done because of the frictional force.

(c) (i) Potential = mgh = 0.05 x 10 x 4.05 J = 2.025 J.

Answer = 2.0 J

(ii) $\frac{1}{2}mv^2 = mgh \Rightarrow v^2 = 2gh = 2 \times 10 \times 4.05 \Rightarrow v = 9.0$ m/s.

(d) (i) Energy gained = Work done = Weight x Vertical distance raised
= 40 x 2 = 80 J.

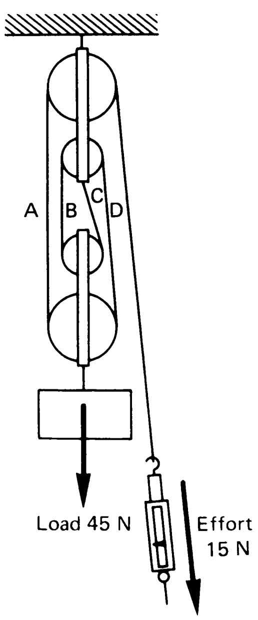
(ii) Power = Work done per second = $\frac{80 \text{ J}}{20 \text{ s}}$ = 4 J/s = 4 W.

(iii) Efficiency = $\frac{\text{Work out}}{\text{Work in}} = \frac{\text{Power out}}{\text{Power in}}$

[see section 4.4 and don't forget to change the 80% to a decimal (i.e. 0.8)]

$\therefore 0.8 = \frac{4}{\text{Power in}}$ $\therefore$ Power in = $\frac{4}{0.8}$ = 5 W

Example 4.10



Draw a labelled diagram of a block and tackle pulley system which has two pulley wheels in each block. **(4 marks)**

How would you measure the effort necessary to lift a load of 45 N using this system? Explain how far the effort would move if the load rises vertically by 20 cm. Calculate the efficiency of the system if an effort of 15 N is required. **(7 marks)**

Why is the efficiency likely to be different for a much smaller load? State *two* methods by which the efficiency could be increased for a given load. **(4 marks)**

(SUJB)

Solution 4.10

Pull the spring balance so that the load of 4.5 kg rises at a constant velocity. The reading on the spring balance is the effort required.

If the load rises 20 cm, each of the 4 strings (labelled A, B, C and D) must each shorten by 20 cm. Therefore the effort must move 20 x 4 = 80 cm.

$$\text{Efficiency} = \frac{\text{Work got out}}{\text{Work put in}} = \frac{\text{Load} \times \text{Distance load moves}}{\text{Effort} \times \text{Distance effort goes}}$$

$$= \frac{45\ \text{N} \times 0.2\ \text{m}}{15\ \text{N} \times 0.8\ \text{m}} = \frac{3}{4} = 75\%$$

The efficiency will be different for a much smaller load because

(i) the work done in lifting the bottom pulley block becomes a greater proportion of the total work done in lifting the load plus the block,

(ii) the work done against friction at the bearings may be less for smaller loads.

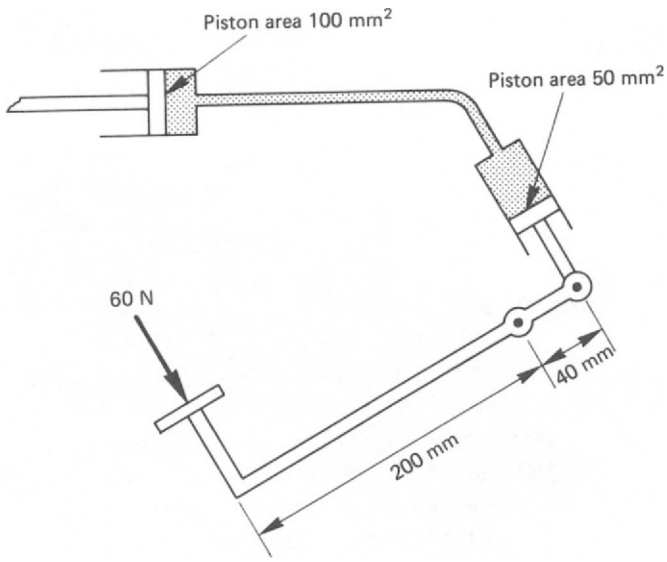
For a given load the efficiency could be increased by

(i) reducing friction, e.g. oiling the bearings of the pulleys,

(ii) using pulleys made of a light alloy thus reducing the weight of the bottom pulley block.

Example 4.11

The figure below represents a hydraulic braking system in which the effort is applied to a pedal at the end of a lever arm, 200 mm from a pivot. On the other side of the pivot, 40 mm away, the lever connects to a piston of area 50 mm². The piston transmits pressure through oil to another piston, of area 100 mm², connected to the brake.



(a) When the effort applied is 60 N, what is:

(i) the force applied to the first piston; **(4 marks)**

(ii) the pressure on the oil? **(4 marks)**

(b) What force is applied to the brake at the end of the system if frictional forces can be ignored? **(4 marks)**

(c) What is the velocity ratio of this system, and what steps could be taken to increase it? **(4, 2 marks)**

(d) With a small amount of air trapped in the oil, why would the system work badly, if at all? **(2 marks)**

(OLE)

Solution 4.11

(a) (i) Let F be the force on the first piston. Taking moments about the fulcrum

Clockwise moments = Anticlockwise moments
$F \times 40$ mm = 60 N x 200 mm
$\therefore$ F = 300 N

(ii) Pressure $= \dfrac{\text{Force}}{\text{Area}} = \dfrac{300 \text{ N}}{50 \text{ mm}^2} = 6 \text{ N/mm}^2 = 6 \times 10^6$ Pa

(b) Force on large piston = Pressure x Area = $6 \text{ N/mm}^2 \times 100 \text{ mm}^2 = 600$ N

(c) If pedal moves 10 mm then the small piston moves $\dfrac{40}{200} \times 10 \text{ mm} = 2$ mm

If the small piston moves 2 mm then the large piston moves 1 mm.

Velocity ratio $= \dfrac{\text{Distance moved by effort}}{\text{Distance moved by load}}$ [see section 4.4] $= \dfrac{10}{1} = 10$

(d) Air is compressible and oil is not. If there were air in the system it would be compressed when the pedal were pushed and the system would not function well.

4.6 Have You Mastered the Basics?

1. Can you state the principle of moments?
2. Can you define centre of gravity, joule, watt, mechanical advantage, velocity ratio, efficiency?
3. Do you know the difference between kinetic energy and potential energy and do you know the formula by which they may be calculated?
4. A uniform plank is balanced at its midpoint. Jack who weighs 500 N sits 2 m from the centre and Jill who weighs 400 N sits on the same side 3 m from the centre. Where must John (who weighs 550 N) sit if the plank is balanced horizontally.
5. A force of 6 N moves through 3 m in 2 s. What is (i) the work done (ii) the power developed?
6. A mass of 2 kg is lifted vertically 3 m and then allowed to fall. What is (i) the potential energy when it is 3 m above the ground, (ii) the velocity just before it hits the ground?
7. A mass of 1.2 kg is raised 4 m by an effort of 3 N moving through 20 m. What is (i) the potential energy gained by the load, (ii) the work done by the effort, (iii) the efficiency?

4.7 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

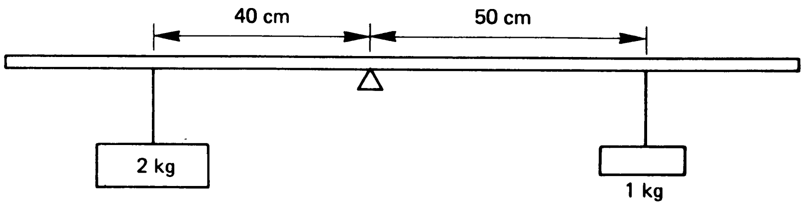
1. See section 4.1.
2. See sections 4.1, 4.2 and 4.4.
3. See section 4.2.
4. Take moments about the centre. Clockwise moments = Anticlockwise moments. $(500 \times 2) + (400 \times 3) = x \times 550$ where x is John's distance from the centre. Answer = 4 m from the centre on the other side of the plank to Jack and Jill.

5. (i) Work done = Force × Distance = 18 J. (ii) Substitute in the equation for power in section 4.2. Power = 18 J/2 s = 9 W.
6. (i) Potential energy = mgh (see section 4.2) = 2 × 10 × 3 = 60 J. (ii) Kinetic energy = $\frac{1}{2}mv^2$ (see section 4.2) and this equals 60 J. Hence $v = \sqrt{60}$ = 7.7 m/s.
7. (i) Potential energy = mgh = 1.2 × 10 × 4 = 48 J. (ii) Use, Work done = Force × Distance, to calculate the work done by the effort. Answer = 60 J. (iii) Use the equation in section 4.4 to calculate the efficiency.
Answer = 0.8 or 80%.

4.8 Questions

(Answers and hints on solutions will be found in Section 2.10.)

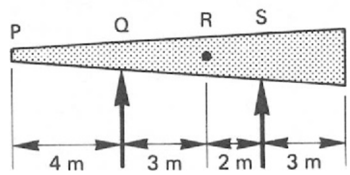
Question 4.1



The diagram shows a uniform beam which is pivoted at its mid-point and from which two loads are suspended. If a third load is attached to balance the system, its mass and distance from the mid-point may be

A 1 kg, 10 cm **B** 1 kg, 50 cm **C** 2 kg, 10 cm **D** 2 kg, 30 cm **E** 3 kg, 10 cm **(AEB)**

Question 4.2

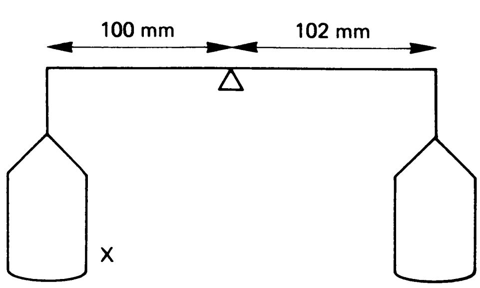


A temporary bridge is made by using a non-uniform tree trunk weighing 1000 N and resting horizontally on two supports at Q and S as shown in the diagram. The centre of mass of the tree is at R. What downward force acting at P will just lift the tree off the support S?

A 500 N **B** 750 N **C** 1000 N **D** 1250 N **E** 2000 N (L)

Question 4.3

(a)



The diagram shows a badly manufactured beam balance with unequal arms. The beam balances with no masses in the pans X and Y. Suggest one reason why this is possible. If a mass of 300 g is placed in pan Y, calculate the mass which must be placed in pan X to restore the balance. **(5 marks)**

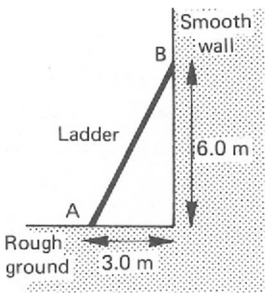
(b) An object put on a beam balance gives the same reading no matter where it is on the earth's surface but if it is on a very sensitive spring balance the reading varies from place to place. Explain why this is so. **(5 marks)**

(c) Suppose that an object is attached to a spring balance on the earth's surface and the earth's speed of rotation is gradually increased. What effect, if any, will this have on
   (i) the gravitational attraction between the object and the earth, and
   (ii) the reading of the spring balance?
   (Give reasons for your answers.) **(6 marks)**

(d) A person of mass 60 kg stands on a spring weighing machine inside a lift which is accelerating upwards at 3 m/s^2. Calculate the reading (in newtons) of the weighing machine. **(4 marks)**

(L)

Question 4.4



(a) The diagram shows a uniform ladder AB resting against a smooth vertical wall. The weight of the ladder is 200 N.
Draw a diagram showing the forces acting on the ladder. **(4 marks)**
By taking moments about a suitable point, calculate the reaction at the wall. **(4 marks)**

(b) Draw a diagram showing all the forces acting on a street lamp supported centrally over the road by cables attached at the same height to tall vertical poles on the pavements. **(3 marks)**
For a lamp supported at a given height, what advantage is to be gained by increasing the height of the poles? **(2 marks)**

(c) A crane is used to lower a container of mass 6000 kg into the hold of a ship.
Calculate the tension in the supporting cable when the container is
   (i) held steady,
   (ii) lowered with a uniform speed of 2 m/s, and
   (iii) lowered with a uniform acceleration of 0.5 m/s^2. **(7 marks)**

(L)

Question 4.5

A mass of 2 kg is 5 m above the floor and falling vertically with a velocity of 20 m/s. What is (i) its kinetic energy and (ii) its potential energy? (The acceleration of free fall is 10 m/s^2.) **(6 marks)**

Question 4.6

An object is acted on by a retarding force of 10 N and at a particular instant its kinetic energy is 6 J. The object will come to rest after it has travelled a further distance, in m, of

A $\frac{3}{5}$ **B** $1\frac{2}{3}$ **C** 4 **D** 16 **E** 60 (AEB)

Question 4.7

(a) Describe how you would determine experimentally the acceleration of free fall. Give details of the readings you would take, and explain how you would use them to calculate your result. **(10 marks)**

(b) (i)

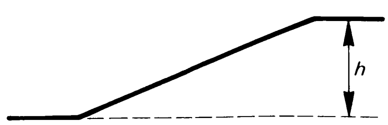


Fig. 1

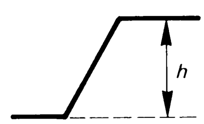


Fig. 2

Figures 1 and 2 show two inclined planes with different slopes, but the same vertical height, h. Identical boxes are placed at the bottom of the slopes. Explain why, if the slopes are smooth, the same quantity of work is done in sliding the box to the top of each slope.

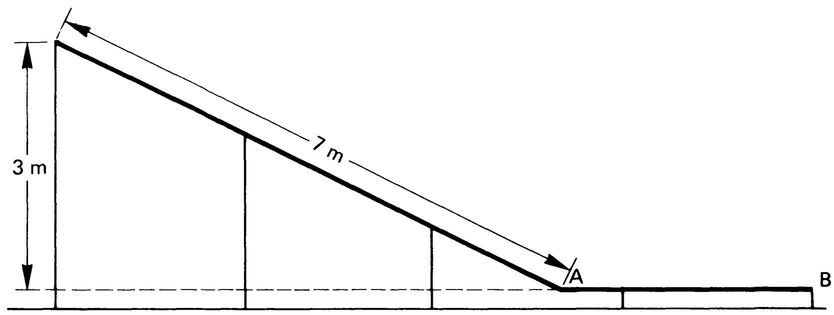


Fig. 3

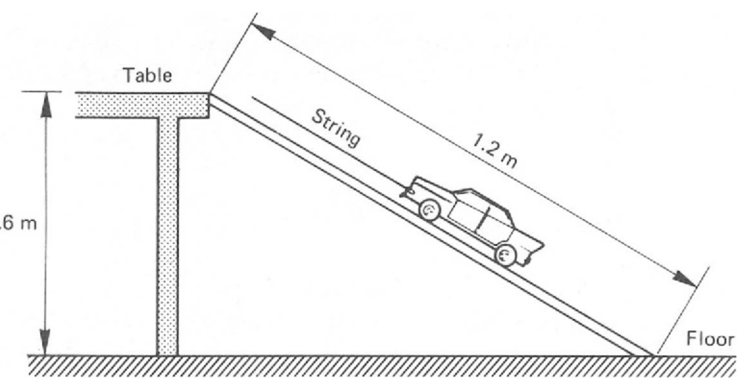
Also explain why, if the slopes are *not* smooth and the same force of friction acts in each case, more work is done in sliding the box up the slope in Fig. 1 than in Fig. 2. **(4 marks)**

(ii) A child slides down the slide shown in Fig. 3. Assuming that the force of friction is the same all along the slide, and equal to one-third of the child's weight, how far along the horizontal section AB does the child slide before coming to rest? **(6 marks)**

(L)

Question 4.8

(a)



A model car, of mass 1.5 kg, with a string attached to its upper end, is placed on a slope as shown in the diagram. The force in the string, parallel to the slope, needed to move the car up the slope at a constant velocity is 10 N.

(i) Describe, with the aid of a diagram, how the force in the string can be measured. **(3 marks)**

(ii) Calculate the gain in the car's potential energy as it moves from the floor to the table. **(2 marks)**

(iii) Calculate the work done by the force as it moves the car up the slope from the floor to the table. **(2 marks)**

(iv) Calculate the efficiency of this arrangement for raising the car. **(2 marks)**

(b) This slope can be considered to be a simple machine used to lift the model car from the floor to the table.

(i) From the information given in part (a), calculate the mechanical advantage of this machine. **(2 marks)**

(ii) The velocity ratio of this machine is 2.0. Explain why this is the case. **(2 marks)**

(iii) State the formula linking *efficiency* of a machine with its *mechanical advantage* and *velocity ratio*. Hence calculate the efficiency of the inclined slope, considering it as a simple machine. **(2 marks)**

(c) The string used in part (a) is now removed and the model is placed at the top of the slope.

(i) Describe the motion of the car as it runs freely down the slope to the floor. **(2 marks)**

(ii) Draw a labelled sketch of the arrangement of the apparatus you would use to investigate the motion of the car as it travels down the slope. **(3 marks)**

(L)

Question 4.9

In an experiment with a certain machine it was found that an effort of 10 N just moved a load of 40 N and that the load was moved 1 m when the effort moved 10 m. The efficiency of this machine is

A 0.4% **B** 4% **C** 10% **D** 25% **E** 40% (AEB)

Question 4.10

(i) Define work, power and efficiency of a machine.

(ii) A system of pulleys is used to raise a load of 3000 N through 2 m. In order to do this the effort of 1000 N moves through 8 m. What is (a) the work done on the load, (b) the work done by the effort, (c) the efficiency of the system?

(iii) Why is the efficiency of the system less than 100%?

4.9 Answers and Hints on Solutions to Questions

1. Difference between the two turning effects is (40 x 2) – (50 x 1) = 30 kg cm. Answer E
2. The trunk will pivot about Q, therefore take moments about Q. If F is force required at P then, $F \times 4 = 1000 \times 3$. Answer B
3. (a) The balance pan X has a greater mass than balance pan Y, or the beam is not uniform. 306 g.
   (b) The extension of a spring balance depends on the gravitational force acting on the mass hung from its end and this force varies over the Earth's surface. With a beam balance the force on the object and on the equal mass on the other pan are always the same and the beam remains balanced.
   (c) (i) The gravitational attraction will not change since gravitational attraction depends only on the mass and its distance from the centre of the Earth. (ii) The spring balance would read less. With increasing speed of rotation of the Earth, more and more of the Earth's gravitational force is needed to provide the force required (centripetal force) to keep the object moving in a circle. The object's weight, which is the difference between the total gravitational force and the centripetal force, is less, and the spring balance therefore reads less.
   (d) Apply $F = ma$ (section 3.2) where F is the resultant force on the person (the force upwards of the scales minus his weight). Let R be the reading (the push upwards of the scales) on the weighing machine; then $R - 600 = 60 \times 3$, hence $R = 780$ N.
4. (a) See Fig. 4.7. To determine R_1 we must take moments about a point so that R_2 and F do not appear in the equation, this means taking moments about a point such that the moment of R_2 and F is zero. Such a point is A. $200 \times 1.5 = R_1 \times 6$, hence $R_1 = 50$ N.

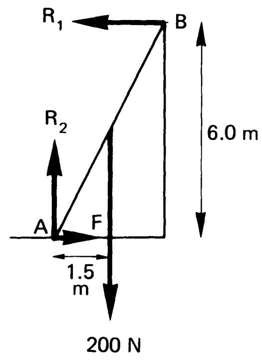


Figure 4.7

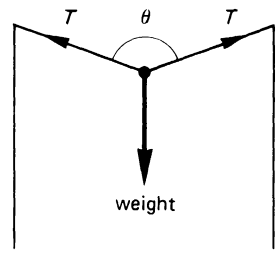


Figure 4.8

(b) See Fig. 4.8. If the height of the poles is increased the tension in each cable is less, so less expensive thinner cables can be used (the sum of the two vertical components of the tensions must equal the weight of the lamp, and the greater the angle θ the greater the tensions in the cable for this to be possible).

(c) When a body is stationary or moving with a constant velocity there is no resultant force on it (see section 3.2), so in (i) 60 000 N, (ii) 60 000 N. Let T be the tension in the cable in (iii). Apply $F = ma$ as in the previous question, then $(60\,000 - T)$ newtons = 6000 x 0.5, hence $T = 57\,000$ N.

5. See section 4.2. Kinetic energy = 400 J, potential energy = 100 J.

6. Work done = Force x Distance (see section 4.2), 6 = 10 x distance, hence distance = 3/5 m.
Answer A

7. (a) See Example 3.5 or 3.7.
(b) (i) At the top both boxes have the same potential energy (mgh) and hence the work done on each must be the same. In Fig. 1 the force is smaller than in Fig. 2 but it acts over a longer distance. In each case the product (force x distance) will be the same. If the slopes are not smooth the work done against friction (frictional force multiplied by distance moved up the slope) in Fig. 1 is greater than in Fig. 2 because the same force moves further in Fig. 1. The same amount of work is done against gravity whatever the value of the friction. (ii) Let W be the child's weight, then frictional force is $W/3$. The child's potential energy at the top of the slide is $3W$. All this energy is used up in work done against the force of friction. So, $3W = W/3$ x (distance moved). Hence distance moved = 9 m. 7 m of this is down the slide, so the child comes to rest 2 m along the horizontal section AB.

8. (a) Your diagram must show a spring balance attached to the end of the string. If you want to be more accurate, two pulleys could be used to guide the string over the surface of the table and a 1 kg mass (producing a force of 10 N) attached to the end of the string. The 1 kg mass falling with constant velocity will produce a force of 10 N. (ii) Gain in potential energy = mgh (see section 4.2) = 1.5 x 10 x 0.6 = 9.0 J. (iii) Work done = Force x Distance (see section 4.2) = 10 x 1.2 = 12.0 J. (iv) Efficiency = 9.0/12.0 (see section 4.4) = 0.75 or 75%.
(b) Mechanical advantage = 15 N/10 N (see section 4.4) = 1.5. (ii) The effort pulling on the string moves twice as far as the load is lifted (when the effort moves 1.2 m the load rises 0.6 m). (iii) Efficiency = M.A./V.R. = 1.5/2 = 0.75 or 75%.
(c) The acceleration will be constant (and less than 10 m/s^2) because a constant force is acting on it. Its velocity will increase by the same amount every

second. (ii) You must draw the car with a long piece of tape attached to its rear which passes through a ticker timer [alternatively, a camera and stroboscope could be used].

9. Work got out of machine = Energy gained by load = 40 x 1 = 40 J.
Work put into machine = Work done by effort = 10 x 10 = 100 J.
Efficiency = 40/100 = 0.4 = 40%.
Answer E

10. See sections 4.2 and 4.4.
(a) 6000 J.
(b) 8000 J.
(c) 75%. (iii) Friction and the weight of the bottom pulley block.

5 Archimedes' Principle and Flotation

5.1 Archimedes' Principle

When a body is completely or partially immersed in a fluid, the upthrust on it is equal to the weight of fluid displaced.

5.2 Principle of Flotation

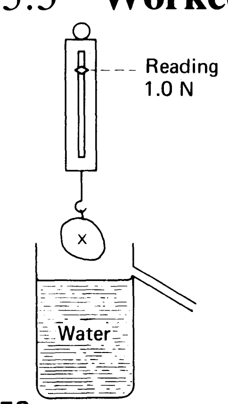
When a body floats, it displaces a weight of fluid equal to its own weight.

A hydrometer is an instrument which floats in a liquid and measures the density (or relative density) of the liquid. When placed in a liquid it will sink until it displaces a weight of liquid equal to its own weight. The smaller the density of the liquid the further it will have to sink until this occurs.

A balloon will rise if the upthrust (weight of air displaced) is greater than the total weight of the balloon (fabric plus contents).

A submarine submerges by filling its tanks with water so that the weight of the submarine is greater than the weight of water displaced. To surface, water is pumped out of the tanks so that the upthrust is greater than the weight.

5.3 Worked Examples



Examples 5.1 and 5.2

The diagram shows an object X hung from a spring balance. The balance reads 1.0 N. The density of X is 5000 kg/m^2 (5 g/cm^3), the density of water is 1000 kg/m^3 (1 g/cm^3) and the Earth's gravitational field is 10 N/kg. The object is slowly lowered into the water until it is completely immersed.

5.1 The volume of water which overflows, in cm^3, is

A 0.2 **B** 0.05 **C** 20 **D** 100 **E** 500

Solution 5.1

[If the force were 10 N the mass would be 1 kg. The force is 1 N, therefore the mass is 100g. 5 g of X occupy 1 cm^3, therefore 100 g of X occupy 20 cm^3. When X is completely immersed it will displace it's own volume of water. 20 cm^3 will flow out of the spout.]

Answer **C**

5.2 When X is completely immersed the reading on the spring balance, in N, will be
A 0.2 **B** 0.4 **C** 0.5 **D** 0.6 **E** 0.8

Solution 5.2

[The water has $\frac{1}{5}$th of the density of the object, so the weight of water it displaces is $\frac{1}{5}$th of the weight of the metal, that is 0.2 N. The upthrust is 0.2 N (see section 5.1). Apparent weight = 1.0 – 0.2 = 0.8 N.]

Answer **E**

Example 5.3

A balloon's fabric weighs 10 N and it has a gas capacity of 2 m^3. The gas in the balloon weighs 2 N. If 1 m^3 of air weighs 13 N, the resultant force on the balloon when it is floating in air is
A 0 N **B** 1 N **C** 13 N **D** 14 N **E** 16 N

Solution 5.3

[Total weight of balloon = 10 + 2 = 12 N
Upthrust = Weight of air displaced = 26 N
Resultant force = 14 N]

Answer **D**

Example 5.4

A hollow glass sphere of mass 60 g floats in water so that two-thirds of its external volume is under water of density 1 gm/cm^3. The volume, in cm^3, of the sphere is
A 16 **B** 24 **C** 40 **D** 66 **E** 90 (AEB)

Solution 5.4

[Since mass is proportional to weight it follows from the principle of flotation that

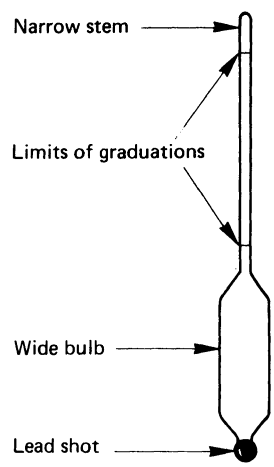
Mass of water displaced = Mass of sphere

$$\frac{2}{3}V \times 1 = 60$$

where V is the volume of the sphere
$\therefore V = 90\ cm^3$]

Answer **E**

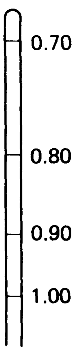
Example 5.5



(a) 'When a body is totally or partially immersed in a fluid it experiences an upthrust equal to the weight of the fluid displaced.'
Describe an experiment which you would perform in a laboratory to verify the above statement for an object which sinks in water, showing clearly how your measurements would be used. **(9 marks)**

(b)
The diagram shows a hydrometer used for measuring the relative density of liquids over the range 0.70 to 1.00.
(i) Sketch the stem of the hydrometer and mark on it a suitable scale from 0.70 to 1.00. **(3 marks)**
(ii) If the stem were longer and narrower, but with the same volume as at present, what effect would this have? **(2 marks)**
(iii) Why does this hydrometer have a *wide* bulb and a *narrow* stem? **(2 marks)**
(iv) Explain the reason for the weighted base. **(2 marks)**
(v) Very often a temperature (e.g. 15°C) is printed on the scale of the hydrometer. What is the reason for this? **(2 marks)**
(L)

Solution 5.5



(a) Hang the body on a spring balance and record its weight (x N). Gently lower the body into a Eureka can filled with water and weigh the water which comes out through the spout (y N). Record the new reading on the spring balance (z N). The readings should be repeated using different fluids and with the body partially as well as totally immersed. In each case it will be found that the upthrust $(x - z)$ N is equal to the weight of liquid displaced (y N).

(b) (i) [Notice that the lower readings are at the top of the scale and that the spaces between the markings get further apart as they move up the stem.]
(ii) The graduations would be further apart and the hydrometer would be more sensitive.

[Sensitive means a large movement for a small change in density.]

(iii) A wide bulb gives greater buoyancy than a narrow bulb of the same length. An hydrometer with a narrow bulb would be very long and unwieldy. A narrow stem results in greater sensitivity than a wide stem.
(iv) The low centre of gravity ensures the hydrometer floats upright. The lead also increases the weight without increasing the volume and this means the hydrometer is compact and not unwieldy.
(v) It states that the scale is accurate at the temperature stated. At a different temperature the hydrometer would occupy a different volume and the scale would not be quite so accurate.

Example 5.6

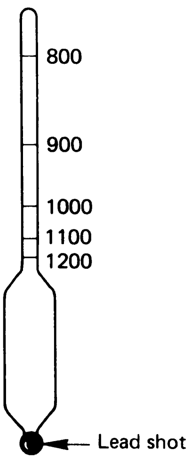
(a) State Archimedes' Principle. **(2 marks)**
(b) (i) Draw a labelled diagram of a bulb and stem hydrometer.
(ii) What physical quantity does a hydrometer measure? **(4 marks)**
(c) Define pressure and write down the formula used to determine the pressure, in Pa, due to a column of liquid. State the meaning of any symbols used. **(2 marks)**
(d) A cube of wood of volume 0.2 m^3 and density 600 kg/m^3 is placed in a liquid of density 800 kg/m^3.

(i) What fraction of the volume of the wood would be immersed in the liquid?
(ii) What force must be applied to the cube so that the top surface of the cube is on the same level as the liquid surface? **(6 marks)**

(e) Describe, with the aid of a labelled diagram, how you would measure the excess pressure, in Pa, of the laboratory gas supply, using a manometer. **(7 marks)**

Data for this question:
Acceleration due to gravity = 10 m/s^2 **(AEB)**

Solution 5.6



(a) When a body is partially or totally immersed in a fluid the upthrust is equal to the weight of fluid displaced.

(b) (i) See diagram. (ii) Density (or relative density).

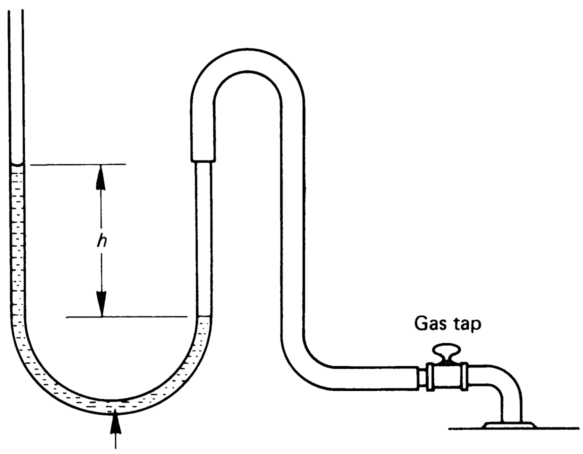
(c) Pressure = $\dfrac{\text{Force}}{\text{Area}}$

Pressure due to a column of liquid = 10 (N/kg) x depth (m) x density (kg/m^3).

(d) (i) Let v = volume of cube immersed.
Since the cube is floating
Upthrust = Weight of cube
(v x 800) x 10 newtons = (0.2 x 600) x 10 newtons
v = 0.15 m^3

Fraction immersed = $\dfrac{\text{Volume below liquid}}{\text{Total volume of cube}} = \dfrac{0.15}{0.2} = 0.75$

(ii) Volume of cube above liquid = 0.05 m^3.
When this is immersed extra upthrust = 0.05 x 800 = 40 N.
Force applied to top of cube to immerse it is 40 N.



(e) Connect one end of the U-tube to the gas supply using a piece of rubber tubing (see diagram). A suitable liquid for the U-tube is water. Turn the gas tap on slowly and when the water has ceased to oscillate measure the height h. The excess pressure in pascal is calculated from the formula given in (c).

5.4 Have You Mastered the Basics?

1. Can you state Archimedes' principle and the principle of flotation?
2. Can you describe an experiment to verify Archimedes' principle?
3. Can you describe an hydrometer and explain how it works?

4. Can you explain how a submarine dives and surfaces, and why hydrogen filled balloons rise?
5. An object weighs 0.45 N in air and 0.40 N when immersed in water.
   (i) What is the volume of the object? (1 m^3 of water weighs 10 000 N).
   (ii) What is the density of the object?
6. A boat with vertical sides measures 25 m by 10 m at the water line, and is floating in sea water of density 1024 kg/m^3. How far will it sink in water if it is loaded with cargo of weight 25 600 N?

5.5 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See sections 5.1 and 5.2
2. See Example 5.5.
3. See section 5.2 and Example 5.5.
4. See section 5.2.
5. (i) Upthrust = (0.45 – 0.40) N = 0.05 N = Weight of water displaced.

   $$\text{Volume of water displaced} = \frac{0.05}{10\,000} = 5 \times 10^{-6}\ \text{m}^3\ (5\ \text{cm}^3)$$

   (ii) Mass of object = 0.45/10 = 0.045 kg

   $$\text{Density} = \frac{\text{Mass}}{\text{Volume}}\ \text{(see section 2.3)} = \frac{0.045\ \text{kg}}{5 \times 10^{-6}\ \text{m}^3} = 9000\ \text{kg/m}^3$$
6. If 25 600 N are added to the boat then the additional upthrust must be 25 600 N, hence
   Additional weight of water displaced = 25 600 N (see section 5.2)
   1 m^3 of sea water weighs 10240 N

   $$\therefore \text{Volume of water displaced} = \frac{25\,600}{10240} = 2.5\ \text{m}^3$$

   Cross-sectional area of boat = 25 x 10 = 250 m^3

   $$\text{Depth to which boat sinks} = \frac{2.5}{250} = 0.01\ \text{m} = 1\ \text{cm}$$

5.6 Questions

(Answers and hints on solutions will be found in section 5.7)

Question 5.1

A body is weighed in air using a spring balance. The balance reads 5 N. The body is now completely submerged in a liquid that produces an upthrust of 1 N. The spring balance now reads, in N,

A 1 **B** 2.5 **C** 4 **D** 5 **E** 6

Question 5.2

An object was hung from a spring balance and the balance read 2.0 N. The object, still hung from the spring balance, was slowly lowered into a measuring cylinder containing some water. When it was completely immersed the level of the water had risen from the 41 cm^3 mark to the 61 cm^3 mark. What was the density of the solid?

The object weighed 1.85 N when immersed in a liquid. What was the density of the liquid? **(10 marks)**

Question 5.3

An ocean-going liner has a cross-sectional area of 15 000 m^2 at its water line. It is floating in port in fresh water when 1000 passengers come on board. If the average weight of a passenger is 750 N, how far does the liner sink as a result of the passengers coming on board? Would you expect it to sink further or not so far in salt water. Explain your answer. Density of water = 1000 kg/m^3. **(7 marks)**

Question 5.4

Explain the following;

(i) When you run over a shingle beach into the sea, the stones hurt less as you get deeper into the water. Assume that the sensitivity of your feet and the nature of the pebbles remain unchanged as you run into the water.

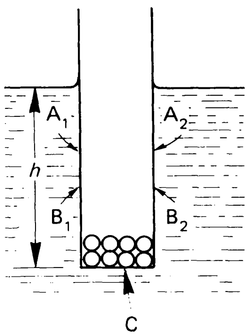
(ii) A ship rises in the water as it passes from a river into the sea. **(8 marks)**

Question 5.5

(a) State the principle of flotation.

(b) A beach ball of volume 9000 cm^3 weighs 5 N. What force is needed to submerge it in water of density 1000 kg/m^3? **(10 marks)**

Question 5.6



The diagram shows a flat-bottomed test tube containing lead shot floating upright in a liquid. Draw a diagram showing the forces per unit area acting on the test tube caused by the liquid at the points indicated by A_1, A_2, B_1, B_2 and C. (The relative sizes of the forces should be indicated.) **(6 marks)**

The following readings were obtained for the total mass, M, of the test tube and lead shot, and the depth, h, of the test tube immersed as lead shot was added to the tube.

M/g	48	55	60	65	73	77	84
h/cm	8	9	10	11	12	13	14

Plot a graph of these readings. (You are advised to start your M axis at 40 g and your h axis at 8 cm.) **(8 marks)**

From your graph find the depth immersed when M is 90 g. Use this result to find the area of the base of the test tube. (Density of the liquid = 1.2 g/cm^3, or 1200 kg/m^3.) **(6 marks)**

(L)

Question 5.7

(a) State Archimedes' principle and describe an experiment to verify it. **(10 marks)**

(b) A polar bear weighs 6000 N and is standing on an iceberg of density 920 kg/m^3 which drifts into warmer water and gradually melts. What is the least volume of ice remaining before the polar bear can no longer avoid getting his feet washed by the sea? (Take the density of warm sea water as 1020 kg/m^3.) **(10 marks)**

Question 5.8

(a) State Archimedes' principle. **(3 marks)**

(b) In one of H. G. Wells' science fiction novels, the body of one of the characters, called Pyecraft, loses all his weight but his volume remains unchanged. Pyecraft then floats fully clothed up to the ceiling. Explain, giving reasons for your answer, whether or not this is a plausible consequence. **(4 marks)**

(c) The fabric of a balloon designed for high altitude research has a mass of 50 g. When filled with hydrogen of density 0.09 kg/m^3 it has a volume of 1 m^3. If the density of air is 1.29 kg/m^3 what is the maximum weight of instruments it can carry? **(5 marks)**

5.7 Answers and Hints on Solutions to Questions

1. Answer C
2. Use Density = Mass/Volume (section 2.3). Density of solid = 10 g/cm^3. Density of liquid = 0.75 g/cm^3.
3. Additional weight of water displaced = 7.5×10^5 N. Ship sinks 0.5 cm. It sinks less in salt water because salt water is denser than fresh water.
4. (i) The deeper you are in the water the greater is the upthrust on you.
   (ii) Sea water is more dense than fresh water. The ship displaces the same weight of each.
5. (a) See section 5.2.
   (b) Weight of ball + Force needed = Upthrust. Force needed = 85 N.
6. You must draw a diagram. All the forces are perpendicular to the sides of the tube. A_1 and A_2 are greater than B_1 and B_2. The vertical force upwards at C is the largest force. From the graph, when the mass is 90 g the depth immersed is 15 cm. To determine the area of the base equate the weight of the tube to the weight of water displaced (principle of flotation, section 5.2).
   Answer = 5 cm^2
7. (a) See section 5.1 and Example 5.5.
   (b) Let V be the volume of ice remaining.
   Use (Weight of bear + Weight of ice) = (Weight of water displaced), $V = 6$ m^3.
8. (a) See section 5.1.
   (b) If his volume remains the same, then the upthrust remains the same. If his weight becomes zero he will rise to the ceiling.
   (c) Use (Weight of hydrogen in balloon) + (Weight of fabric) + (Weight of instruments) = (Weight of air displaced) ⇒ Weight of instruments = 11.5 N.

6 Expansion, Gas Laws, Thermometers, Kinetic Theory and Molecular Size

6.1 Expansion

Gases, solids and liquids usually expand when heated. For a given temperature rise, gases expand more than liquids and liquids expand more than solids. Water has the unusual property of contracting as it is heated from 0°C to 4°C; it has its maximum density at 4°C (see Example 6.12).

6.2 The Gas Laws

(i) *Boyle's Law*

For a fixed mass of gas at constant temperature the pressure is inversely proportional to the volume (see Examples 6.1, 6.2 and 6.3).

(ii) *The Pressure Law*

For a fixed mass of gas at constant volume the pressure is proportional to its kelvin temperature (see Example 6.5).

(iii) *Charles's Law*

For a fixed mass of gas at constant pressure the volume is proportional to its kelvin temperature.

These laws may be summarised by the equation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

where the suffix 1 represents the initial state of the gas and the suffix 2 represents the final state. *Remember that T must be in kelvin, that is* (°C + 273).

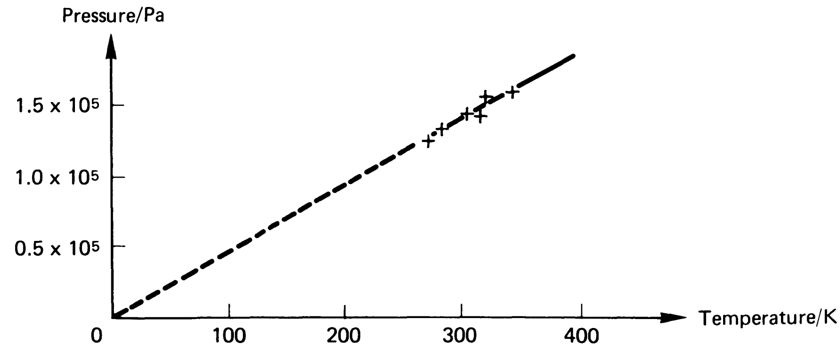


Figure 6.1 Graph of pressure against temperature for a fixed mass of gas at constant volume. A graph of volume against temperature (pressure constant) is the same shape and goes through 0 K.

Figure 6.1 is a graph of pressure (p) against temperature (T), the volume being kept constant. The dotted part of the line is what we might expect to happen if we went on cooling the gas and it never liquefied. The absolute zero of temperature is the temperature at which the pressure would become zero.

6.3 Thermometers

A mercury thermometer depends for its functioning on the fact that mercury expands more than glass when heated. In order to calibrate a thermometer, two fixed points are needed.

The *lower fixed point* is the temperature at which pure ice melts at normal atmospheric pressure.

The *upper fixed point* is the temperature of steam from water boiling at normal atmospheric pressure.

To calibrate a thermometer in °C, mark the lower fixed point (0°C) and the upper fixed point (100°C) and then mark one hundred equal divisions between the two points.

6.4 Kinetic Theory

The molecules of a solid vibrate about fixed positions. When heat is supplied the molecules vibrate faster and through greater distances than before. If sufficient heat energy is supplied, the solid melts. The molecules no longer vibrate about fixed positions and move freely amongst each other. The forces between the molecules are enough to give a liquid a definite volume but not a definite shape. As more heat energy is supplied the molecules gain enough energy to break right away from each other and move independently. The liquid has started to boil. The molecules of a gas are in random motion. They are continually colliding with one another and with the walls of the container causing a pressure on the walls of the containing vessel. If the temperature is increased the molecules move faster and hit the walls more often and harder, causing the pressure to increase. At the absolute zero of temperature the molecules have their lowest possible kinetic energy.

Evaporation is the escape of the faster moving molecules from the surface of a liquid and this takes place at all temperatures. Boiling occurs when bubbles of vapour form in the body of the liquid, and rise and escape from the surface of the liquid. Boiling takes place at a particular temperature.

6.5 Evidence for Kinetic Theory

(a) Brownian Motion (see Examples 6.8 and 6.9)

This provides evidence for the kinetic theory of matter. Brownian motion may be observed by using a microscope to view illuminated smoke particles in a smoke cell. The specks of light (the light reflected and scattered by the smoke particles) jostle about in a random irregular manner as they are bombarded by the invisible moving air molecules.

(b) Diffusion (see Example 6.10)

This also provides evidence for the motion of molecules.

6.6 Molecular Size: The Oil Drop Experiment (see Example 6.10)

An oil drop of measured radius is dropped into the middle of a large area of clean water which has a light powder sprinkled on its surface. By equating the volume of the drop ($\frac{4}{3}\pi r^3$) to the volume of the film on the surface (area of surface × thickness), the thickness of the film may be calculated. The thickness of the film is an indication of the size of a molecule.

6.7 Linear Expansivity

The linear expansivity is the increase in length of unit length for a 1°C rise in temperature. Hence

$$\text{Linear expansivity } (\alpha) = \frac{\text{Increase in length}}{\text{Original length} \times \text{Temperature rise}} \qquad \text{(Unit per K)}$$

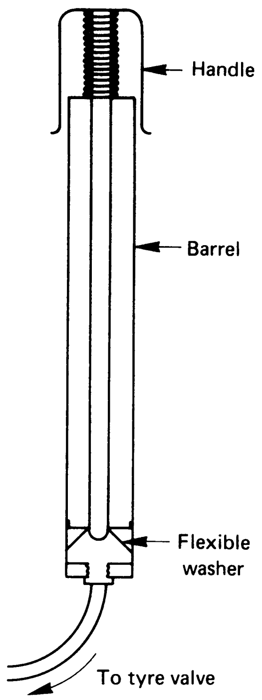
6.8 Worked Examples

Example 6.1

(a) Describe how you would investigate the relationship between the volume and pressure of a fixed mass of dry air at a constant temperature. Show clearly how the values of volume and pressure are measured and state any precautions which are taken. **(8 marks)**
Assuming that you have been provided with the following results, use them to obtain a *straight line* graph. What two features of the graph show that Boyle's law holds?

Pressure/10^4 Pa	2.0	3.0	4.0	5.0	6.0	8.0
Volume/10^{-4} m^3	4.0	2.7	2.0	1.6	1.3	1.0

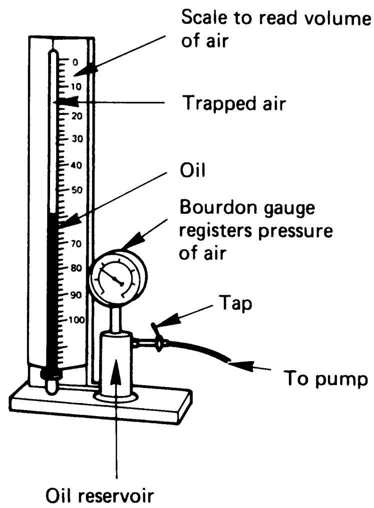
(8 marks)



(b) The diagram shows the barrel and washer of a bicycle pump. Describe what happens during one upstroke of the pump, with special reference to the action of the washer and tyre valve and the part played by atmospheric pressure. (No constructional detail of the tyre valve is expected.) **(4 marks)**
(L)

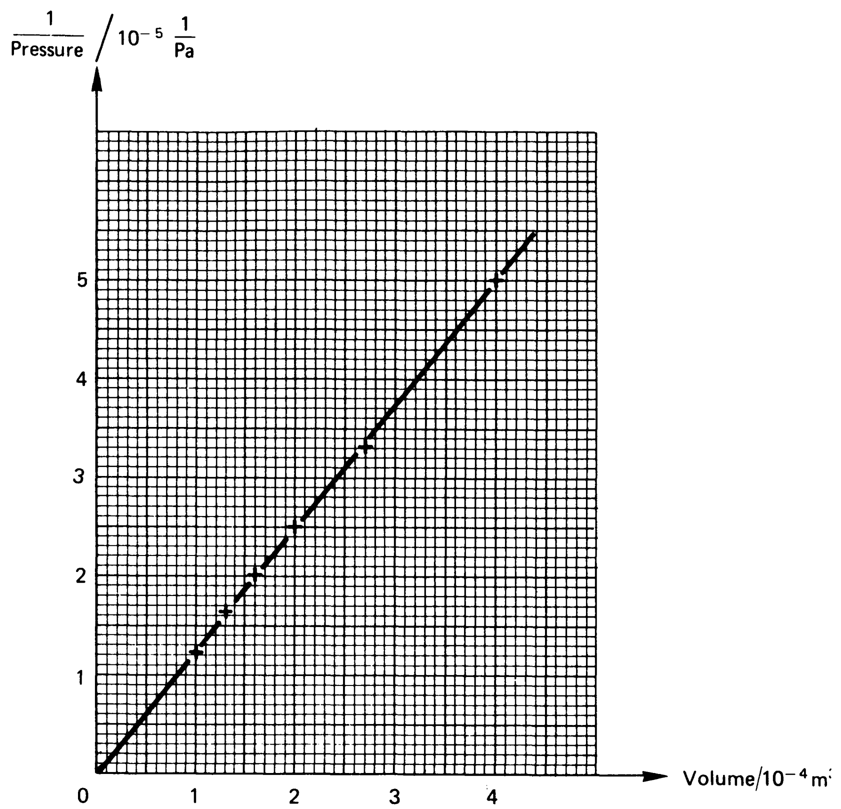
Solution 6.1

(a) The diagram shows the apparatus. The volume of the trapped air is read on the graduated scale behind the air column and the pressure is read on the Bourdon gauge. The tap is opened and a car pump is used to force the oil up the tube decreasing the volume of the gas. The volume and pressure are again read. By opening and closing the tap a series of readings are obtained. Each



time the oil is lowered in the tube a short time must elapse before the reading of the volume is taken. This allows time for the oil on the sides of the tube to run down the tube and time for the air to reach room temperature inside the tube. Throughout the experiment it is important to check that the temperature of the laboratory remains constant.

$\dfrac{1}{Pressure} \Big/ 10^{-5}\ \dfrac{1}{\text{Pa}}$	5.0	3.3	2.5	2.0	1.6(6)	1.2(5)
$Volume/10^{-4}$ m^3	4.0	2.7	2.0	1.6	1.3	1.0



The graph is a straight line through the origin confirming that the volume is inversely proportional to the pressure.

(b) On the upstroke the pressure below the flexible washer decreases. The tyre valve is closed so no air comes out of the tyre. The atmospheric pressure pushing down on the top of the flexible washer forces air past the sides of the flexible washer into the space below.

Example 6.2

A fixed mass of air has a volume of 12 cm^3 when the pressure is 3.6×10^5 N/m^2. If the volume becomes 8 cm^3 the pressure in N/m^2 at the same temperature will be

A 1.8×10^5 **B** 2.4×10^5 **C** 3.6×10^5 **D** 5.4×10^5 **E** 5.4×10^6

Solution 6.2

[The problem concerns a fixed mass of gas at constant temperature with the pressure and volume changing. We apply Boyle's law

$P_1 V_1 = P_2 V_2$ (see the gas equation in section 6.2 when $T_1 = T_2$)

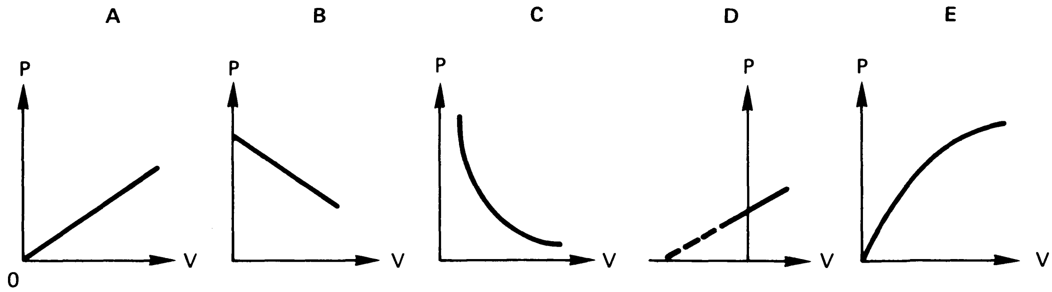
$3.6 \times 10^5 \times 12 = P_2 \times 8$

$P_2 = 5.4 \times 10^5$ N/m^2]

Answer **D**

Example 6.3

Which of the graphs below best represents the results of an experiment to verify Boyle's law?

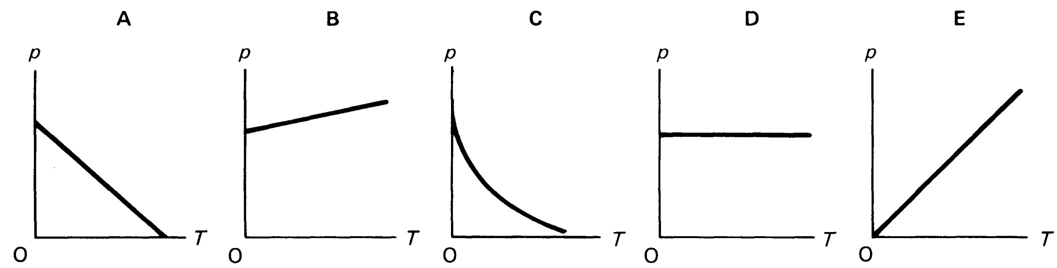


Solution 6.3

Answer C

Example 6.4

Which one of the following graphs correctly represents the variation of pressure with absolute temperature for a fixed mass of an ideal gas at constant volume?



(AEB)

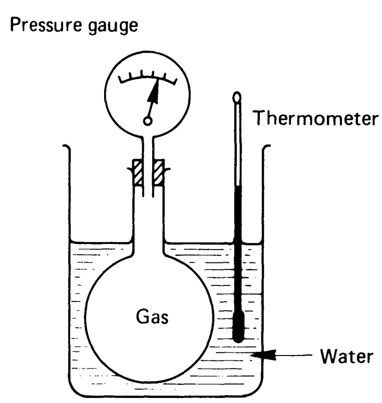
Solution 6.4

[The pressure is directly proportional to the kelvin (absolute) temperature. Direct proportion is represented by a straight line graph through the origin.]

Answer E

Example 6.5

(a) A pupil investigates the relationship between the pressure and temperature of a fixed mass of gas using the apparatus shown.



He heats the water continuously using a Bunsen burner and records the pressure and temperature readings every minute.

(i) State two ways in which this experiment may be improved.

(ii) Using the results from an improved experiment, describe how the relationship between pressure and temperature on the kelvin scale may be found. **(4 marks)**

(b) A cylinder of oxygen at 27°C has a gas pressure of 3×10^6 Pa.

(i) Calculate the pressure of the gas if the cylinder is cooled to 0°C.

(ii) Describe what happens to the gas molecules as the gas is cooled and indicate how this results in a reduction of pressure. **(4 marks)**

(c) When air in a bicycle pump is compressed by moving the piston, the temperature of the air in the pump increases. Explain this temperature rise in terms of the kinetic theory of gases. **(2 marks)**

(10 marks)

(SEB)

Solution 6.5

(a) (i) Include a stirrer to ensure that all the water is at the same temperature. Remove the bunsen burner and stir for some time before taking a reading.

(ii) A graph should be drawn of pressure against temperature, with the temperature axis going down to about −300°C. The graph will be found to be a straight line through the absolute zero. This shows that the pressure is proportional to the kelvin temperature.

(b) (i) $\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$

$$\therefore \frac{3 \times 10^6}{(273 + 27)} = \frac{P_2}{273}$$

$$\therefore P_2 = \frac{273 \times 3 \times 10^6}{(273 + 27)} = 2.73 \times 10^6 \text{ Pa}$$

(ii) As the gas is cooled the average kinetic energy of the gas molecules decreases. The temperature is a measure of the average kinetic energy of the molecules, so the temperature falls.

(c) As the moving piston strikes the moving molecules, the velocity of the molecules is increased. The average kinetic energy of the molecules has increased, and therefore the temperature has increased.

Example 6.6

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

When applying the equation $\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$ to a gas kept at constant volume which of the following statements are/is correct?

(1) The mass of gas must be kept constant

(2) The initial pressure P_1 and the final pressure P_2 could both be in cm Hg
(3) The initial temperature T_1 and the final temperature T_2 could both be in degrees celsius

Solution 6.6

[The equation only applies to a fixed mass of gas. Provided both P_1 and P_2 are in the *same* unit then it does not matter what that unit is. T_1 and T_2 must always be in kelvin (see section 6.2).]

Answer C

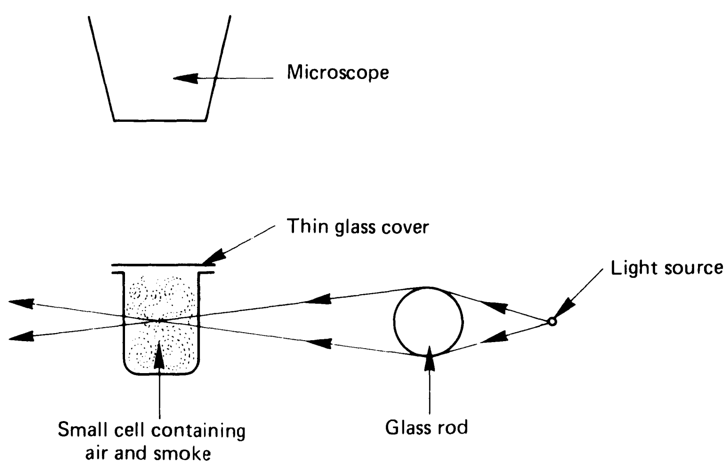
Example 6.7

(i) Explain why the glass of the bulb of a thermometer is thin even though this makes it fragile.
(ii) On an Arctic expedition an alochol filled thermometer might be preferred to a mercury filled one. **(6 marks)**

Solution 6.7

(i) If the glass were thick it would take a long time for the heat to conduct through the glass. There would be a waiting period until the mercury reached the temperature of the surroundings in which it is placed. A thermometer with thin glass would reach the temperature of its surroundings much more quickly.
(ii) Alcohol freezes at a lower temperature than mercury. On Arctic expeditions it is possible that the temperature could fall below the freezing point of mercury and if this happened a mercury thermometer would be useless.

Example 6.8



The diagram shows one form of apparatus used to observe the Brownian motion of smoke particles in air. A student looking through the microscope sees tiny bright specks which he describes as 'dancing about'.
(a) What are the bright specks?
(b) Why are the specks 'dancing about'?
(c) What is the purpose of the thin glass cover? **(5 marks)**
(L)

Solution 6.8

(a) The specks of light are light which is reflected and scattered by the smoke particles.
(b) The smoke particles are being bombarded by the air molecules which are in rapid random motion.
(c) To reduce air (convection) currents and to stop the smoke escaping.

Example 6.9

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

Brownian motion is observed by observing smoke particles under a microscope. Which of the following statements is/are correct?
(1) The smoke particles move about in a random manner
(2) The motion is caused by the air molecules colliding with the smoke particles
(3) If larger smoke particles were used the Brownian motion would become more rapid

Solution 6.9

[(1) and (2) are correct (see section 6.5). Larger smoke particles would show *less* rapid motion. They are more massive than smaller particles and are therefore accelerated less for a given force (see section 3.2).]

Answer C

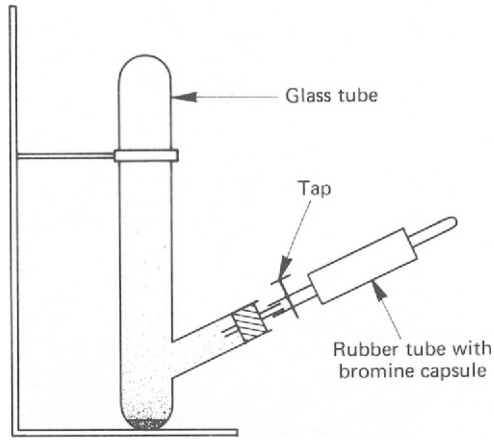
Example 6.10

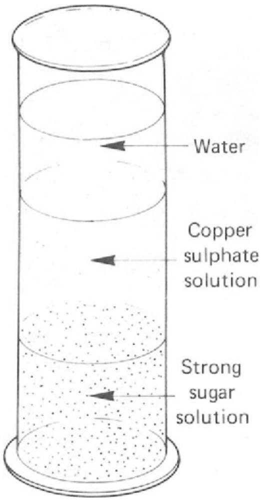
(a) Describe one experiment to demonstrate the diffusion of gases (i) and one experiment to demonstrate the diffusion of liquids (ii). Each answer must include a diagram of the apparatus. **(8 marks)**
(b) How is diffusion explained by the kinetic theory of gases? **(4 marks)**
(c) In the oil drop experiment to estimate the length of an oil molecule a drop of oil of radius 0.25 mm is dropped on to the surface of water. A patch of oil of radius 12 cm is formed on the surface of the water. Use these figures to estimate the length of an oil molecule. **(8 marks)**

Solution 6.10

(a) (i) ***Diffusion of Gases***

A capsule of bromine is placed in the rubber tubing and the end of the tubing sealed with a glass rod. The tap is opened and the bromine capsule broken by squeezing the rubber tube with a pair of pliers. The liquid bromine escapes into the glass tube. The dark colour of the bromine vapour will be seen to move slowly (diffuse) up the tube.





(ii) ***Diffusion of Liquids***

A strong sugar solution is poured into a gas jar. A strong copper sulphate solution is poured very slowly and very carefully on top of the sugar solution. Water is very carefully poured on top of the copper sulphate solution. If these operations are carried out carefully there will be a fairly sharp dividing line between the layers. The blue copper sulphate will be observed to diffuse downwards and upwards.

(b) When two substances whose molecules are in motion are put in contact with each other, the moving molecules pass across the boundary between the two substances. Some will collide almost immediately with molecules of the other substance, others will move a little further in the spaces between the molecules before colliding with another molecule. In this way the molecules of one substance gradually move into the other substance.

(c) Volume of drop = $\frac{4}{3}\pi r^3 = \frac{4}{3}\pi (0.25)^3 = 0.0654\ \text{mm}^3$

Area of circle on surface = $\pi r^2 = \pi(120)^2 = 45\,239\ \text{mm}^2$

Let Thickness of oil on surface = x mm

But Volume of oil on surface = Volume of oil drop

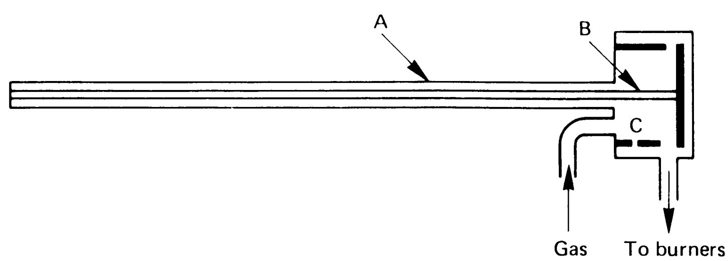
$\therefore 45\,239 \times x\ 0.0654$

$x = \frac{0.0654}{45\,239} = 1.4 \times 10^{-6}$ mm

Length of oil molecule is about 1.4×10^{-6} mm

Example 6.11

(a)



The diagram shows a thermostat which could be fitted with the tube protruding inside a gas oven. The outer tube is made of a metal A and the inner rod of a different metal B.

(i) What is the purpose of a thermostat? **(1 mark)**

(ii) Explain carefully, with reference to the expansivities of metals A and B, how this thermostat works. **(4 marks)**

(iii) Why is the small hole C necessary? **(1 mark)**

(b) An ungraduated mercury thermometer is attached to a millimetre scale. When the thermometer is placed in pure melting ice the scale reading is 45 mm, and when it is placed in steam above boiling water (at standard atmospheric pressure) the reading is 150 mm. When held in the open air the reading is 65 mm. Calculate the air temperature in °C.

(4 marks)

If the experiment had been performed on a day when atmospheric pressure was much lower, what differences, if any, would you expect in each of the scale readings? Give reasons for your answers. (You may assume that the air temperature was the same.)

(6 marks)

The graduations on this thermometer would be too close together for precise reading. State, and justify, *two* modifications in design which would make a more accurate thermometer. **(4 marks)**

(L)

Solution 6.11

(a) (i) To regulate the supply of gas, in order to control the oven temperature.

(ii) The tube A is in the oven. As the oven heats up A and B both expand, but the linear expansivity of A is greater than the linear expansivity of B. The gap through which gas passes to get to the burners therefore gets smaller as the oven heats up and will close completely at a preset temperature. As the oven cools the reverse happens and gas is again supplied to the burners.

(iii) The gap at C means that the gas supply to the burners is never completely cut off. In the absence of the gap C the burners would go out and when the gas came on again it would not ignite and there would be a dangerous escape of gas.

(b) 105 mm represents a change of temperature of 100°C

20 mm represents a change of temperature of $\frac{100}{105} \times 20°C = 19°C$

[When the reading is 65 mm it is 20 mm up the scale from the 45 mm mark.]

A decrease in pressure lowers the boiling point. In the steam the reading will be less than 150 mm. A decrease in pressure raises the freezing point. In the pure melting ice the reading will be greater than 45 mm. The room temperature is still the same and the thermometer will still read 65 mm at room temperature.

A thinner capillary tube and a larger bulb of mercury would both mean that for a given change of temperature the mercury would move further up the tube. The thermometer is then more sensitive (larger movements of mercury for a given change in temperature) and provided the scales were put on accurately the thermometer would be more accurate.

[Accuracy depends on how carefully and accurately the scale is put on. Sensitivity depends on how far the mercury moves for a given change in temperature. A thermometer could be very sensitive but have quite the wrong figures against the markings on the scale.]

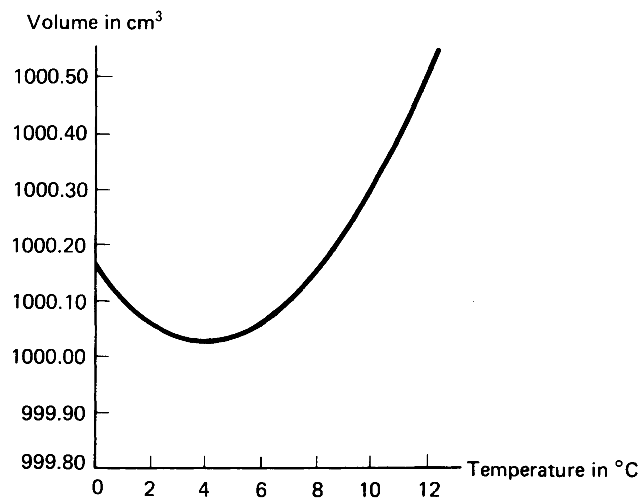
Example 6.12

Directions summarised				
A	**B**	**C**	**D**	**E**
1, 2, 3 all correct	**1, 2** only correct	**2, 3** only correct	**1** only correct	**3** only correct

The graph shows how the volume of a given mass of water changes with temperature. This shows that water

1 freezes at 4°C
2 can expand on cooling
3 is of greatest density at 4°C

(AEB)



Solution 6.12

[When the water is cooled from 4°C to 0°C the volume increases so 2 is correct. The volume is least at 4°C so water does have its maximum density at 4°C. The graph tells us nothing about the freezing point.]

Answer C

Example 6.13

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

Which of the following statements is/are true about the boiling and evaporation of water?

(1) Boiling takes place throughout the body of the water
(2) Evaporation is molecules escaping from the surface of the water
(3) With the same external conditions boiling takes place at one definite temperature but evaporation can take place at many different temperatures

Solution 6.13

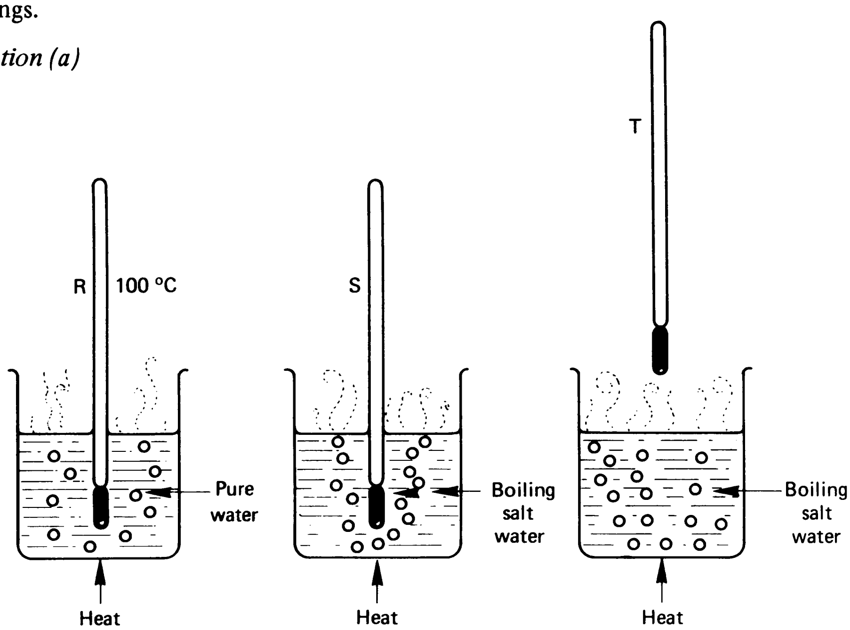
[see section 6.4]

Answer E

Example 6.14

The diagrams illustrate three situations involving thermometers which are labelled R to Z. In each situation, the thermometers (which you may assume to be accurate) indicate different readings.

Situation (a)



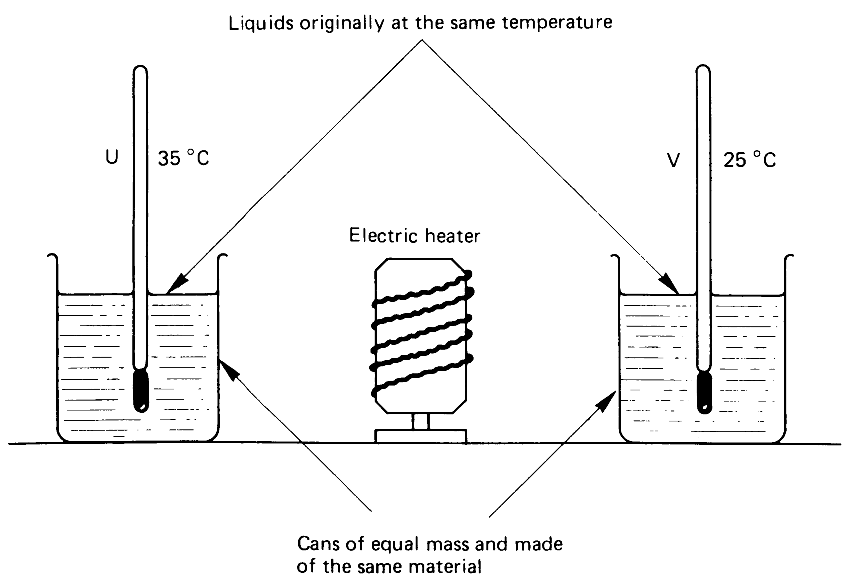
(i) What approximate reading would you expect thermometer S to give? Give a reason for your answer.

(ii) What approximate reading would you expect thermometer T to give? Give a reason for your answer.

(iii) How are the answers to the above questions made use of in calibrating a thermometer?

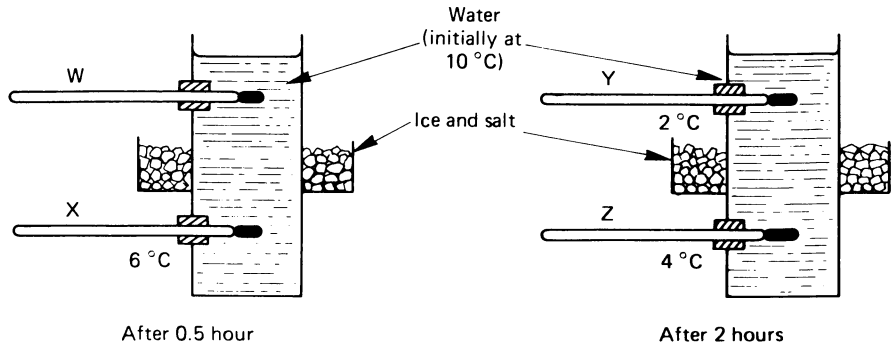
(8 marks)

Situation (b)



(i) Why does very little heat from the electric heater reach the containers by conduction and convection?
(ii) Suggest *two* possible reasons why the reading of thermometer U is greater than that of thermometer V. **(7 marks)**

Situation (c)



(i) Suggest a possible value for the reading of thermometer W.
(ii) Why is the reading of thermometer Y less than that of thermometer Z.
(iii) Is there any occasion when the upper and lower thermometers would give the same reading? If there is, state what the reading is. If there is no occasion, suggest a reason for this. **(5 marks)**

(L)

Solution 6.14

(a) (i) 103°C [anything between 100°C and 105°C would be reasonable.] Adding salt to water raises the boiling point (see section 7.3).
(ii) About 97°C. The salt remains in solution and steam above boiling salt water is at 100°C, but because of the space around the thermometer air from the room will affect the temperature so the thermometer will read something below 100°C.
(iii) To mark the upper fixed point the thermometer must be in steam above pure boiling water when the atmospheric pressure is normal. The temperature is then 100°C.

(b) (i) Air is a bad conductor so little heat would be conducted through the air. The air heated by convection rises upwards and the rising hot air will not reach the cans (see sections 8.2 and 8.3).
(ii) The specific heat capacity of the liquid on the left is less than the specific heat capacity of the liquid on the right.
[A lower specific heat capacity will mean that less heat is needed to raise its temperature a given amount.]
The outside of the left-hand can might be painted black and a black surface is a better absorber of radiation than a shiny surface (see section 8.4).
[Alternatively, the right-hand can could have a shiny surface.]

(c) (i) 8°C [6°C to 10°C].
(ii) Water has its maximum density at 4°C. Once the water below the freezing mixture has reached 4°C further cooling of the water in the middle will mean that it becomes less dense and rises, thus cooling the water above the middle.
(iii) 4°C.

6.9 Have You Mastered the Basics?

1. Can you state Boyle's Law and describe an experiment to verify it?
2. Can you define (a) lower fixed point (b) upper fixed point.
3. Can you distinguish between evaporation and boiling?
4. Can you describe the oil drop experiment, experiments to demonstrate diffusion and Brownian motion?
5. Can you use the kinetic theory of gases to explain how the pressure of a gas in a container changes if the temperature is changed?
6. A fixed mass of gas at 0°C has a volume of 546 cm^3 at a pressure of 3 atmospheres. It is heated until its temperature reaches 77°C. If the new volume is 1050 cm^3, what is the new pressure?
7. What is the linear expansivity of a rod of length 0.5 m which expands by 0.1 mm when heated from 10°C to 20°C?

6.10 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See section 6.2 and Example 6.1.
2. See section 6.3.
3. See section 6.4 and Example 6.13.
4. See sections 6.5, 6.6 and Examples 6.8, 6.9 and 6.10.
5. See section 6.4.
6. Substitute in the equation in section 6.2. Don't forget to put the temperatures in kelvin. T_1 is 273°C and T_2 is (273 + 77)°C.
   Answer 2 atmospheres.
7. Substitute in the equation in section 6.7. Be careful to put both the original length and the increase in length in the same unit of length.
   Answer 2×10^{-5} per K.

6.11 Questions

Question 6.1

(a) Describe how you would investigate the variation of volume with pressure of a fixed mass of air kept at constant temperature.

(b) The table below shows a series of readings of pressure and volume for such an experiment. Make a table of pressure and $\frac{1}{\text{volume}}$. Plot a graph of pressure against $\frac{1}{\text{volume}}$ and use your graph to determine the volume when the pressure is 160 kN/m^2.

Pressure (kN/m^2)	400	267	200	120
Volume $(mm)^3$	3.0	4.5	6.0	10.0

Question 6.2

(a) In Boyle's law,
 (i) which two physical quantities are related to one another?

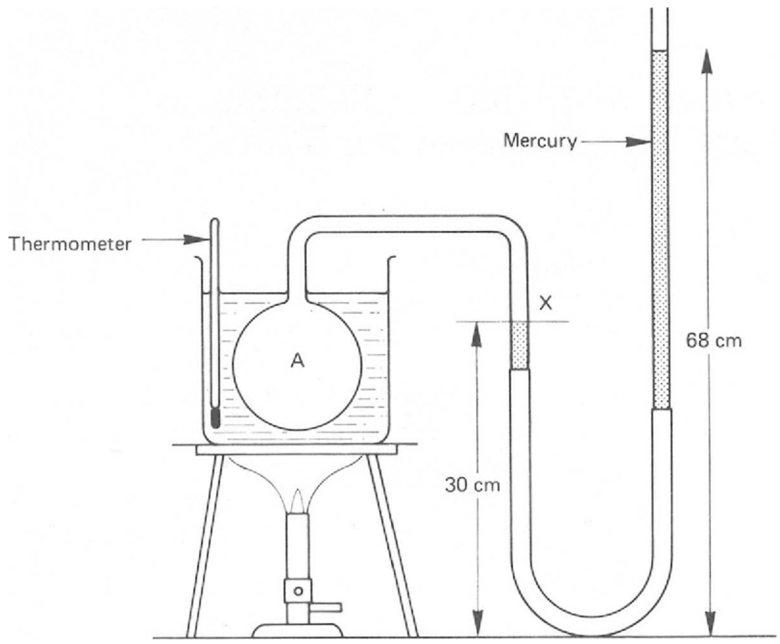
(ii) what is their relationship?

(iii) which physical quantities are kept constant?

(b) Explain why a bubble of air increases in volume as it rises from the bottom of a lake to the surface. If a bubble doubles its volume as it travels from the bottom of a lake to the surface, what is the depth of the lake? (Take the atmospheric pressure as 10^5 Pa and the density of water as 1000 kg/m^3. Assume that the temperature of the water is uniform.)

(c) A narrow tube of uniform bore is closed at one end and contains some dry air trapped by a pellet of mercury 0.15 m long. When the tube is vertical and the open end upwards, the air occupies a length of 0.20 m. When the tube is inverted the air occupies 0.30 m. Calculate the atmospheric pressure. Express your answer in Pa. (The density of mercury is 13 600 kg/m^3.)

Question 6.3



(a) The diagram shows an apparatus which can be used to investigate how the pressure of a fixed mass of air at a constant volume trapped in the bulb A varies with temperature.

(i) How would you ensure that all the air trapped in the bulb A was at the temperature recorded by the thermometer? **(2 marks)**

(ii) Why, when taking readings of the pressure, is it necessary to ensure that the mercury level coincides each time with the mark X? **(2 marks)**

(iii) Using the values given in the diagram, calculate the total pressure of the air trapped in the bulb A, given that the height of a mercury barometer in the laboratory is 76 cm. (The pressure of 76 cm of mercury is equivalent to 1×10^5 Pa.) **(3 marks)**

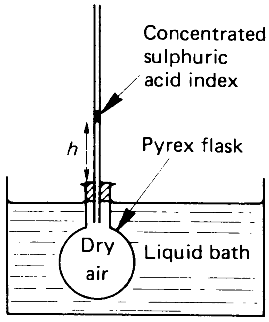
(iv) Sketch a graph of the results that would be obtained from such an experiment. What conclusion could be drawn from the graph? What do you understand by absolute zero of temperature? **(6 marks)**

(v) Explain briefly how the kinetic theory of gases accounts for the results obtained in the above experiment. **(4 marks)**

(b) A bottle is corked when the air inside is at 20°C and the pressure is 1.0×10^5 Pa. If the cork blows out when the pressure is 3.0×10^5 Pa, calculate the temperature to which the bottle must be heated for this to happen. (Assume that the bottle does not expand.) **(3 marks)**

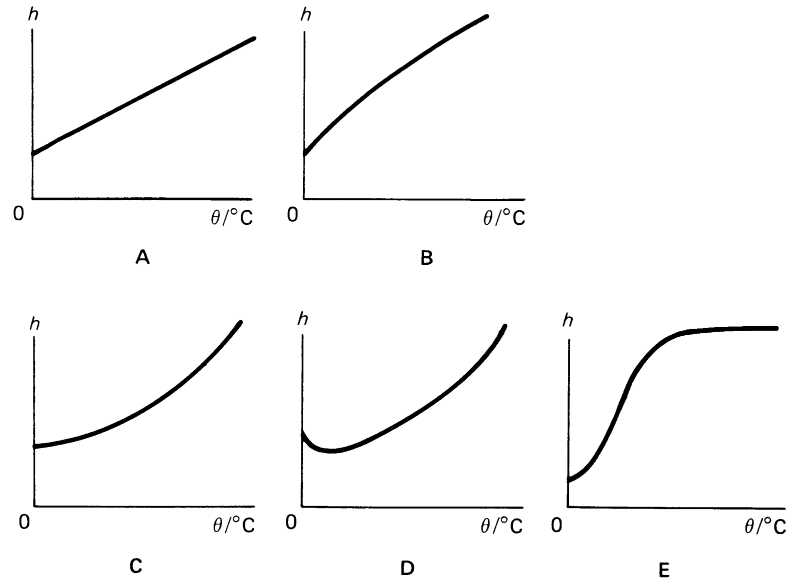
(L)

Questions 6.4 and 6.5



In the arrangement shown, the liquid bath is maintained at various steady temperatures and the height of the index above the bung, h, is plotted against temperature, θ.

6.4 Which of the graphs best represents the recorded observations?



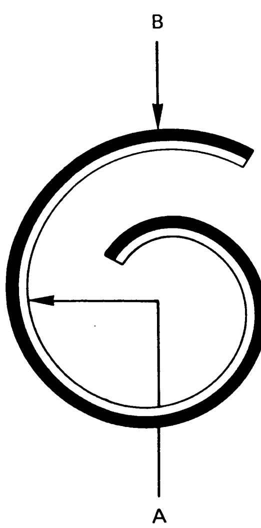
6.5 An identical but water-filled flask indicating the same level at room temperature is put in the liquid bath alongside the air flask.

The temperature of the liquid bath is slowly reduced from room temperature to 0°C. In the range from 4°C down to 0°C the water level in the tube

A rises slowly and then more rapidly
B rises and then falls again
C remains unchanged
D falls and then rises again
E falls to a steady level

(L)

Question 6.6



PART I

(a) The diagram shows a bimetal strip wound into a flat spiral. Metal A has a higher expansivity than metal B.
Describe and explain what happens when the strip is heated. **(3 marks)**

(b) When constructing a thermometer for normal laboratory use, the bulb is made of thin glass, the bore of the tube is narrow, and mercury is used as the thermometric liquid. Explain why
(i) the bulb is of thin glass,
(ii) the bore is narrow,
(iii) mercury is chosen. **(5 marks)**

PART II

(c) Draw a labelled diagram of a clinical thermometer and state *two* ways in which it differs from a normal laboratory thermometer. **(7 marks)**

(d) Before starting a long journey a motorist checked his tyre pressures and found them to be 3×10^5 Pa. At the end of the journey, the pressures were found to be 3.3×10^5 Pa.

The temperature of the tyres and contained air at the start of the journey was 17°C. Assuming the volume of the tyres remains constant, determine the temperature of the air in the tyres at the end of the journey. **(6 marks)**

(AEB)

Question 6.7

(a) (i) Sketch a graph to show how the pressure of a fixed mass of gas varies with the temperature as the temperature changes from 0°C to 100°C, if the volume of the gas remains constant.

(ii) Sketch a graph to show how the volume of a fixed mass of gas varies with the pressure provided the temperature is kept constant. **(5 marks)**

(b) You are provided with a mercury thermometer which only has two markings on it, namely 0°C and 100°C. How would you use it to measure the temperature of a block of ice cream? **(5 marks)**

(c) 'A certain mercury thermometer is not very accurate but it is very sensitive.' Explain the meaning of this statement. Which features in its design make it sensitive? **(5 marks)**

(d) Explain, using the kinetic theory of gases, why the pressure of a fixed mass of gas increases as its temperature rises. **(4 marks)**

Question 6.8

(a) Describe a laboratory experiment which demonstrates Brownian motion. State clearly what you observe and explain your observations.

(b) Describe an experiment to illustrate diffusion in a gas.

(c) A cylinder contains 60 litres of air when the pressure is 2×10^5 Pa and the temperature 27°C. What will the temperature in the cylinder be when the volume is 180 litres and the pressure is 10^5 Pa?

6.12 Answers and Hints on Solutions to Questions

1. See Example 6.1. 7.5 mm^3.
2. (a) See section 6.2.
   (b) The volume increases because the pressure decreases. Let p be the pressure at the bottom of the lake. Then applying $P_1 V_1 = P_2 V_2 \Rightarrow 2v \times 10^5 = v \times p$, hence $p = 2 \times 10^5$ Pa. The pressure due to the water is 10^5 Pa. Apply the equation in section 2.4 to determine the depth. Depth = 10 m.
   (c) $P_1 V_1 = P_2 V_2 \Rightarrow (A + 0.15) \times 0.20 = (A - 0.15) \times 0.30 \Rightarrow A = 0.75$ m Hg. Using the equation in section 2.4 we get $A = 1.02 \times 10^5$ Pa.
3. (a) (i) Remove the bunsen and stir for some time before taking a reading. (ii) This keeps the volume constant. (iii) The pressure of the trapped air is (atmospheric + pressure due to 38 cm Hg) = 76 + 38 cm Hg = 1.5×10^5 Pa. (iv) See section 6.2. (v) See section 6.4.
   (b) Use $P_1/T_1 = P_2/T_2$, temperature is 606°C.
4. See section 6.2.
   Answer A.
5. See Example 6.12.
   Answer A
6. (a) Because A expands more than B, the curvature of the metal will decrease and the strip will uncurl.
   (b) (i) Heat will conduct through the thin glass quicker than if the glass were thick and the thermometer will reach the temperature it is measuring quickly. (ii) The mercury moves further for a given change in temperature

and hence the markings on the scale are further apart and the thermometer is more sensitive. (iii) Mercury has a high boiling point and a reasonably low freezing point; a mercury thermometer therefore has a large range. Mercury is easily visible and doesn't stick to the sides of the tube.

(c) Your diagram should show the constriction just above the bulb and the narrow range from 35°C to 42°C. The glass surrounding the capillary tube is curved to act as a magnifying glass.

(d) Use $P_1/T_1 = P_2/T_2$. Temperature = 319 K = 46°C.

7. (a) (i) See section 6.2. (ii) See Example 6.3.

(b) Measure the distance between the 0 mark and the 100 mark. Suppose it is 10 cm, then 1 cm represents 10°C. Put the thermometer in the ice cream and measure the distance below the 0 mark of the mercury. If it is 0.5 cm then the ice is at −5°C.

(c) If a thermometer is sensitive the mercury moves a long way for a small change in temperature. A thermometer could be very sensitive but very inaccurate, i.e. it could read 20°C when the temperature was 30°C if the scale had been incorrectly marked. A large bulb and a narrow bore make it sensitive.

(d) See section 6.4.

8. (a) See section 6.5 and Example 6.8.

(b) See Example 6.10.

(c) Use PV/T is constant. Temperature = 450 K = 177°C.

7 Specific Heat Capacity, Specific Latent Heat, Vapour Pressure, Refrigeration, Boiling and Melting

7.1 Specific Heat Capacity

The *specific heat capacity* of a substance is the heat energy required to raise 1 kg of it through 1 K. Its units are J/(kg K).

It follows that if m kg of a substance of specific heat capacity c J/(kg K) are raised T K then

Heat required, $Q = m\ c\ T$ joules

To measure c heat may be supplied to a known mass of substance by an immersion heater connected to the power supply via a joulometer. The rise in temperature is measured and the equation above used to calculate c (see Example 7.2).

If the substance is a solid, a hole is drilled in a block of it so that the immersion heater may be inserted. The thermometer is inserted into a second hole in the block.

7.2 Specific Latent Heat

The *specific latent heat* is the quantity of heat required to change the state of 1 kg of substance without change in temperature. Its units are J/kg (you might meet kJ or MJ; 1 kJ = 10^3 J and 1 MJ = 10^6 J). If the change is from liquid to vapour, then it is the specific latent heat of vaporisation (note the spelling!) and if the change is from solid to liquid then it is the specific latent heat of fusion. It follows that to change the state of m kg of a substance of specific latent heat L J/kg

Heat required, $Q = mL$ joules

The measurement of the specific latent heat of vaporisation is described in Examples 7.5 and 7.6. The latent heat of fusion of ice may be measured by putting an immersion heater in a funnel and surrounding it with ice. The water from the melted ice is collected and weighed. The heat supplied (measured on a joulemeter) to melt a known mass of ice (m kg) is known and hence L can be calculated from the equation $Q = mL$. (In practice it is best to have a similar funnel packed with ice without a heater, so that the mass of ice which melts in the absence of a heater may be subtracted from m, in order to get the mass of ice melted by the heater.)

7.3 Effect of Impurities and Pressure on the Boiling and Melting Points

If salt is added to water it raises the boiling point and lowers the freezing point. Salted water for cooking vegetables therefore boils above 100°C and salt put on roads in cold weather lowers the freezing point of water, and any ice or snow on the roads melts. Increase in pressure raises the boiling point and lowers the freezing point. In pressure cookers the water boils at a temperature above 100°C. Snowballs do not 'bind' on a very cold day because the increase in pressure on squeezing does not lower the freezing point below that of the snow so the snow does not melt. Usually on squeezing the snow melts and refreezes when the pressure is removed so the snowball 'binds'.

7.4 Vapour Pressure

Vapour above a liquid exerts a pressure. If the vapour is in a confined space and is in contact with its liquid the vapour is said to be saturated and the pressure it exerts is its saturated vapour pressure. A liquid boils when its saturated vapour pressure is equal to the external pressure.

7.5 Refrigerators

A compressor compresses a very volatile vapour (the refrigerant) and it liquefies. The refrigerant expands through a valve into tubes which are in the ice compartment. As it expands it again becomes a vapour. The energy needed to convert the liquid to a vapour is drawn from the ice compartment which is therefore cooled. The vapour is compressed outside the refrigerator where it gives out its latent heat (see Example 7.9).

7.6 Worked Examples

Example 7.1

5632 joules of heat energy raise the temperature of 0.4 kg of aluminium from 20°C to 36°C. The specific heat capacity of aluminium, in J/(kg K), is given by

A $5632 \times 0.4 \times 16$ **B** $\dfrac{5632}{0.4 \times 16}$ **C** $\dfrac{5632 \times 16}{0.4}$ **D** $\dfrac{5632 \times 0.4}{16}$ **E** $\dfrac{0.4 \times 16}{5632}$

(AEB)

Solution 7.1

$$\left[Q = mcT \text{ (see section 7.1)} \Rightarrow 5632 = 0.4 \times c \times 16 \text{ J} \right.$$
$$\left. \Rightarrow c = \frac{5632}{0.4 \times 16} \text{ J/(kg K)}\right]$$

<u>Answer **B**</u>

Example 7.2

(a) Define specific heat capacity. **(3 marks)**

(b) In an experiment to measure the specific heat capacity of a liquid, 100 g of the liquid was contained in a copper calorimeter whose mass was 60 g. A 25 W immersion heater was placed in the liquid and the temperature rose from 15°C to 35°C in 4 minutes. The calorimeter was lagged so that heat losses were negligible. Calculate

  (i) the quantity of heat supplied by the heater during the experiment **(3 marks)**

  (ii) the quantity of heat absorbed by the calorimeter during the experiment **(3 marks)**

  (iii) the specific heat capacity of the liquid. **(4 marks)**

(c) What considerations determine the best rise in temperature when carrying out this experiment? **(5 marks)**

(d) State one precaution not mentioned above which is necessary to ensure an accurate result. **(2 marks)**

[The specific heat capacity of copper is 400 J/(kg K).]

Solution 7.2

(a) The specific heat capacity of a substance is the quantity of heat needed to raise the temperature of 1 kg of a substance through 1 K.

(b) (i) 25 W is 25 J/s (see section 4.2c).
In (4 x 60) s, heat supplied = 25 x 4 x 60 = 6000 J

  (ii) Heat absorbed by calorimeter = $(mcT)_{\text{calorimeter}} = (0.06 \times 400 \times 20)$ J
$= 480$ J

  (iii) Let c = specific heat capacity of the liquid

$$\begin{pmatrix}\text{Heat given out}\\ \text{by heater}\end{pmatrix} = \begin{pmatrix}\text{Heat taken up}\\ \text{by liquid}\end{pmatrix} + \begin{pmatrix}\text{Heat taken up by}\\ \text{calorimeter}\end{pmatrix}$$
$$= (mcT)_{\text{liquid}} + (mcT)_{\text{calorimeter}}$$

$6000 = (0.1 \times c \times 20) + 480$

$6000 = 2c + 480$

$2c = 5520$

$c = 2760$ J/(kg K)

(c) The main considerations are (i) If the temperature rise is large then the amount of heat lost to the atmosphere is large. When calculating the heat supplied to the liquid, we calculate the heat given out by the heater. If heat is lost to the atmosphere the heat the liquid gets is less than the calculated value. The higher the temperature rise the greater is the error due to the heat loss. (ii) If the temperature rise is kept small then the percentage error in the calculation of the temperature rise is large, i.e. if the temperature rise is 2°C and the thermometer can be read to the nearest 0.5°C, then the maximum error is 1 in 2 or 50%, whereas if the temperature rise is 20°C the percentage error is reduced to 5%. In practice a compromise has to be reached between these two requirements.

In order to compensate for heat lost from the liquid to its surroundings the experiment is sometimes conducted with the liquid initially 10°C below room temperature, and its final temperature 10°C above room temperature.

(d) Lag the calorimeter.

Example 7.3

If the specific latent heat of steam at 100°C is 2.26×10^6 J/kg the heat, in J, required to evaporate 2 g of water at 100°C is

A 2.00×10^2 **B** 1.13×10^3 **C** 4.52×10^3 **D** 1.13×10^6 **E** 4.52×10^6 (AEB)

Solution 7.3

[Heat supplied = mL (see section 8.2) = $0.002 \times 2.26 \times 10^6 = 4.52 \times 10^3$ J.]

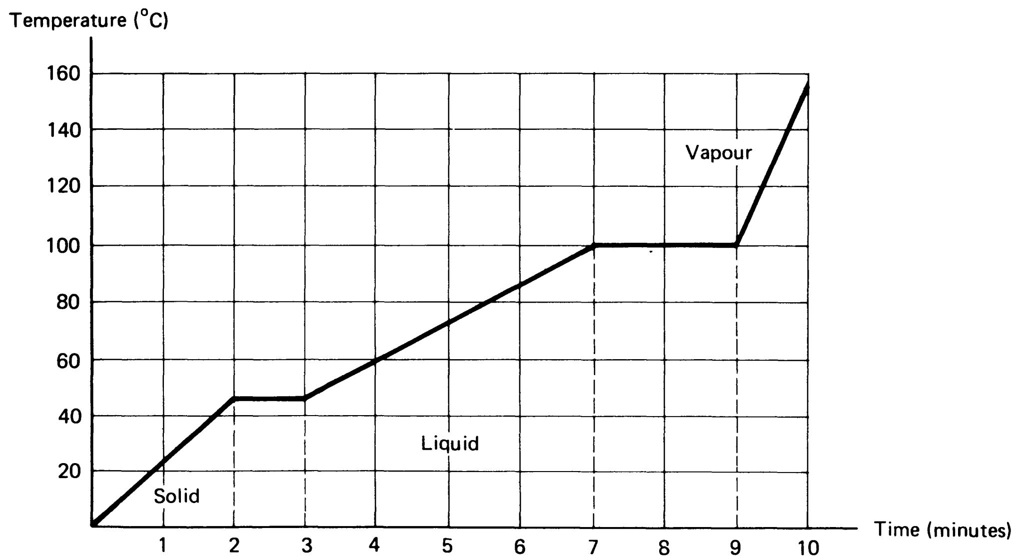
Answer C

Example 7.4

The graph shows the change in temperature when heat is applied at 20 000 joule/minute to 1 kilogram of a substance.

The specific latent heat of fusion of the substance in joule/kilogram is

A 2000 **B** 10 000 **C** 20 000 **D** 40 000 **E** 80 000 (AEB)



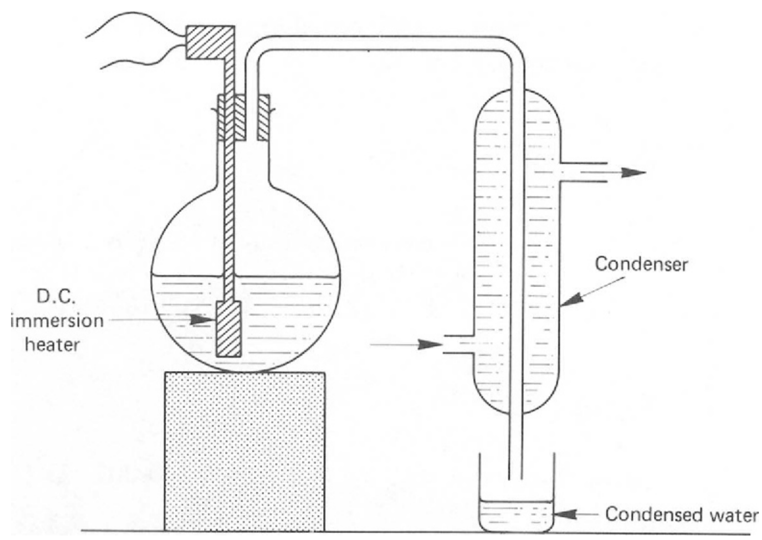
Solution 7.4

[It takes 1 min for the solid to melt and become a liquid. Heat supplied in 1 min = 20 000 J.]

Answer C

Example 7.5

(a)



In an experiment to determine the specific latent heat of vaporisation of water an immersion heater was placed in a round-bottomed flask containing water. After a while the water boiled and drops of water fell from the lower end of the condenser delivery tube to be collected in the beaker.

(i) Draw a circuit diagram to show how the electrical supply was connected to the immersion heater so that the energy supplied to the water could be calculated. **(3 marks)**

(ii) List the measurements you would take in order to calculate a value for the specific latent heat of vaporisation of water. **(5 marks)**

(iii) Explain how you could use these measurements to obtain the specific latent heat of vaporisation of water. **(3 marks)**

(iv) How could you improve on the accuracy of your result using this apparatus? **(2 marks)**

(b) In a coffee-making machine steam at 100°C was passed into a mixture of cold milk and coffee of mass 0.2 kg at 8°C until its temperature rose to 100°C. Assuming that the specific heat capacity of the coffee and milk mixture is 4000 J/kg K and the specific latent heat of vaporisation of water is 2 300 000 J/kg, calculate

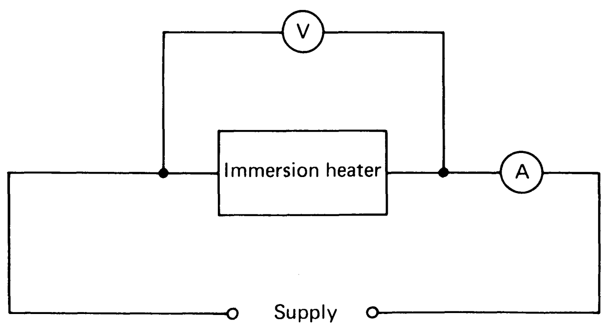
(i) the energy gained by the coffee and milk mixture,

(ii) the mass of steam that condensed to warm the mixture, if no heat was lost during the operation, and

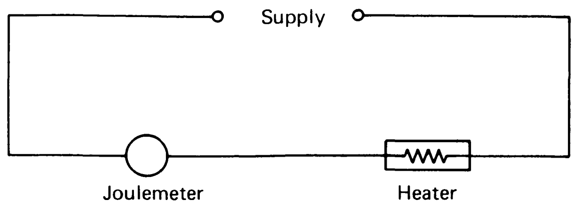
(iii) the mass of hot coffee finally produced. **(7 marks)**

Solution 7.5

(a) (i) [Don't forget to show the supply.]



or



(ii) Initial reading on joulemeter.
Final reading on joulemeter.
Initial mass of beaker and contents.
Final mass of beaker and contents.

(iii) Specific latent heat = $\dfrac{\text{Heat supplied}}{\text{Mass of liquid vaporised}}$

$= \dfrac{\text{Difference in joulometer readings}}{\text{Change in mass of beaker and contents}}$

(iv) Lag the flask so that the heat which escapes into the atmosphere is reduced to a minimum. Repeat the experiment a number of times and take the average value for the result. [Don't forget this last sentence.]

(b) (i) Energy gained by coffee and milk mixture, $Q = mcT = 0.2 \times 4000 \times 92 = 73\,600$ J.

(ii) If the 73 600 J of heat are provided by m kg of steam then using $Q = mL$ we have $73\,600 = m \times 2\,300\,000$ J
$m = 0.032$ kg = 32 g
Mass of steam = 32 g

(iii) Mass of coffee = 0.2 kg + 0.032 kg = 0.232 kg.

Example 7.6

An electric kettle about half filled with water was switched on and left until the water was boiling steadily. While the water was boiling steadily at 100°C, 250 g of water at 20°C was added to the water in the kettle. It took 30 s before the water was again boiling steadily.

(i) What is the power of the heating element in the kettle? [Specific heat capacity of water is 4200 J/(kg K)]. **(6 marks)**

(ii) The power could have been found by finding the time for the water to rise from, say, 20°C to 40°C. What is the main advantage of the above method? **(3 marks)**

(iii) Describe an experiment using the same kettle which you could do to measure the specific latent heat of vaporisation of water at 100°C. **(7 marks)**

(iv) Explain in terms of the kinetic theory of gases why it is necessary to supply energy to change water to steam at 100°C. **(4 marks)**

Solution 7.6

(i) Heat supplied to water, $Q = mcT$ (see section 7.1)
$= 0.25 \times 4200 \times 80 = 84\,000$ J

[The water in the kettle at the time the cold water was poured in is at the same temperature at the beginning of the experiment as it is at the end of the experiment (100°C), hence the heat supplied by the element is used to heat 0.25 kg of water through 80°C.]

Power = Rate of supply of heat = $\dfrac{\text{Heat supplied}}{\text{Time}} = \dfrac{84\,000 \text{ J}}{30 \text{ s}} = 2800$ J/s

= 2800 W.

(ii) If the time for the water to rise 20°C is measured, the kettle also takes up heat and this must be included in the calculation. In the above method the temperature of the kettle is the same at the end as it was at the beginning. During the experiment it has taken up the same amount of heat as it gave out when the cold water was poured in.

(iii) Weigh the kettle empty and again when the element is well covered with water. Bring the water to the boil and leave it boiling for, say, 3 minutes. Weigh the kettle again in order to determine the mass of water (m kg) which has boiled away. Then if L is the specific latent heat of vaporisation of water

Heat supplied in 3 minutes = Heat to boil away m kg of water
$2800 \times (3 \times 60) = m \times L$ joules

m is known and L can therefore be calculated.

(iv) The molecules must be given enough kinetic energy (1) to break away from the attractive forces between them and become a vapour and (2) to give them enough energy to push back the atmosphere as they break away from the water.

Example 7.7

Summarised directions for recording responses to multiple completion questions				
A (1) alone	B (3) alone	C (1) and (2) only	D (2) and (3) only	E (1), (2) and (3)

Which of the following statements is/are true about the boiling and freezing point of water?

(1) The boiling point of water is raised if the pressure above it is increased
(2) The freezing point of water is raised if the pressure above it is increased
(3) If salt is added to water both the freezing point and the boiling point are raised

Solution 7.7

[See section 7.3.]

Answer A

Example 7.8

(a) Describe an experiment which shows that water can be made to boil at temperatures below 70°C. **(7 marks)**

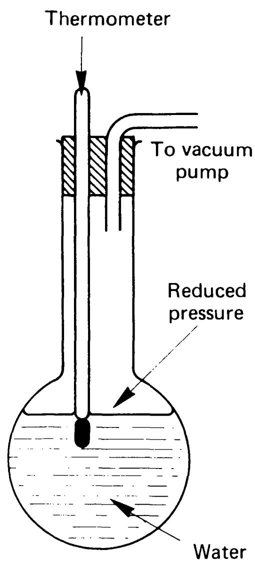
(b) The table below shows the temperature of a liquid in a beaker as it cools in a laboratory.

Temperature/°C	86	60	55	55	55	55	49	41
Time/minutes	0	1	2	3	4	5	6	7

(i) Draw a graph of temperature against time.
(ii) Explain the shape of the graph. **(10 marks)**

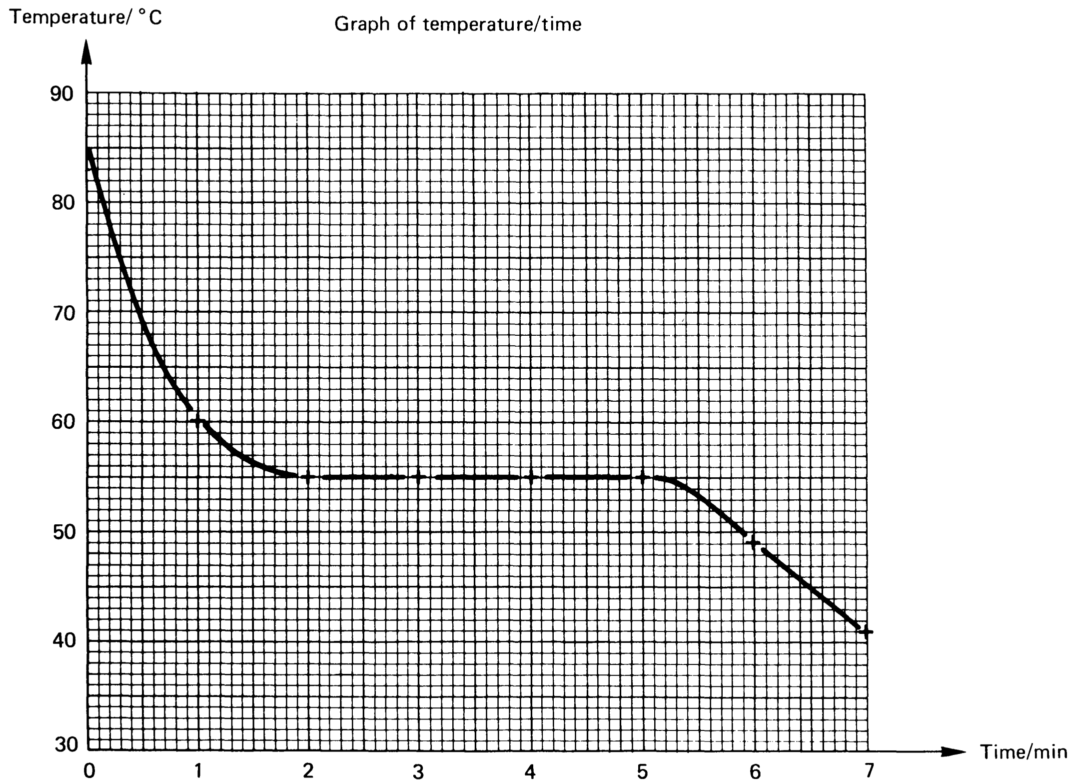
(c) Calculate the total quantity of heat which would be required to change 100 g of ice at −5.0°C into steam at 100°C (specific heat capacity of ice = 2100 J/(kg K), specific heat capacity of water = 4200 J/(kg K), specific latent heat of fusion of ice = 336 000 J/kg, specific latent heat of vaporisation of water = 2 260 000 J/kg). **(8 marks)**

Solution 7.8



(a) The apparatus is shown in the diagram. The flask initially contains water at 70°C. When the vacuum pump is switched on the pressure above the water is reduced. As the pressure above the water decreases the boiling point of the water goes down. The water begins to boil and continues boiling as the temperature and pressure further decrease.

(b) (i)



(ii) Heat is continually being lost from the beaker and passing into the atmosphere. The liquid loses heat and its temperature falls. When the freezing point is reached the temperature remains at 55°C until all the liquid has frozen. The latent heat of fusion is being released. Once the liquid has frozen the temperature of the solid falls as heat continues to pass into the atmosphere.

(c) Quantity of heat required =

$$\begin{pmatrix}\text{Heat for ice at } -5°\text{C} \\ \text{to become ice at } 0°\text{C}\end{pmatrix} + \begin{pmatrix}\text{Heat for ice at } 0°\text{C} \\ \text{to become water at } 0°\text{C}\end{pmatrix} +$$

$$\begin{pmatrix}\text{Heat for water at } 0°\text{C} \\ \text{to become water at } 100°\text{C}\end{pmatrix} + \begin{pmatrix}\text{Heat for water at } 100°\text{C} \\ \text{to become steam at } 100°\text{C}\end{pmatrix}$$

$$= (mcT)_{\text{ice}} + (mL)_{\text{ice}\to\text{water}} + (mcT)_{\text{water}} + (mL)_{\text{water}\to\text{steam}}$$

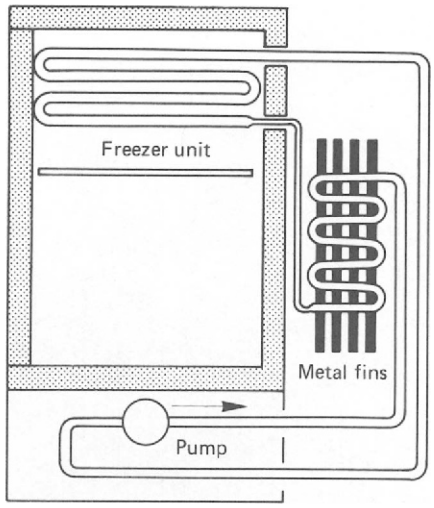
$$(0.1 \times 2100 \times 5) + (0.1 \times 336\,000) + (0.1 \times 4200 \times 100) + (0.1 \times 2\,260\,000) \text{ joule}$$

$$= 1050 + 33\,600 + 42\,000 + 226\,000 \text{ joule}$$

$$= 3.0 \times 10^5 \text{ joule}$$

Example 7.9

(a)



The diagram shows the basic components of a refrigerator system which contains a volatile liquid known as the refrigerant.

(i) Explain how the action of the circulating refrigerant as it passes through the freezer unit reduces the temperature of its contents. **(4 marks)**

(ii) What is the purpose of the pump? **(2 marks)**

(iii) Explain why the external metal fins become warm while the refrigerator is in operation. What is the source of this heat energy? **(3 marks)**

(iv) When a tray of water is placed in the freezer unit the temperature of the water falls from room temperature (15°C) to freezing point in approximately 15 minutes. However, it is necessary to wait a further $1\frac{1}{2}$ hour before the ice becomes completely frozen. Explain why it is quite usual to wait such a long time for completely solid ice to form in the refrigerator. **(4 marks)**

(b) 1 kg of orange juice at 23°C was poured into a vacuum flask containing ice cubes at 0°C. After a few minutes when all the ice had melted the chilled juice was found to be at 5°C.

(i) Calculate the heat energy lost by the orange juice. **(2 marks)**

(ii) Calculate the mass of the ice cubes originally in the flask. **(5 marks)**

(Assume that the specific heat capacity of orange juice is the same as that of water, i.e. 4000 J/kg K, and that the specific latent heat of ice is 340 000 J/kg.) (L)

Solution 7.9

(a) (i) The tubes in the freezer unit are on the low pressure side of the pump. The liquid entering this low pressure region evaporates and takes up its latent heat. This heat is supplied from the refrigerator compartment which consequently cools.

(ii) The pump circulates the refrigerant. It reduces the pressure on the freezer side of the system so that the refrigerant evaporates becoming a vapour. On the high pressure side it compresses the vapour so that it liquefies. [There is no expansion valve shown in the diagram. Compare the diagram on page 96. Why is the valve important?]

(iii) The vapour liquefies in the part of the tubes attached to the fins. As it liquefies it gives out its latent heat. The metal tube and fins are good conductors of heat and are warmed up by the heat from the condensing refrigerant.

(iv) Heat is continually being withdrawn from the freezing compartment but because the latent heat of fusion of ice is large a lot of heat has to be withdrawn before all the water present has frozen. The heat that must be withdrawn to cool the water from 15°C to 0°C is about one-sixth of that needed to freeze the water at 0°C.

Ice is a poor conductor of heat so the rate of energy transfer slows down as the ice thickens.

(b) (i) The temperature of the orange juice falls by 18°C.
Heat energy lost by orange juice = $mcT = 1 \times 4000 \times 18 = 72\,000$ J.

(ii) Heat taken up when m kg of ice at 0°C becomes m kg of water at 0°C = 340 000 m joule.
Heat energy taken up when m kg of water at 0°C becomes water at 5°C = $m \times 4000 \times 5 = 20\,000\,m$ joule.
Total heat needed for m kg of ice at 0°C to become m kg of water at 5°C = 340 000 m + 20 000 m joule = 360 000 m joule.
Heat lost by orange juice = Heat taken up by ice
72 000 = 360 000 m joule
m = 0.2 kg.
Mass of ice initially present = 0.2 kg.

Example 7.10

A flask containing some warm water is connected to a vacuum pump. The pressure inside the flask is reduced. Explain
(i) why the water begins to boil as the air is withdrawn,
(ii) why the temperature of the water falls as it boils. **(8 marks)**

Solution 7.10

(i) The boiling point of water depends on the pressure above its surface. If the pressure is reduced the water boils at a lower temperature. It will begin to boil when the pressure above the water is equal to the saturated vapour pressure at the temperature of the water. The saturated vapour pressure decreases as the temperature decreases. Hence the boiling point goes down as the pressure above the water is reduced.
(ii) For the water to change to vapour it must take up its latent heat. It gets this from the water itself.

7.7 Have You Mastered the Basics?

1. Can you define specific heat capacity and specific latent heat? Can you describe experiments to measure them?
2. Do you know how impurities and pressure affect the boiling and melting points of liquids and solids?
3. Can you describe how a refrigerator works?
4. The specific heat capacity of water is 4200 J/(kg K). How much heat is needed to raise 2 kg through 5°C?
5. The latent heat of vaporisation of water is 2.26×10^6 J/kg, how much heat is needed to change 2 kg of water to steam at 100°C?

7.8 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See sections 7.1, 7.2 and Examples 7.2, 7.5 and 7.6.
2. See section 7.3.
3. See section 7.5 and Example 7.9.
4. $Q = mcT$ (see section 7.1) = 2 x 4200 x 5 = 42 000 J.
5. $Q = mL$ (see section 7.2) = 2 x 2.26 x 10^6 = 4.52 x 10^6 J = 4.52 MJ.

7.9 Questions

Question 7.1

A mass of 0.4 kg of oil in a container is warmed from 20°C to 24°C by 3360 J of energy. The specific heat capacity of the oil, in J/(kg K), is

A 0.4 x 4 x 3360 **B** $\frac{0.4 \times 4}{3360}$ **C** $\frac{0.4 \times 3360}{4}$ **D** $\frac{3360}{0.4 \times 4}$ **E** $\frac{4 \times 3360}{0.4}$ (AEB)

Question 7.2

The water at the foot of a waterfall has a higher temperature than the water at the top even though the surrounding temperatures are equal. What is this temperature difference for a waterfall 100 m in height, given that all the available energy appears as heat in the water? (Assume specific heat capacity of water = 4000 J/kg K, acceleration of free fall = 10 m/s^2.)

A $\frac{1}{8}$ K **B** $\frac{1}{4}$ K **C** $\frac{1}{2}$ K **D** 2 K **E** 4 K (L)

Question 7.3

(a) A 100 W electric immersion heater is placed in a 2.00 kg block of aluminium. If the heater is left on for 5.00 minutes, what will be the temperature rise of the block? (Specific heat capacity of aluminium = 840 J/(kg K).)

(b) (i) Explain a useful application of the fact that water has a high specific heat capacity.
(ii) Why are good fruit growing areas in the world often found near lakes?

Question 7.4

(a) (i) Why is it easier to skate on ice at –2°C than on ice at –20°C?
(ii) Explain why it would take much longer to boil an egg at the top of a high mountain than at sea level. **(6 marks)**

(b) 30 g of ice at 0°C is added to 300 g of water at 20°C. The beaker containing the water is stirred until all the ice has melted.
(i) How much heat is needed to melt the ice?
(ii) What is the lowest temperature reached by the water in the beaker?
(iii) In practice would the lowest temperature reached be higher or lower than the temperature calculated above. Explain your answer. **(14 marks)**

(Specific heat capacity of water = 4200 J/(kg K), specific latent heat of fusion of ice = 336 000 J/kg.)

Question 7.5

(a) Describe briefly the difference between the behaviour of molecules in the solid, liquid and gaseous state. **(3 marks)**

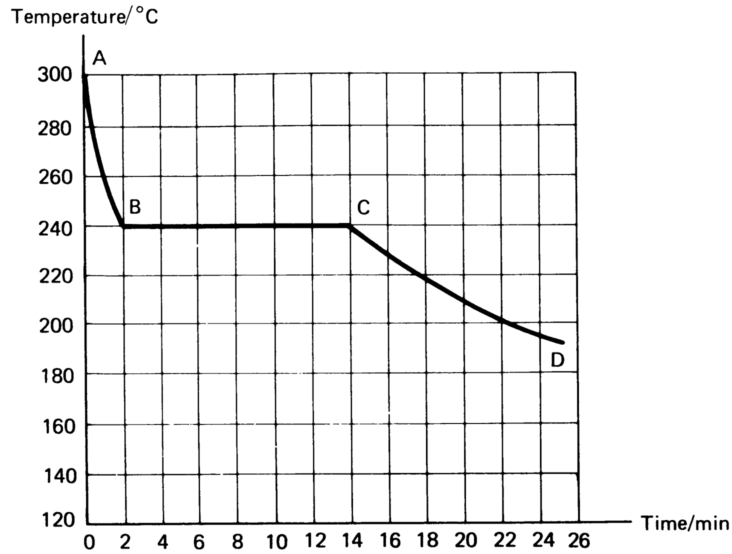
On the basis of molecular behaviour explain why

(i) energy is needed to change a solid at its melting point into liquid without a change in temperature, **(3 marks)**

(ii) evaporation can take place at temperatures below the boiling point, **(3 marks)**

(iii) the pressure of a constant volume of enclosed gas increases when its temperature is raised. **(4 marks)**

(b)



The graph shows the variation of temperature with time for a pure metal cooling from 300°C. In what state is the metal in stage

(i) AB,

(ii) BC,

(iii) CD? **(3 marks)**

If the average rate of heat loss during stage BC is 120 J/min and the mass of metal is 80 g, what is the specific latent heat of fusion of the metal? **(4 marks)**

(L)

Question 7.6

The melting point of a solid is 80°C. It has a specific heat capacity of 1300 J/(kg K) and a specific latent heat of fusion of 1.5×10^5 J/kg. How much heat is needed to change 2 kg of this solid at 50°C to liquid?

A $1300 \times 2 \times 30$ J

B $(1300 \times 2 \times 30) + (1.5 \times 10^5 \times 80)$ J

C $(1300 \times 2 \times 30) + (1.5 \times 10^5 \times 2)$ J

D $(1300 \times 2 \times 50) + (1.5 \times 10^5 \times 2)$ J

E $(1300 \times 2) + (1.5 \times 2)$ J

Question 7.7

Describe an experiment you could perform to find the specific latent heat of vaporisation of water. State the readings you would take and how you would use them to obtain your result. List any precautions you would take to obtain an accurate result. **(10 marks)**

An electric kettle of power 2500 W contains 2 kg of water at 20°C. When the kettle has been switched on, determine the minimum time required for the water to reach its boiling point of 100°C. **(5 marks)**

Give *two* reasons why the actual time would be longer than your calculated value. **(2 marks)**

Show whether or not the kettle will boil dry if it is left on for a further 15 min after the water has reached its boiling point. (Take the specific heat capacity of water to be 4 kJ/kg K or 4000 J/kg K, and the specific latent heat of vaporisation of water to be 2000 kJ/kg or 2 000 000 J/kg.) **(3 marks)**

(L)

Question 7.8

An 8 W heating coil is embedded in a 0.2 kg block of ice standing in an insulated container without a lid. A thermometer in the block reads –20°C at the start. The heater extends throughout the block so that it is in contact with all the ice.

[Take the specific heat capacity of ice to be 2000 J/kg K, the specific heat capacity of water to be 4000 J/kg K, and the specific latent heat of fusion of ice to be 300 000 J/kg.]

(a) Explain what is meant by the terms (i) *specific heat capacity* and (ii) *specific latent heat of fusion.* **(3 marks, 3 marks)**

(b) Without calculation, draw a sketch-graph to show how the temperature changes with time, from the moment the heater is switched on until the temperature rises to 20°C. Explain the shape of the sketch-graph. **(3 marks, 3 marks)**

(c) Once all the ice melts, how long does it take to raise the temperature of the water from 0°C to 20°C? **(4 marks)**

(d) With the heater still on, the temperature of the water continues to rise but more and more slowly and eventually settles at 82°C for a long time. How is this accounted for? **(4 marks)**

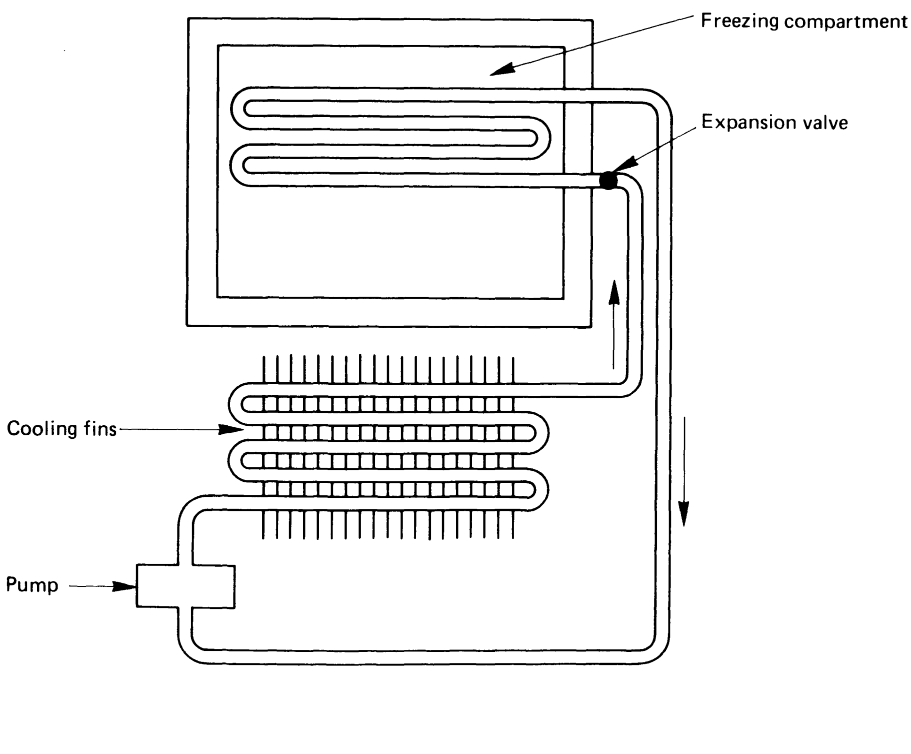
(OLE)

Question 7.9

PART I

(a) Define and name the units of
  (i) specific heat capacity,
  (ii) specific latent heat. **(6 marks)**

(b)



The diagram shows a simple refrigerator and the arrows indicate the direction in which the refrigerant flows. Explain what is happening

(i) in the tubes in the freezing compartment,

(ii) in the tubes connected to the cooling fins.

For each location name the *state* of the refrigerant. **(6 marks)**

PART II

(c) A manufacturer designs an immersion heater which has a power output of 120 W. The heater is used to raise the temperature of 2 kg of a liquid from 15°C to 35°C in 10 minutes. Assuming that 25% of the energy supplied by the heater is lost from the liquid to the surroundings, calculate

(i) the energy supplied by the heater in 10 minutes,

(ii) the specific heat capacity of the liquid.

The immersion heater is made of insulated wire of resistance 12 Ω/m. If the immersion heater is designed for use with the 240 V main supply, calculate

(iii) the current through the immersion heater,

(iv) the resistance of the immersion heater,

(v) the length of wire required. **(19 marks)**

(AEB)

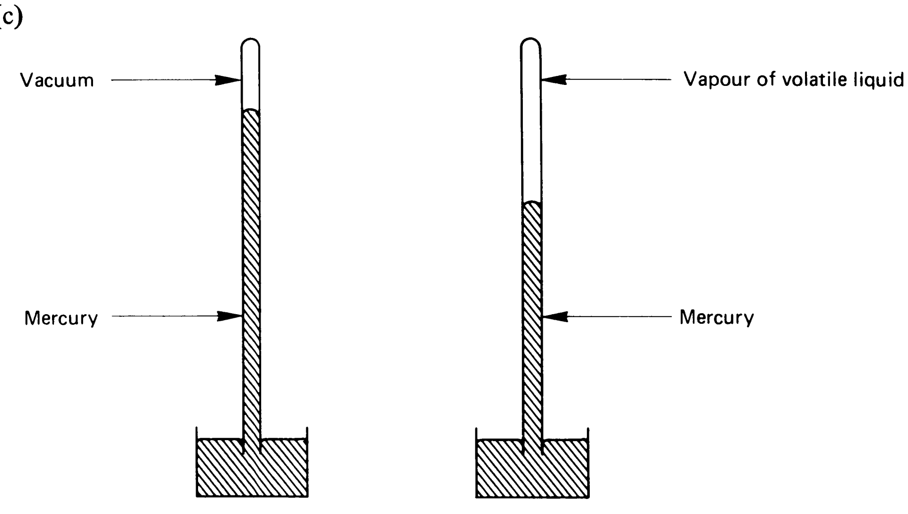
Question 7.10

PART I

(a) Name *two* factors which affect the boiling point of water, and in each case state how the boiling point is affected. **(2 marks)**

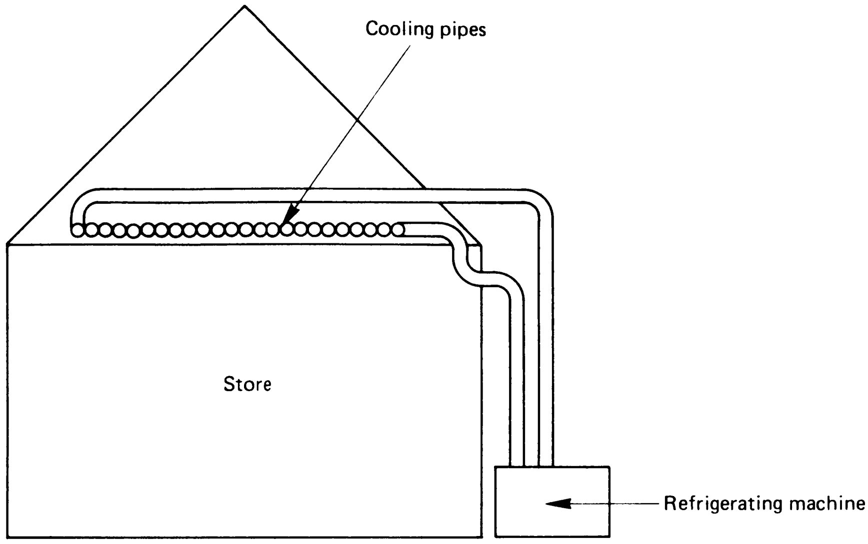
(b) Distinguish between *evaporation* and *boiling*. **(4 marks)**

(c)



The diagrams show a glass tube before and after a small amount of a volatile liquid has been introduced into the space above the mercury. Explain why the mercury in the right hand tube is lower than that in the left hand tube. **(2 marks)**

(d)



The diagram shows the essential parts of a cold store.

(i) Why are the cooling tubes in the roof?

(ii) Explain carefully why the refrigerating machine is outside the store.

(iii) Why, even if the refrigerating machine runs continuously, do the contents not get colder and colder? **(6 marks)**

(e) A copper block of mass 0.68 kg is suspended in a freezing mixture at –50°C for some time and then transferred to a large volume of water at 0°C. A layer of ice is formed on the block.

(i) Explain why the ice is formed.

(ii) What will be the temperature of the copper block after this change is complete?

(iii) Calculate the mass of ice formed. **(7 marks)**

Data for this question:

Specific heat capacity of copper = 400 J/(kg K)

Specific latent heat of ice = 340 000 J/kg (AEB)

7.10 Answers and Hints on Solutions to Questions

1. Answer D
2. Equate the potential energy of 1 kg of water at the top of the waterfall to the heat needed to raise the temperature of 1 kg through t°C. $t = \frac{1}{4}$ K. Answer B
3. Heat supplied by heater = Heat taken up by block. $100 \times 5 \times 60 = 2 \times 840 \times T$, hence $T = 17.8$°C.
4. (a) (i) The heat produced by friction will melt ice at –2°C more easily than ice at –20°C. Also the pressure of the skate on the ice will lower the melting point and may cause the ice to melt. Both mean that there is water under the skate and the skate flows more smoothly over the ice. (ii) The pressure is less so the boiling point of water decreases. It takes longer to provide sufficient heat to 'boil' the egg.

   (b) (i) 10 080 J. (ii) Heat given out by water in cooling from 20°C to t°C = (Heat taken up by the ice in melting) + (Heat taken up by the water formed when the melted ice rises to t°C). Therefore $[0.3 \times 4200 \times (20 - t)] = (0.03 \times 336\,000) + (0.03 \times 4200 \times t)$, hence $t = 10.9$°C. (iii) Higher because heat is gained from the surroundings.

5. (a) (i), (ii) and (iii) see section 6.4.
   (b) (i) liquid, (ii) liquid and solid present together, i.e. the liquid is solidifying, (iii) solid. $120 \times (14 - 2) = 0.080 \times L$ hence $L = 1.8 \times 10^4$ J/kg.
6. Heat needed to raise solid through 30°C plus heat needed to melt solid. Answer C
7. See Examples 7.5 and 7.6. Heat required = mcT_{water} and it is supplied at 2500 J/s. Time = 4 min 16 s. The time will be longer because of the heat taken up by the kettle and the heat lost to the atmosphere. Heat supplied in 15 min is 2.25×10^6 J and the heat needed to boil the kettle dry is 4×10^6 J.
8. (a) See sections 7.1 and 7.2.
   (b) See Example 7.4. The graph is horizontal during a change in state.
   (c) 8 J/s are supplied until the water has received 16 000 J. Time 2000 s.
   (d) The higher the temperature of the water, the greater is the rate of loss of heat to the atmosphere. At 82°C the rate of loss of heat to the atmosphere is equal to the rate of supply of heat by the heater, i.e. 8 W.
9. (a) See sections 7.1 and 7.2.
   (b) (i) The refrigerant passes onto the low pressure side of the system, becomes a gas and cools. (ii) The gas under pressure liquifies and gives out its latent heat.
   (c) (i) 72 000 J. (ii) $54\,000 = 2 \times c \times 20$ hence $c = 1350$ J/(kg K). (iii) Use the equation in section 12.3, Current = 0.5 A. (iv) Use equation (2) in section 12.1. Resistance = 480 Ω. (v) Length of wire = 40 m.
10. (a) See section 7.3.
   (b) See section 6.4.
   (c) The volatile liquid above the mercury evaporates. The vapour molecules moving about above the mercury hit the surface of the mercury and exert a pressure on it. The pressure pushes the mercury column down.
   (d) (i) Cold air is denser than warm air. (ii) Heat is given out when the refrigerant becomes a liquid. (iii) The colder the inside the greater is the rate of flow of heat from the outside into the refrigerator.
   (e) (i) Heat passes from the water to the block. The water gives up its latent heat and becomes ice. (ii) 0°C. (iii) Heat supplied to block = $0.68 \times 400 \times 50$ J = mL (see section 7.2), $m = 0.04$ kg.

8 Transfer of Heat, Convection, Conduction, Radiation, Thermos Flask and the Greenhouse Effect

8.1 Heat Transfer

Heat energy may be transferred from one place to another by conduction, convection and radiation.

8.2 Conduction

Conduction is the flow of heat energy through a body which is not at uniform temperature, from places of higher temperature to places of lower temperature, without the body as a whole moving.

If a metal rod is placed on a tripod and one end heated with a bunsen burner, then heat flows down the rod by the process of conduction and the other end begins to warm up. The energy is passed down the rod by the free electrons in the metal and also by the vibrating atoms passing on their energy to adjacent atoms.

Bad conductors are used to insulate roofs, water pipes and storage tanks, and for the handles of saucepans and teapots. Air is a poor conductor of heat, and cellular blankets, string vests and fur coats depend for their insulating properties on the air which is trapped in them. Good conductors are used as bases for saucepans and for cooling fins in air cooled engines.

8.3 Convection

Convection is the transfer of heat energy by the circulation of a fluid (a liquid or a gas) due to temperature difference within it.

The essential difference between convection and conduction is that in convection the less dense hot body rises and takes its heat with it, and in conduction heat flows through the body which does not move. Hot water systems, coastal breezes from land to sea at night and the hot air rising above radiators are examples of convection.

8.4 Radiation

Radiation is the transfer of heat energy from one place to another by means of electromagnetic waves.

Heat energy from the Sun reaches us by electromagnetic waves. Radiation is the only means of heat transfer which can take place in a vacuum. Black surfaces are good absorbers and good radiators. Shiny surfaces are poor radiators and poor absorbers.

A thermos (vacuum) flask (page 6) is designed to reduce heat flow by convection, conduction and radiation. The vacuum prevents heat flow by conduction and convection. With a hot liquid in the flask the shiny surface on the liquid side of the vacuum is a poor radiator and reduces heat loss by radiation. The shiny surface on the far side reflects back the small amount of radiation that does take place. The main loss of heat is by conduction up the sides and through the cork at the top.

8.5 The Greenhouse Effect

The shorter wavelength infra-red radiation and visible light from the Sun pass through the glass of a greenhouse and are absorbed by the soil and the plants, raising the temperature. The infra-red radiation emitted by the soil and plants is of much longer wavelength than the infra-red radiation emitted by the Sun (the higher the temperature the shorter is the wavelength of the radiation emitted). The longer wavelength infra-red radiation does not pass through the glass and so energy is not lost from the greenhouse; it is trapped in the greenhouse and the greenhouse temperature rises.

8.6 Worked Examples

Example 8.1

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

Which of the following statements about heat transfer is/are correct?
(1) Conduction takes place in both solids and liquids
(2) Convection can take place in both liquids and gases
(3) The amount of heat energy radiated every second by a body increases rapidly as its temperature rises

Solution 8.1

[Conduction can take place in any medium. Convection requires that the warmer less dense part of the medium can rise and take its heat with it. Very little radiation takes place at low temperatures but the amount of heat radiated from a body does increase very rapidly as the temperature rises.]

Answer E

Example 8.2

The windows of many modern buildings are 'double-glazed' (i.e. have two thicknesses of glass with a small air space between) to reduce heat losses to the outside. This is mainly because

A evaporation of moisture from the outside of the windows is reduced
B convection currents cannot pass through the extra layer of glass
C radiated heat is not transmitted through the air space
D air is a very bad conductor of heat
E glass is a very bad conductor of heat **(AEB)**

Solution 8.2

[The air trapped between the sheets of glass is a bad conductor of heat and this reduces the heat loss from the house. It is also true that glass is a bad conductor and this fact also reduces the heat loss, but the *main* reason is the poor conductivity of air. A thick sheet of glass would be cheaper but not so effective.]

Answer D

Example 8.3

In cold weather the metal blade of a knife feels colder than the wooden handle because the

A metal is at a lower temperature than the wood
B metal is a better conductor of heat than the wood
C metal has a smaller specific heat capacity than the wood
D metal has a brighter surface than the wood
E molecules in the metal are vibrating more vigorously than those in the wood **(AEB)**

Solution 8.3

[Because the metal is a good conductor of heat, when it comes into contact with skin the heat from the skin can easily pass through the metal blade. Wood is not such a good conductor and the heat cannot easily pass from the hand to the wood.]

Answer B

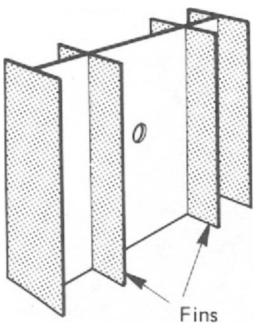
Example 8.4

A person sitting on a beach on a calm hot summer's day is aware of a cool breeze blowing from the sea. Explain why there is a breeze. **(6 marks)**
(L)

Solution 8.4

The land has a lower specific heat capacity than the sea and in daytime the land is hotter than the sea. The air above the land is warmer and less dense than the air over the sea, and it rises, the cold air from the sea coming in to take its place.

Example 8.5



(a) Heat energy may be transferred by conduction, convection and radiation. Describe three experiments, one for each process, to illustrate the methods of heat transfer. **(12 marks)**

(b) Some electrical devices, such as power transistors, can become so hot that they do not function properly. In order to prevent this they are fastened in good thermal contact with a 'heat sink , such as a piece of aluminium sheet with aluminium fins as shown in the diagram.

(i) What is meant by 'good thermal contact'?

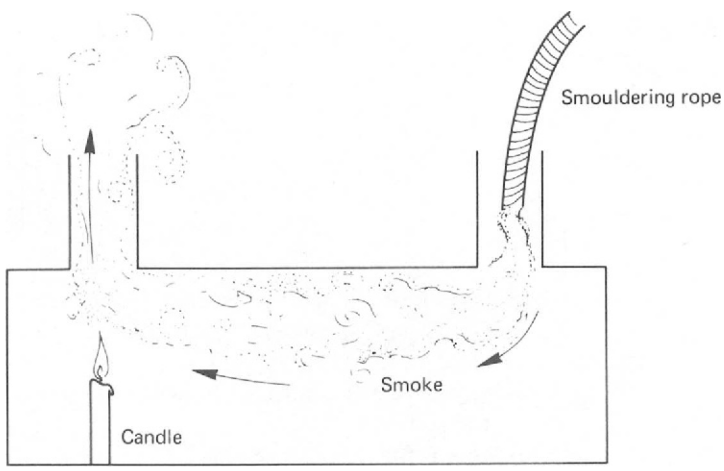
(ii) Explain how the heat is carried away from the electrical device to the air outside it.

(iii) Why does the heat sink have fins?

(iv) Discuss whether the heat sink would operate better if it were placed with its fins horizontal, rather than vertical as shown in the diagram. **(8 marks)**

Solution 8.5

(a) A metal rod is placed on a tripod. The rod should be long enough to ensure both ends are well clear of the tripod. A bunsen burner is placed under one end. Very soon the other end becomes warm; its temperature rises. This can be detected simply by feeling the end of the rod. Heat has been passed down the rod by conduction.



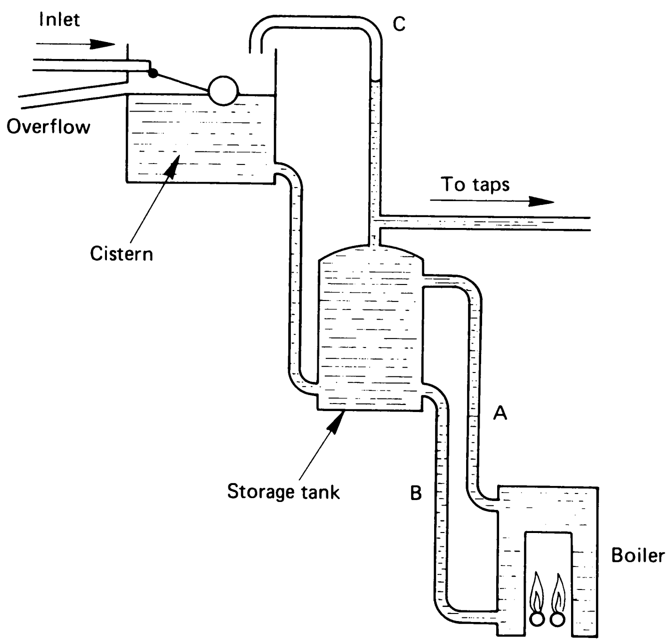
Convection may be demonstrated using the apparatus shown in the diagram. A box has two chimneys as shown. A lighted candle is placed under one of the chimneys and the glass front closed. Very soon smoke from the smouldering taper will be seen passing through the box and out of the chimney above the candle. Convection currents of air are passing through the box.

Sit in front of an electric fire which has a shiny reflector behind it. You will feel the radiation reflected on to your body. The heat has not arrived by conduction because air is a bad conductor. Hot air convection currents will rise above the element and circulate around the room but this is not how most of the heat reaches your body. Most of it has arrived as a result of radiation from the element falling on your body.

(b) (i) Contact so that heat can flow from one body to the other. Some air between the two bodies would prevent good thermal contact.
(ii) Heat is conducted from the device along the aluminium sheet and through the fins. The air in contact with the aluminium and fins becomes warm and the less dense warm air rises carrying its heat with it. Denser colder air replaces the warm air and the process continues. At low temperatures very little heat is lost by radiation.
(iii) The fins increase the area of surface in contact with the air, thus increasing the heat loss from the metal surfaces.
(iv) It operates better if placed vertically because the convection currents can flow more freely.

Example 8.6

(a)



The diagram shows part of a household hot water system.

(i) Why is pipe A connected between the top of the boiler and the top of the storage tank? **(3 marks)**
(ii) Why is pipe B connected between the bottom of the boiler and the bottom of the storage tank? **(3 marks)**
(iii) What is the function of pipe C? **(2 marks)**
(iv) Suggest, with reasons, what might be added to the hot water system above to make it more efficient. **(3 marks)**

(b) The temperature of the water inside an aquarium can be controlled by a thermostat which switches an electric heater on and off. Draw a diagram showing how this may be done using a bimetallic strip. (Your diagram must clearly show the construction of the bimetallic strip.)

How may different constant temperatures be achieved using your arrangement? **(5 marks)**

(c) The hot water tap of a bath delivers water at 80°C at a rate of 10 kg/min. The cold water tap of the bath delivers water at 20°C at a rate of 20 kg/min.

Assuming that both taps are left on for 3 minutes, calculate the final temperature of the bath water, ignoring heat losses. **(4 marks)**

(L)

Solution 8.6

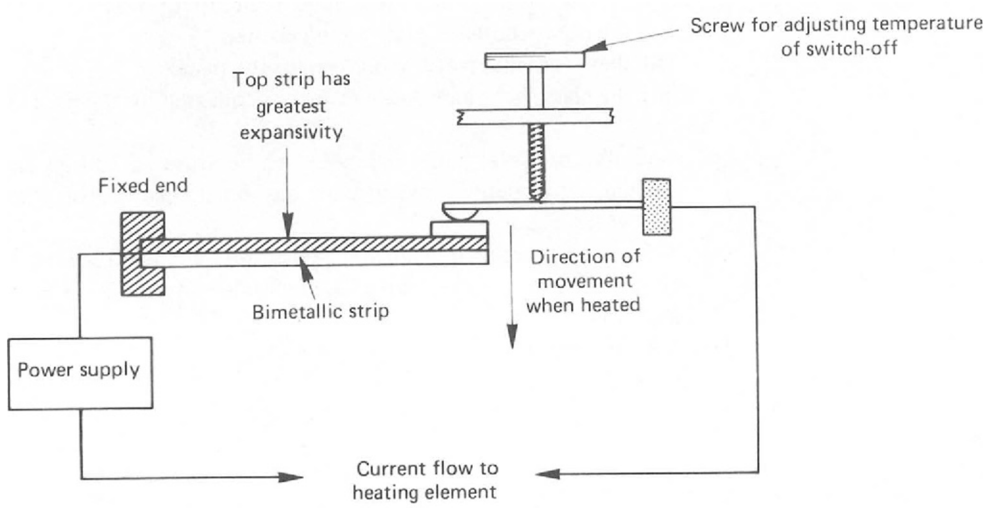
(a) (i) and

(ii) The hot, less dense water in the boiler rises and goes via the pipe A to the top of the storage tank. The denser, colder water from the bottom of the storage tank passes into the boiler. The pipe A is connected to the top of both tanks because hot water is less dense than cold water, and pipe B is connected to the bottom of both tanks because cold water is more dense than hot water.

(iii) C is an expansion pipe. It is a safety precaution to allow steam to escape should the water boil. It also allows any dissolved air which is released from the heated water to escape, thus helping to prevent air locks.

(iv) Lagging should be added round all the hot pipes and round the hot water tank. This will reduce the heat lost to the atmosphere and make the system more efficient.

(b) If the screw is screwed down the thermostat will switch off at a higher temperature.



(c) Heat given out by hot water = Heat gained by cold water

$(10 \times 3) \times c \times (80 - \theta) \quad = (20 \times 3) \times c \times (\theta - 20)$

where c is the specific heat capacity of water and θ is the final temperature.

$2400 - 30\theta = 60\theta - 1200$

$90\theta = 3600$

$\theta = 40°C$

Final temperature = 40°C

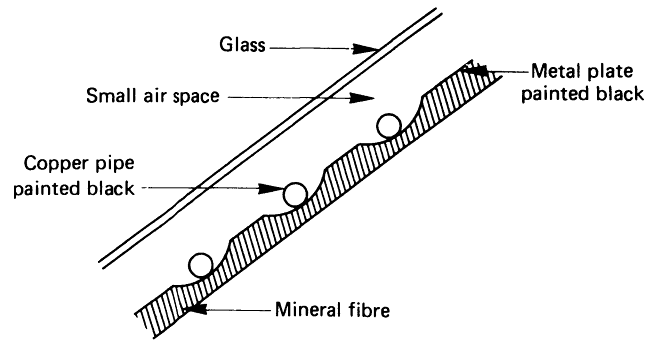
Example 8.7

PART I

Start a new page

(a) How would you demonstrate that water is a poor conductor of heat? **(4 marks)**

(b) Explain how energy is transferred from the heating element throughout the water in an electric kettle. **(4 marks)**



Construction of the panel

PART II

Start a new page

(c) The diagram shows the essential features of a solar heating panel. A small electric pump circulates a liquid through the pipes. State briefly why
(i) the pipes and back plate are blackened
(ii) there is a mineral fibre backing to the panel
(iii) the glass sheet increases the energy collected by the panel by a large factor.
(5 marks)
(d) Each day the solar panel raises the temperature of 200 kg of water from 5°C to 35°C. Calculate the energy incident each day on the panel if only 20% of this energy is absorbed by the panel. **(5 marks)**
(e) If no solar panel were available an electric immersion heater could be used. What would be the daily cost if the charge for electricity were 5p per kW h? (Neglect heat lost to the surroundings.) **(3 marks)**

Data for this question
Specific heat capacity of water = 4200 J/(kg K). (AEB)

Solution 8.7

(a) Put some ice wrapped in a metal gauze (so that it sinks) in a test tube which is nearly full of water. Carefully heat the water at the top of the tube until it boils. The water and ice at the bottom of the tube remain cold because the water (and of course the glass) are poor conductors of heat [a diagram of the experiment is in Question 8.8 at the end of this chapter].
(b) The water in contact with the heating element gets hotter. Hot water is less dense than cold water so the hot water rises. The denser surrounding cold water flows in to take its place. These circulating convection currents gradually transfer the heat throughout the water in the kettle.
(c) (i) Black surfaces are better absorbers of heat than shiny or light coloured surfaces. The solar panel works better if as much heat as possible is absorbed from the Sun's rays.
(ii) The mineral fibre is a poor conductor and this reduces the heat escaping from the copper pipes.
(iii) The electromagnetic waves emitted by the copper pipes are of much longer wavelength than the rays arriving from the Sun. They are not transmitted by the glass.
(d) Energy gained by water = mcT (see section 7.1) = 200 x 4200 x 30 J
= 2.52×10^7 J
= 25.2 MJ

This is 20% or $\frac{1}{5}$th of the incident energy.
⇒ Energy incident each day = 5 x 25.2 MJ
= 126 MJ

(e) 1 kWh = 1000 J/s x 3600 s = 3.6 MJ
3.6 MJ costs 5p

$\therefore$ 25.2 MJ costs $\frac{5 \times 25.2}{3.6} = 35$ p

Cost is 35p

8.7 Have You Mastered the Basics?

1. Can you distinguish between convection, conduction and radiation?
2. Can you describe experiments to illustrate each of them?
3. Can you explain how a vacuum flask works?
4. Do you know what surfaces are the best radiators and absorbers of heat?
5. Can you explain how a household hot water system works?

8.8 Answers to 'Have You Mastered the Basics?'

1. See sections 8.1, 8.2, 8.3 and 8.4.
2. See sections 8.2, 8.3 and Example 8.5.
3. See section 8.4 and p.6.
4. See section 8.4.
5. See Example 8.6.

8.9 Questions

Questions 1-3

Some ways in which heat may be transferred are
A Conduction only
B Convection only
C Radiation only
D Convection and conduction
E Conduction and radiation
In each of the following three questions choose from A to E above and select the one which best describes the process or processes by which heat is transmitted.

1. From the Sun to the Earth
2. From the hot metal element of an electric kettle, which is in contact with the water, to the rest of the water in the kettle
3. From the inside glass surface of a vacuum flask to the outside of the outermost glass surface

Question 8.4

Summarised directions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

Each of the following statements are concerned with the transmission of heat. Which of them are true?

(1) Radiant heat will be refracted as it passes from air to glass
(2) The main way in which heat is lost from a liquid in a vacuum flask is by convection through the plastic or cork stopper
(3) Convection can only take place in a gas

Question 8.5

Explain each of the following:

(i) A candle placed at the bottom of a gas jar soon goes out, but if a partition is carefully lowered down the middle of the jar so that the top half of the jar has a partition in it, the candle will stay alight.
(ii) Many good insulators of heat are porous materials.
(iii) A greenhouse without artificial heat is warmer inside than the air temperature outside.

Question 8.6

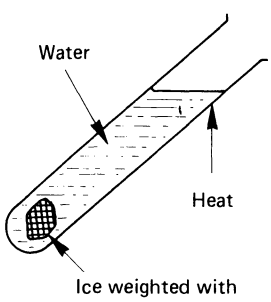
(a) (i) 'The *double walls* of a *vacuum* flask are *silvered* to reduce heat transfer between the contents of the flask and its surroundings.' Explain the purpose of each of the three features in italics in this statement. **(4 marks)**
(ii) List the possible reasons why the contents of a well-sealed vacuum flask eventually reach the same temperature as that of its surroundings. **(3 marks)**
(b) In coastal regions during periods of hot sunny weather a steady light wind, reversing its direction every twelve hours, is often noticed. Account for the existence of the *day-time* breeze and with the help of a diagram show the direction of the air currents over the land. **(7 marks)**
(c) Many householders in Great Britain have built 'sun porches' (rooms with very large windows) on the south side of their houses. Explain, with the aid of a diagram, why the day-time temperature of these rooms is always higher than that of the air outside. **(6 marks)**

(L)

Question 8.7

(a) Heat energy may be transferred from one body to another by convection, conduction and radiation. Describe how the heat energy is transferred in each case. **(10 marks)**
(b) Describe three experiments, one for each process, to illustrate the methods of transfer. **(9 marks)**
(c) Explain the part played by each of the three processes in heating a room using a hot water radiator. **(6 marks)**

Question 8.8



(a) Describe an experiment which you would carry out to show how the nature of a surface affects the heat radiated from that surface in a given time. **(5 marks)**
State any precautions which you would take and state your findings for two named surfaces. **(3 marks)**
How would you then show that the surface which was the better radiator was also the better absorber of radiation? **(4 marks)**
(b) As the surface of a pond freezes it is found that each equal increase in the thickness of the ice takes longer to form, even when the air above the ice remains at the same low temperature. Explain why this is so. **(4 marks)**
(c) In the experiment shown the ice remains intact for several minutes as heating progresses. Explain how this can be so. **(4 marks)**

(L)

8.10 Answers and Hints on Solutions to Questions

1. **C**
2. **D** [mainly convection but water does conduct (though poorly)].
3. Conduction through the glass and radiation across the vacuum.
   Answer E
4. Heat is lost from a vacuum flask by *conduction* through the cork. Convection can take place in a liquid.
   Answer A
5. (i) Warm air rises up one side of the partition and cold air comes down the other side supplying oxygen to the flame.
   (ii) The trapped air is a poor conductor.
   (iii) See section 8.5.
6. (a) See sections 8.4 and p. 6. There must also be a very small loss due to radiation across the vacuum.
   (b) See Example 8.4.
   (c) This is the greenhouse effect, see section 8.5.
7. (a) In convection the warm fluid rises. The average kinetic energy of the molecules in the warm fluid is higher than those in the colder parts of the fluid. The energy is thus transported by the moving fluid. In conduction the molecules at the hotter end are vibrating with greater energy than the molecules further down the body. They jostle the molecules near them and pass on their energy through the body. In metals, the free electrons at the hot end have a greater kinetic energy than the electrons at the cold end. They 'wander about' in the metal and transfer their energy to the colder parts of the metal. In radiation the energy is carried by the electromagnetic wave.
   (b) See Example 8.5.
   (c) Conduction through the metal of the radiator, convection currents in the air and a small amount of radiation.
8. (a) Heat a copper plate which is shiny on one side and blackened on the other. Clamp the plate vertically and place your cheek near to each side in turn. Alternatively detect the heat with a thermopile (a detector of radiant heat, the deflection of the galvanometer attached to it is a measure of the heat entering the thermopile). You must ensure that the heat reaching the detector comes from the emitting surface. Black surfaces are much better radiators than shiny surfaces. Place two surfaces, one blackened, with thermometers in good thermal contact with their surfaces, at equal distances from a cylindrical heating element. The thermometer on the black surface rises faster than the one on the shiny surface.
   (b) Ice is a bad conductor of heat.
   (c) The water and glass are bad conductors of heat.

9 Reflection, Refraction, Colour and the Electromagnetic Spectrum

9.1 Shadows and Eclipses

Because light travels in straight lines, shadows are cast by opaque objects. An eclipse of the Sun occurs when the Moon comes between the Sun and the Earth and the Moon's shadow falls on the Earth.

9.2 Laws of Reflection

1. The reflected ray lies in the plane formed by the incident ray and the normal to the reflecting surface at the point of incidence. The two rays lie on opposite sides of the normal.

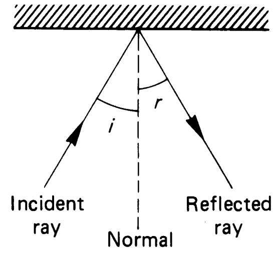


Figure 9.1 The angle of incidence i is equal to the angle of reflection r.

2. The angle of incidence is equal to the angle of reflection (Fig. 9.1).

9.3 Plane Mirrors

The image formed by a plane mirror lies on the normal from the object to the mirror and is as far behind the mirror as the object is in front (Fig. 9.2). The image is virtual, laterally inverted and the same size as the object.

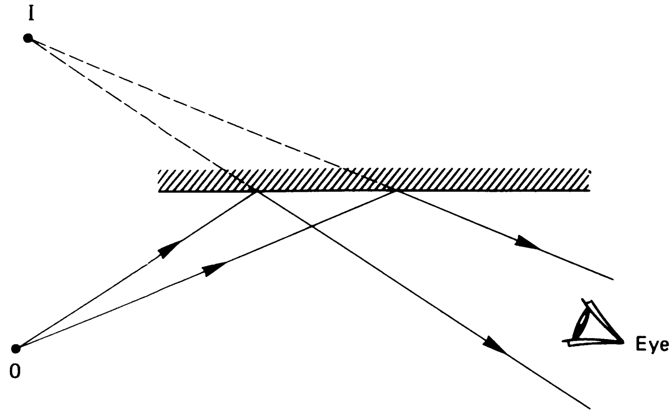


Figure 9.2 The image lies on the perpendicular bisector of the mirror and is as far behind the mirror as the object is in front.

A simple periscope may be constructed using two reflecting prisms or two plane mirrors (see Example 9.10).

Plane mirrors are often placed behind a scale over which a pointer passes. By aligning the eye with the pointer and its image the error due to parallax in reading the scale is avoided.

9.4 Refraction

When light (or other wave motion) crosses a boundary between two different media, it is refracted. Refraction results from the change in speed of the wave as it crosses the boundary. The greater the change in the speed the greater is the refraction of the light. The ratio

$\frac{\text{Speed in air}}{\text{Speed in medium}}$ is known as the refractive index (n) from air to the medium.

or $\frac{v_{air}}{v_{medium}} = {}_{air}n_{medium}$

If an object under water or under a glass block is viewed vertically from above then the apparent depth is less than the real depth (see Example 9.7) and

$$\frac{\text{Real depth}}{\text{Apparent depth}} = n$$

9.5 Critical Angle, Prisms

The critical angle for any medium is the angle of incidence of light on the boundary such that the angle of refracti2n is 90° (Fig. 9.3). If the angle of incidence is greater than the critical angle, total internal reflection occurs. Total internal reflection can only occur when light is passing from an optically denser to an optically less dense medium (i.e. from glass to air).

Isosceles totally internally reflecting prisms are often used instead of plane mirrors because (i) they do not form multiple images (see section 9.8, Example 9.4), and (ii) there is no silvering to wear off.

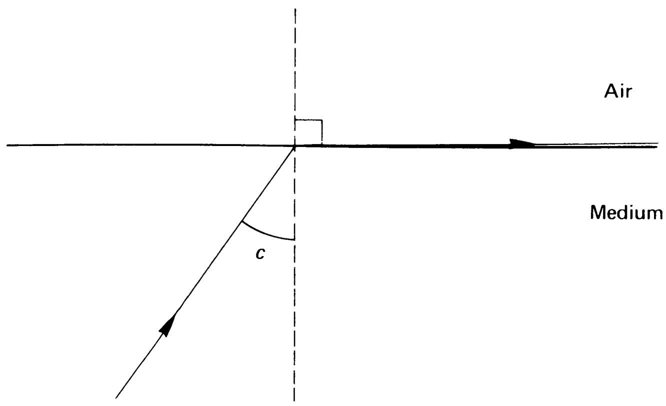


Figure 9.3 A ray of light incident at the critical angle.

9.6 Colour

When a ray of white light falls on a prism the different colours composing the white light are each refracted a different amount and a spectrum is formed. A pure spectrum is formed when light of only one colour falls on to any part of the screen, so that the colours do not overlap.

Almost all colours may be produced by suitably mixing the primary colours red, green and blue. Thus

Red + Green = Yellow
Green + Blue = Peacock blue (also called cyan or turquoise)
Blue + Red = Magenta

All three primary colours added together give white. The result is also white if the three secondary colours peacock blue, magenta and yellow are added. These results may be expressed by means of a colour triangle as shown in Fig. 9.4.

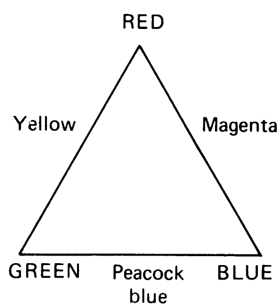


Figure 9.4 The colour triangle.

The colours of pigments are due to reflected light, most colours in the incident light being absorbed. When pigments are mixed they reflect only the colours that neither pigment absorbs. For example, yellow paint reflects red and green light; peacock blue reflects blue and green light; the colour which both pigments reflect is green, so if yellow and peacock blue paints are mixed the resulting colour is green.

9.7 The Electromagnetic Spectrum

Electromagnetic waves are characterised by oscillating electric and magnetic fields. In a vacuum they all travel at the speed of light. The spectrum of these waves includes γ-rays, X-rays, ultra-violet rays, visible light, infra-red rays, radar waves and radio waves. The list is in order of increasing wavelength (decreasing frequency), γ-rays having the shortest wavelength (largest frequency).

9.8 Worked Examples

Example 9.1

Which one of the following is not a property of the image of an object placed 12 cm in front of a plane mirror?

A It is behind the mirror
B It is 12 cm from the mirror
C It is laterally inverted
D It is real
E A line joining the top of the object to the top of the image is perpendicular to the plane of the mirror

Solution 9.1

[No light travels from the object to points behind the mirror. The rays of light reflected at the mirror *appear* to come from a point behind the mirror. The image is virtual.]

Answer **D**

Example 9.2

(i) A girl stands at a distance of 2 m in front of a plane mirror, and a boy stands at a distance of 3 m in front of the same mirror. How far from the boy is the girl's image in the mirror? **(3 marks)**

(ii) The girl stands still and the mirror is moved away from her at 3 m/s. At one instant the girl and her image are 6 m apart. How far apart will they be 2 s later? **(5 marks)**

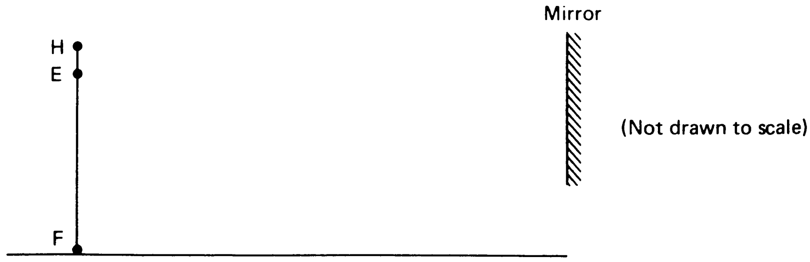
Solution 9.2

(i) The girl's image is 2 m behind the mirror. The boy is 3 m in front of the mirror. Therefore the girl's image is 5 m from the boy.

(ii) When they are 6 m apart the girl is 3 m in front of the mirror and her image is 3 m behind the mirror. 2 s later she is 9 m in front of the mirror and her image is 9 m behind the mirror. They are 18 m apart.

Example 9.3

(a) A pin is placed in front of a plane mirror. Describe an experiment you would do to locate the position of the pin's image. **(9 marks)**



(b) In the diagram the straight line HEF represents a girl standing in front of a plane mirror. H is the top of her head, E her eyes and F her feet. The girl is 140 cm high and her eyes are 10 cm below the top of her head. Draw a ray diagram (which need not be to scale) showing

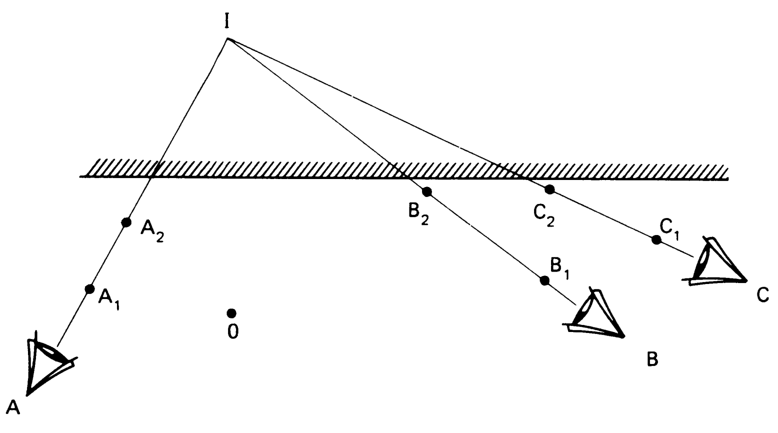
(i) a ray of light which travels from the top of her head to her eyes and

(ii) a ray of light which travels from her feet to her eyes.

(c) What is the minimum length of the mirror that would be required in order to enable her to see a full length image of herself in the mirror? **(11 marks)**

Solution 9.3

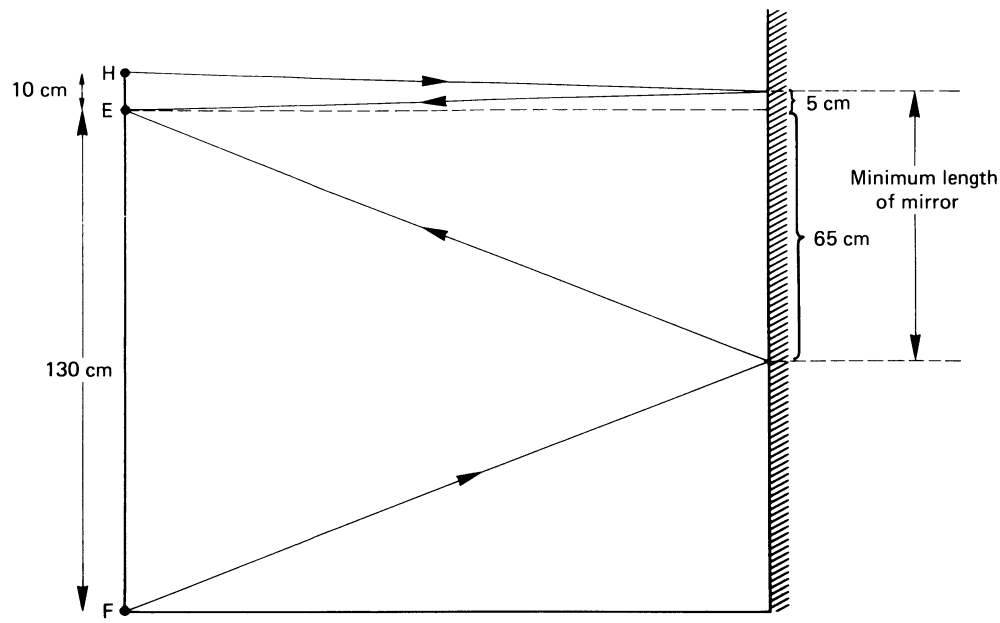
(a) The plane mirror is placed on a sheet of paper with its surface vertical and the object pin O placed in front of the mirror. With the eye at A two pins A_1 and



A_2 are placed so that they are in line with the image I. The procedure is repeated with the eye at B and C. The mirror is removed and the lines A_1A_2, B_1B_2 and C_1C_2 are drawn. They intersect at the position of the image I.

(*Continued on next page.*)

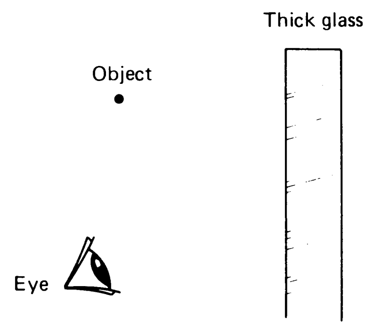
(b)



(c) As shown in the diagram the minimum length of the mirror is 70 cm.

Example 9.4

An object is placed in front of a thick sheet of glass.

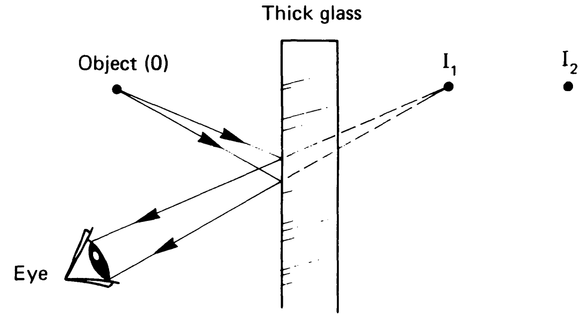


(a) An image, I_1, is formed by reflection from the front surface of the glass.
  (i) Mark and label the exact position of I_1.
  (ii) Draw a ray diagram to show how this image is seen by the eye.
(b) A second image, I_2, will also be seen by the same observer.
  (i) What causes the formation of this second image?
  (ii) Mark on the diagram the position of this second image, I_2. **(4 marks)**

(AEB)

Solution 9.4

(a) [On the scale of the diagram O is 2.2 cm in front of near surface of glass, so I_1 is 2.2 cm behind near surface of glass. Draw lines from either side of the pupil directed towards I_1. When they hit the near surface they go to the object. Don't forget to dot the virtual rays and to put arrows on light rays from the object going into the eye.]

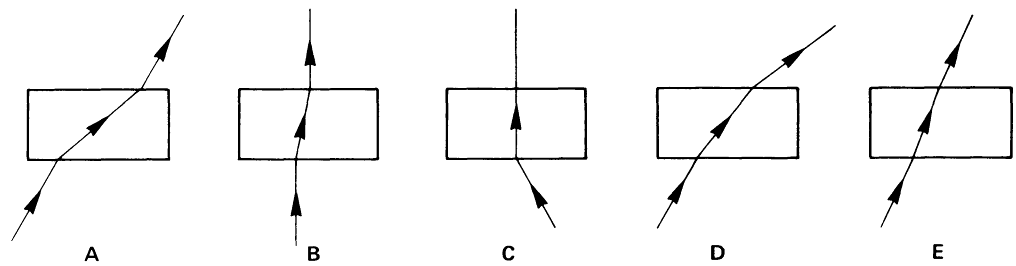


(b) (i) Reflection at the rear surface of the glass of light refracted at the first interface.

(ii) [The object is 3 cm in front of this rear surface and the image I_2 is nearly 3 cm behind it. It would be exactly 4 cm if there were no refraction at the front surface of the glass.]

Example 9.5

Which one of the diagrams correctly shows the path of the ray through the glass block?



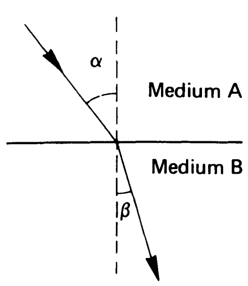
Solution 9.5

[When light passes from air to glass it is bent towards the normal. It is bent away from the normal when it passes from glass to air. It emerges parallel to the incident ray.]

Answer E

Example 9.6

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only



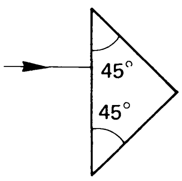
A ray of light crosses a boundary between medium A and medium B. The diagram shows the refraction of the ray as it crosses the boundary. It follows that

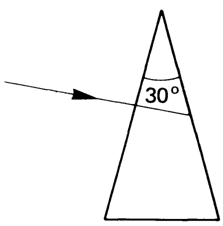
1 Medium A could be air and medium B could be glass
2 The angle β is less than the critical angle for the two media
3 The velocity of light in medium B is less than the velocity of light in medium A

Solution 9.6

[Light is bent towards the normal as it passes from air to glass because the velocity of light in glass is less than the velocity of light in air. If α is 90° then the angle β would be the critical angle, so β must be less than the critical angle.]

Answer **A**





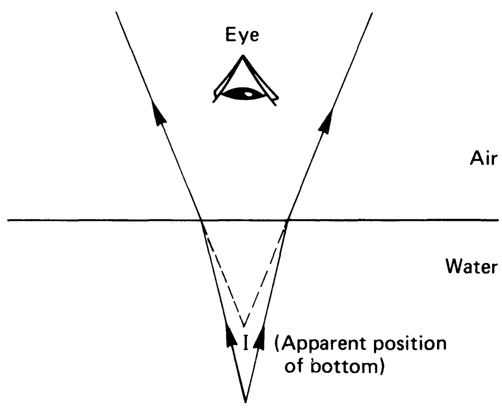
Example 9.7

(a) When you look vertically down into a pond, the pond appears to be shallower than it really is. Draw a ray diagram to illustrate this phenomena. Mark clearly on your diagram the position of the bottom of the pond and where the bottom appears to be. **(5 marks)**

(b) The diagrams show a ray of light incident on a glass prism. In each case complete the diagrams showing the subsequent path of the ray. **(5 marks)**

Solution 9.7

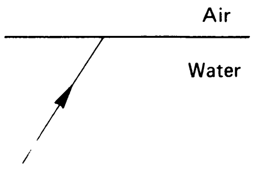
(a)



(b)

[In the first diagram the rays are incident on the glass at an angle greater than the critical angle and are totally internally reflected. In the second diagram the angle of incidence on the glass is much less than the critical angle (the critical angle is about 42° for glass) and the ray passes into the air, being bent away from the normal.]

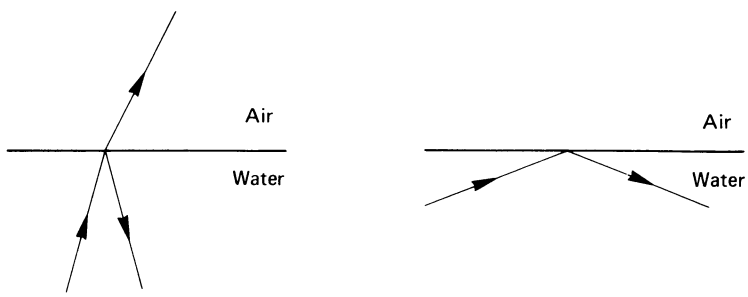
Example 9.8



(a) The diagram shows a ray of light in water incident on a water/air boundary. Draw sketches to show what would happen to the ray of light when the angle of incidence is
  (i) about 15°
  (ii) about 60°. **(5 marks)**

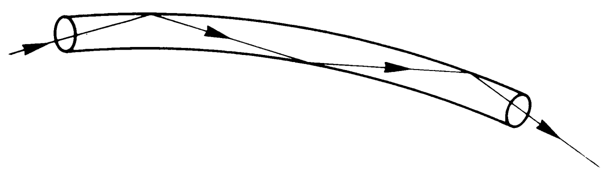
(b) The diagram shows a light beam incident on a curved transparent plastic tube. Explain why the light will stay in the tube and come out at the other end. **(4 marks)**

Solution 9.8



(a) [When the angle of incidence is 15° the light passes into the air being refracted away from the normal. Some light will be reflected. At an angle of incidence of 60°, total internal reflection occurs and no light passes into the air. Total internal reflection occurs whenever the angle of incidence in the glass exceeds 42°.]

(b)



The diagram shows the path of the ray. Each time it is incident on the plastic/air surface the angle of incidence is greater than the critical angle and it is totally internally reflected.

Example 9.9

(i) Draw a diagram showing how a ray of white light entering a 60° glass prism is refracted and dispersed. **(5 marks)**

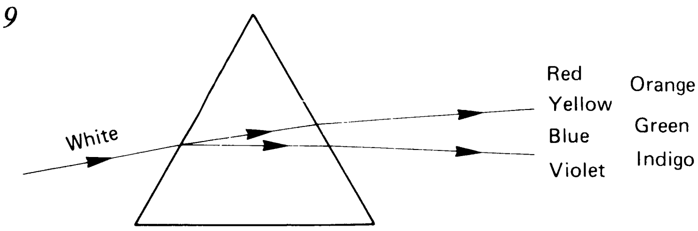
(ii) Draw a ray diagram which shows how a pure spectrum of white light may be produced on a screen. Explain clearly the purpose of any optical apparatus you use other than the prism. Why is the spectrum said to be a pure one? **(8 marks)**

(iii) Beyond the red end of the spectrum there is some invisible radiation. How would you detect this radiation? **(6 marks)**

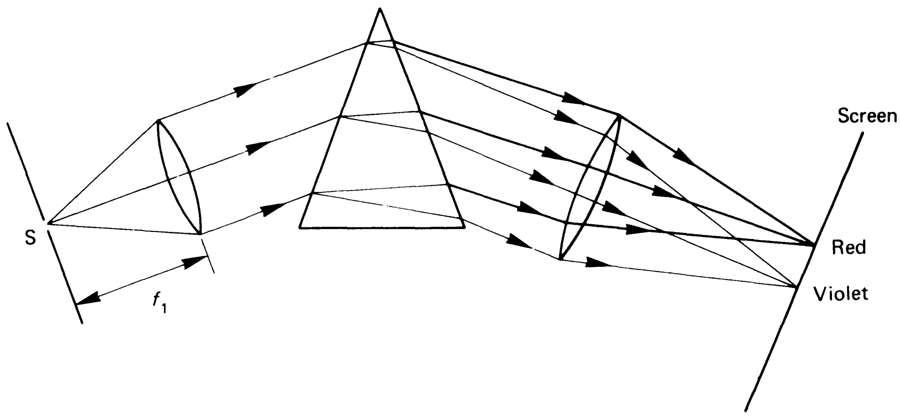
(iv) State, putting them in order of increasing wavelength, five regions of the electromagnetic spectrum. **(6 marks)**

Solution 9.9

(i)



(ii) White light passes through a narrow slit S. The slit S serves as a point source of light at the principal focus of the first lens (focal length f_1). The light leaving the lens is therefore a parallel beam of light. It is dispersed at the prism splitting up into its various colours. All the red rays are parallel to each other and all the violet rays are parallel to each other. The lens on the far side of the prism brings all the red rays to a focus and all the violet rays to a different focus. The other colours of the spectrum are focused at a point in between. The spectrum is pure because light of only one colour falls on to any one part of the screen so that the colours do not overlap.

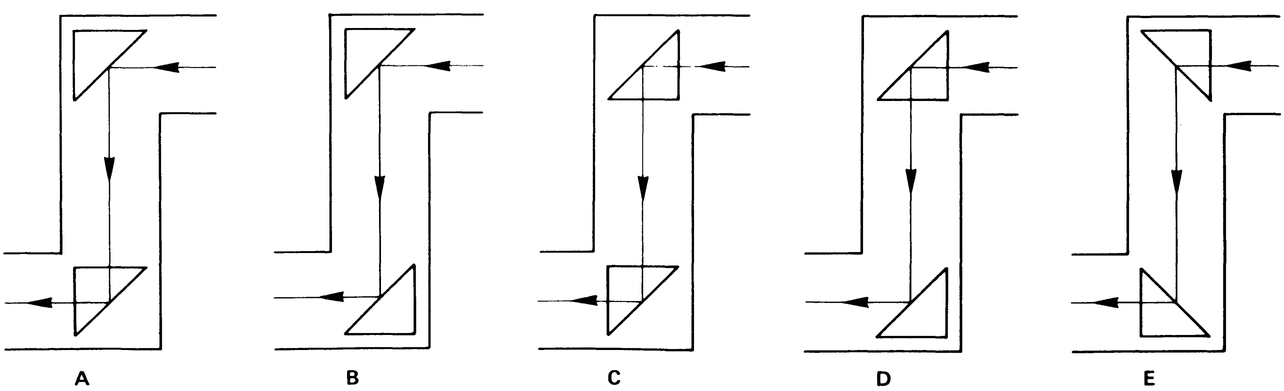


(iii) Infra-red radiation may be detected by using a phototransistor connected in series with a battery and a milliameter. The reading on the milliameter is a measure of the infra-red radiation falling on the phototransistor. The phototransistor is moved through the spectrum and into the region beyond the red end. In this position the reading on the milliameter increases.

(iv) Gamma rays, x-rays, ultra-violet light, infra-red light and radio waves.

Example 9.10

Which one of the five diagrams below best represents the path of a ray of light through a periscope?



Solution 9.10

[Prisms are used to reflect light by making use of total internal reflection.]

<u>Answer C</u>

Example 9.11

Two ribbons, one pure red and the other pure green are in a dark room. They are illuminated first by (a) pure green light and then by (b) pure yellow light. Describe the appearance of the ribbons in each case. **(5 marks)**

Solution 9.11

(a) The red ribbon will look black and the green ribbon will look green. [The red ribbon looks black because it only reflects red light and there is no red light falling on it.]

(b) The red ribbon will look red and the green ribbon will look green. [Yellow light is a mixture of red light and green light. The red will reflect the red light falling on it, and the green will reflect the green light falling on it.]

9.9 Have You Mastered the Basics?

1. Can you state the laws of reflection and describe an experiment to verify them.
2. Do you know the relationship between refractive index and the speed of light in two media?
3. Can you describe experiments and draw diagrams to illustrate refraction, total internal reflection, critical angle, real and apparent depth and dispersion?
4. Can you describe how to produce a spectrum?
5. Do you know how to detect infra-red radiation?
6. Can you draw and use the colour triangle?

9.10 Answers and Hints on Solutions to 'Have You Mastered the Basics?

1. See section 9.2, Fig. 9.1. An experiment could be done with a beam of light incident on a mirror as shown in the diagram.
2. See section 9.4.
3. Use beams of light and diagrams as shown in Example 9.5(E), section 9.5 (Fig. 9.3) and Examples 9.7, 9.8 and 9.9.
4. See Example 9.9.
5. See Example 9.9.
6. See section 9.6, Example 9.11 and section 9.11, Question 9.8.

9.11 Questions

Question 9.1

A man whose eyes are 1.50 m from the ground looks at his reflection in a vertical plane mirror 2.00 m away. The top and bottom of the mirror are 2.00 m and 1.00 m from the ground respectively. What distance, in m, below his eyes can the man see of himself?

A 0.25 **B** 0.50 **C** 0.75 **D** 1.00 **E** 1.50 (AEB)

Question 9.2

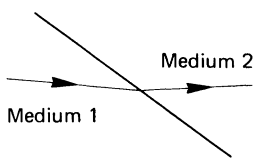
(i) Draw a diagram showing a ray of light being reflected from a plane mirror. Mark on your diagram the incident ray, the reflected ray, the normal at the point of incidence and the angles of incidence and reflection.
(ii) A witness giving evidence in a court case said that the time the crime was committed was at 6.20. The detective knew that this must be wrong and realised that the witness had seen the clock in a plane mirror. What was the time of the crime?

Question 9.3

(a) Explain why light and heat from the sun disappear simultaneously when the sun becomes totally eclipsed.
(b) Draw a diagram illustrating how two glass prisms may be used to make a simple periscope.
(c) Explain why a pond looks shallower than it really is.

Question 9.4

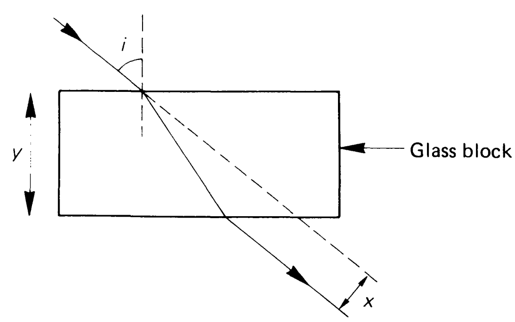
Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



The diagram shows a ray of light crossing an interface between two different media. Which of the following statements is/are correct?
(1) Medium 1 could be water and medium 2 could be air
(2) The frequency of the light in medium 1 is greater than the frequency of the light in medium 2
(3) The velocity of light in medium 1 is greater than the velocity of light in medium 2

Question 9.5

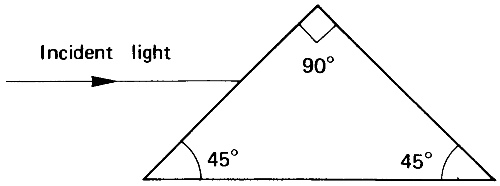
Directions summarised				
A	**B**	**C**	**D**	**E**
1, 2, 3 all correct	**1, 2** only correct	**2, 3** only correct	**1** only correct	**3** only correct



The diagram shows a ray of light passing through a rectangular glass block. The distance between the incident ray and the emergent ray is marked x. Which of the following factors would influence the value of x?

1 The velocity of the light in the glass
2 The angle of incidence marked i
3 The thickness (y) of the glass block

Question 9.6



(a) The diagram shows a beam of light incident on a glass prism. Complete the diagram to show the subsequent path of the light until it emerges from the prism (the critical angle for glass is 42°)
(b) How would you use the same prism to produce a spectrum? Draw a diagram to illustrate your answer and mark clearly on the diagram the position of the emergent violet light and red light.

Question 9.7

(a) Describe how you could verify that the infra-red radiation emitted by a hot soldering iron obeys the law of reflection that the angle of incidence is equal to the angle of reflection.
(b) What effect does the change of speed of light as it enters a glass block have on
 (i) the wavelength of the light
 (ii) the frequency of the light.

Question 9.8

A red ball is resting on a blue carpet. If white light is shone on them and they are viewed through a green filter, the observer will see a
A Black ball on a black carpet
B Red ball on a blue carpet
C Green ball on a green carpet
D Yellow ball on a peacock blue carpet
E Magenta ball on a peacock blue carpet

9.12 Answers and Hints on Solutions to Questions

1. If you are stuck draw a diagram like the one in Example 9.3. A ray from 1 m below his eyes is reflected from the bottom of the mirror to his eyes. A ray from lower down striking the mirror will pass above his eyes.
 Answer D
2. (i) See section 9.2, Fig. 9.1.
 (ii) 5.40 (set a clock to 6.20 and hold it in front of a mirror if you find this question difficult).
3. (a) Both are electromagnetic waves which travel with the same velocity.
 (b) See Example 9.10.
 (c) See Example 9.7.

4. The ray is passing into an optically denser medium in which its velocity is less. The frequency does not change.
Answer B
5. Answer A
6. (a) The light is bent towards the normal on entering the block and is incident on the far glass surface at an angle of incidence which is greater than the critical angle; at this boundary it is totally internally reflected. It hits the bottom face of the prism and is refracted away from the normal as it leaves the prism. (b) See Example 9.9.
7. Infra-red radiation from a soldering iron may be detected using a phototransistor connected to a milliammeter. Two metal tubes should be positioned horizontally near a vertical metal plate. The soldering iron is held at the far end of one of them, and the phototransistor placed at the far end of the other tube. The infra-red radiation will only be detected by the phototransistor when $\hat{i} = \hat{r}$.
8. The green filter will not pass either red or blue light.
Answer A

10 Lenses, the Eye, the Camera and the Slide Projector

10.1 Lenses

The principal terms used to describe the action of a lens are shown in Fig. 10.1. Rays parallel to the principal axis converge to a point called the *principal focus*. The distance from the principal focus to the optical centre (or pole) is the *focal length* of the lens.

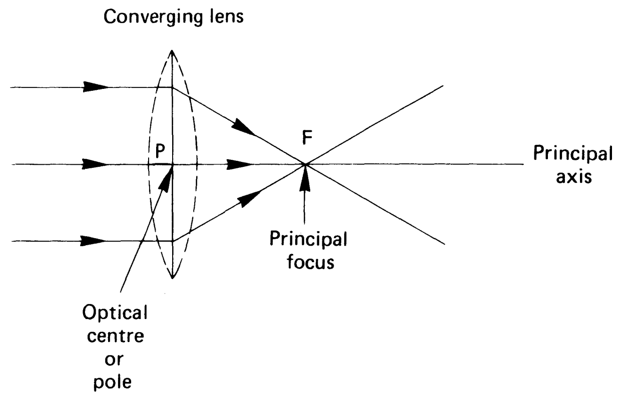


Figure 10.1

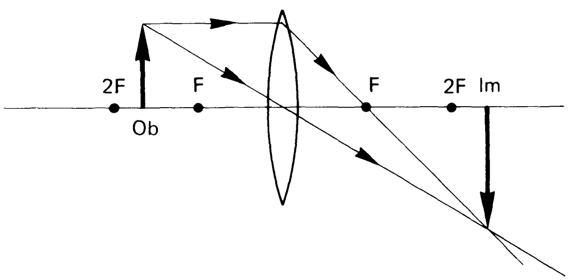
Image positions may be determined by drawing ray diagrams (see Examples 10.3 and 10.4).

$$\text{Magnification} = \frac{\text{Height of image}}{\text{Height of object}}$$

Table 10.1 shows the position and nature of images formed by converging lenses.

Table 10.1 Images formed by a convex lens

Object distance	*Image*	*Nature of image*	*Uses*
At infinity	At F	real inverted smaller	objective of telescope
Between infinity and 2F	Between F and 2F	real inverted smaller	camera eye
Between 2F and F	Between 2F and infinity	real inverted enlarged	enlarger slide projector
Between F and lens	Same side of lens as object and at a greater distance	virtual erect enlarged	magnifying glass eyepiece of telescope



F = principal focus Ob = Object Im = Image

10.2 The Eye and the Camera

The eye and the camera both have a converging lens which forms a real, diminished, inverted image of the object on a light sensitive area (the *retina* in the eye, the film in a camera). The camera is focused by moving the lens backwards or forwards. The eye focuses using the *ciliary muscles* to change the focal length of the lens. The ability of the eye to focus objects at different distances is called the *power of accommodation*. The amount of light entering the eye and the camera is controlled by the size of the aperture. This is changed in the camera by adjusting a *diaphragm*, and in the eye by the *iris* (the coloured part of the eye).

10.3 The Slide Projector

A slide projector (Fig. 10.2) has a *projection lens* which forms a real, inverted, magnified image on a screen. The concave mirror and the condenser lens both serve to increase the illumination of the slide.

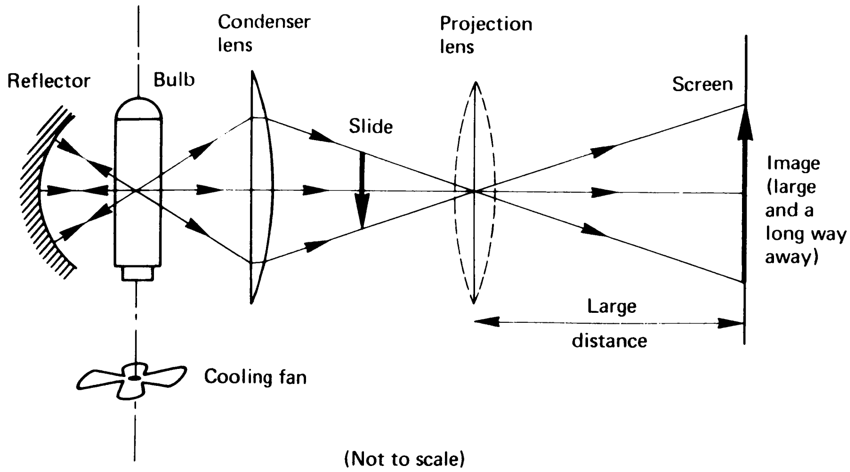


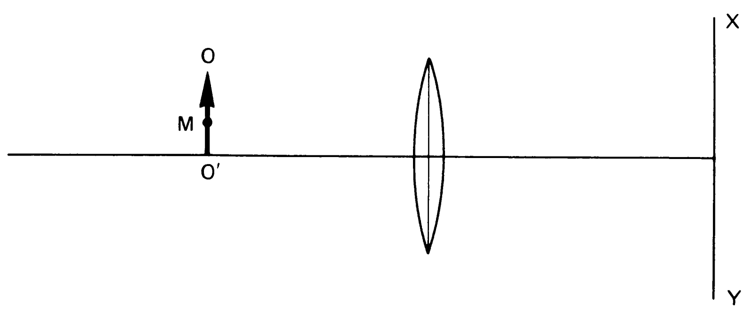
Figure 10.2 A slide projector.

10.4 Worked Examples

Example 10.1

(a) Describe how you would determine the focal length of a converging lens (assume that you cannot see any distant object). **(8 marks)**

(b) The diagram shows an object OO′ placed in front of a converging lens. The image is formed on the line XY.



(i) Draw *three* rays leaving O (the arrow head at the top of the object) and passing through the lens. Show clearly the position of the image. **(6 marks)**

(ii) Show the path of two rays leaving M (the mid-point of OO′), which pass through the lens and travel to the image. **(3 marks)**

(iii) Where must the eye be positioned in order to observe the image? **(2 marks)**

(c) The object is now moved closer to the lens so that it is less than a distance of one focal length from the lens. Describe the image. **(3 marks)**

(d) Suppose the lens was dropped and broken into two approximately equal pieces. What effect, if any, would this have on the brightness and size of the image formed in (b) (i). **(3 marks)**

Solution 10.1

(a) A plane mirror and illuminated object are positioned on opposite sides of the lens as shown in Fig. 10.3. The object is moved until the image appears in focus beside the object. The distance from the object to the lens is measured.

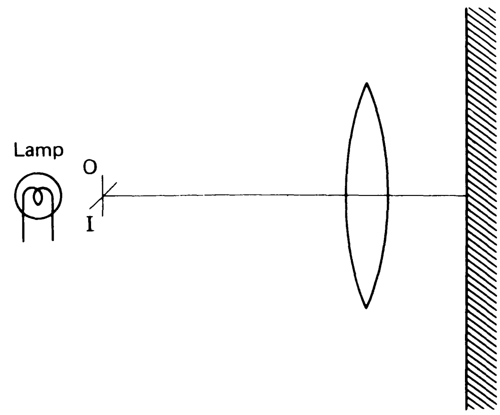


Figure 10.3

The object is moved and the experiment repeated a number of times. If the distance from the object to the lens were found to be 10.1 cm, 10.2 cm, 10.0 cm, then the focal length of the lens would be 10.1 ± 0.1 cm.

(b) (i) and (ii) (see Fig. 10.4).

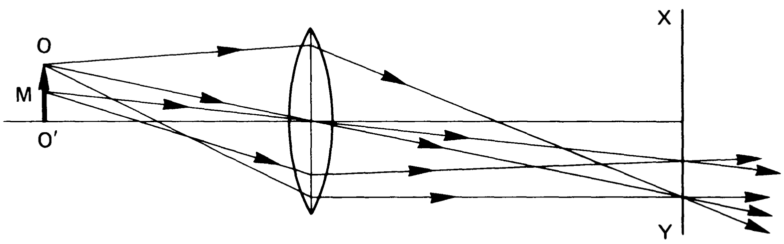


Figure 10.4

[The ray through the centre of the lens passes through undeviated. Where this meets the line XY is the position of the image. Once this position is fixed any other ray leaving 0 goes through this same point on the image. All rays leaving M go through the mid-point of the image.]

(iii) The eye must be positioned so that the rays coming from the image enter the eye. It must be more than 25 cm beyond the image.

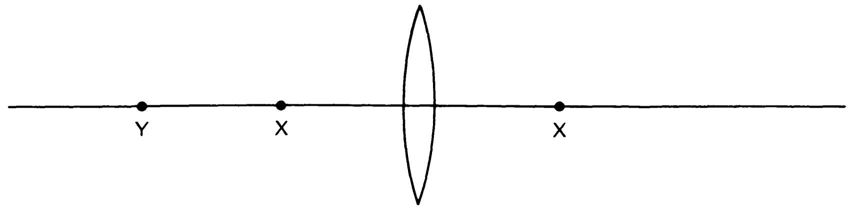
(c) Magnified, virtual and erect.
[When the object is less than one focal length from the lens, the lens behaves as a magnifying glass (see Example 10.4).]

(d) The rays of light passing through the remaining half will travel the same path as when the whole of the lens was present. The image will therefore be the same size. Since only half the light will reach the image, the image will be less bright.

Example 10.2

The diagram shows a point object X on the principal axis of a converging lens. The image is formed at X′.

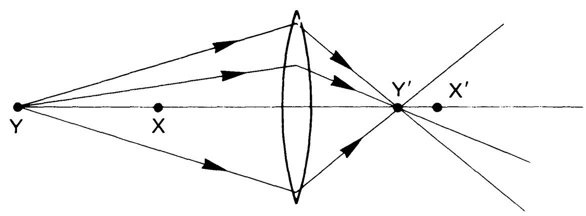
(i) Draw three rays from Y, another point on the principal of the lens and show a possible path for each of these rays after they pass through the lens. Mark the position of the image Y′. **(4 marks)**



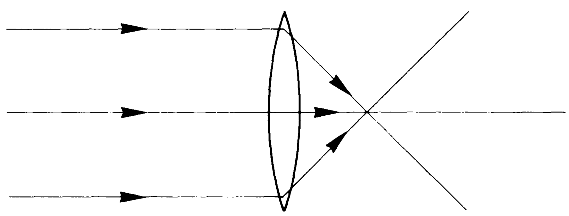
(ii) Draw another diagram showing the paths of rays coming from a distant object and passing through the lens. **(3 marks)**

Solution 10.2

(i)

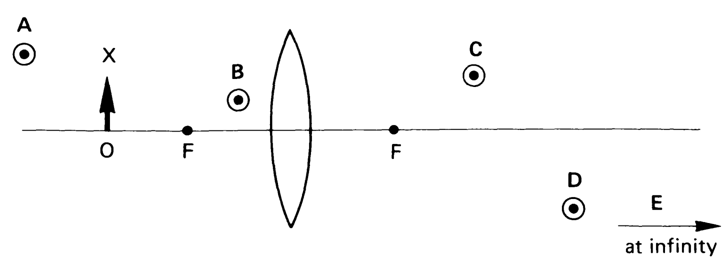


(ii)



[As the object distance increases the image distance decreases. When the object is a long way from the lens the rays arrive at the lens nearly parallel. They pass through the principal focus which is closer to the lens than Y′.]

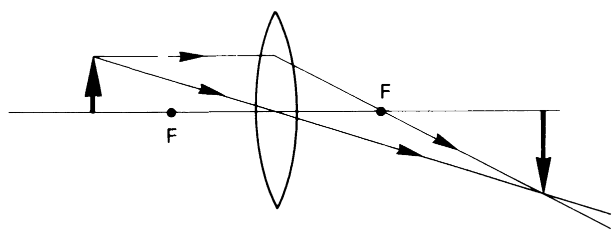
Example 10.3



The figure represents a thin converging (convex) lens with a small object, OX, perpendicular to the principal axis of the lens. F indicates the principal focus on each side. Points **A, B, C, D** and **E** are possible positions for an image to be formed. At which one of these points will the image of the TOP of the object (point X) be? **(AEB)**

Solution 10.3

[The ray diagram shows that the image is at **D**]



Answer **D**

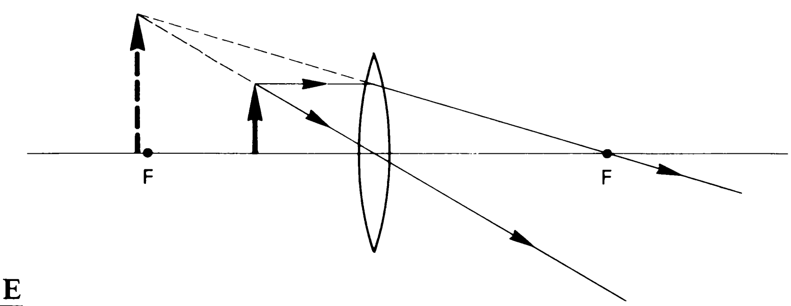
Example 10.4

A magnified erect image is obtained when an object is positioned in front of a converging lens. The distance of the object from the lens will be

A Greater than three focal lengths
B Equal to two focal lengths
C Between one and two focal lengths
D Equal to one focal length
E Less than one focal length

Solution 10.4

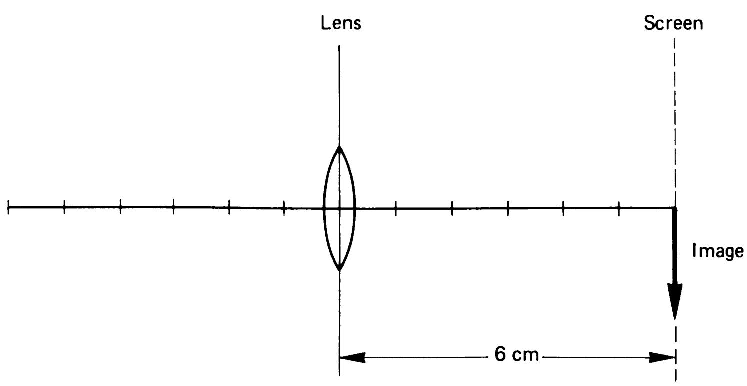
[A magnified erect image will be obtained when the object is positioned less than one focal length from the lens.]



Answer **E**

Example 10.5

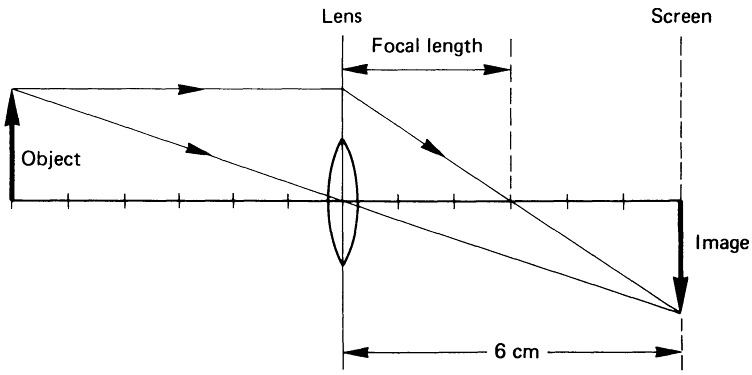
The diagram shows a converging (convex) lens and the image of an object it has formed on a screen.



(a) The image is the same size as the object, but inverted. *Find* and *mark* on the diagram
   (i) the position of the object,
   (ii) the focal length of the lens.
(b) If the object is now placed between the principal focus and the lens, compare the size and nature of the image now produced with that in (a).
   (i) size,
   (ii) nature. **(5 marks)**
(AEB)

Solution 10.5

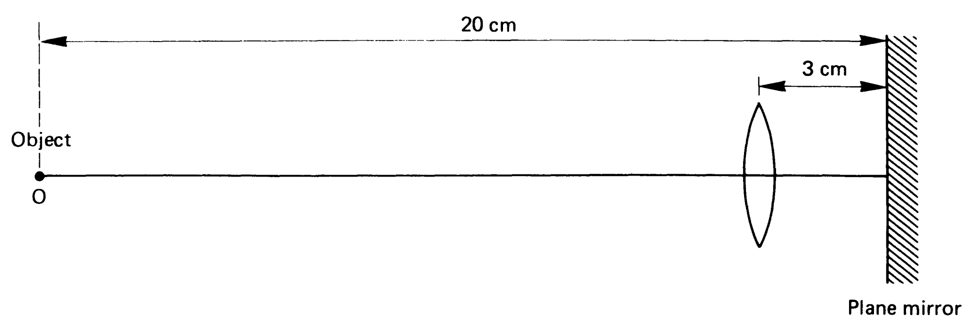
(a) [When the object and the image are the same size they are the same distance from the lens. You can check this by drawing the ray through the centre of the lens. Once you have fixed the position of the object, draw the ray parallel to the principal axis which after refraction goes through the image. Measure the distance from the lens to where this ray crosses the principal axis.]



(b) (i) The image is magnified, that is it is larger than the object.
   (ii) It is virtual and erect.

Example 10.6

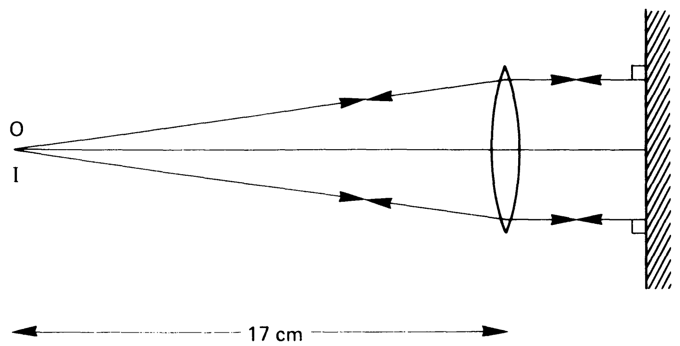
Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



In the diagram a real image of a point object O is formed at O. Which of the following statements about the arrangement is/are true?
(1) The object is at the principal focus of the lens
(2) The focal length of the lens is 17 cm
(3) If the mirror is moved so that it is 6 cm from the lens the image will also move.

Solution 10.6

[The diagram shows that the rays of light leaving O return along their own path because they hit the mirror normally. The rays returning from the mirror are parallel to the principal axis and therefore pass through the principal focus. Both O and I are at the principal focus. Notice that the rays will still strike the mirror



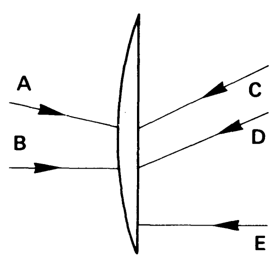
normally if the mirror is moved away from the lens and the rays will still return along the same path. The object and image position do not change when the mirror is moved. This experiment provides a quick accurate method of determining the focal length of a convex lens (see Example 10.1).]

Answer C

Examples 10.7–10.9

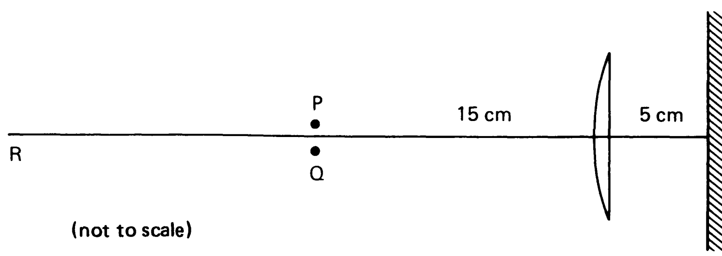
A series of experiments is performed to investigate the properties of the plano-convex lens shown in margin.

10.7 To examine the deviation of rays by the lens, it is placed in a smoke-filled box and narrow beams of light are directed at different parts of its surface, one at a time, as indicated in the diagram below.



Which of these beams of light would undergo the greatest deviation on passing through the lens?

10.8 The lens is now placed 5 cm in front of a plane mirror, as shown.



A small source of light is placed at P, 15 cm from the lens and just off the principal axis. The image of this source is formed at Q, just the other side of the principal axis from P. R is a point near the principal axis, about 50 cm from the lens.

To observe the image, which of the following methods is *not* suitable?

A Place a small white screen at Q
B Look from R towards the lens, and focus the eye at the distance of P
C Place a photographic plate at Q, shielded from direct light from P
D With the eye at Q, focus on the lens
E With the eye between P and R, examine the region below P with a magnifying glass

10.9 What is the focal length of the lens?
A 7.5 cm **B** 10 cm **C** 15 cm **D** 20 cm
E It is not possible to know from the information given. (L)

Solution 10.7

[The deviation of a ray depends on the distance from the centre of the lens. **A** and **C** will both be deviated about the same amount. **B** and **D** will be deviated the same amount but more than **A** and **C**.]

Answer **E**

Solution 10.8

[The rays of light reflected at the mirror and forming an image at Q will enter the eye at R. Since R is more than the least distance of distinct vision (about 25 cm) from Q, an eye at R will see the image at Q. The image at Q is real so it can be examined with a magnifying glass.]

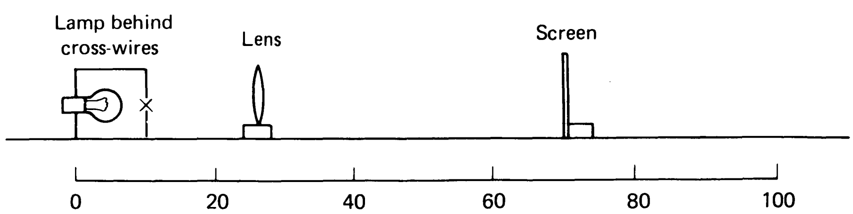
Answer **D**

Solution 10.9

[See Example 10.6.]

Answer **C**

Example 10.10



Some illuminated cross-wires were fixed in front of a convex lens as shown in the diagram. A screen was moved until a sharp image was formed on it. A ruler, placed as illustrated, was used to record the position of the cross-wires, the lens and the screen. Two sets of readings are shown in the table.

Position of object/cm	Position of lens/cm	Position of screen/cm	Object distance/cm	Image distance/cm	Magnification
10.0	30.0	70.0			
10.0	50.0	70.0			

(i) Complete the table and compare the sizes of the two images. **(8 marks)**

(ii) No image could be obtained on the screen when the illuminated cross-wires were 10 cm from the lens. Suggest a reason for this. How could you see the image formed in this case? Describe the position, nature and magnification of the image. **(6 marks)**

Solution 10.10

(i)

Position of object/cm	Position of lens/cm	Position of screen/cm	Object distance/cm	Image distance/cm	Magnification
10.0	30.0	70.0	30.0 − 10.0 = 20.0	70.0 − 30.0 = 40.0	$\frac{40.0}{20.0} = \times 2$
10.0	50.0	70.0	50.0 − 10.0 = 40.0	70.0 − 50.0 = 20.0	$\frac{20.0}{40.0} = \times \frac{1}{2}$

The first image is four times the size of the second one.
[The equation for calculating the magnification is given in section 10.1.]

(ii) The object was at a distance of less than one focal length from the lens. The image could be seen by positioning the eye on the screen side of the lens and looking through the lens towards the cross-wires.

The image is on the same side of the lens as the object, it is virtual and magnified.

Example 10.11

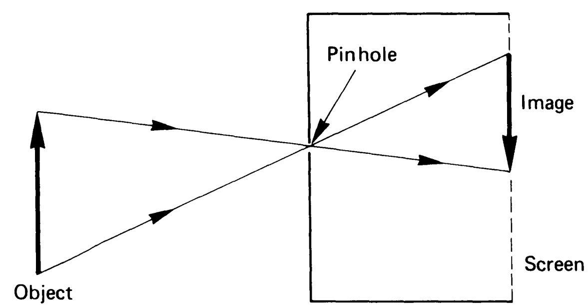
(a) Draw a diagram showing the action of a pinhole camera. Your diagram should show two rays, one from the top of the object and one from the bottom of the object, to the screen. Mark clearly the position of the image. **(6 marks)**

(b) (i) If the pinhole is made larger, how would the brightness and the sharpness of the image change?

(ii) If the object is moved further from the pinhole, how would the size and the sharpness of the image change?
Give reasons for your answers. **(8 marks)**

Solution 10.11

(a)



(b) (i) When the hole is enlarged more light enters the camera and the image is brighter. The enlarged pinhole will mean that the image is less sharp because the light from any point on the object falls on a larger area of the screen.

(ii) As the object is moved further from the pinhole, the image decreases in size because the light leaving the object falls on a smaller area of the screen. The image is slightly sharper because light from every point on the object falls on a smaller area of screen.

Example 10.12

A camera has a lens of focal length 50 mm.

(a) When taking a photograph of a distant object, where should the film be placed? **(2 marks)**

(b) What adjustments can be made to adapt the camera to take photographs in bright sunlight? **(4 marks)**

(c) What adjustment is needed to the lens in order to take photographs of close objects? **(2 marks)**

Solution 10.12

(a) Rays from a distant object are brought to a focus in the focal plane of the lens and the film must therefore be placed at the focal plane of the lens.

(b) The amount of light entering the camera can be reduced. This may be done by (i) decreasing the aperture or (ii) decreasing the exposure time. Another way is to use a film of lower sensitivity.

(c) The lens must be moved away from the film.
[The distance of the image from the lens increases as the object gets closer. The lens must be moved so that the distance from the lens to the film increases.]

10.5 Have you Mastered the Basics?

1. Can you explain the terms principal focus and focal length?
2. Can you draw ray diagrams to show how converging lenses form (i) a real image and (ii) a virtual image?
3. Can you describe the position and properties of images formed by converging lenses?
4. Can you explain how a camera and a slide projector work?

10.6 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See section 10.1.
2. See section 10.1 and Examples 10.3 and 10.4.
3. See section 10.1.
4. See sections 10.2 and 10.3.

10.7 Questions

Question 10.1

1. (a) You are provided with a converging lens. Describe, giving full experimental details, how you would measure its focal length.

(b) An object is placed at a distance of 10 focal lengths from a converging lens and gradually moved towards the lens until it reaches the lens. With the aid of ray diagrams explain the changes that take place in the position and nature of the image.

Question 10.2

Explain the term *focal length* as applied to a converging lens. An object 5 mm high is placed 4.5 cm in front of a converging lens of focal length 2.5 cm. Draw a ray diagram to enable you to determine the position and size of the image. Is the image real or virtual?

Where must the eye be placed in order to see the image clearly?

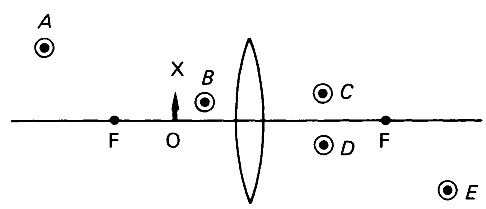
Question 10.3

An object is placed 50 cm from a converging lens of focal length 30 cm. The image produced will be

A inverted and the same size as the object
B inverted and diminished
C inverted and magnified
D erect and diminished
E erect and magnified

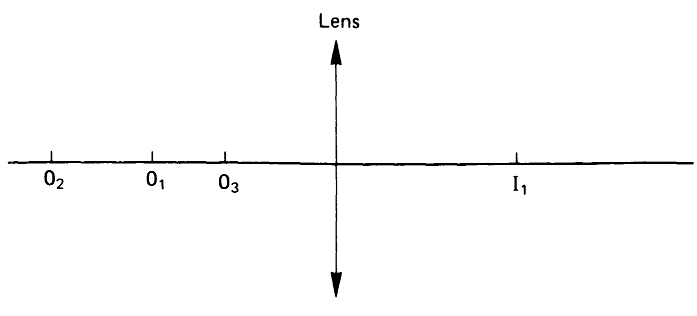
Question 10.4

The diagram shows a converging lens with an object OX perpendicular to the principal axis of the lens. F shows the positions of the principal foci. Points *A, B, C, D* and *E* are possible positions of the image of the top of the object (point X). Which one is the correct position?



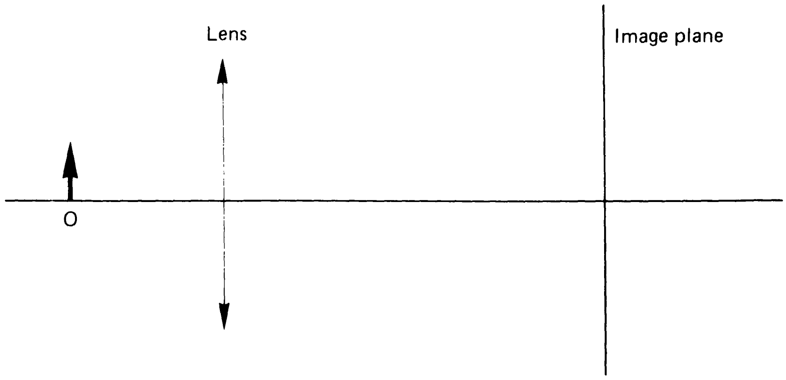
Question 10.5

The diagram shows a lens with an object marked O_1 on the principal axis of the lens. Rays from O_1 pass through the lens and converge at its image point I_1. The lens is midway between O_1 and I_1. Draw rays from O_2 and O_3 in the diagram showing where they would converge approximately after passing through the lens. Label these image points I_2 and I_3 respectively.



Question 10.6

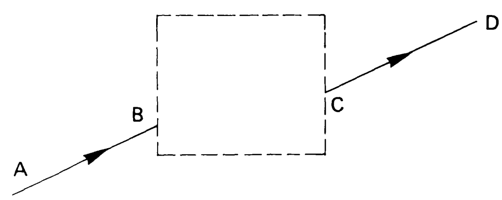
(a) Draw *two* rays on the figure below from the top of the object O to the top of its image. The image plane is marked with a straight line.



(b) Measure the magnification.
(c) What sort of lens is being used here?

Question 10.7

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



A ray of white light AB enters and leaves a region which is enclosed by the broken lines as shown in the diagram. This effect could be produced by correctly positioning within the broken lines
(1) a thin converging lens
(2) a semicircular glass block
(3) a rectangular glass block

Question 10.8

(a) A converging lens has an object placed 4 cm in front of it and a virtual image is formed 8 cm from the lens. Draw a diagram showing the lens, the object and the image. On your diagram draw *three* rays which leave the top of the object (a point not on the principal axis of the lens) and pass through the lens.
(b) An object 3 cm high is placed two focal lengths from a converging lens. What is (i) the nature (ii) the position and (iii) the size of the image?

Question 10.9

(a) (i) Draw a ray diagram to show how a pinhole camera produces an image.

(ii) State *two* ways in which the appearance of the image produced by a pinhole camera will change if the pinhole is made larger.

(b) (i) Describe the image produced by a lens camera.

(ii) A photograph is taken with a lens camera at a shutter speed of 1/100 s. The area of the aperture is doubled. What shutter speed is now needed to get the same activation of the film?

10.8 Answers and Hints on Solutions to Questions

1. (a) See Example 10.6.

   (b) Draw diagrams like the ones in section 10.1 and Examples 10.3 and 10.4. Initially the image is just outside the principal focus and is real, inverted and diminished. As the object moves towards the lens the image moves away from the lens increasing in size. When the object is 2 focal lengths from the lens, the image is 2 focal lengths from the lens and the same size as the object. As the object moves from 2 focal lengths to 1 focal length from the lens, the image moves to infinity and gets larger. Once the object is less than 1 focal length from the lens the image is virtual, erect and magnified. As the object moves from 1 focal length up to the lens the virtual image moves from infinity to the lens and decreases in size. This is summarised in the table in section 10.1.

2. Draw a ray diagram like the one in Example 10.3. The image is 5.6 cm from the lens, its size is 6.25 cm, and it is real. The eye must be more than 25 cm beyond the image.

3. Answer **C**

4. Answer **A**

5. The rays leaving O_2 pass through a point on the principal axis closer to the lens than I_1. Those leaving O_3 pass through a point on the principal axis further from the lens than I_1. O_1 and I_1 are at 2F (see table in section 10.1) and I_2 must be at a distance from the lens of more than one focal length.

6. (a) The tip of the image will be where the ray from the top of the object hits the image plane after passing straight through the centre of the lens. *Any* other ray from the top of the object will pass through the tip of the image.

   (b) Magnification is 2.4.

   (c) A converging lens.

7. The semicircular glass block would behave like a rectangular glass block in Example 9.5 if the ray were incident on the centre of the circular part where the tangent was parallel to the plane face. A lens could not produce the ray CD. Answer **D**

8. (a) A diagram like the one in Example 10.4. All the rays leaving the top of the object must appear to come from the tip of the image. Don't forget to put arrows on your rays.

   (b) The image is real, two focal lengths from the lens and 3 cm high (see section 10.1 and Example 10.5 where the object and image are two focal lengths from the lens).

9. (a) (i) and (ii) See Example 10.11.

   (b) (i) Inverted, real and diminished. (ii) 1/200 s.

11 Wave Motion, Sound, Resonance and Stationary Waves

11.1 Wave Motion and Sound

(a) Energy, Speed, Frequency and Wavelength

In all wave motion, a disturbance (energy) travels through a medium without the medium moving bodily with it. The wave transmits energy from the source to the receiver.

The amplitude of the waves is their biggest displacement from the undisturbed level and is a measure of the energy of the waves. The frequency is the number of oscillations occurring every second (unit: a hertz (Hz)). The wavelength is the distance between successive crests or successive troughs.

The speed v of any wave is related to the frequency f and the wavelength λ by the equation $v = f\lambda$. The speed of a wave depends on the medium in which it is travelling.

(b) Longitudinal and Transverse Waves

In a transverse wave, oscillations are perpendicular to the direction of propagation of the wave (water waves and electromagnetic waves are transverse). In a longitudinal wave the media oscillates along the direction in which the wave travels (sound waves are longitudinal).

(c) Reflection, Refraction and Interference

Waves can be reflected, refracted, diffracted and show interference effects. Refraction results from a change in speed as the wave crosses a boundary between two different media; the wavelength of the wave also changes, but the frequency does not change.

(d) Sound

Every source of sound has some part which is vibrating. Sound needs a medium in which to travel and cannot travel through a vacuum. Sound waves consist of a series of alternate compressions and rarefactions travelling away from the source. The pitch of a note depends on its frequency; if the frequency increases the pitch of the note goes up.

11.2 Resonance

Resonance is a term used to describe a situation in which oscillations of large amplitude are built up by the application of impulses of small amplitude to a system having a natural frequency equal to the frequency of the applied impulses. One example of resonance is the vibration of panels of buses and parts of a car at a particular engine speed. It occurs when the frequency of the engine is equal to the natural frequency of the panel or the part of the car which is vibrating.

11.3 Young's Slits

This classic experiment demonstrated the constructive and destructive interference of light from a double slit. It was an important experiment in the establishment of the wave theory of light.

A similar experiment may be conducted with sound. Two loudspeakers are connected to the same signal generator and placed about 50 cm apart. The variation in intensity resulting from the interference of the waves from the two sources may be heard by walking along a line parallel to the line joining the two speakers.

11.4 Stationary Waves

The standing (stationary) waves in a string result from the fact that two progressive waves of equal frequency and amplitude are travelling in opposite directions. In the resulting vibration (Fig. 11.1) (i) some points, nodes, are permanently at rest. Midway between nodes are antinodes, where the amplitude of the vibration is a maximum, (ii) points between successive nodes are all vibrating with the same frequency and the same phase, (iii) the distance between successive nodes is $\lambda/2$.

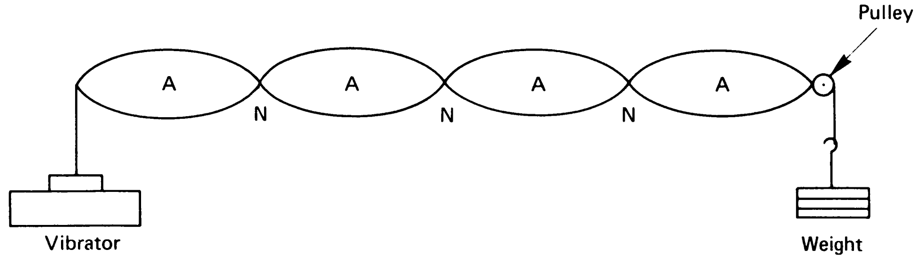


Figure 11.1 The nodes (N) are permanently at rest and the antinodes (A) are vibrating with maximum amplitude.

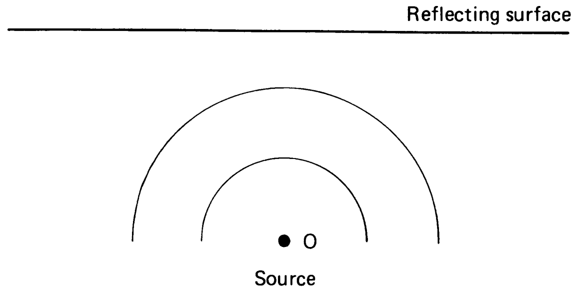
Standing waves may also be produced in pipes. They result from a plane progressive wave travelling down the pipe and being reflected at the far end.

The standing waves set up in pipes and strings give rise to the sound emitted by many musical instruments.

11.5 Worked Examples

Example 11.1

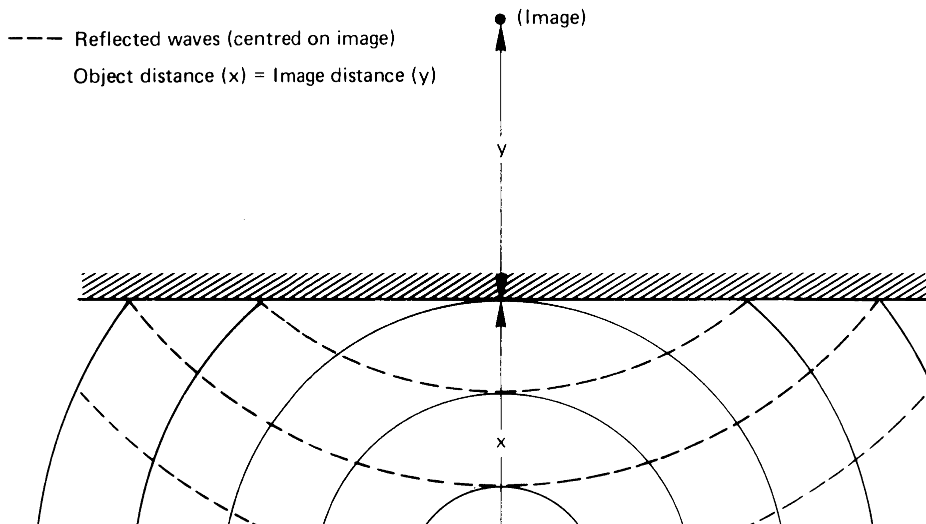
(a) The diagram shows waves spreading out from a point source O and travelling towards a plane reflecting surface. Complete the diagram showing what happens to the waves as they arrive at, and leave, the reflecting surface. Show the position of the image of the source on your diagram. **(5 marks)**



(b) Plane waves in a ripple tank have a frequency of 6 Hz. If the wave crests are 1.5 cm apart, what is the speed of the waves across the tank? **(3 marks)**

Solution 11.1

(a)



(b) $v = f\lambda$ [see section 11.1]
$v = 6 \times 0.015 = 0.09$ m/s

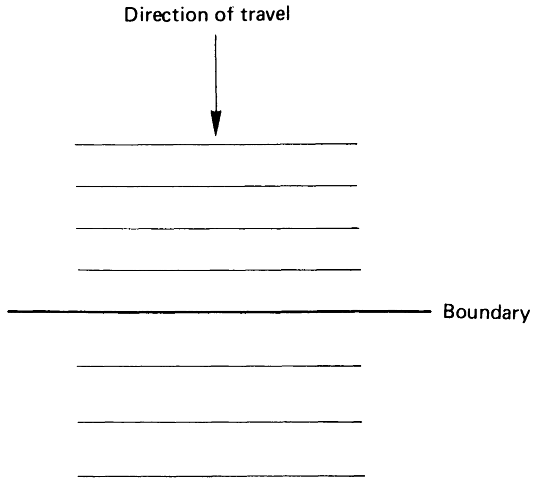
Example 11.2

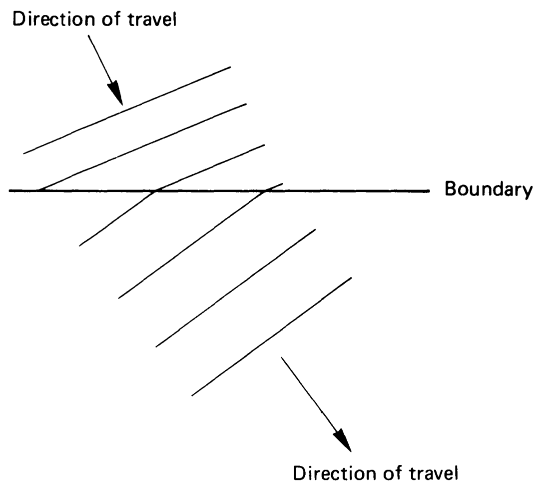
(a) Draw two diagrams showing plane waves crossing a straight boundary and passing into a medium in which their speed is greater, (i) when the wavefronts of the incident wave are parallel to the boundary and (ii) when the wavefronts make an angle with the boundary. **(5 marks)**

(b) What change occurs in (i) the frequency, (ii) the speed and (iii) the wavelength, as a result of refraction when light passes into an optically less dense medium. **(3 marks)**

Solution 11.2

(a)





(b) The frequency remains constant. The speed and wavelength increase.

Example 11.3

(a) Describe an experiment to measure the speed of sound in air. **(6 marks)**

(b) A girl observes a man hammering a post into the ground repeatedly and she hears the sound at the same time as he strikes each blow. Explain this observation. If the interval between the blows is 2 second and the speed of sound in air is 330 m/s, how far is she from the man? **(4 marks)**

Solution 11.3

(a) Stand 100 metres (measured with a tape measure) from a large vertical wall. Make sure a wall is chosen so that there are no other walls which would produce a substantial echo. One person claps their hands at a steady rate and the rate is adjusted until the echo returns at the same time as the next clap. When this is achieved a second person times 50 claps. The sound has travelled 200 m in the time interval between claps. If 50 claps take t seconds then

$$\text{Speed of sound} = \frac{200\text{ m}}{t/50\text{ s}} = \frac{10\,000}{t}\text{ m/s}$$

(b) She hears the sound from the first blow at the time she sees the second blow.

Distance from man = 330 x 2 = 660 m

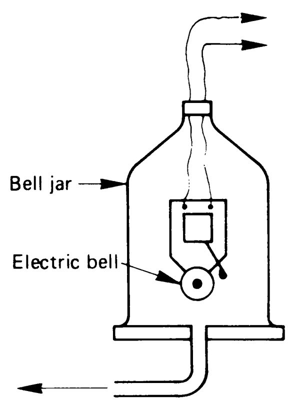
She could also be 1320 m from the man if she heard the first blow when she observed the third blow, or 1980 m if she heard the first blow when she observed the fourth blow.

Example 11.4

(a) Describe an experiment to show that sound cannot travel in a vacuum. **(6 marks)**
(b) Why is the Moon sometimes referred to as 'the silent planet'? **(2 marks)**
(c) The velocity of sound in air is 330 m/s. What is the wavelength of a note of frequency 110 Hz? **(4 marks)**

Solution 11.4

(a) An electric trembler bell is suspended inside a bell jar from which the air can be removed. When the lowest pressure has been reached, the ringing can no longer be heard (the faint vibration which is audible results from the passage of the sound along the suspension).



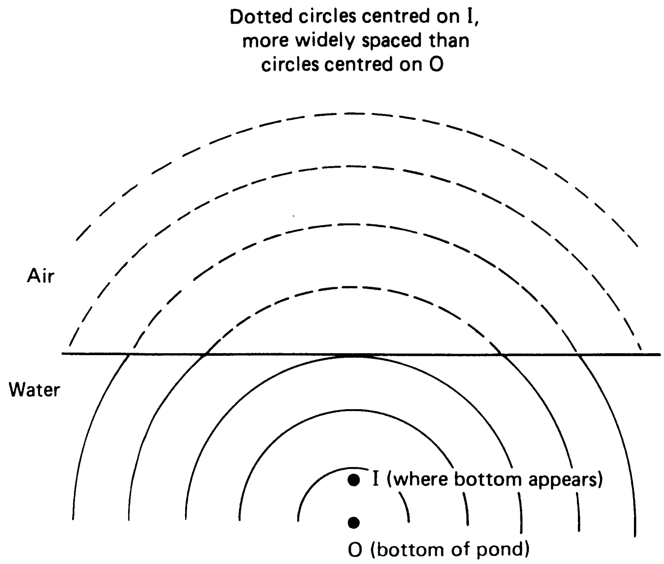
(b) The Moon has no atmosphere and there is therefore no gas through which the sound can travel. The only way sound can travel is by vibration on the surface.
(c) $v = f\lambda$ [see section 11.1].

$$330 = 110 \times \lambda \Rightarrow \lambda = \frac{330}{110} = 3\text{ m}$$

Example 11.5

Draw a *wave* diagram to illustrate why a pond appears shallower than it really is. Mark clearly the point on the bottom of the pond from which your waves originate and the position in which the point appears to be when viewed from above the pond. **(5 marks)**

Solution 11.5



Example 11.6

(a) Draw diagrams to illustrate what happens when plane waves are incident on a slit, (i) when the width of the slit is large compared with the wavelength of the waves **(3 marks)**
(ii) when the width of the slit is small compared with the wavelength of the waves **(3 marks)**

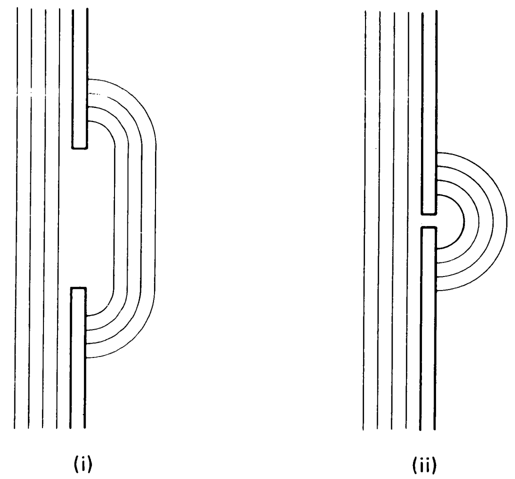
(b) A student set up a demonstration using two loudspeakers connected to the same oscillator which was producing a note of fixed frequency. The loudspeakers were placed at A and B and they emitted waves which were in phase. An observer walked along the line PQRS. A loud note was heard at Q and a faint note at R.

(i) On the same axes sketch two graphs showing how the displacement of the vibrating air molecules varies with the time for the disturbance at Q, one for the waves from A and one for the waves from B. On the same axes sketch a third graph showing the displacement at Q for both sets of waves arriving together. **(4 marks)**

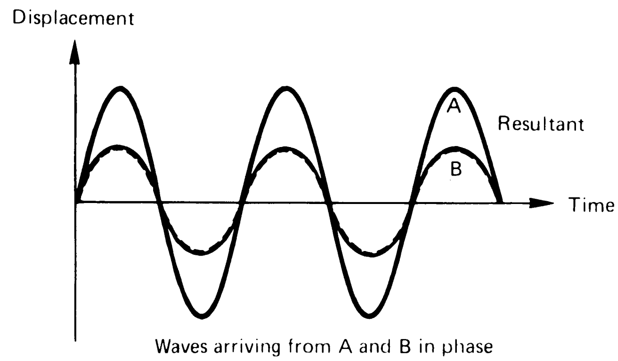
(ii) Repeat (i) for waves arriving at R. What is the relationship between the distances AR and BR? **(5 marks)**

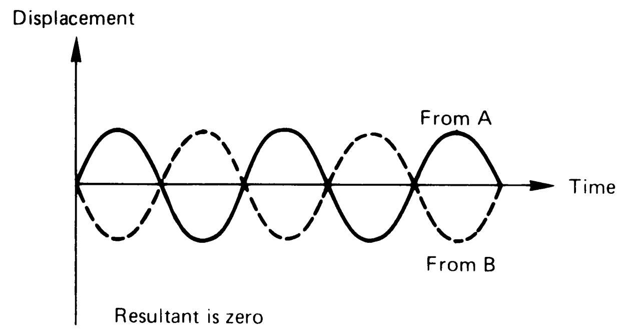
Solution 11.6

(a)



(b)





AR − BR = λ/2

[When the path difference is λ/2 then the waves arrive at R 180° out of phase.]

Example 11.7

(a) A microphone is connected, via an amplifier, to a cathode-ray oscilloscope. Three different sounds are made, one after the other, near the microphone. The traces produced on the screen are shown in the diagrams below. During the experiment the controls of the oscilloscope were not altered.

(i) Which trace results from the sound having the highest frequency? **(2 marks)**

(ii) Which trace results from the loudest sound? **(2 marks)**

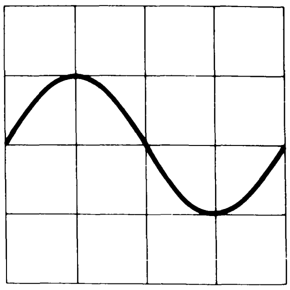


Fig. 1

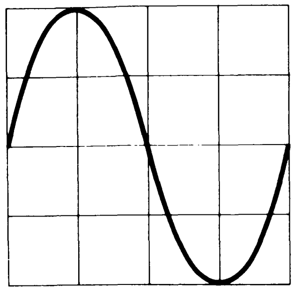


Fig. 2

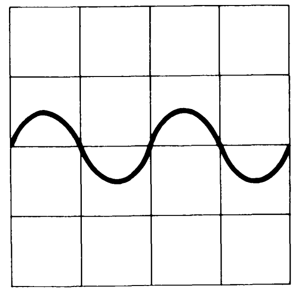


Fig. 3

(b) If in Fig. 1 the time base on the oscilloscope is set at 1 ms/cm and the lines on the grid on the screen are 1 cm apart, what is the frequency of the note which emits the sound giving the trace shown in Fig. 1. **(4 marks)**

Solution 11.7

(a) (i) Fig. 3 [In Fig. 1 and Fig. 2 a whole cycle takes four grid squares. In Fig. 3 a whole cycle only takes two grid squares.]

(ii) Fig. 2 [The amplitude is greatest in Fig. 2.]

(b) [There is one complete cycle on the screen. 4 ms = $\frac{4}{1000}$ s = $\frac{1}{250}$ s]

The time for 1 cycle is 4 ms

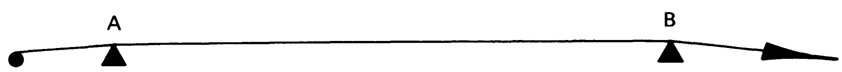
$\therefore$ It takes $\frac{1}{250}$ s for 1 cycle

$\therefore$ There are 250 cycles every second

Frequency = 250 Hz

Example 11.8

The figure represents a string of a musical instrument, a cello.



(a) Complete the figure below to show the string vibrating in its fundamental mode when played with a bow between A and B. The frequency of this vibration is 64 Hz.

(b) (i) Complete the figure below to show the string vibrating at a higher frequency when played with a bow while the string is lightly touched mid-way between A and B.

(ii) What is the frequency of this vibration?

(c) When one particular note is played on this instrument a much louder sound is unintentionally produced. What is the reason for this? **(6 marks)**

(L)

Solution 11.8

(a)

(b) (i)

(ii) The wavelength has halved so the frequency has doubled.
Frequency = 128 Hz.

(c) The natural frequency of vibration of the air in the wooden box to which the string is fixed is the same frequency as the note played and resonance is taking place.

11.6 Have You Mastered the Basics?

1. Can you explain the difference between longitudinal and transverse waves?
2. Can you explain the terms wavelength, frequency and amplitude.
3. Can you state the relationship between velocity, frequency and wavelength of a wave?
4. Can you describe an experiment to illustrate interference of waves?
5. Can you explain what is meant by resonance and give examples of it?
6. Can you draw wave diagrams to illustrate reflection and refraction of waves?
7. A radio programme is broadcast on a wavelength of 1500 m. If the speed of radio waves is 3×10^8 m/s, what is the frequency of the transmission?
8. Can you explain how stationary waves are produced?

11.7 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See section 11.1b.
2. See section 11.1a.
3. See section 11.1a.
4. See section 11.3. Also Example 11.6.
5. See section 11.2 and Example 11.8.
6. See Examples 11.1 and 11.2.
7. $v = f\lambda$ (see section 11.1a) $\Rightarrow 3 \times 10^8 = f \times 1500 \Rightarrow f = 20$ Hz.
8. See section 11.4.

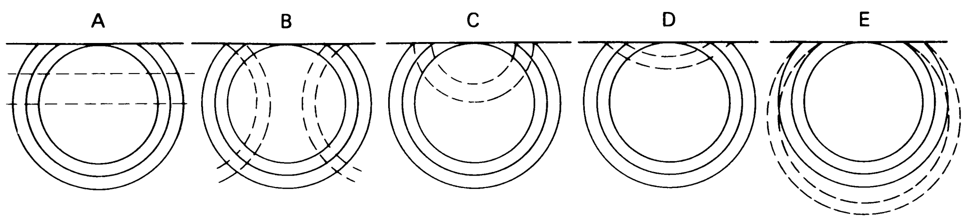
11.8 Questions

Question 11.1

Which one of the following diagrams best illustrates the reflection of a wavefront by a plane reflecting surface in a ripple tank?

——— incident wavefront

- - - - - - reflected wavefront (AEB)



Question 11.2

Figure 1 is a full-size diagram representing the crests of circular water ripples which are travelling outwards and about to meet a plane reflector.

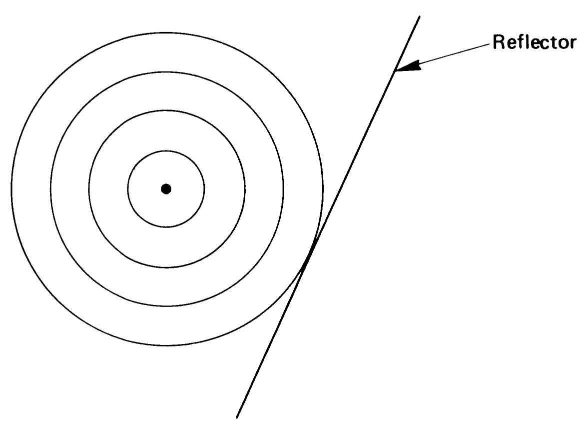


Fig. 1

(a) Describe the source and its action by which a continuous series of such ripples could be produced. **(3 marks)**

(b) Find from the diagram the wavelength of the ripples. **(1 mark)**

(c) Add to the diagram the crest of the previous ripple in the series, including its reflected part. **(2 marks)**

(d) Mark on the diagram the point C on which the reflected ripples are centred. **(2 marks)**

(e) What happens to the amplitudes of the ripples as they move further from the source? Explain. **(2 marks)**

(OLE)

Question 11.3

Assuming you have a ripple tank with a suitable quantity of water in it, describe how you would demonstrate (i) refraction and (ii) diffraction of water waves. Your answer should include diagrams showing the result you would expect to observe. **(10 marks)**

Question 11.4

(a) Define *wavelength, frequency*, and *amplitude* of a wave. State how, if at all, they are related to one another. **(6 marks)**

(b) With the aid of a diagram, describe a method of generating a regular series of longitudinal waves which can be seen. Explain what determines their frequency and describe how their wavelength may be measured. **(6 marks)**

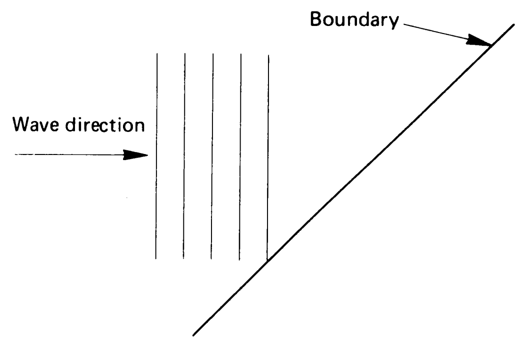
(c) List three different observations which suggest that the speed of a wave varies according to the medium in which it travels. **(3 marks)**

(d) Draw a careful diagram to show the reflection at a plane barrier of wavefronts which come from a point source, as in a ripple tank. Mark (and label X) the point from which the reflected waves appear to have originated. **(5 marks)**

(OLE)

Question 11.5

(a)



The diagram above shows a group of straight waves about to meet a straight-line boundary between two regions through which the waves can travel. The waves are *refracted* as they cross the boundary.

Copy the diagram into your answer book and show what happens to the waves as they cross the boundary. (Take care to show clearly in your diagram the shape and position of the waves as well as the direction of their motion.) **(6 marks)**

Explain, in terms of waves, why refraction occurs. **(3 marks)**

(b) Draw a labelled diagram of the arrangement of one piece of apparatus you could use to demonstrate refraction of waves. **(5 marks)**

(c) Describe how you would demonstrate that sound waves can be transmitted through a material medium but not through a vacuum. **(6 marks)**

(L)

Question 11.6

(a) In Young's double slit experiment using red light, the central fringe is bright and there are dark fringes on either side of it. Explain why the fringes are dark. **(5 marks)**

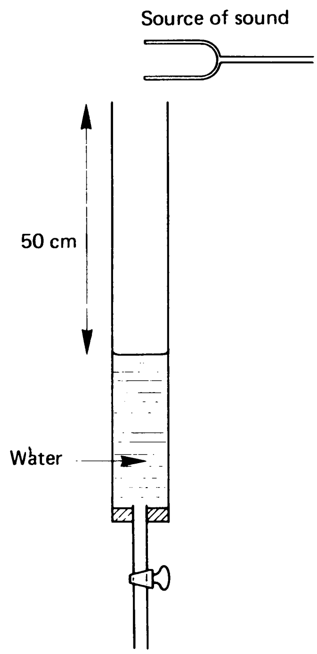
(b) State and explain how the fringes would alter if (i) the screen were moved further away from the double slits, (ii) the slit separation were increased, (iii) blue light were used instead of red light, (iv) white light were used. **(12 marks)**

(c) Write a brief note explaining the historical significance of the experiment. **(3 marks)**

Question 11.7

(a) What is (i) a transverse wave, (ii) a longitudinal wave? **(4 marks)**

(b) A source of sound of frequency 170 Hz is held above a glass tube containing water. The water is slowly run out of the tube. A loud note is heard when the air column is 50 cm long.



(i) Explain why a loud note is heard for a certain length of air column. (ii) Use the information to calculate the velocity of sound in air. (iii) Explain what is meant by resonance, and give two examples of it. **(16 marks)**

11.9 Answers and Hints on Solutions to Questions

1. **D**
2. (a) A small sphere being made to bob up and down in the water with a fixed frequency.
   (b) Wavelength = 0.5 cm.
   (c) and (d) See Example 11.1.
   (e) The amplitude decreases as the energy becomes more spread out.
3. Plane waves may be produced by suspending a bar using rubber bands so that the bar is just touching the surface of the water. When the bar is made to vibrate up and down plane waves are produced. To demonstrate refraction, a shallow area is required. This may be produced by putting a thick sheet of glass on the bottom of the tank at an angle to the on-coming waves. Diffraction will need two vertical barriers arranged with a small gap between them. For diagrams see Examples 11.2 and 11.6.
4. (a) See section 11.1.
   (b) One way is to use a 'slinky' with a vibrator attached to one end so that it is vibrating parallel to the length of the 'slinky'. Stationary waves will be set up (see section 11.4).
   (c) You could mention (i) refraction of light, (ii) the sound of an approaching train heard via the line and through the air and (iii) a pulse travelling down a rubber tube and a steel spring.
   (d) See Example 11.1.
5. (a) See Example 11.2 (the waves could speed up or slow down on crossing the boundary and a drawing showing either would be acceptable). You must show the change of direction and the change of wavelength.
   (b) You could show light waves refracted at a glass block or draw a simple diagram of a ripple tank with waves entering shallower water (there are only 5

marks so do not spend a lot of time drawing a beautiful three-dimensional diagram of a ripple tank).

(c) See Example 11.4. No sound can be heard but the hammer can be seen to be vibrating.

6. (a) The path difference is $\lambda/2$ and destructive interference takes place.

(b) (i) Further apart, (ii) closer together, (iii) closer together, (iv) coloured fringes would be seen with a white fringe at the centre.

(c) See section 11.3.

7. (a) See section 11.1b.

(b) (i) If a compression sent down the tube by the source arrives at the top of the tube just as the source is moving upwards, the two will be in step and reinforce. This means that the air molecules will be moved in the same direction by the returning compression and the source. The natural frequency of vibration of the air column and the source are the same and resonance occurs. A stationary wave pattern is set up in the tube and a loud sound is heard. (ii) The open end of the tube is a displacement antinode and the water end a node. Length of tube = $\lambda/4$. λ = 200 cm = 2 m. Speed = $f\lambda$ = 170 x 2 = 340 m/s. (iii) See section 11.2 and Example 11.8.

12 Circuits, Series and Parallel, Electrical Units, Household Electricity and Electronics

12.1 Circuits

(a) Basic Units

When an ammeter reads 1 ampere (A) then 1 coulomb (C) of charge is flowing every second. 1 A = 1 C/s.

The potential difference (in volts) between two points is the work done in joules in moving 1 coulomb of charge between them. 1 V = 1 J/C.

The e.m.f. (electromotive force) is the total energy supplied by a source to each coulomb of charge that passes through it, including any energy that may be lost as heat in the source itself.

The potential difference in volts across the terminals of a cell is the energy which is delivered to the external circuit by each coulomb of charge.

$$\text{Resistance (ohms)} = \frac{\text{Potential difference across the object (volts)}}{\text{Current flowing through the object (amps)}}$$

or $R = \dfrac{V}{I}$

You must learn to write the above equation as $V = IR$ and $I = V/R$.

An object has a resistance of 1 ohm if a potential difference across it of 1 volt results in a current of 1 amp flowing through it.

If the total e.m.f. of a circuit is E volts then

$E = I \times$ (total resistance of the circuit)

If the resistance of the source is not negligible, the source's internal resistance must be added to the resistance of the circuit in order to obtain the 'total resistance of the circuit'.

(b) Ohm's Law

Ohm's law states that the current flowing through a conductor is proportional to the potential difference across it provided the temperature is kept constant.

(c) Laws for Series Circuits

(i) The same current flows through each part of the circuit.
(ii) The applied potential difference is equal to the sum of the potential difference across the separate resistors $V = V_1 + V_2 + V_3$ (Fig. 12.1).
(iii) The total resistance is equal to the sum of the separate resistances $R = R_1 + R_2 + R_3$.

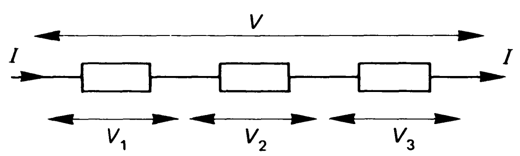


Figure 12.1 Resistors in series. $V = V_1 + V_2 + V_3$.

(d) Laws for Parallel Circuits

(i) The potential difference across each resistor is the same.
(ii) The total current is equal to the sum of the currents in the separate resistors $I = I_1 + I_2 + I_3$ (Fig. 12.2).

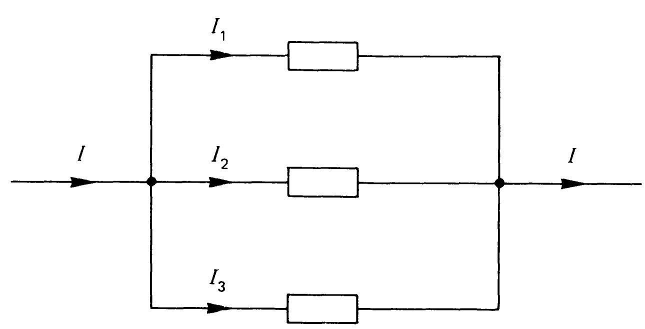


Figure 12.2 Resistors in parallel. $I = I_1 + I_2 + I_3$.

(iii) The combined, or total, resistance of a number of resistors in parallel is less than the value of any of the separate resistors and is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

12.2 Electrical Power and Energy

Power (watts) = Potential difference (volts) × Current (ampere)
or Power P = ($V \times I$) joule/second

Substituting using the definition of resistance given above, namely

Potential difference (V) = Current (I) × Resistance (R)

we have

Power = ($I^2 \times R$) joule/second

Thus, the energy dissipated in a resistor is $I^2 \times R$ joules/second. Hence, the total energy dissipated in t seconds is given by

Energy dissipated = $I^2 \times R \times t$ joule.

A meter supplied by the electricity company records the energy consumption in kilowatt-hours. One kilowatt-hour (kWh) is the total amount of energy supplied to a 1 kW appliance when it is connected to the supply for 1 h. As a 1 kW appliance is supplied with energy at a rate of 1000 J/s, a total of 3.6×10^6 J of energy will be supplied in 1 h (3600 s) thus

1 kWh = 3.6×10^6 joule.

12.3 Earthing

Appliances with metal casing have an earthed wire connected to the metal casing. This is a safety device. For example, if the element in an electric fire breaks and the live end touches the metal case, the connection to Earth has a very low resistance, and the current surges to a large value. The fuse in the circuit is designed to melt and break the circuit when the current reaches a predetermined value. The large current that results when the live wire touches the case melts the fuse, the circuit is broken and is thus safe. In many modern circuits the fuse is replaced by a circuit breaker. 'Double insulated' appliances have their metal parts surrounded by thick plastic, making it impossible for the user to touch a metal part. When wiring double insulated appliances, no earth lead is necessary.

12.4 Electronics

(a) Transistors

A transistor is a semiconductor device. It is considered to be 'off' when very little current flows in the collector circuit and 'on' when a much larger current flows in the collector circuit. The transistor stays 'off' unless the base voltage, and hence the base current, rises above a certain minimum value. When the base current rises above this minimum value a much larger current flows in the collector circuit (Fig. 12.3). A small base current can therefore be used to switch the transistor 'on' and 'off'.

Because a small base current can cause a large collector current, a transistor may also be used as an amplifier.

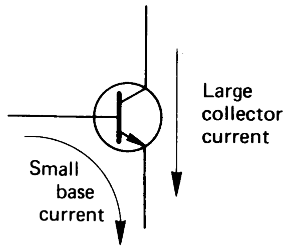


Figure 12.3 A small base current results in a large collector current.

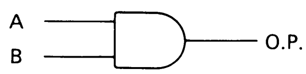
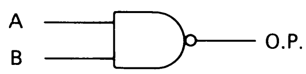
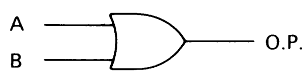
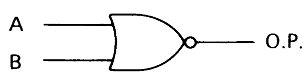
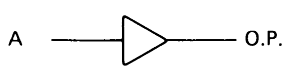
(b) Light Dependent Resistors and Thermistors

The resistance of a light dependent resistor decreases as the intensity of the light falling on it increases.

The resistance of most thermistors decreases as their temperature increases.

(c) Gates

The symbols and truth tables of a number of gates are shown below.

Name of gate	Symbol	Truth table	Description of gate
AND		A B O.P 0 0 0 0 1 0 1 0 0 1 1 1	The output is high if both A *AND* B are high
NAND		0 0 1 0 1 1 1 0 1 1 1 0	Opposite of *AND* gate
OR		0 0 0 0 1 1 1 0 1 1 1 1	The output is high if A *OR* B *OR* both are high
NOR		0 0 1 0 1 0 1 0 0 1 1 0	Opposite of *OR* gate. Output high if neither A *NOR* B is high
NOT		A O.P 0 1 1 0	An inverter

(d) The Bistable

Two NAND gates may be combined as shown in Fig. 12.4 to form a bistable. Suppose Q is at logic 0 and $\overline{Q}$ is at logic 1, and A and B are both high (logic 1). If A is made low (logic 0), then Q goes high (logic 1). If B is then made low, Q resets to a low. If inputs A and B are both high, the circuit remains in one of its two stable states depending on which of the AB inputs was last at a low voltage. With

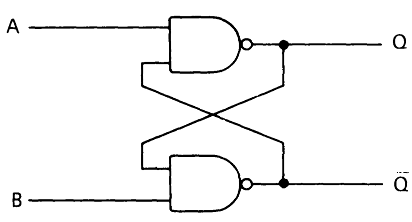


Figure 12.4 Two NAND gates connected together to make a bistable.

slight modifications the bistable may be switched from one state to the other every time a pulse is fed to the input. The bistable forms the basis of memory circuits and with additional logic, binary counters.

(e) Capacitors

A capacitor may be used to store charge and energy. In a transistor circuit it may be used to produce a time delay. Figure 12.5 is such a circuit. When the switch S is closed, no current flows in the base circuit of the transistor and the transistor is

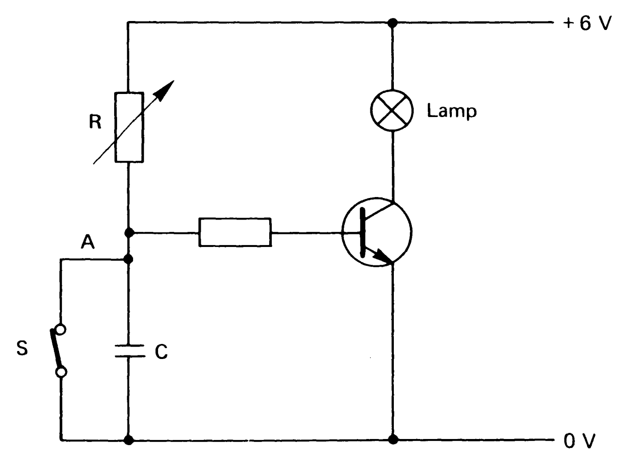


Figure 12.5 A capacitor being used to produce a time delay.

'off'. When the switch S is opened, the capacitor charges up through the resistor R. When the voltage at A is high enough, the current in the base circuit switches the transistor 'on' and the lamp lights. Increasing the value of the capacitor or the resistor will increase the time delay.

(f) A Bridge Rectifier Circuit

A semiconductor diode is a device which allows current to flow easily in one direction only. The four diodes shown in Fig. 12.6 are arranged to form a 'bridge rectifier'. They 'steer' the current in the desired direction. The current can only flow in the direction shown by the arrows. It will always flow through the load from A to B.

Figure 12.7(a) shows the current through the load. The output from the bridge rectifier is said to be full-wave rectified.

If a capacitor is placed across the load (i.e. across the output from the bridge rectifier) the variations in the current are reduced. The capacitor charges up while

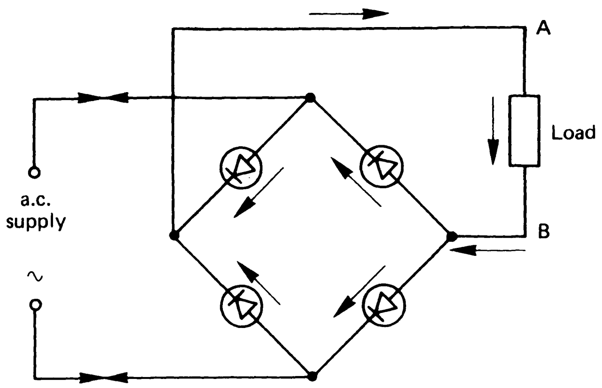


Figure 12.6 A bridge rectifier circuit.

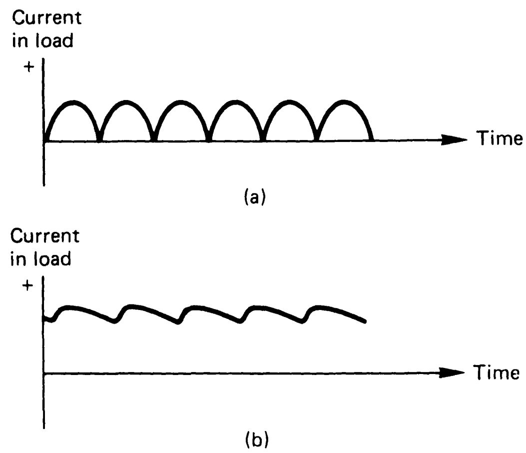


Figure 12.7 (a) Unsmoothed d.c. (b) Smoothed d.c.

the output voltage is rising, and discharges when the output voltage is falling. The smaller variations in the current which remain are known as the ripple current (Fig. 12.7(b)).

(g) Amplifiers

An amplifier is a device which is used to increase the amplitude of a small alternating voltage. One form of operational amplifier (op amp) is shown in Fig. 12.8

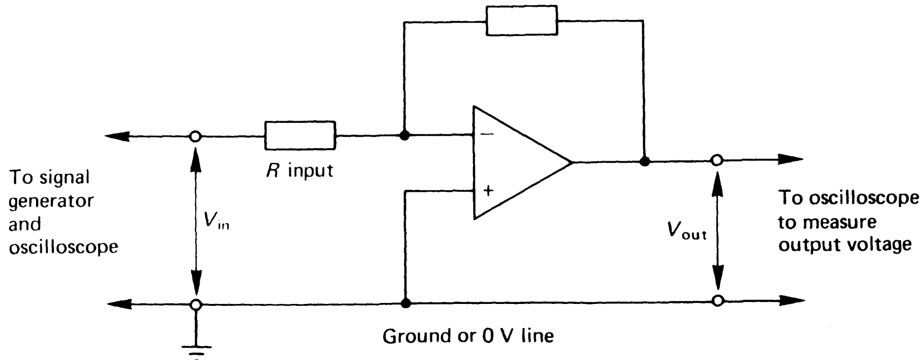


Figure 12.8 An operational amplifier.

(the connections to the power supply are not shown). The negative input terminal gives an inverted output and the positive input terminal gives a non-inverted output.

$$\text{Voltage gain} = \frac{\text{Amplitude of output voltage}}{\text{Amplitude of input voltage}}$$

The gain may be investigated by connecting a signal generator across the input and measuring the amplitude of the input and output using a CRO. The gain will be found to depend on the frequency.

The maximum amplification depends on the voltage of the power supply. The output voltage can never exceed the supply voltage. For the op amp shown in the diagram

$$\frac{V_{out}}{V_{in}} = \frac{R_{feedback}}{R_{input}}$$

With the operational amplifier connected as in Fig. 12.9 (in comparator mode)

if $V_2 > V_1$ then V_0 is positive (+9 V).
if $V_2 < V_1$ then V_0 is negative (−9 V).
if $V_2 = V_1$ then V_0 is zero.

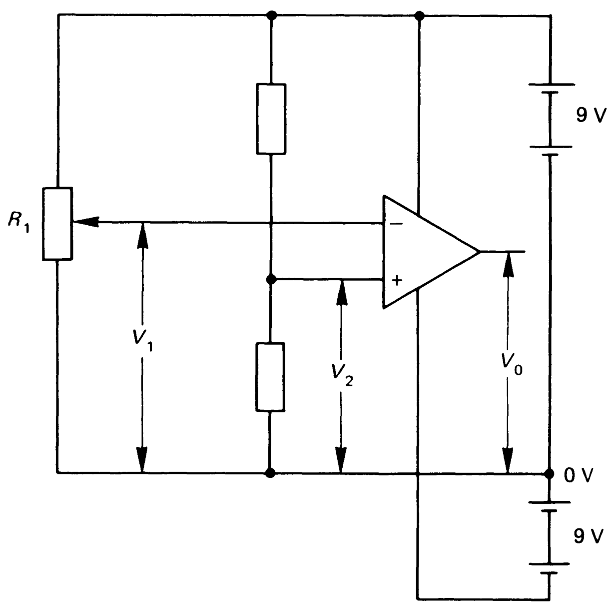


Figure 12.9 An operational amplifier in comparator mode. The output may be positive, negative or zero.

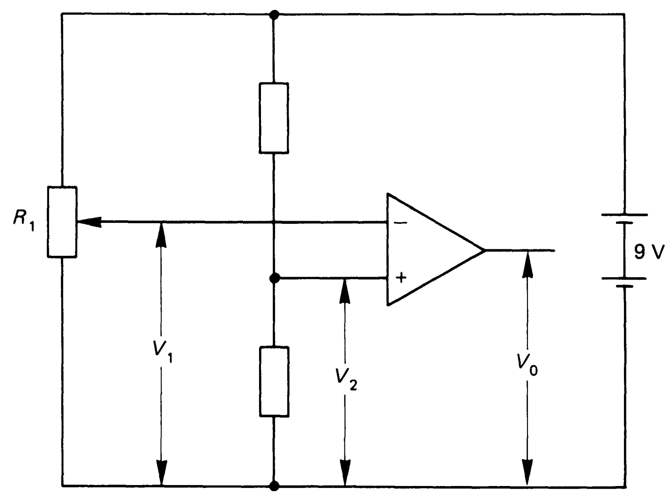


Figure 12.10 An operational amplifier in comparator mode. The output may be 'high' or 'low'.

With the operational amplifier connected as in Fig. 12.10 the output as a comparator is either 'high' or 'low'.

If $V_2 > V_1$ then V_0 is 'high' (+9 V).
If $V_2 < V_1$ then V_0 is 'low' (−9 V).

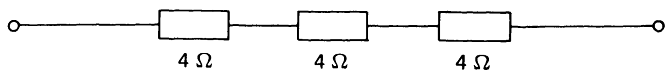
It is this swing from 'high' to 'low' which enables the op amp to be used as a switch.

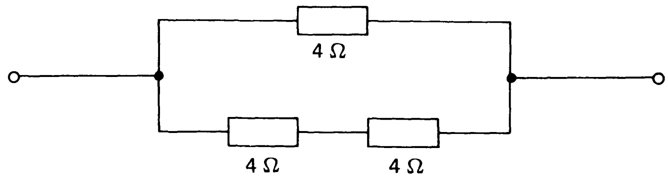
12.5 Worked Examples

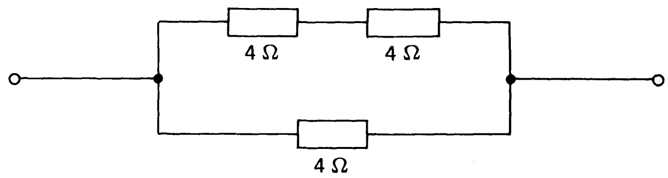
Example 12.1

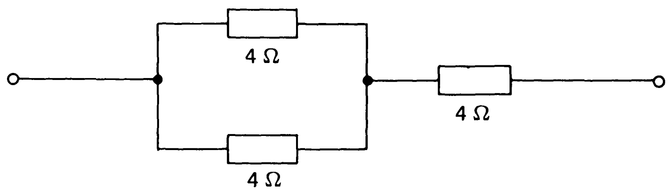
Three resistors, each of resistance 4 Ω, are to be used to make a 6-Ω combination. Which arrangement will achieve this?

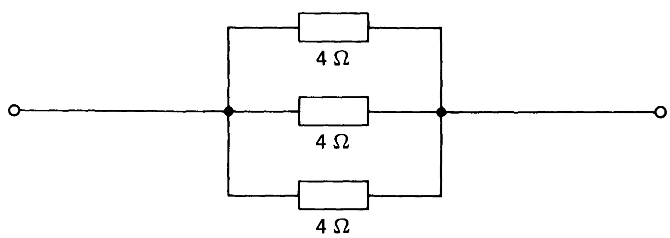
(L)

A


B


C


D


E


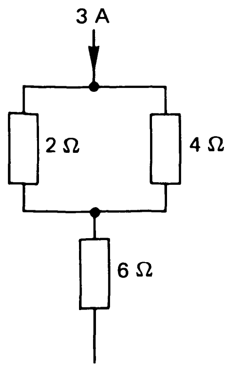
Solution 12.1

[When answering this type of question, don't waste time calculating the effective resistance of every combination. Glance at the various answers and see if you can spot the correct one, then check it by calculation. In this case a glance at **D** will tell you that this is the correct answer. The two 4 Ω's in parallel have an effective resistance of 2 Ω. This 2 Ω is connected in series with 4 Ω and hence the total resistance is 6 Ω].

Answer **D**

Example 12.2

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



In the section of the circuit shown the
(1) current in the 2 Ω resistor is 2 A
(2) current in the 4 Ω resistor is 1 A
(3) current in the 6 Ω resistor is 3 A

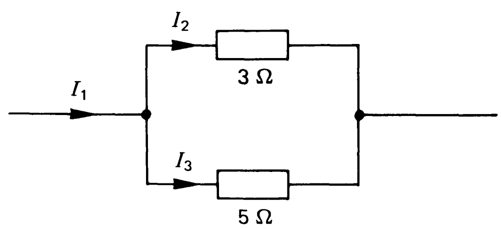
Solution 12.2

[In a parallel circuit the current divides in the ratio of the resistances, 4:2, i.e. 2:1, and the larger current passes through the lower resistance. So 2 A passes through the 2 Ω and 1 A passes through the 4 Ω. The 2 A and 1 A combine to pass through the 6 Ω. Resistors in parallel means that the same potential difference is across each of them so you can check your answer by using $V = IR$. $V_{4\Omega} = 1 \times 4 = 4$ volts and $V_{2\Omega} = 2 \times 2 = 4$ volts.]

Answer E

Example 12.3

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



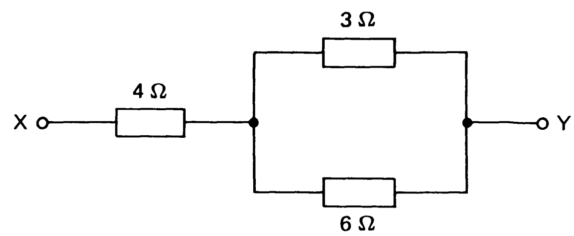
The diagram shows two resistors connected in parallel. Which of the following statements is/are correct?
(1) $I_1 = I_2 - I_3$
(2) $3I_2 = 5I_3$
(3) The potential difference across the 5 Ω resistor is equal to the potential difference across the 3 Ω resistor

Solution 12.3

[In a parallel circuit the potential difference across each resistor is the same, therefore $I_2 \times 3 = I_3 \times 5$. $I_1 = I_2 + I_3$]

Answer D

Example 12.4



In the given circuit, the effective resistance, in ohms, between X and Y is

A 4.5 **B** 5 **C** 6 **D** 8.5 **E** 13

Solution 12.4

[For resistors in parallel $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \therefore \frac{1}{R} = \frac{1}{3} + \frac{1}{6} = \frac{3}{6} = \frac{1}{2} \therefore R = 2\ \Omega$.

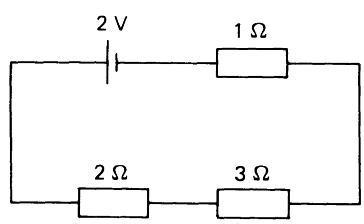
Total resistance = 4 + 2 = 6 Ω.

You may find it easier to remember the formula for two resistances in parallel as

$R = \frac{R_1 \times R_2}{R_1 + R_2}$, i.e. $\frac{\text{Product}}{\text{Sum}} = \frac{3 \times 6}{3 + 6} = 2\ \Omega$]

Answer **C**

Example 12.5



The potential difference, in V, across the 3 Ω resistor, is

A $\frac{1}{9}$ **B** $\frac{1}{2}$ **C** 1 **D** $\frac{6}{5}$ **E** 2 (AEB)

Solution 12.5

[The total resistance is 6 Ω. $V = IR \therefore 2 = I \times 6$ where I is the current in the circuit. Hence $I = \frac{1}{3}$ A. For the 3 Ω resistor $V_{3\Omega} = I \times 3 = \frac{1}{3} \times 3 = 1$ volt]

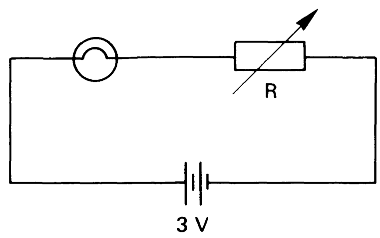
Answer **C**

Example 12.6

(a) Define resistance.

(b) The diagram shows an incomplete circuit for an experiment to investigate how the resistance of a torch bulb varies with the current flowing through it.

(i) Add to the circuit diagram an ammeter for measuring the current through the bulb and a voltmeter for measuring the p.d. across the bulb.



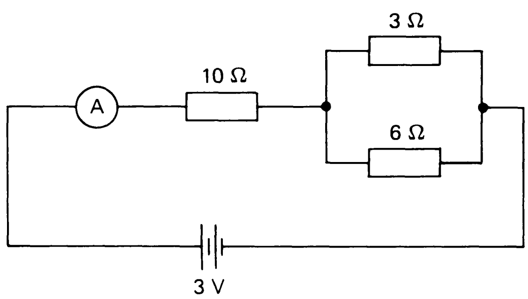
(ii) State clearly how you would obtain the readings needed to carry out the investigation.

(iii) How would you calculate the resistance of the bulb?

(iv) If the bulb is 2.5 V and takes 0.25 A at its working temperature, calculate the resistance of the bulb at the working temperature.

(v) The resistance of the bulb when the filament is cold is 5 ohm. Sketch the graph you would expect to obtain if you plotted resistance against current for the bulb.

(c) The diagram shows an electrical circuit containing a battery of e.m.f. 3 V, an ammeter of negligible internal resistance and three resistors with resistances shown.



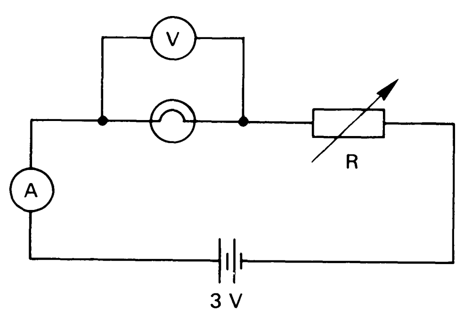
What is (i) the resistance of the parallel combination? (ii) the reading on the ammeter and (iii) the potential difference across the 3 ohm resistor?

Solution 12.6

(a) Resistance is defined by the equation

$$\text{Resistance (in ohms)} = \frac{\text{Potential difference across object (in volts)}}{\text{Current flowing through object (in amperes)}}$$

(b) (i)

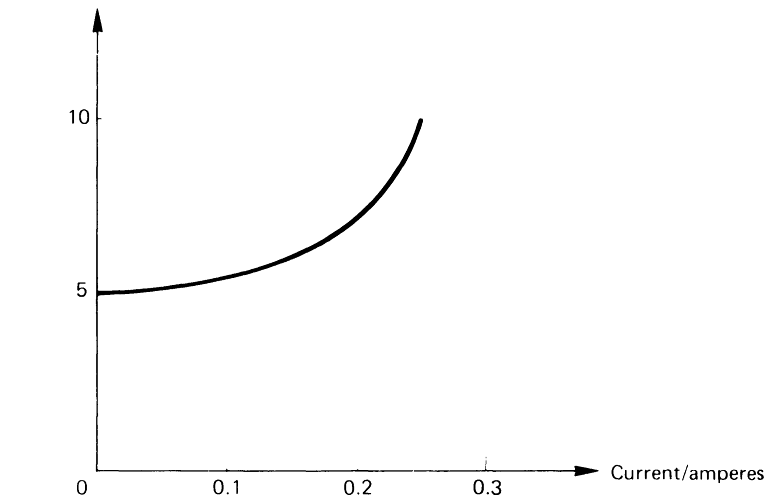


(ii) The resistance R is set at its highest value and the readings on the ammeter and the voltmeter are recorded. The value of the resistance R is decreased and the reading on each meter again recorded. Continuing in this way a series of readings are obtained. The readings are continued until the bulb is burning brightly.

(iii) The resistance for each pair of readings is calculated from the definition given in (a), that is by dividing the voltmeter reading by the ammeter reading.

(iv) $R = \frac{V}{I} = \frac{2.5}{0.25} = 10$ ohm

(v)



[The same circuit is used to investigate the voltage/current relationship for other components such as a resistor or a diode.]

(c) (i) $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \therefore \frac{1}{R} = \frac{1}{3} + \frac{1}{6} = \frac{2}{6} + \frac{1}{6} = \frac{3}{6} \therefore R = 2\ \Omega$

[Some people prefer to remember the formula as

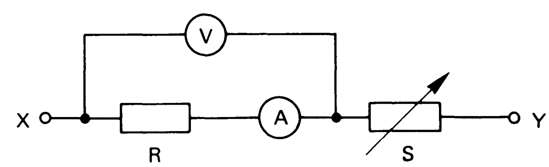
$R = \frac{R_1 \times R_2}{R_1 + R_2}$, i.e. $R = \frac{\text{Product}}{\text{Sum}} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\ \Omega$]

(ii) $I = \frac{V}{R} = \frac{\text{Voltage of cell}}{\text{Total resistance}} = \frac{3\ \text{V}}{12\ \Omega} = 0.25$ A

(iii) P.D. across 3 Ω and 6 Ω = IR = 0.25 x 2 = 0.5 V

Example 12.7

In the circuit shown, R is a fixed resistor, S is a variable resistor, V is a voltmeter of infinite resistance and A is an ammeter of negligible resistance.



With R at 10 Ω and S at 15 Ω, what resistance must be connected in parallel with R (only) to give an ammeter reading of 1.0 ampere when a potential difference of 20 V is applied between X and Y?

A 5 Ω **B** 10 Ω **C** 15 Ω **D** 20 Ω **E** 30 Ω (L)

Solution 12.7

[The voltmeter has an infinite resistance so no current flows through it and it has no effect on the calculation. The total resistance between X and Y must be 20 Ω (apply $V = IR$). Since S is 15 Ω the effective resistance across R must be 5 Ω. Let the resistor connected across R have a resistance of x ohms. Then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \therefore \frac{1}{5} = \frac{1}{10} + \frac{1}{x} \therefore \frac{1}{x} = \frac{1}{5} - \frac{1}{10} = \frac{2}{10} - \frac{1}{10} = \frac{1}{10} \text{ or}$$

$x = 10\ \Omega$. If you find it easier use $R = \dfrac{R_1 \times R_2}{R_1 + R_2}$ instead of $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2}$.]

Answer **B**

Example 12.8

Define *potential difference*. **(2 marks)**

A coil of resistance 20 Ω is joined in series with a coil X and a D.C. source of e.m.f. 15 V. If the potential difference across the 20 Ω coil is to be 10 V, calculate the resistance of X. (Neglect the resistance of the source and connecting leads.) Draw the circuit diagram; include an ammeter and a voltmeter to check this value for the resistance of X. What readings would you expect on these meters. **(6 marks)**

Calculate the energy dissipated in the 20 Ω coil in 10 minutes if the current remains steady. **(3 marks)**

If X and the 20 Ω coil had been joined in parallel, what would the current from the source have been? **(4 marks)**

(SUJB)

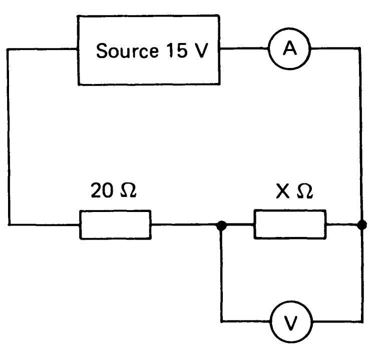
Solution 12.8

The potential difference between two points is the work done in joules in moving 1 coulomb of charge between them.

P.d. across 20 Ω coil is 10 V, therefore current through circuit = $\dfrac{10}{20}$ = 0.5 A.

10 V across the 20 Ω coil means that there is 5 V across X.

$R = \dfrac{V}{I} = \dfrac{5}{0.5} = 10\ \Omega$. X has a resistance of 10 Ω.



The voltmeter reads 5 V and the ammeter reads 0.5 A.

Energy dissipated = I^2Rt joule [see section 12.2]

$= (0.5)^2 \times 20 \times (10 \times 60)$ joule

$= 3000$ J

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{10} = \frac{1}{20} + \frac{2}{20} = \frac{3}{20}$$

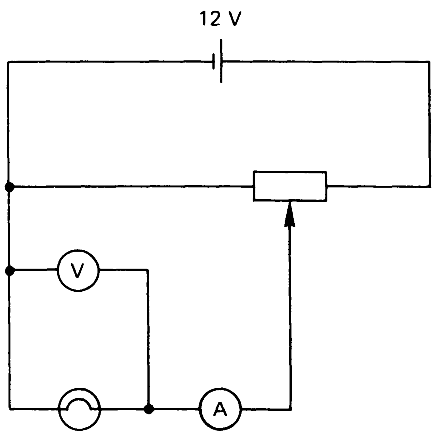
$\therefore R = \frac{20}{3}\,\Omega$ $\left[\text{or } R = \frac{\text{Product}}{\text{Sum}} \text{ (see Example 12.6)} = \frac{20 \times 10}{20 + 10} = \frac{20}{3}\,\Omega\right]$

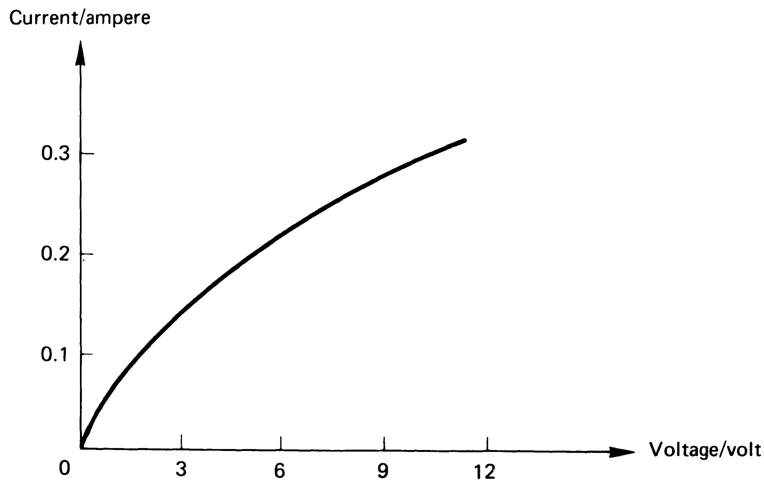
and $I = \frac{V}{R} = 15 \div \frac{20}{3} = 15 \times \frac{3}{20} = 2.25$ A

Example 12.9

A 12 V battery is used, together with a potential divider, to provide a variable voltage across a 12 V car bulb. Sketch the circuit you would use to measure the current in the lamp for various voltages across it. Sketch the graph you would expect to obtain. **(8 marks)**

Solution 12.9





[As the slider is moved from the right-hand end of the variable resistor to the left-hand end, the voltage across the bulb varies from 12 V to 0 V (this arrangement is known as a potential divider). Remember that voltmeters are connected across the appliance and ammeters in series.]

Example 12.10

An electric kettle has a heating element which is rated at 2 kW when connected to a 250 V electrical supply. Calculate

(i) the current which flows in the element when it is connected to a 250 V supply,
(ii) the resistance of the element,
(iii) the heat produced in 1 minute by the element,
(iv) the cost of running the kettle for 10 minutes a day for 360 days, if a unit of electricity costs 5p. **(10 marks)**

Solution 12.10

(i) Watts = Volts x Amps (see section 12.2)
2000 = 250 x Amps
Current = 8 A

(ii) $R = \frac{V}{I} = \frac{250}{8} = 31.2\,\Omega$

(iii) Heat produced = I^2Rt (see section 12.2)

$$= 8^2 \times \frac{250}{8} \times 60 \text{ joules}$$

$$= 120\,000 \text{ J}$$

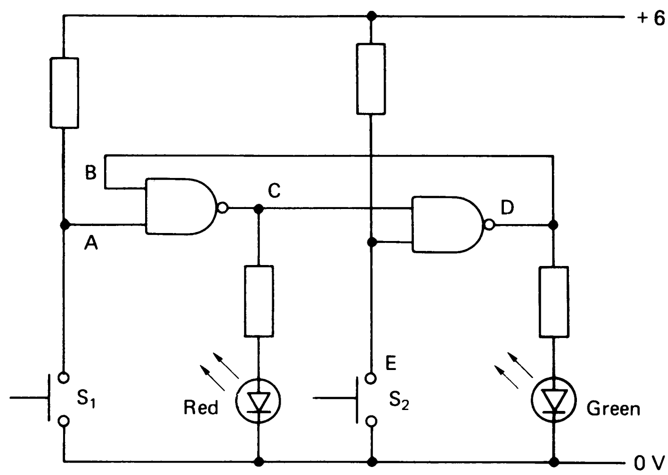
(iv) Kettle is run for $\frac{360 \times 10}{60} = 60$ hour

Number of units used = Kilowatt x Hour
= 2 x 60
= 120 kWh

Cost = 120 x 5 = 600p= £6

Example 12.11

The circuit below is designed to operate a signal on a model railway.



(a) Draw a truth table for one of the two input NAND gates. **(3 marks)**

(b) The green light is 'on'.

(i) Is the red light 'on' or 'off'? **(2 marks)**

(ii) What happens to the lights when the following sequence of events is carried out in order?

(1) switch S_1 is closed,
(2) switch S_1 is opened,
(3) switch S_2 is closed,
(4) switch S_2 is opened. **(8 marks)**

Explain your answer in each case.

(iii) Explain how the train going round the track could be made to operate the switches S_1 and S_2. **(2 marks)**

(iv) How could the above circuit be used as a burglar alarm? Explain which switch would be closed when the burglar opened a window and how the system could be reset after the window had been opened and the alarm set off. **(5 marks)**

Solution 12.11

(a)

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

(b) (i) The red light is off.

(ii) (1) The green light goes out and the red light comes on. When S_1 is closed, A goes low. As the table above shows, if A goes low, then C goes high. Both inputs to the second NAND gate are high and hence D is low and the green light is off.

(2) No change occurs. The input B is still low and hence C remains high.

(3) One of the inputs to the second NAND gate goes low, and hence D goes high, turning the green light on. B has therefore gone high, and both inputs to the first NAND gate are high, and hence C has gone low, turning the red light out.

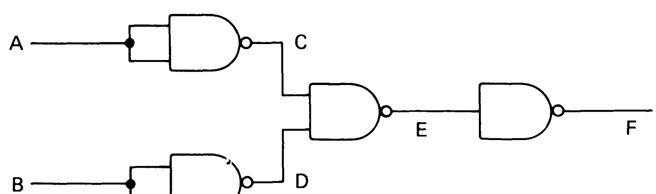
(4) No change occurs, because one of the inputs to the second NAND gate is still low and hence D remains high and the green lamp stays on.

(iii) Switches should be placed under the track such that the weight of the train going over a switch closes that switch.
[Another way would be to have a real switch in the middle of the track and a magnet tied under the train.]

(iv) Switch S_1 would be placed on a window. When the window was opened, the switch should be arranged so that it then closed. The red lamp would light showing the presence of an intruder. Closing the window, and thus closing S_1 would not switch the red light off.
The system could be reset by closing the window and momentarily depressing switch S_2.

Example 12.12

The circuit below contains four NAND gates connected together as shown.



Complete the truth table shown below.

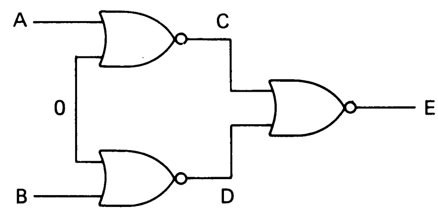
A	B	C	D	E	F
0	0				
0	1				
1	0				
1	1				

What is the resulting gate called?
Show how three NOR gates may be connected so that they form an AND gate and write the truth table for the arrangement.

Solution 12.12

A	B	C	D	E	F
0	0	1	1	0	1
0	1	1	0	1	0
1	0	0	1	1	0
1	1	0	0	1	0

The above gate is a NOR gate.



A	B	C	D	E
0	0	1	1	0
0	1	1	0	0
1	0	0	1	0
1	1	0	0	1

Example 12.13

(a) Draw a truth table for the two input NAND gate shown in Fig. 1. **(2 marks)**

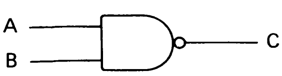


Fig. 1

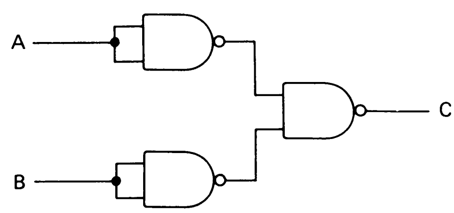


Fig. 2

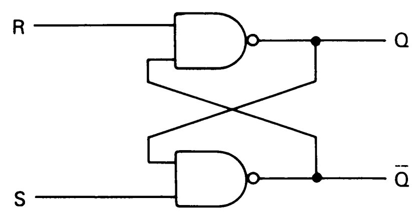


Fig. 3

(b) Three NAND gates are connected as shown in Fig. 2. Draw the truth table for the arrangement. What is the resulting gate called? **(3 marks)**

(c) Two NAND gates are connected as shown in Fig. 3. Complete the truth table shown on the next page. The initial condition is shown on the first line of the sequence and you must make each change in the sequence indicated, moving one line at a time down the table. **(4 marks)**

	R	S	Q	$\bar{Q}$
1	1	1	0	1
2	0	1		
3	1	1		
4	1	0		
5	1	1		

sequence ↓

(d) The above logic is that of the burglar system shown in Fig. 4. The alarm rings when it receives a logic 1 from the output of the NAND gate to which it is connected. A switch will close when a window in the house is opened and open again when the window is closed. Explain why
   (i) the alarm rings when one of the switches is closed, **(3 marks)**
   (ii) the alarm does not stop ringing if the burglar closes the window. **(3 marks)**

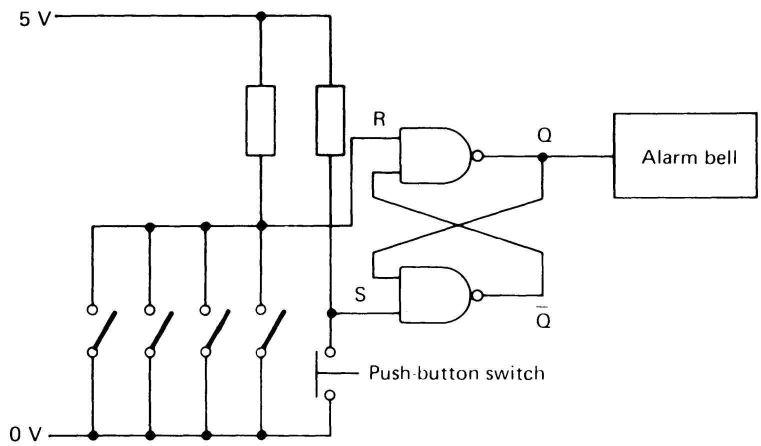


Fig. 4

(e) How can the alarm be switched off and reset? **(2 marks)**

(f) Why are two NAND gates connected as shown in Fig. 2 referred to as (i) a *bistable*, (ii) a *flip-flop*? **(3 marks)**

Solution 12.13

(a)

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

(b)

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

An OR gate

[The first two NAND gates which have their two inputs joined together are NOT gates and invert the input.]

(c)

	R	S	Q	$\overline{Q}$
1	1	1	0	1
2	0	1	1	0
3	1	1	1	0
4	1	0	0	1
5	1	1	0	1

(d) (i) When one of the switches is closed the input R goes low (logic 0). As shown in the table above when R goes to logic 0, Q goes to logic 1 and the alarm will ring.

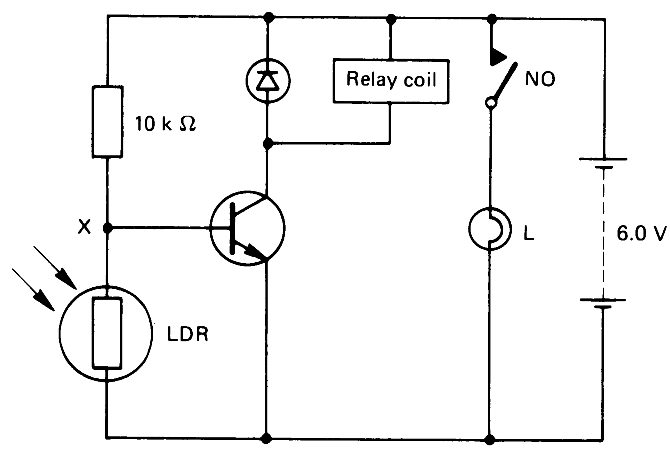
(ii) Closing the window causes the logic of R to change from logic 0 to logic 1 and as shown in the table above the output Q remains at logic 1 and the alarm continues ringing.

(e) Close all the windows, then push and release the push-button switch.

(f) It is called a bistable because it has two stable states. The outputs are either logic 0 and logic 1, or logic 1 and logic 0. It is called a flip-flop because it flips from one state to the other when R goes from logic 1 to logic 0 and 'flips' back again when S goes from logic 1 to 0.

Example 12.14

In the circuit shown below the lamp L is lit when the light falling on the LDR falls below a certain intensity.



(i) What do the letters 'LDR' stand for? **(2 marks)**

(ii) What do the letters 'NO' stand for? **(2 marks)**

(iii) The resistance of the LDR varies between 300 Ω and 10 kΩ. What is the voltage at the point X when its resistance is
(a) 300 Ω
(b) 10 kΩ? **(6 marks)**

(iv) What change occurs in the current flowing from the collector to the emitter of the transistor as the light falling on the LDR suddenly decreases in intensity so that the resistance of the LDR changes from 300 Ω to 10 kΩ? **(2 marks)**

(v) Explain why this change in current switches the lamp on. **(3 marks)**

Solution 12.14

(i) Light-dependent resistor.

(ii) Normally open.

(iii) Let I be current flowing through the 10 kΩ resistor and then

(a) $V = IR$

$$6 = I(10\,000 + 300) \therefore I = \frac{6}{10\,300}\text{ A}$$

$$\text{Voltage drop across 10 k}\Omega\text{ resistor} = \frac{6}{10\,300} \times 10\,000 = 5.82\text{ V}$$

$V_X = 6.0 - 5.82 = 0.18$ V

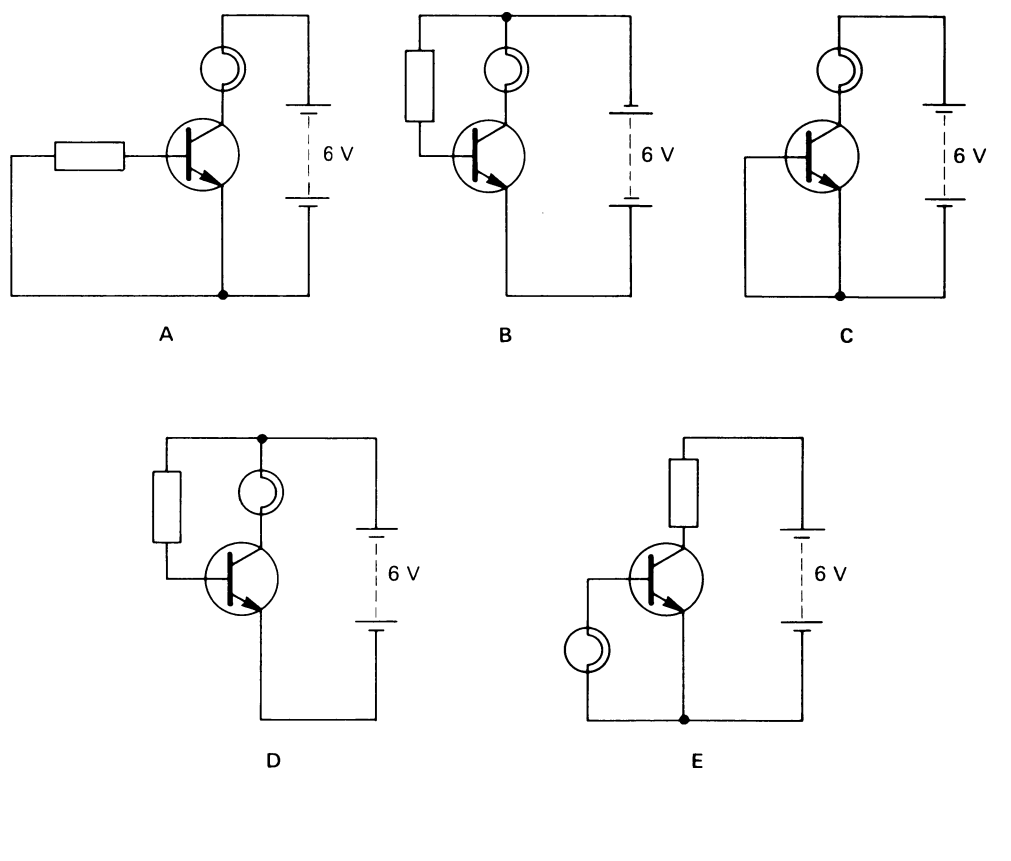
(b) If the resistance of the LDR is equal to the resistance of the resistor then the voltage drop across each will be the same, namely 3.0 V. Hence V_X = 3.0 V.

(iv) The voltage at X changes from 0.18 V to 3 V and the transistor switches on. A current flows from the collector to the emitter.

(v) The current flowing from the collector to the emitter flows through the relay. The switch closes and the lamp lights.

Example 12.15

In only one of the circuits below the lamp lights. Which circuit is it?



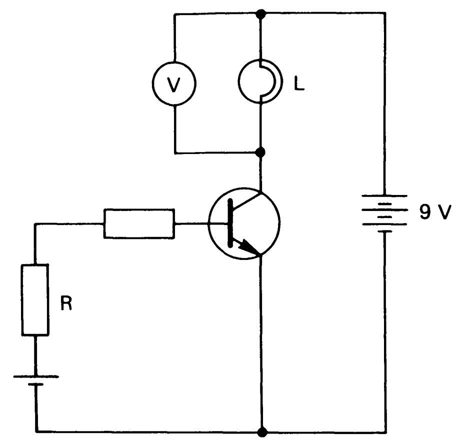
Solution 12.15

[A small current flows from the base to the emitter and this switches 'on' the transistor causing a large current to flow from the collector to the emitter.]

<u>Answer **D**</u>

Example 12.16

In the circuit below a voltmeter V is connected across lamp L.



Which of the following changes *could* occur at lamp L and voltmeter V, if the resistor R is reduced in value?

	Lamp *L*	Reading on voltmeter *V*
A	goes out	decreases
B	goes out	increases
C	no change	no change
D	lights up	decreases
E	lights up	increases

(SEB)

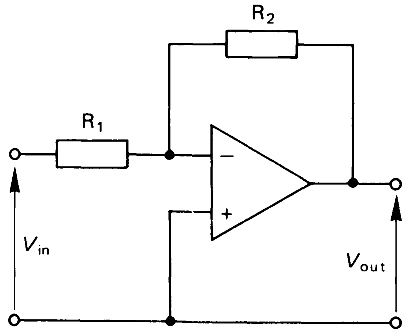
Solution 12.16

[If the current in the resistor R is increased the current in the base of the transistor will increase. This could switch the transistor on and the lamp could light. If this happened a current would flow in the lamp and the voltage across it would increase.]

Answer E

Example 12.17

An operational amplifier is connected as shown in this diagram.



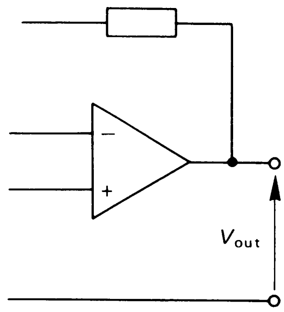
Write down the equation which links the output voltage (V_{out}) and the input voltage (V_{in}) with the two resistances. **(3 marks)**

The power supplies for the operational amplifier, which are not shown on the circuit diagram, are ± 9 V.

(a) If the values of the two resistors in the above circuit are:
R_1 = 2.2 kΩ
R_2 = 22 kΩ;
calculate the output voltage when:
(i) the input voltage is + 0.5 V,
(ii) the input voltage is + 1.0 V. **(4 marks)**

(b) Complete the circuit diagram to show how you would use the operational amplifier to amplify an input voltage of + 0.1 V to an output voltage of + 2.3 V.
Calculate the value of any additional components and indicate the values on the circuit diagram. **(5 marks)**

(AEB)



Solution 12.17

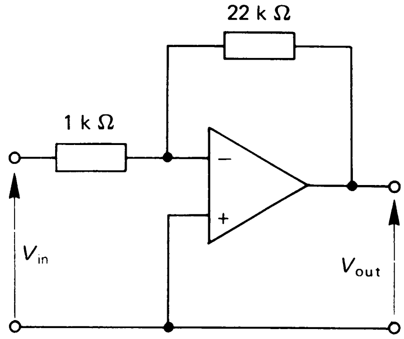
$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_1}$$

(a) (i) $\frac{V_{out}}{0.5} = \frac{22}{2.2} \Rightarrow V_{out} = 5$ volt

(ii) $\frac{V_{out}}{1.0} = \frac{22}{2.2} \Rightarrow V_{out} = 10$ volt

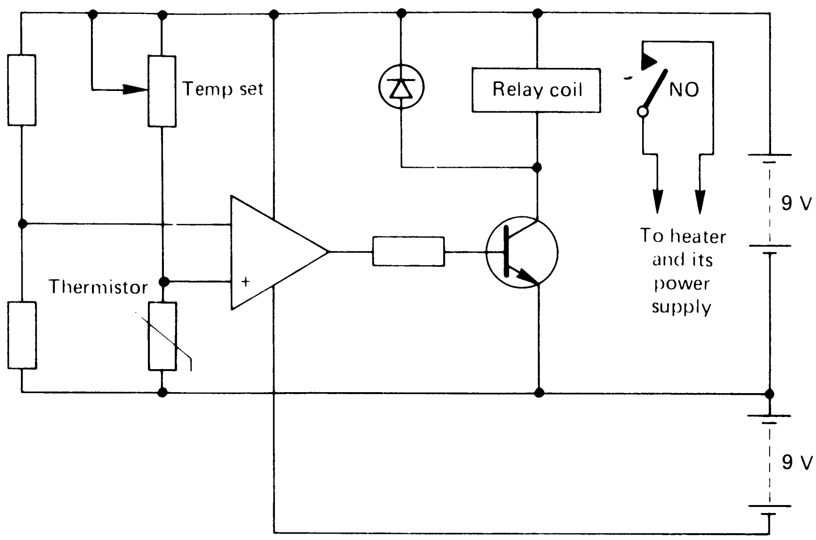
(b) $\frac{2.3}{0.1} = \frac{22}{R_1}$

$R_1 = 1$ kΩ



Example 12.18

The circuit shows a temperature sensing device using an operational amplifier. The resistance of the thermistor decreases with an increase in temperature.



If the temperature goes from high to low

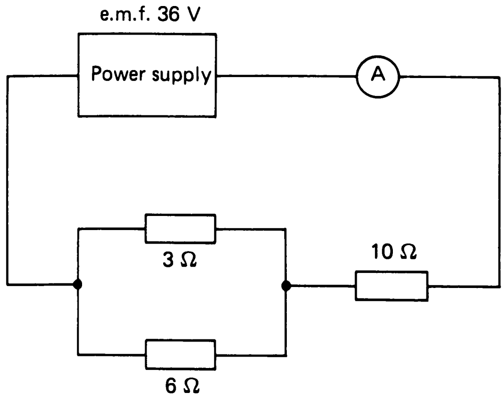
(a) What change takes place in the output of the operational amplifier? **(3 marks)**
(b) What happens to the current in the collector circuit of the transistor? **(3 marks)**
(c) Why does the heater switch on? **(3 marks)**
(d) Why is the diode connected across the relay coil as shown in the diagram? **(3 marks)**

Solution 12.18

(a) The output goes from negative to positive (see section 12.4g).
(b) The transistor switches 'on' and a large current flows in the collector circuit (see section 12.4a).
(c) The current of the collector circuit energises the relay coil which operates the switch in the heater circuit.
(d) It protects the transistor when it switches off. When the current in the coil suddenly falls to zero, there is a large e.m.f. induced in the coil [see section 13.4] and this could destroy the transistor.

12.6 Have You Mastered the Basics?

1. Can you define a coulomb, potential difference, a volt, resistance, an ohm, e.m.f. and kilowatt-hour?
2. Can you write an equation for calculating the power dissipated in a resistor?
3. Can you state Ohm's law?
4. Do you understand the laws for series and parallel circuits concerning (i) the total resistance, (ii) the relationship between potential differences and (iii) the relationship between currents?
5. A power supply of e.m.f. 36 V and negligible internal resistance is connected in a circuit as shown in the diagram. What is
   (i) the current flowing in the ammeter,



(ii) the current through the 3 Ω resistor,
(iii) the p.d. across the 10 Ω resistor?

6. How much does it cost to run a 2 kW fire for 3 hours if electricity costs 5p per kilowatt-hour?
7. Can you describe how a transistor may be used as a switch?
8. Can you describe circuits using a transistor to make (i) a burglar alarm, (ii) temperature-sensitive, light-sensitive and time-delay switches?
9. Can you draw truth tables for the different logic gates and for a combination of logic gates?
10. Can you describe how the gain of an amplifier may be investigated using a signal generator and oscilloscope?
11. Can you describe how to use an operational amplifier in comparator mode to switch a heater on and off?

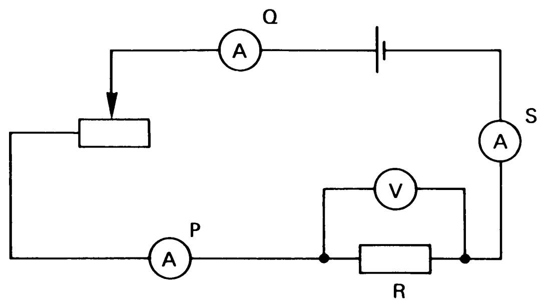
12.7 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See sections 12.1 and 12.2.
2. See section 12.2.
3. See section 12.1(b).
4. See section 12.1(c) and (d).
5. (i) Use $1/R = 1/R_1 + 1/R_2$ or $R = \dfrac{\text{Product}}{\text{Sum}}$ (see Example 12.4) to calculate the equivalent resistance of the 3 Ω and 6 Ω in parallel. Hence calculate the total resistance of the circuit (12 Ω). Use $E = I \times$ (total resistance) see section 12.1(a), to calculate the current (3 A).
   (ii) The current divides in the ratio of the resistances (see Example 12.2) so 2 A passes through the 3 Ω resistor.
   (iii) Use $V = IR$, potential difference = 30 V.
6. Energy used = 2 x 3 kWh = 6 kWh. Cost = 6 x 5 = 30p.
7. See section 12.4(a) and Examples 12.15 and 12.16.
8. See Examples 12.11, 12.14 and 12.15. Also sections 12.4(a), (b) and (e).
9. See section 12.4(c) and Examples 12.11, 12.12 and 12.13.
10. See section 12.4(g).
11. See section 12.4(g) and Example 12.18.

12.8 Questions

Question 12.1

Directions summarised				
A	**B**	**C**	**D**	**E**
1, 2, 3	**1, 2**	**2, 3**	**1**	**3**
correct	only	only	only	only



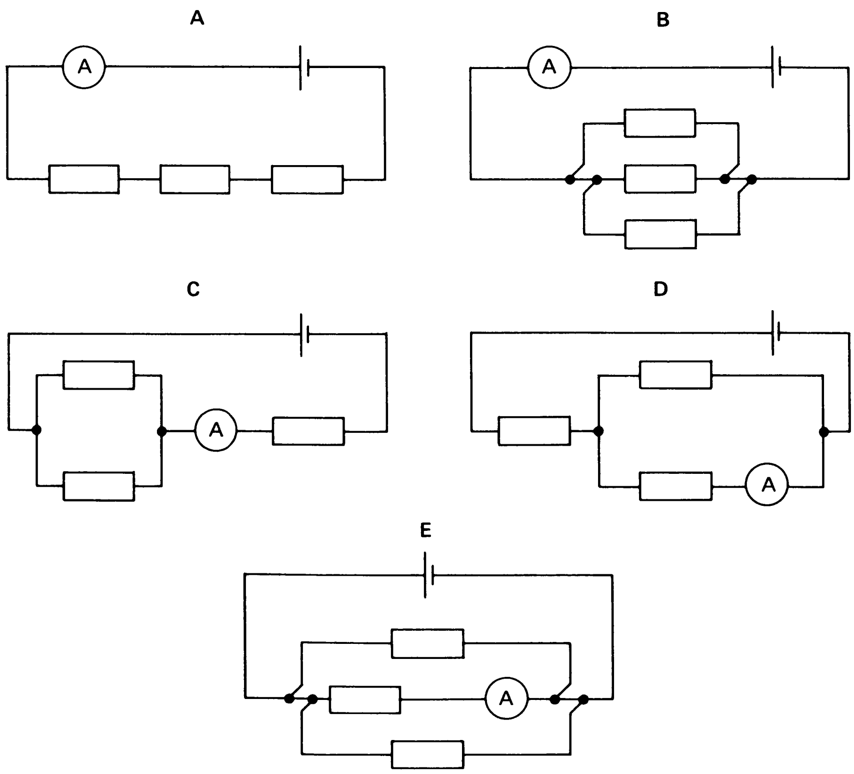
The circuit above is set up to measure the resistance R. V is a voltmeter and P, Q and S are ammeters. Neglecting the current flowing through V, the current through R is measured by ammeter

1 P **2** Q **3** S (AEB)

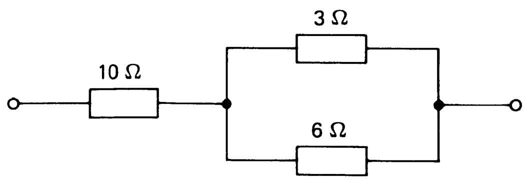
Question 12.2

A 2 volt accumulator of negligible internal resistance is connected to an ammeter and three 1 Ω resistors as shown. In which one of the arrangements does the ammeter give the largest reading?

(AEB)



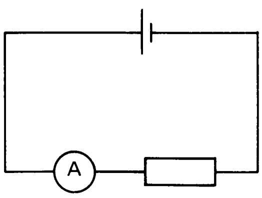
Question 12.3

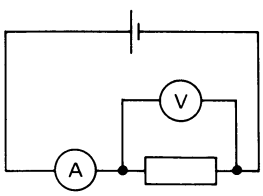


The effective resistance, in Ω, of the above circuit is

A $10\frac{1}{2}$ **B** 12 **C** 13 **D** $14\frac{1}{2}$ **E** 19 (AEB)

Question 12.4





A one-metre length of resistance wire, an ammeter and a 2.0-V cell are connected in series as shown in the figure. (The ammeter and the cell have negligible resistance.)

(a) The ammeter reads 0.50 A. Calculate the resistance of the resistance wire.

(b) The resistance wire is replaced by a one-metre length of wire of the same material but of twice the cross sectional area. What is

(i) the resistance of this wire,

(ii) the new ammeter reading?

(c) A voltmeter is now connected across the resistance wire as shown in the figure.

Will the ammeter reading increase, decrease or remain the same? Give a reason for your answer. **(6 marks)**

(L)

Question 12.5

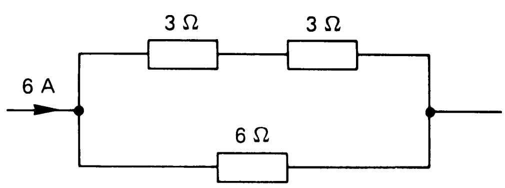
(a) Show how you would connect three resistors, each of resistance 6 Ω, so that the combination has resistance (i) 9 Ω, (ii) 4 Ω. **(4 marks)**

In case (i) the combination is connected across the terminals of a battery of e.m.f. 12 V and negligible internal resistance. Calculate (iii) the current through each resistor, (iv) the p.d. across each resistor, (v) the total power consumed. **(6 marks)**

(b) Describe how you would measure the resistance of a coil of wire by the method of substitution. **(5 marks)**

(SUJB)

Question 12.6



(a) The diagram shows a network of resistors.

(i) What current flows in the 6 Ω resistor?

(ii) What charge passes through the 6 Ω resistor in 3 s?

(iii) What is the p.d. across the 6 Ω resistor? **(3 marks)**

(b) A 3 kW, 250 V electric fire is connected across a 250 V mains.

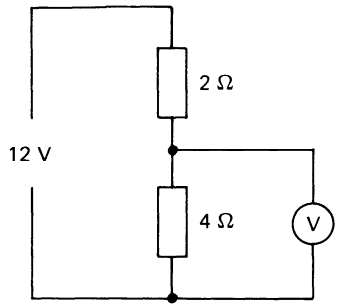
(i) How much current does the fire take?

(ii) What energy does it consume if left on for 5 hours?

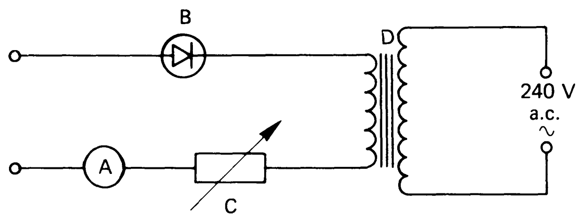
(iii) How much would it cost to leave it on for 5 hours if the cost of a unit of electrical energy (a kWh) is 6p? **(5 marks)**

Question 12.7

(a) A potential divider is constructed as shown in the diagram. What is the reading on the high resistance voltmeter?

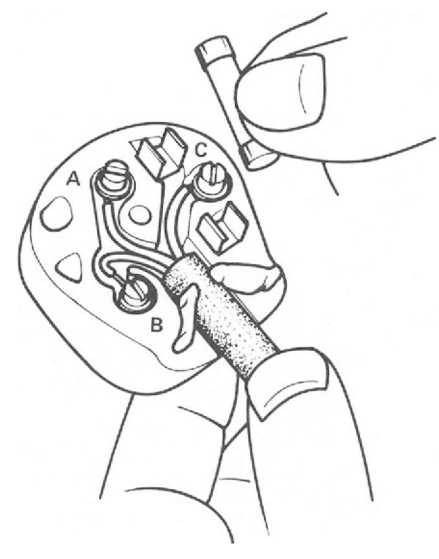


(b) The diagram shows a circuit which could be used to charge a 12 V car battery.



(i) State the name of each of the components labelled A, B, C and D.
(ii) State the function performed by each of the components A, B, C and D. **(10 marks)**

Question 12.8



(a) The diagram shows the type of 3-pin electrical plug with the cover removed used in the United Kingdom. The electric cable connected to the plug contains three wires with colour-coded insulation, namely brown, blue and green/yellow stripe. Identify each of the colour-coded wires by stating to which of the terminals A, B or C in the diagram they should be connected. **(2 marks)**

Identify the terminal through which no current passes in normal circumstances. What is the purpose of the wire connecting this terminal to an electrical appliance such as an electric fire? Describe how it works.

What is the purpose of the device, held above C in the diagram, that is about to be inserted into the plug? Describe how it works. **(10 marks)**

(b) An electric cooker has the following specification:

Item	*No. of items*	*Power of item*/W
Ceramic hob, *small* heating area	2	1250
Ceramic hob, *large* heating area	2	1500
Grill	1	2000
Oven	1	2500

Calculate how much energy (in kWh) the cooker will use in 30 minutes when all the items are used simultaneously.

How much will it cost to run the cooker during this time if electrical energy costs 6p for 1 kWh?

Calculate the maximum current that will be carried by the cable connecting this cooker to a 250-V mains supply. **(8 marks)**

(L)

Question 12.9

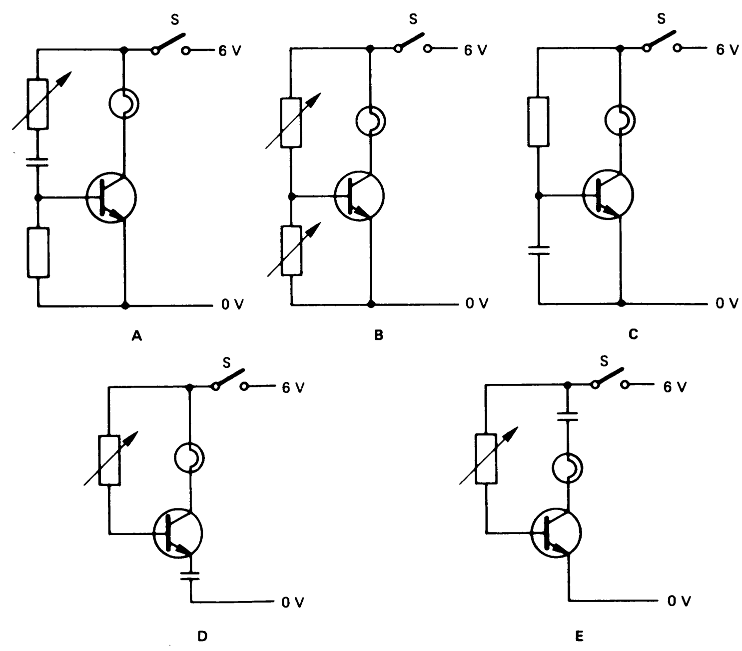
(a) A sealed box has two terminals on it and nothing else is visible. It may contain any one of the following: a diode, a coil of nichrome wire, a torch bulb.
  (i) Draw the circuit you would use to enable you to obtain readings from which you could draw the current–voltage characteristic for the device that is in the box.
  (ii) Outline the experiment you would carry out to determine which of the three components is in the box and sketch the graphs you would expect to obtain for each of the three devices. **(13 marks)**

(b) Three fuses are available rated at 2 A, 10 A and 13 A. Which fuse would you choose for an electric fire rated at 3 kW, 250 V? Show how you arrive at your answer. **(4 marks)**

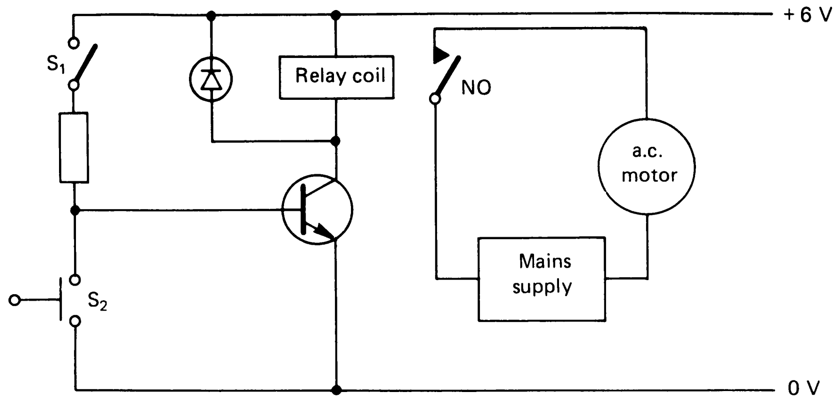
(c) 60 joule of heat were dissipated in a resistor when 20 C flowed for 5 s. Calculate
  (i) the potential difference across the resistor,
  (ii) the resistance of the resistor,
  (iii) the average power dissipated in the resistor. **(8 marks)**

Question 12.10

Which of the circuits below could be used to arrange for the lamp to light about 5 seconds after the switch S is closed?



Question 12.11



The circuit shown in the diagram is designed to switch the motor on and off.

(i) With the switches in the position shown is

(a) the motor on or off? **(2 marks)**

(b) a current flowing in the collector of the transistor? **(2 marks)**

(ii) Switch S_1 is closed and switch S_2 left open. Is the motor on or off? Explain your answer. **(4 marks)**

(iii) S_2 is now closed (S_1 being left closed). What changes take place

(a) in the current in the collector,

(b) in the operation of the motor? **(3 marks)**

(iv) The switch S_2 is replaced by an LDR. Will the motor be on or off

(a) in bright daylight,

(b) in darkness? Explain your answers. **(4 marks)**

Question 12.12

(a) In the circuits shown in Fig. 1 a switch which is open represents the logic state 0 and a switch which is closed represents the logic state 1. The lamp is lit when the output is logic state 1. What type of gate is represented by the circuits in Fig. 1(i) and (ii)? **(4 marks)**

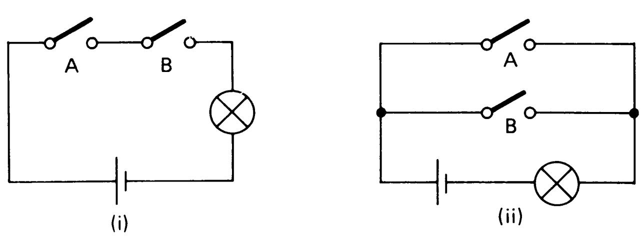


Fig. 1

(b) Draw the truth table for the combination of 3 NOR gates shown in Fig. 2, and state the name of the gate resulting from such a combination. **(4 marks)**

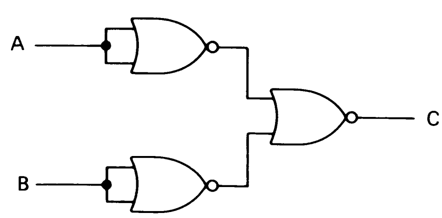
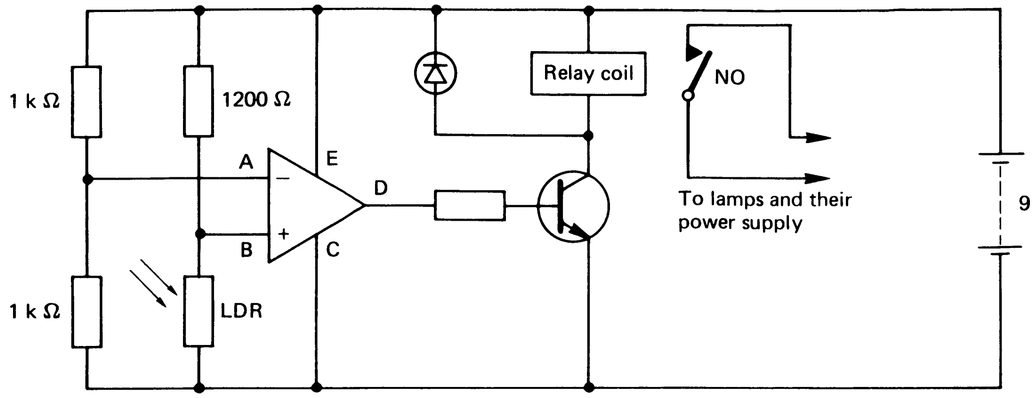


Fig. 2

Question 12.13

The circuit diagram shows a circuit for automatically switching on lights when it gets dark. When light is shining on the LDR its resistance is 600 Ω.



(a) Which of the connections labelled A B C D E is
   (i) the non-inverting input, **(1 mark)**
   (ii) the output? **(1 mark)**

(b) What is the voltage at B when the resistance of the LDR is 600 Ω **(3 marks)**

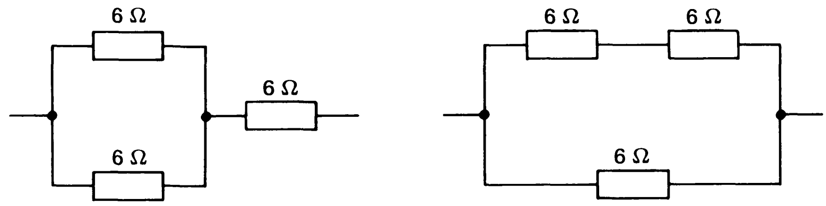
(c) When it is dark the resistance of the LDR is 2400 Ω. What is the voltage at B when it is dark? **(3 marks)**

(d) Explain what happens in this circuit when the light shining on the LDR goes out. **(5 marks)**

(e) Why is there a resistor in the base circuit of the transistor? **(2 marks)**

12.9 Answers and Hints on Solutions to Questions

1. The current flowing at all points in a series circuit is the same. All the ammeters are in series with the resistor.
   Answer A
2. As resistors are added in parallel the total resistance goes down (see section 12.1(d)) **B** and **E** have the lowest resistance. The ammeter in **E** registers the current through one of the resistances whilst the ammeter in **B** registers the sum of the currents through the 3 resistors.
   Answer **B**
3. Use $1/R = 1/R_1 + 1/R_2$ to get equivalent resistance of 3 Ω and 6 Ω in parallel. Total resistance = (10 + 2) = 12 Ω.
   Answer B
4. (a) Use the definition of resistance in section 12.1(a). Resistance = 4 Ω.
   (b) (i) The new wire has twice the cross sectional area and this is equivalent to joining two of the original wires in parallel. New resistance = 2 Ω. (ii) 1 A.
   (c) Slight increase. The voltmeter is in parallel with the resistor and hence the total resistance of the circuit is decreased (see sections 12.1(d) and 12.5, Example 12.4) and the current increases. If the voltmeter resistance is very high the increase will be negligible.
5. (a) (i) and (ii) See Fig. 12.11. (iii) Use $V = IR$, current in each 6 Ω resistor in parallel arrangement is $\frac{2}{3}$ A and in the other 6 Ω is $\frac{4}{3}$ A. (iv) p.d.'s are 4 V and 8 V. (v) Power = I^2R (see section 12.2) = $(\frac{4}{3})^2 \times 9 = 16$ W (alternatively the value of I^2R could be worked out for each resistor in turn and the result added up but this would take longer and the method given above is therefore preferred).



Combined resistance = 9 Ω

(i)

Combined resistance = 4 Ω

(ii)

Figure 12.11

(b) Put the unknown resistance X in series with a milliameter and a source of e.m.f. sufficient to give nearly a full scale deflection on the meter. Remove X and substitute a resistance box. Adjust the resistance of the resistance box until the reading on the meter is the same as before. The method is only accurate to the nearest ohm, but the accuracy may be increased by plotting a graph of meter reading against standard resistance and reading off the unknown quantity from the graph.

6. (a) The arrangement is equivalent to two 6 Ω resistors in parallel. (i) The current divides equally, 3 A flowing in each branch. (ii) 3 C/s, hence in 3 s charge is 9 C. (iii) Use $V = IR$ (see section 12.1); p.d. = 18 V.
   (b) (i) Use watts = volts x amps (section 12.2), current = 12 A, (ii) 3000 J/s; in 5 hours, 54 MJ, (iii) cost = kWh x 6 = 3 x 5 x 6 = 90p.
7. (a) Current in resistors = 2 A. Use $V = IR$ = 2 x 4 = 8 V.
   (b) (i) A is an ammeter, B a diode, C a variable resistor and D is a step-down transformer. (ii) A records the current, B will only pass current in one direction, C enables the current to be adjusted, D reduces the p.d. to about 15 V.
8. (a) The live brown wire to C, the blue neutral wire to B and the Earth yellow/green striped wire to A. No current passes in A in normal circumstances (see section 12.3).
   (b) $\{(2 \times 1.25) + (2 \times 1.5) + 2 + 2.5\} \times \frac{1}{2} = 5$ kWh. Cost = 30p. Maximum power = 10 kW, use Watts = Volts x Amps (see section 12.2), maximum current = 40 A.
9. (a) The experiment is described in Example 12.6. Alternatively the circuit in Example 12.9 could be used. The graph for a torch bulb is drawn in Example 12.9. The graph for the coil will be a straight line through the origin (it obeys Ohm's law), the diode will be discovered by turning the box round and connecting the opposite ends to the battery. In one direction there will be a very high resistance and very little current will flow. For negative (reversed) voltages the current will be very small and the graph is very nearly horizontal just below the voltage axis.
   (b) Current is 12 A and hence the 13 A fuse will be needed.
   (c) (i) Voltage is J/C (see section 12.1), hence p.d. is 3 V. (ii) Current is 4 A, hence resistance is 0.75 Ω. (iii) Power is (60 J)/(5 s) = 12 W.
10. Answer C.
   The lamp will light when a current flows in the base-emitter circuit of the transistor and switches the transistor on. In C, this will happen after the capacitor has charged up.
11. (i) (a) off, (b) No.
   (ii) On. The current flowing in the base-emitter circuit of the transistor switches the transistor on. The current in the collector circuit operates the relay and the motor switches on.
   (iii) When S_2 is closed the transistor switches off. (a) There is no current in

the collector circuit and the relay switch is open. (b) The motor is off.

(iv) (a) In daylight the resistance of the LDR will be low and the transistor will be switched off. In darkness the resistance of the LDR will be high and the transistor will be switched on and the motor will be on.

12. (a) (i) is an AND gate and (ii) An OR gate.
    (b) You must draw the truth table. The combination is an AND gate.
13. (a) (i) B, (ii) D.
    (b) 3 V.
    (c) 6 V.
    (d) B's voltage goes from 3 V to 6 V and D goes from 'low' to 'high' (see section 12.4(g) and Example 12.18). The transistor switches on and the resulting current in the relay coil operates the switch and lights the lamps.
    (e) It limits the base current to prevent the transistor being destroyed.

13 Magnetism, Electromagnetism, Motors, Dynamos, Transformers and Cells

13.1 Magnetism

The region of space around a magnet where its magnetic influence may be detected is known as a magnetic field, and contains something we call magnetic flux. The flux patterns may be shown by sprinkling iron filings around a magnet and gently tapping the surface, or by using plotting compasses.

Magnets attract unmagnetised pieces of iron and steel. To discover whether a bar of iron or steel is magnetised, bring each end up to the N-pole of a suspended magnet. If one end repels the N-pole the bar is magnetised (like magnetic poles repel each other). If both ends attract the N-pole, the bar is not magnetised.

A bar of magnetic material may be magnetised by putting it in a solenoid carrying a current. It may be demagnetised by withdrawing it slowly from a solenoid in which an alternating current is flowing.

13.2 Electromagnetism

When a conductor carries a current it produces a magnetic field. The effect is used in electromagnets which are usually solenoids wound round soft iron. The direction of the field may be found by the 'screw rule' which states that if a right-handed screw is turned so that it moves forwards in the same direction as the current, its direction of rotation gives the direction of the magnetic field.

13.3 Electric Motor and Dynamo (see also Examples 13.4 and 13.9)

These basically consist of a coil which can rotate in a magnetic field. In the motor a current flows in the coil and the resulting forces on the coil cause it to rotate. A split ring commutator reverses the direction of the current every half revolution thus ensuring continuous rotation. In the dynamo the coil is rotated and as the wires cut the lines of flux an e.m.f. is induced across the ends of the coil. In an a.c. dynamo the ends of the coil are connected to slip rings. If a commutator replaces the slip rings the output is d.c.

13.4 Faraday's Law and Lenz's Law

(i) Faraday's Law

Whenever an e.m.f. is induced in a conductor due to the relative motion of the conductor and a magnetic field, the size of the induced e.m.f. is proportional to the speed of the relative motion.

Alternatively, the law may be stated:
Whenever there is a change of magnetic flux linked with a circuit an e.m.f. is induced. The e.m.f. is proportional to the rate of change of flux linked with the circuit.

(ii) Lenz's Law

The direction of any current induced is such that it opposes the motion or change producing it.

13.5 Transformers

A primary and secondary coil are wound on a continuous core made of a magnetic alloy (cores of modern alloys have largely replaced soft iron cores). The alternating current flowing in the primary causes a changing flux in the secondary and hence an induced e.m.f. across the secondary coil. Most modern transformers are made so that there is negligible magnetic flux loss and

$$\frac{\text{e.m.f. across secondary}}{\text{e.m.f. across primary}} = \frac{\text{Number of turns on secondary}}{\text{Number of turns on primary}}$$

$$\text{Efficiency} = \frac{\text{Power out}}{\text{Power in}} = \frac{(VI)_{\text{secondary}}}{(VI)_{\text{primary}}}$$

Electricity is transmitted across the countryside on the National Grid. High voltages are used as low voltage power lines are wasteful and inefficient because of the large currents needed.

13.6 Left-hand Rule (for the motor effect)

Hold the first finger, second finger and thumb of the left-hand mutually at right angles, so that the *F*irst finger points in the direction of the magnetic *F*ield, the seCond finger in the direction of the Current, then the *THuMb* points in the direction of the *THrust* or *Motion*.

13.7 Right-hand Rule (for the dynamo effect)

Hold the first finger, second finger and thumb of the right-hand mutually at right angles, so that the *First* finger points in the direction of the *Field*, the thu*M*b in the direction of the *Motion*, then the se*C*ond finger points in the direction of the induced *C*urrent.

13.8 Cells

A simple cell consists of zinc and copper electrodes in dilute sulphuric acid. The e.m.f. falls quickly in use because a layer of bubbles of hydrogen form on the copper plate. This is known as polarisation. In the dry (Leclanché type) cell the manganese dioxide prevents polarisation.

A car battery is a secondary cell (one which can be recharged). The lead–acid accumulator has a very low internal resistance which means that the battery can supply a large current without an appreciable drop in the p.d. across its terminals. The plates must be kept covered by 'topping-up' with distilled water.

Rechargeable dry cells also have a low internal resistance, and are damaged if their terminals are shorted, because of the large currents which then flow.

13.9 Worked Examples

Example 13.1

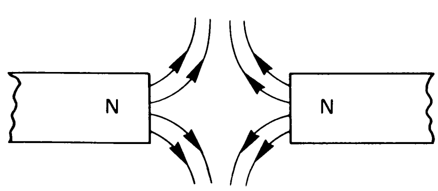
(a) Two bar magnets are placed on a horizontal table with their N-poles facing each other. Sketch the lines of force between the poles. **(3 marks)**

(b) Explain the following:
  (i) the strength of a magnet cannot be increased beyond a certain limit;
  (ii) an increase in temperature weakens or destroys the magnetism of a magnet. **(4 marks)**

(c) Explain why soft iron rather than steel is used in electromagnets. State two ways of increasing the strength of an electromagnet. **(3 marks)**

Solution 13.1

(a)



(b) Both statements may be explained by the domain theory of magnetism. Domains are groups of atoms which behave as tiny magnets.

  (i) When a magnet is made, the domains are aligned so that all the tiny magnets point in the same direction. Once they are all aligned the magnet cannot be further magnetised.

(ii) When a substance is heated the molecules vibrate with greater energy. This increased vibration destroys the alignment of the tiny magnets and the magnetism decreases.

(c) Soft iron is more easily magnetised than steel and loses its magnetism more easily. When the magnetising current is switched off the soft iron would lose its magnetism but the steel would retain some magnetism. Increase the number of turns, increase the current.

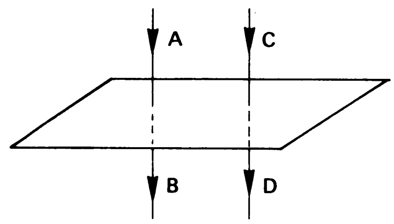
Example 13.2

The diagram shows two long vertical wires passing through a horizontal piece of card.

(i) Draw the magnetic field pattern that will result when a current is flowing in **AB** in the direction shown, but no current is flowing in CD.

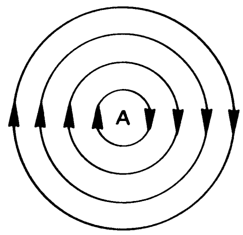
(ii) Draw the resultant magnetic field pattern that results when currents of the same magnitude are flowing in both wires in the directions shown.

(iii) What forces act on the wires in (ii) and in what direction do they act? **(8 marks)**

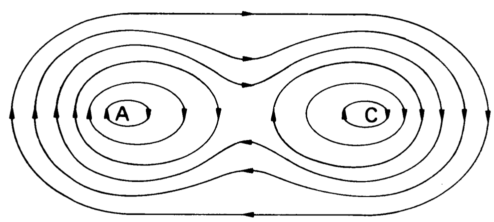


Solution 13.2

(i)



(ii)



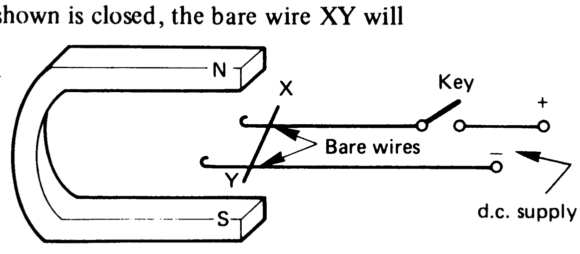
(iii) [The lines of force may be considered to be in tension, each is catapulted towards the other.]

Each wire has a force on it which is acting directly towards the other wire. The wires are attracted to each other.

Example 13.3

When the key in the circuit shown is closed, the bare wire XY will

A rise up off the bare wires
B press down more strongly
C move to the left
D move to the right
E remain stationary



(AEB)

Solution 13.3

[Use the left-hand rule. *F*irst finger for *F*ield, Se*C*ond finger for *C*urrent (+ to –) and Thu*M*b for *M*otion. The wire will move to the right.]

<u>Answer **D**</u>

Example 13.4

(a) Draw a labelled diagram of a d.c. electric motor. **(6 marks)**

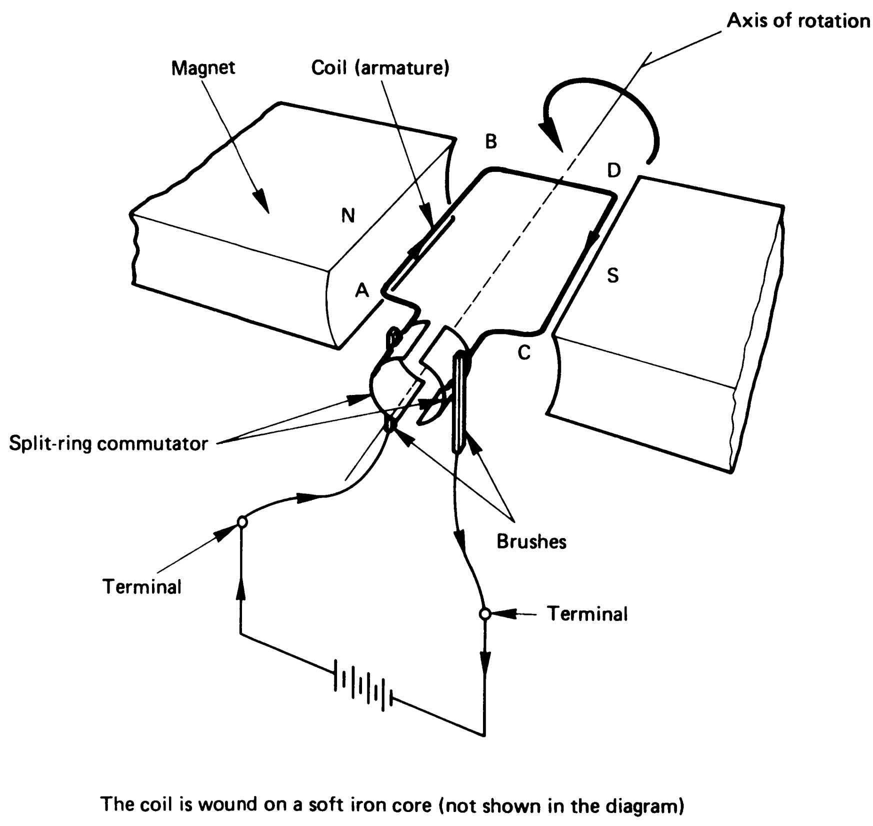
(b) Explain why the coil of the motor rotates continuously when the motor is connected to a d.c. supply. **(6 marks)**

(c) (i) What would happen to the direction of rotation if the direction of the current in the coil were reversed at the same time as the direction of the field was reversed? **(2 marks)**

(ii) Why is the initial current through the motor large when the motor is first switched on and why does it decrease as the motor speeds up? **(4 marks)**

Solution 13.4

(a)



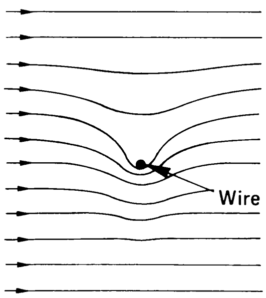
The coil is wound on a soft iron core (not shown in the diagram)

(b) The wires AB and CD are current carrying conductors and they are in a magnetic field which is perpendicular to the wire. Each side of the coil has a force acting on it. The force on AB is downwards and the force on CD is upwards. This couple [two equal and opposite parallel forces] would cause the coil to rotate through 90° from the position shown. As the coil passes through the vertical position the two sections of the split ring commutator are connected, via the brushes, to the opposite terminals of the battery. The current in the coil is reversed and the forces acting on the sides of the coil are reversed in direction. The forces rotate the coil through 180° until it is next in the vertical position, when the current and the forces are again reversed. The coil thus continues to rotate.

(c) (i) If both the current and the field were reversed at the same time, the forces would continue to act in the same direction and the coil would not rotate continuously.

(ii) When the coil is stationary and the motor is switched on, there is simply a copper wire of low resistance in the circuit and the current is a maximum. As the coil rotates it is cutting lines of flux and there is an induced e.m.f., called the back e.m.f., because it acts in a direction to oppose the change producing it (Lenz's law). If the applied e.m.f. is E and the back e.m.f. is E_b then the current I is given by $I = (E - E_b)/R$ where R is the resistance of the windings. If the coil rotates faster E_b increases and I decreases.

Example 13.5



A long straight wire placed in, and perpendicular to, a uniform magnetic field, is connected to a d.c. power source so that a current can flow. When the current is in a direction out of the page, the resultant field is that shown in the diagram. The force on the wire is

A to the left
B to the right
C upwards (towards the top of the page)
D downwards (towards the bottom of the page)
E towards the observer (out of the page) (AEB)

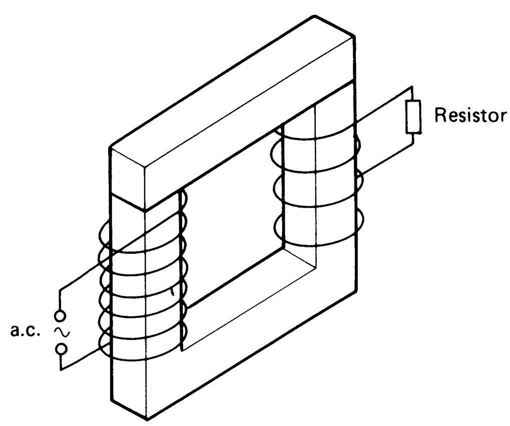
Solution 13.5

[Lines of force can be considered to be in longitudinal tension. They always try to be as short as possible. The wire is therefore catapulted upwards by the field.]

Answer C

Example 13.6

The diagram represents a transformer with a primary coil of 400 turns and a secondary coil of 200 turns.



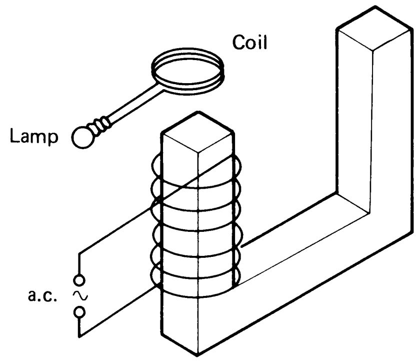
(a) If the primary coil is connected to the 240-V a.c. mains what will be the secondary voltage? **(1 mark)**

(b) Explain carefully how the transformer works. **(4 marks)**

(c) Calculate the efficiency of the transformer if the primary current is 3 A and the secondary current 5 A. **(4 marks)**

(d) Give reasons why you would expect this efficiency to be less than 100%. **(3 marks)**

(e)



The secondary coil is removed and a small coil connected to a low voltage lamp is placed as shown. Explain the following observations:

(i) the lamp lights, **(2 marks)**

(ii) if the coil is moved upwards, the lamp gets dimmer, **(2 marks)**

(iii) if a soft iron rod is now placed through the coil, the lamp brightens again, **(2 marks)**

(iv) the lamp will not light if a d.c. supply is used instead of an a.c. one. **(2 marks)**

(London)

Solution 13.6

(a) 120 V [This assumes that there are no flux losses.]

(b) When an a.c. is connected to the primary coil there is a constantly changing magnetic flux in the soft iron core. This continuously changing flux passes through the secondary coil, and hence there is an induced e.m.f. in the secondary coil. Since the same e.m.f. is induced in each turn of the secondary coil and all the turns are in series, halving the number of turns of the secondary coil halves the induced e.m.f.

(c) Power input = $(VI)_{\text{primary}} = 240 \times 3 = 720$ W

Power output = $(VI)_{\text{secondary}} = 120 \times 5 = 600$ W

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \text{ (see section 13.5)} = \frac{600}{720} = 0.83 = 83\%$$

(d) The efficiency is less than 100% because of

(i) Copper losses, that is the heat produced in the wires.

(ii) Eddy currents flowing in the soft iron core produce heat.

(iii) Magnetic leakage. Not all the flux in the soft iron on the primary side reaches the secondary side.

(iv) The work done in continually magnetising and demagnetising the soft iron core (this is called the hysteresis loss).

(e) (i) Some of the magnetic flux around the primary passes through the coil. This changing flux means that an e.m.f. is induced in the coil. This e.m.f. produces a current in the coil which lights the lamp.

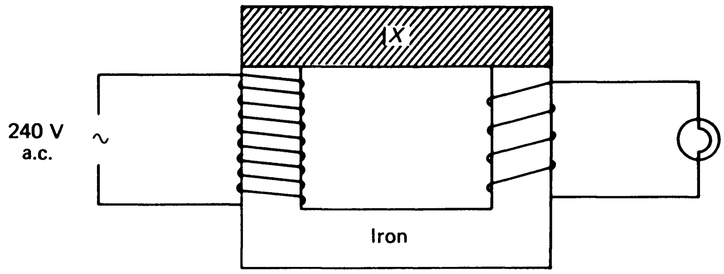
(ii) When the coil is moved further away from the primary,the flux passing through it decreases. The rate of change of flux is less and the magnitude of the induced e.m.f. is reduced.

(iii) The soft iron rod will become magnetised and will increase the flux passing through the coil. The rate of change of flux is increased and hence the e.m.f. is increased.

(iv) When a d.c. supply is used the flux through the coil is constant. If there is no change of flux there is no induced e.m.f.

Example 13.7

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only



The circuit shown in the diagram was set up in order to demonstrate a step-down transformer. The lamp glowed dimly. The lamp would glow more brightly if

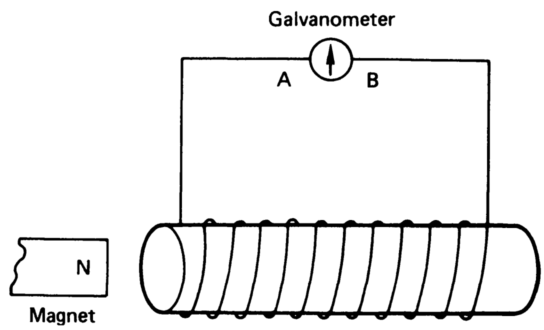
1 the number of turns on the primary coil were reduced
2 the iron were replaced by copper
3 the shaded section of iron, X, were removed (AEB)

Solution 13.7

[The e.m.f. across the secondary coil depends on the turns ratio (section 13.5). Reducing the number of turns on the primary coil increases the turns ratio and hence increases the e.m.f. across the secondary coil. Copper is non-magnetic so is not suitable for the core. The flux through the secondary coil will be reduced if the magnetic circuit is not complete, so removing X will decrease the e.m.f. across the secondary coil.]

Answer D

Example 13.8



(a) The diagram shows a solenoid connected to a galvanometer. Explain why
   (i) if the magnet is held stationary at the end of the coil, there is no deflection of the galvanometer pointer,
   (ii) if the magnet is moved towards the solenoid there is a deflection of the galvanometer pointer,

(iii) the faster the magnet moves towards the solenoid the greater is the deflection of the galvanometer pointer,

(iv) if the magnet is moved away from the solenoid the direction of the current is from A to B through the galvanometer. **(10 marks)**

(b) A transformer has 400 turns in the primary winding and 10 turns in the secondary winding. The primary e.m.f. is 250 V and the primary current is 2.0 A. Calculate

(i) the secondary voltage, and

(ii) the secondary current, assuming 100% efficiency. **(6 marks)**

Transformers are usually designed so that their efficiency is as close to 100% as possible. Why is this?

Describe *two* features in transformer design which help to achieve high efficiency. **(4 marks)**

Solution 13.8

(a) (i) If the magnet is stationary the flux through the coil is not changing. An e.m.f. will only be induced in the coil if the flux through it is changing.

(ii) When the magnet is moved towards the solenoid the flux through the coil is changing and hence there is an induced e.m.f.

(iii) The magnitude of the induced e.m.f. depends on the rate of change of flux. If the magnet is moved faster the rate of change of flux is greater and hence the induced e.m.f. increases and the resulting current increases.

(iv) If the magnet is moved away from the solenoid the end of the coil nearest to the magnet must become a S-pole because the induced current is in such a direction that it opposes the motion. A N-pole and a S-pole will attract one another.

For the left-hand end of the solenoid to be a S-pole the current must flow from A to B through the galvanometer.

(b) (i) $$\frac{\text{Voltage across secondary}}{\text{Voltage across primary}} = \frac{\text{Number of turns on secondary}}{\text{Number of turns on primary}}$$

[see section 13.5]

$$\frac{\text{Voltage across secondary}}{250} = \frac{10}{400}$$

Voltage across secondary = 6.25 volts

(ii) $(VI)_{\text{primary}} = (VI)_{\text{secondary}}$

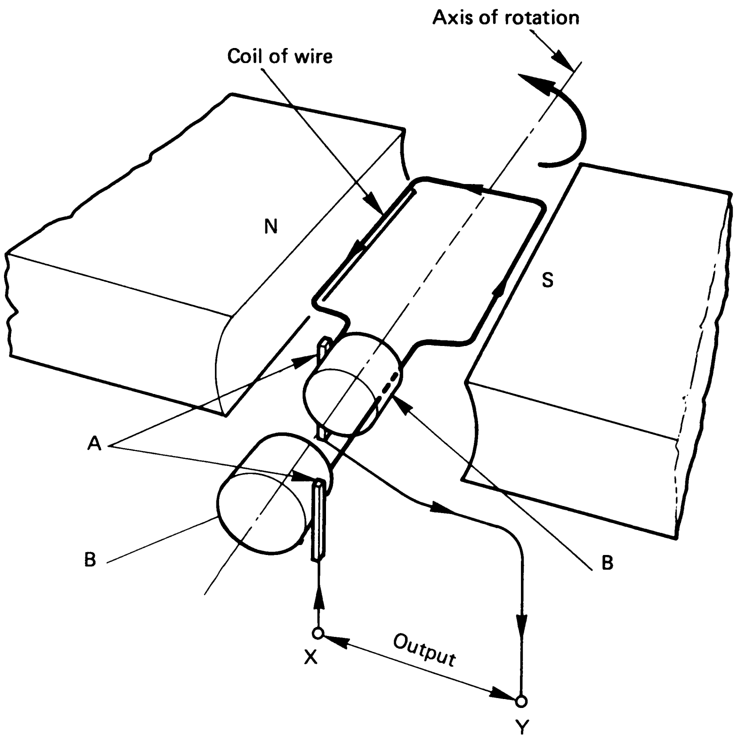
$250 \times 2.0 = 6.25 \times I_{\text{secondary}}$

$I_{\text{secondary}} = 80$ A

The greater the losses the greater is the cost of running the transformer and the hotter the transformer becomes when being used. Large transformers have to be cooled and this can be expensive. The core is laminated, that is, it is made up of strips each insulated from each other. This reduces the eddy currents. The coils are wound using low resistance material so that the heating effect in the coils is reduced to a minimum.

Example 13.9

The diagram shows a simple form of a.c. dynamo.



(a) (i) What are the names of the parts labelled A and B?
(ii) What would be the effect of doubling the number of turns on the coil if the speed of rotation remained unchanged?
(iii) Which of the output terminals is positive if the coil is rotating in the direction shown in the diagram (anticlockwise)? **(8 marks)**

(b) What is the position of the rotating coil when p.d. across its ends is zero? Explain why the p.d. is zero when the coil is in this position. **(3 marks)**

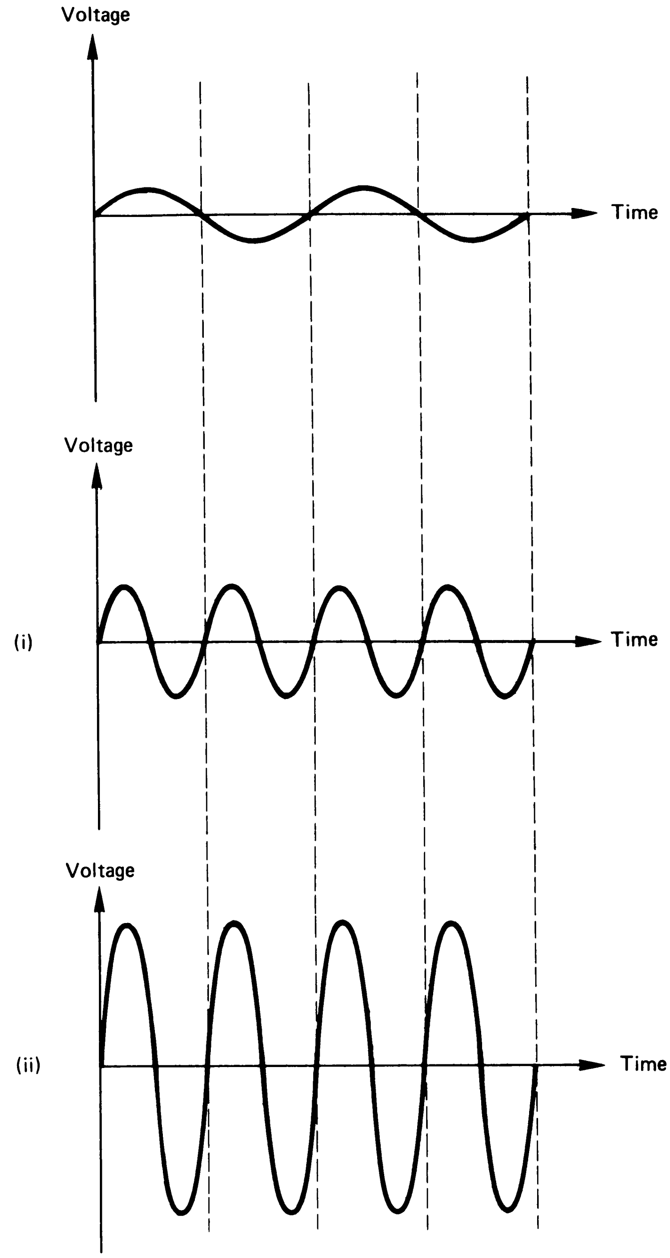
(c) Sketch a graph showing how the p.d. across the ends of the rotating coil varies with time for an a.c. dynamo. On the same sheet of paper and vertically below the first graph and using the same time scale, sketch graphs to show the effect of (i) doubling the speed of rotation and at the same time keeping the field and the number of turns constant; (ii) doubling the number of turns on the coil and at the same time doubling the speed of rotation of the coil, keeping the field constant. **(9 marks)**

Solution 13.9

(a) (i) The brushes are labelled A and the slip rings labelled B.
(ii) The induced e.m.f. would double.
(iii) Y is the positive terminal.

(b) The p.d. across the ends of the coil is zero when the coil is in a vertical plane. In this position the sides of the coil are moving parallel to the lines of flux and the flux through the coil is not changing, hence there is no induced e.m.f.

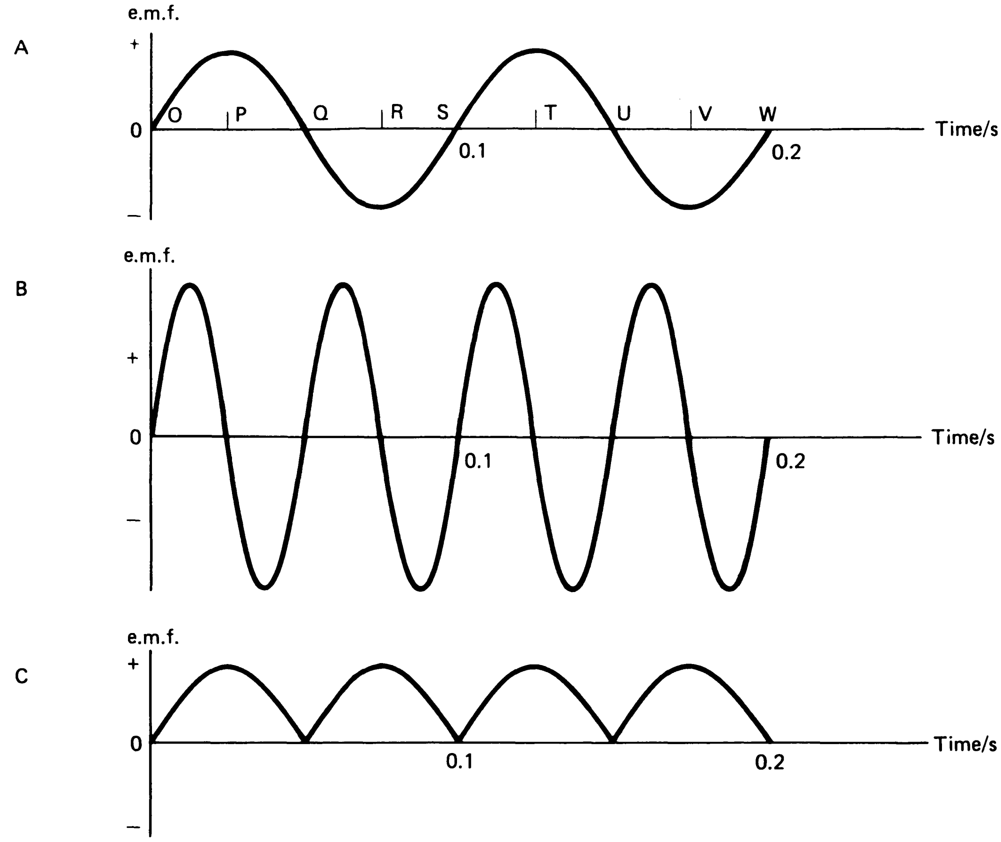
(c)



[In (ii) the voltage goes up by a factor of 4 because doubling the number of turns doubles the voltage, and doubling the speed of rotation also doubles the voltage. Doubling the speed of rotation also *doubles the frequency*.]

Example 13.10

(a)



Graph A above shows how the e.m.f. produced by a simple dynamo varies with time. Graphs B and C show how the e.m.f. produced by the same dynamo varies with time after certain alterations and modifications have been made.

(i) How many revolutions has the coil of the dynamo made in the time interval OT on graph A? **(1 mark)**

(ii) What is the frequency of the alternating e.m.f. as shown by graph A? **(2 marks)**

(iii) Which letters on graph A correspond to the plane of coil of the dynamo being parallel to the magnetic field? **(2 marks)**

(iv) Explain why the e.m.f. at Q is zero. **(3 marks)**

(v) What alteration has been made for the dynamo to produce the e.m.f. represented by graph B? **(2 marks)**

(vi) What modification has been made to the dynamo for it to produce the e.m.f. represented by graph C? Illustrate your answer with sketches showing the original and the modified arrangements. **(4 marks)**

(b) A dynamo is driven by a 5-kg mass which falls at a steady speed of 0.8 m/s. The current produced is supplied to a 12-W lamp which glows with normal brightness. Calculate the efficiency of this arrangement. **(6 marks)**

(L)

Solution 13.10

(a) (i) 1.25.

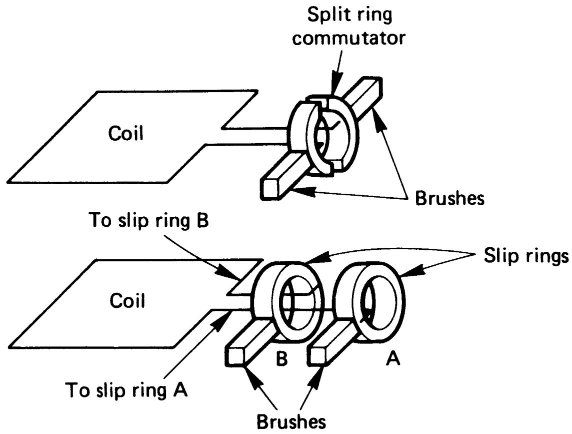
(ii) 1 cycle takes 0.1 s. Frequency = 10 Hz.

(iii) P; R; T; V. The e.m.f. is a maximum because the wire on the sides of the coil is cutting the field at the greatest rate.

(iv) At Q the plane of the coil is perpendicular to the magnetic field. The sides of the coil are moving parallel to the field so they are not cutting the lines of flux and the rate of change of flux is zero.

(v) The speed of rotation has been doubled.

(vi) Slip rings have been replaced by split rings (see diagram).

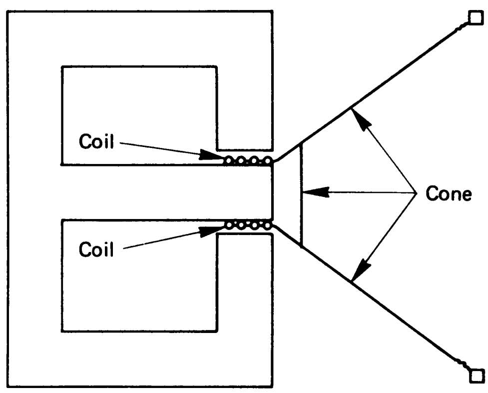


(b) Work done in 1 s by mass falling = force x distance = 50 x 0.8 = 40 W.
Work got out = 12 W.

$$\text{Efficiency} = \frac{\text{Work out}}{\text{Work in}} = \frac{12}{40} = 0.3 \text{ or } 30\%$$

Example 13.11

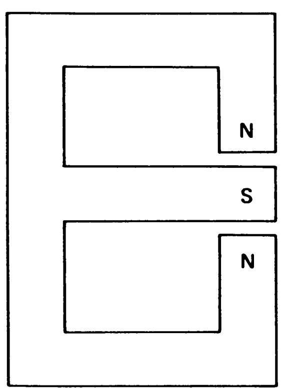
(i) The diagram below shows a moving coil loudspeaker. Make a sketch of the magnet and show on your sketch the nature and the position of the magnetic poles.



(ii) Explain what would be heard if a 1 V 50 Hz supply were connected across the terminals of the loudspeaker. What difference would be heard if the supply were changed to a 2 V 100 Hz one? **(8 marks)**

Solution 13.11

(i)



(ii) The wire of the coil is in a magnetic field. When a current flows in the wire of the coil a force acts on the wire. This force is perpendicular to both the field and the current. When an alternating current is flowing in the coil, the coil will move to the left and then to the right each time the current changes direction. The cone will move in and out fifty times every second and a note of 50 Hz will be heard.

If the supply were changed to 2 V 100 Hz, the amplitude of the vibration would be greater so a louder note would be heard. The cone would complete 100 cycles every second and a note of 100 Hz would be heard.

Example 13.12

(a) Explain why on the National Grid system
  (i) very high voltages are used,
  (ii) alternating current is used. **(5 marks)**

(b) A town receives electricity via the National Grid system at 100 kV at a rate of 40 MW. The cable connecting the town to the power station has a total resistance of 4 ohm. What is
  (i) the current flowing in the cable,
  (ii) the power loss as a result of heating in the cable? **(5 marks)**

Solution 13.12

(a) (i) A certain amount of energy may be transmitted by using a high voltage and a low current, or a low voltage and a high current. The former is chosen because the heating effect depends on the square of the current and the loss as heat is reduced markedly by using a high voltage. Low current also means that the wires do not have to be so thick and the cost of supporting the wires is reduced.

(ii) Using alternating current means that transformers can be used to step up the voltage before transmission and also they reduce it again at the end of the power line.

(b) (i) Watt = Volt x Ampere [see section 12.2]
$40 \times 10^6 = 100 \times 10^3 \times \text{Amps}$
Current = 400 A

(ii) Heat = $I^2 R$ watt [see section 12.2]
$= 400^2 \times 4 = 6.4 \times 10^5$ watt

Example 13.13

(a) Calculators may be powered by the mains using an adaptor or by dry batteries.
  (i) Why is an adaptor necessary if the mains is used? **(2 marks)**
  (ii) Outline the principle by which the adaptor works (no details of the electrical circuit or a diagram are necessary). **(4 marks)**
  (iii) Draw a labelled diagram of a dry (Leclanché) cell. **(6 marks)**

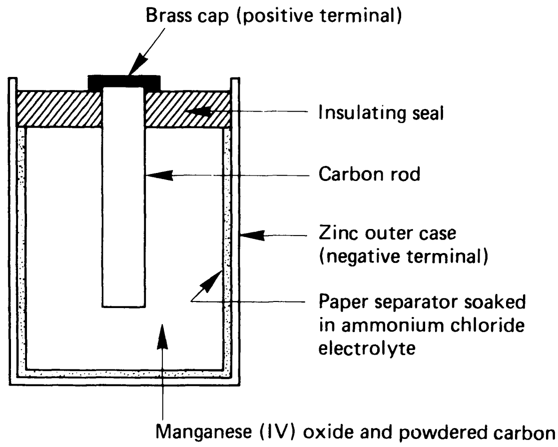
(b) (i) Explain why lead-acid accumulators are used in car batteries rather than dry cells. **(3 marks)**
  (ii) State two precautions you would take, giving your reasons, in order to maintain the efficiency of a lead-acid accumulator. **(4 marks)**

Solution 13.13

(a) (i) Calculators run off about 6 V and the mains is 240 V. The adaptor reduces the mains voltage before supplying the calculator.

(ii) The adaptor has a transformer which consists of a primary coil and a secondary coil wound on a magnetic alloy. The 240 volts is connected across the primary coil. This alternating voltage causes a changing flux in the soft iron core, and this changing flux passes through the secondary coil. The changing flux in the secondary coil results in an e.m.f. being induced in it. The secondary coil has only one fortieth of the turns the primary coil has on it and hence the voltage is reduced by one fortieth (if 6 V is required). A rectifier converts the a.c. voltage to a d.c. voltage.

(iii)



(b) (i) Large currents are needed to turn the starter motor. Dry cells cannot provide these large currents. Accumulators can provide much larger currents than dry cells because they have a much lower internal resistance. The maximum current a cell can produce is given by E/r, where E is the e.m.f. and r is the internal resistance.

(ii) The cell is damaged if the plates are not kept covered with liquid and the cell must be topped up from time to time with distilled water. If left in a discharged state for long periods it deteriorates very rapidly, so it should be charged regularly.

[Another precaution is to avoid short circuiting it, as the large currents which pass damage the plates.]

13.10 Have You Mastered the Basics?

1. Do you understand the laws of electromagnetic induction (Faraday's law and Lenz's law)?
2. Can you draw a diagram of a motor and a dynamo, and describe how they work?
3. Can you draw a diagram of a transformer and describe how it works? Do you know how to calculate the efficiency of a transformer?
4. Can you draw a labelled diagram of a dry cell?
5. A transformer reduces a mains voltage of 240 V to 6 V. If the transformer is 100% efficient what is
   (i) the turns ratio,
   (ii) the current drawn from the mains if the current in the secondary is 1 A?

13.11 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See section 13.4.
2. See section 13.3 and Examples 13.4 and 13.9.
3. See section 13.5 and Examples 13.6, 13.7 and 13.8.
4. See Example 13.13.
5. $$\frac{\text{Number of turns on secondary}}{\text{Number of turns on primary}} = \frac{\text{e.m.f. across secondary}}{\text{e.m.f. across primary}} \quad \text{(see section 13.5)}$$
$$= \frac{6}{240} = \frac{1}{40}$$

Turns ratio = 1:40
The transformer is 100% efficient therefore
Power in = Power out
$(VI)_{\text{primary}} = (VI)_{\text{secondary}}$ (see section 13.5)
$240 \times I_{\text{primary}} = 6 \times 1$
$I_{\text{primary}} = 0.025$ A

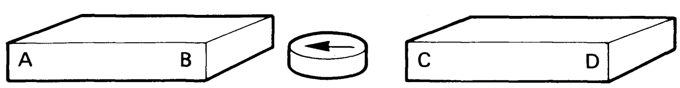
13.12 Questions

Question 13.1

This question is about magnetic fields and an electromagnetic switch.

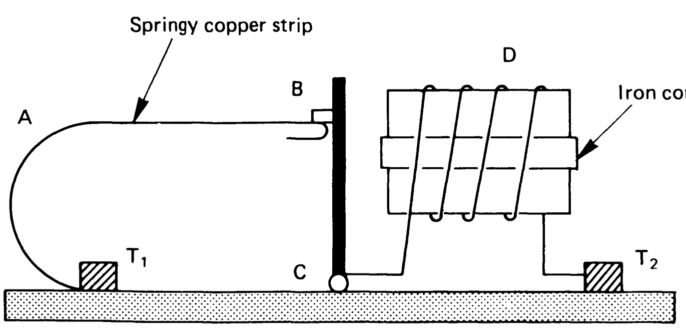
(a) (i) Describe how you would show experimentally the shape and direction of the magnetic field lines in a horizontal plane around a vertical wire connected to a d.c. source.
(ii) Draw a diagram showing clearly the direction of the current and the direction of the magnetic field lines.
(iii) If a.c. were used in place of d.c., what effect would this have on your experiment? Give a reason. **(8 marks)**

(b)



The diagram shows a small plotting compass placed between two strong magnets. The tip of the arrow represents the N pole of the compass.
(i) What is the polarity of the end C of the right hand magnet?
(ii) Draw a diagram of the magnets only as seen from above and sketch the magnetic field lines in the region between B and C. **(3 marks)**

(c)



The diagram shows a model circuit breaker designed to switch off the current in a circuit when it becomes excessive. The current enters the circuit breaker at T_1, passes along the copper strip A, the iron armature BC, the coil D, and leaves at terminal T_2. The iron armature BC is pivoted at C.

(i) Describe how the circuit breaker works.

(ii) State the effect on the operation of the circuit breaker of each of the following changes. Give a reason in each case.

(1) The removal of the iron core from the coil.

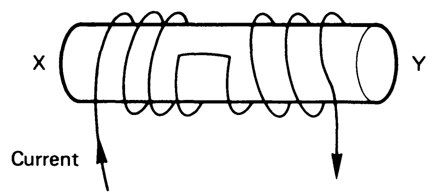
(2) The use of a.c. instead of d.c. **(6 marks)**

(L)

Question 13.2

Summarised Instructions				
A	**B**	**C**	**D**	**E**
1, 2, 3 all correct	**1, 2** only correct	**2, 3** only correct	**1** only correct	**3** only correct

Insulated copper wire is wound uniformly around a soft iron bar so that the wire turns in one direction for the first half of the bar and is then reversed for an equal number of turns along the second half. A direct current is passed through the wire in the direction shown by the arrow.



It follows that the

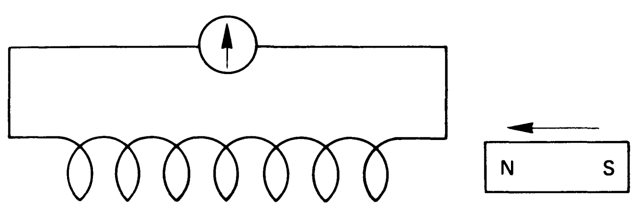
1 end Y acquires north-seeking polarity

2 end X acquires north-seeking polarity

3 poles at the ends X and Y have equal strengths (L)

Question 13.3

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only



In an experiment on electromagnetic induction a magnet is moved towards a stationary coil with its north pole end nearer to the coil – as shown in the diagram. During this motion the needle of the centre zero ammeter connected to the coil is deflected to the *right*. The needle would also be deflected to the right if the magnet were moved

1 away from the coil with its north pole end nearer to the coil

2 towards the coil with its south pole end nearer to the coil

3 away from the coil with its south pole end nearer to the coil (AEB)

Question 13.4

(a)

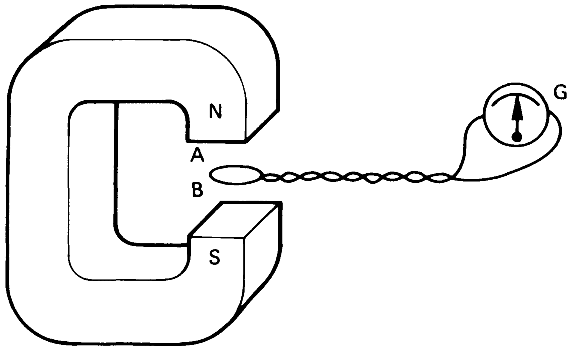


Figure 1

Figure 1 represents a flat circular coil AB placed between the poles of a strong magnet and connected to a sensitive galvanometer, G. Explain carefully why

(i) in the position shown, with the side A of the coil uppermost, there will be no deflection of the galvanometer, **(2 marks)**

(ii) when the coil is rotated quickly through 180° so that side B of the coil is uppermost there will be a deflection, **(2 marks)**

(iii) when the coil is pulled quickly away from the magnet there will be a deflection. **(2 marks)**

(b)

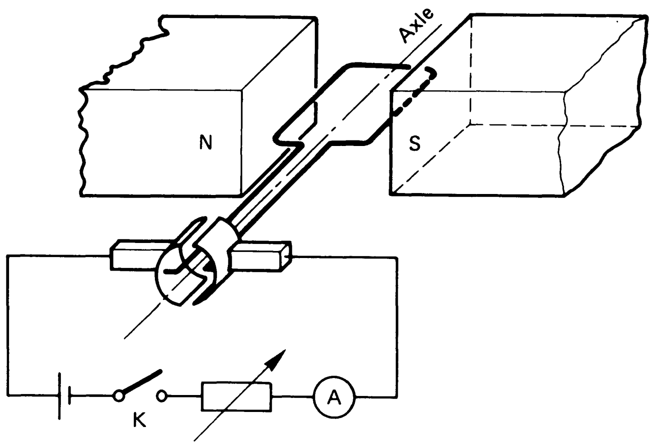


Figure 2

Figure 2 represents a coil, the ends of which are connected to a split ring commutator. The coil is placed between the poles of a strong magnet and connected by brushes to the circuit shown. Explain why, when the key K is closed,

(i) the coil starts to rotate, and give the direction of rotation, **(3 marks)**

(ii) the coil continues to rotate. **(3 marks)**

(c)

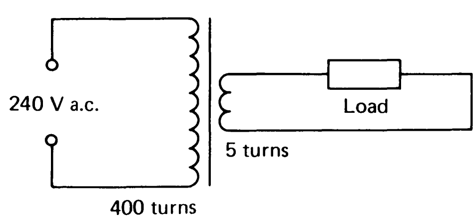


Figure 3

Figure 3 represents a transformer with 400 turns in the primary winding and 5 turns in the secondary winding. The primary e.m.f. is 240 V and the primary current is 2 A.

(i) What is the secondary voltage? **(2 marks)**

(ii) Assuming no power loss, what is the secondary current? **(2 marks)**

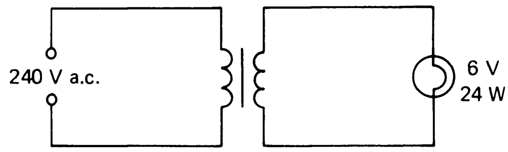
(iii) Energy is wasted in the transformer. Give *two* reasons why your calculated value in (ii) will be larger than the true value of the current. **(2 marks)**

(iv) Suggest a purpose for which this transformer may be used. **(2 marks)**

(L)

Question 13.5

(a)



It is required to run a 6-V, 24-W lamp from a 240-V a.c. mains using a transformer as shown above.

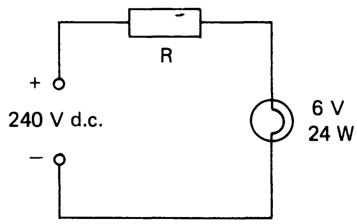
(i) Calculate the current that would be taken by the lamp when operating normally. **(2 marks)**

(ii) Calculate the turns ratio of the transformer you would use. **(2 marks)**

(iii) Calculate the current taken by the primary coil of the transformer, assuming it to be 100% efficient. **(2 marks)**

(iv) Why, in practice, is the efficiency of the transformer less than 100%? **(3 marks)**

(b) Alternatively the 6-V, 24-W lamp can be operated normally from a 240-V d.c. supply using a suitable fixed resistor, R, as in the diagram.



(i) What is the resistance of the lamp? **(2 marks)**

(ii) What is the p.d. across the resistor? **(2 marks)**

(iii) What is the resistance of the resistor? **(2 marks)**

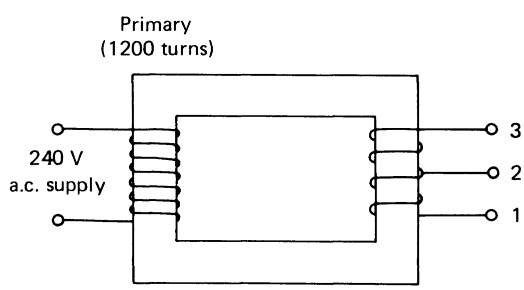
(iv) How much energy is dissipated in the resistor in 1 s? **(2 marks)**

(c) Why may the method used to light the lamp described in (a) be preferable to that described in (b)? **(3 marks)**

(L)

Question 13.6

The diagram shows a step-down transformer with three tappings on the secondary.



(a) Describe how a transformer works. **(7 marks)**

(b) Why is the efficiency less than 100%? **(5 marks)**

(c) When a 2 Ω resistor is connected between 1 and 2 the current flowing is 0.4 A. When the same resistor is connected between 2 and 3 the current is 0.6 A. If the transformer is 100% efficient calculate

(i) the potential difference across terminals 1 and 2,

(ii) the potential difference across terminals 1 and 3,

(iii) the number of turns on the secondary coil between terminals 1 and 2,

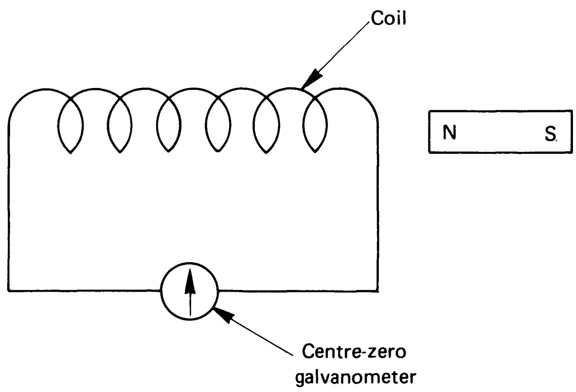
(iv) the number of turns on the secondary coil between terminals 1 and 3. **(8 marks)**

Question 13.7

PART I

(a) The diagram shows a permanent bar magnet.
Copy the diagram on your paper and draw the magnetic field pattern of the bar magnet, indicating the direction of the flux lines. **(4 marks)**

(b)



(i) When the magnet is pushed into the coil, the needle of the centre-zero galvanometer deflects. Give an explanation for this.

(ii) What happens to the needle of the galvanometer if the magnet is now pulled out **from the other side** of the coil? **(4 marks)**

PART II

(c) Using the domain or molecular theory of magnetism, explain why

(i) a piece of soft iron, although a magnetic material, does not behave as a magnet,

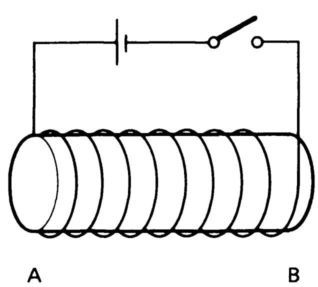
(ii) the same piece of soft iron can be made into a magnet by a magnetising field, and

(iii) above a certain value of the magnetising field, the strength of the magnet does not increase. **(4 marks)**

(d) Draw a labelled diagram of a simple a.c. generator (alternator), and explain in detail how it works. Sketch the waveform of the output of the generator. **(9 marks)**

(AEB)

Question 13.8



(a) An unmagnetised steel rod is placed in a solenoid connected as shown, and the current is switched on. After a short time the current is switched off and the rod is removed from the solenoid. Each end of the rod is then brought up to the North-seeking pole of a compass. The entire procedure is then repeated using an initially unmagnetised soft iron rod.

(i) Describe and account for the changes which occur in each of the rods when they are placed in the solenoid and the current is switched on. **(4 marks)**

(ii) Describe and account for the behaviour of the North-seeking pole of the compass when the ends of each of the rods are then brought up in turn to it. **(6 marks)**

(iii) Which rod would be suitable to make the magnet of a small electric motor and which would be suitable to make the core of a relay? Give a reason for each choice. **(4 marks)**

(b) A cell of e.m.f. 1.5 V and internal resistance 4 Ω is connected in series with a cell of e.m.f. 2 V and internal resistance 2 Ω so that the cells assist each other. If the arrangement is connected to the ends of a 1-Ω resistor, calculate

(i) the current in the resistor, **(3 marks)**

(ii) the heat produced in the resistor if the current is maintained for 5 minutes. **(3 marks)**

(L)

13.13 Answers and Hints on Solutions to Questions

1. (a) (i) Pass a vertical wire through a horizontal card with plotting compasses on it. (ii) The lines are circles in a clockwise direction if you are looking in the direction in which the current is travelling. (iii) If a.c. were used then the pattern would be changing continuously so fast that no field pattern would be observed. The compasses could not respond quickly enough.
   (b) (i) N-pole. (ii) Draw a diagram with lines parallel but curved near the edges of the magnet; direction C to B.
   (c) (i) When current is excessive the electromagnet attracts B and the circuit is broken. (ii) (1) A *much* larger current would be needed before the circuit breaker operated. (2) It would still work.
2. Answer A.
   The lines of force spread out from both X and Y which are therefore N-poles.
3. Answer E.
4. (a) (i) There is no change in flux so no induced e.m.f. (ii) and (iii) There is a change of flux and hence an induced e.m.f. (see sections 13.3 and 13.4).
   (b) See Example 13.4.
   (c) See section 13.5 and Examples 13.6, 13.7 and 13.8. (i) 3 V. (ii) 160 A. (iii) See Example 13.6. (iv) Such high currents are used in welding and induction furnaces.
5. (a) (i) See section 12.2. Current = 4 A. (ii) See section 13.5. Ratio is 40:1. (iii) See section 13.5 and Example 13.8. Current = 0.1 A. (iv) See Example 13.6.
   (b) (i) See section 12.2. Resistance = 1.5 Ω. (ii) (240 − 6) = 234 V. (iii) See section 12.1a. Resistance is 58.5 Ω. (iv) See section 12.2. Energy dissipated is 936 W.
   (c) Less energy lost as heat.
6. (a) and (b) See section 13.5 and Example 13.6.
   (c) (i) 0.8 V, (ii) 2 V, (iii) 4 turns, (iv) 10 turns.
7. (a) Don't forget to put arrows on the lines pointing from the N-pole to the S-pole.
   (b) (i) See Example 13.8. (ii) The galvanometer deflects in the same direction.
   (c) (i) The domains are orientated randomly. (ii) The domains are aligned. (iii) See Example 13.1.

8. (a) (i) Both rods will become magnetised with their N-pole at the end A. (ii) When the current is switched off the soft iron will lose its magnetism and the steel will retain its magnetism. Therefore for steel, A repels and B attracts the N-pole. For soft iron, A and B attract the N-pole, because the N-pole of the compass induces a S-pole at the end of the bar. (iii) Steel retains its magnetism and is suitable for a permanent magnet. The soft iron would be suitable for a relay.

(b) See section 12.1. (i) e.m.f. = 3.5 V, R = 7 Ω (all three resistances are in series). ∴ Current = 0.5 A. (ii) See section 12.2. Heat produced = 75 J.

14 Electrostatics, Electron Beams and Radioactivity

14.1 Electrostatics

There are two sorts of charge, positive and negative. A polythene rod rubbed with wool becomes negatively charged, and a cellulose acetate rod rubbed with wool becomes positively charged. Like charges attract and unlike charges repel. Charge may be detected using a gold leaf electroscope (see Example 14.5). If the leaf of a charged electroscope diverges further when a body is brought up to it, that body is charged. The sign of the charge on the body is the same as that on the electroscope.

14.2 Beams of Electrons

A heated filament emits electrons from the surface of the metal (thermionic emission). A beam of electrons may be produced by positioning a positively charged anode with a small hole in it, close to the filament. In a *cathode-ray oscilloscope (CRO)*, the beam is passed through X-plates which produce an electric field that deflects the beam horizontally and Y-plates which produce an electric field that deflects it vertically. When the beam strikes the fluorescent screen at the end of the tube a spot of light is produced (see Examples 14.1 and 14.3).

14.3 Radioactivity

(a) Origin and Detection

Radioactivity originates in the nucleus of the atom and is a random process. Radioactive substances have the ability to ionise the air surrounding them and it is this property which is used to detect them. In a cloud chamber alcohol vapour condenses along the path of the ionising radiation. In a Geiger–Müller tube, a pulse of current, produced by the ionising particle entering the tube, flows between the central electrode and the metal tube surrounding it. These pulses may be counted by a ratemeter or a scaler.

(b) α, β and γ-radiation

(i) ***α-radiation***

This is the emission of positively charged helium nuclei from the nucleus of an atom. It is stopped by a sheet of paper. It can be deflected by electric and magnetic fields, but the experiment cannot be conducted in air because the path of an α-particle in air is only about 5 cm. α-radiation is the most highly ionising of the three radiations.

(ii) ***β-radiation***

This is the emission of electrons from the nucleus of the atom. It is absorbed by about 2 mm of aluminium foil. It is easily deflected by electric and magnetic fields and is less ionising than α-particles.

(iii) ***γ-radiation***

This is the emission of electromagnetic waves from the nucleus of an atom. It is unaffected by electric and magnetic fields. It is very penetrating but about 4 cm of lead will absorb most of it. It is only weakly ionising.

(c) Law of Decay

The law of radioactive decay states that the rate of radioactive decay at any instant is proportional to the quantity of radioactive material present at that instant.

(d) Half-life

The half-life of a radioactive source is the time it takes for the activity of the source to fall to half its original value (irrespective of what this value may be).

(e) Geiger and Marsden's Experiment, Proton Number, Nucleon Number

If α-particles are fired at a thin sheet of gold foil (Geiger and Marsden's experiment), some pass straight through, others are deviated through a small angle but occasionally a particle is turned through an angle greater than 90°. This result is consistent with the theory that all the positive charge of the atom and all its mass is concentrated into a very small volume within the atom called the nucleus. Electrons, spread over a large volume, surround the nucleus. The nucleus consists of positively charged protons, and uncharged particles of almost the same mass as a proton, called neutrons.

proton number (atomic number) = number of protons in nucleus
nucleon number (mass number) = number of protons in nucleus + number of neutrons in nucleus

All atoms of the same element have the same number of protons in the nucleus and hence contain the same number of orbiting electrons.

(f) Isotopes

Isotopes are atoms of a given element which differ only in the number of neutrons in the nucleus. Isotopes have the same proton number but a different nucleon number.

(g) Equations for Radioactive Decay

If an element X decays by α ($^4_2$He) emission into an element Y then

$$^{M}_{A}X \rightarrow {}^{M-4}_{A-2}Y + {}^{4}_{2}He$$

If an element P decays by β ($_{-1}^{\ 0}$e) emission into an element Q then

$$^{M}_{A}P \rightarrow {}^{\ \ M}_{A+1}Q + {}^{\ 0}_{-1}e$$

(h) Some Uses of Radioactivity

(i) ***Tracers***

A small quantity of a radioactive isotope is mixed with a non-radioactive isotope enabling the path of the element to be followed in a plant or animal or human.

(ii) ***Sterilisation***

γ-rays can be used to kill bacteria on such things as hospital blankets and certain foods.

(iii) ***Thickness Control***

In paper mills the thickness of paper can be controlled by measuring how much β radiation is absorbed by the paper.

(iv) ***Radiotherapy***

The controlled use of γ-rays may be used to kill malignant cancer cells.

(i) Safety

Radiation is dangerous because it can harm living cells. The greatest risk comes from swallowing minute traces and therefore sources should never be held in the hand and no eating or drinking should take place near a radioactive source. Other precautions are (i) cover any cuts or sores, (ii) keep sources at a safe distance by holding them with long tweezers, (iii) never point the sources towards the human body and (iv) when not in use keep the sources in their lead-lined boxes.

14.4 Worked Examples

Example 14.1

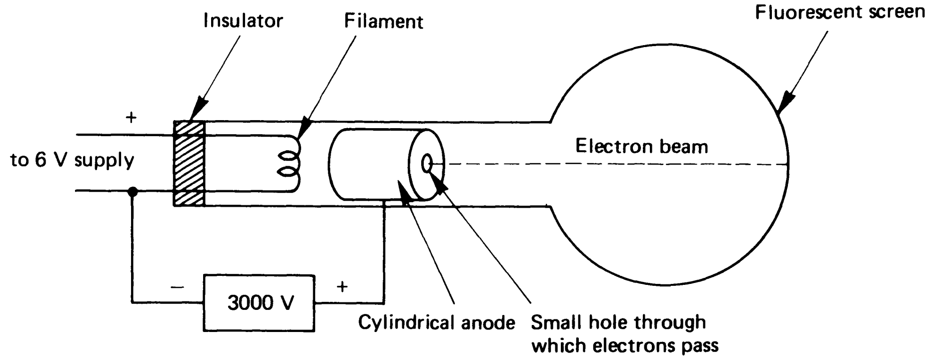
(a) Draw a labelled diagram of the apparatus you would use to produce a beam of electrons.

Show clearly the magnitude of the power supplies and where they are connected. How is the path of the beam made visible? **(7 marks)**

(b) Draw a diagram showing the path of a beam of electrons as they pass through an electric field. Can you deduce the sign of the charge on an electron from the deflection? If so, how? **(3 marks)**

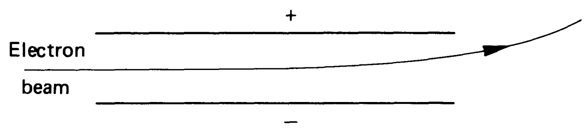
Solution 14.1

(a)



A spot of light is seen on the fluorescent screen when the beam strikes it. The path of the beam in the tube may be made visible by introducing some hydrogen gas at low pressure. The electrons ionise the hydrogen molecules and a blue glow is observed in the path of the beam.

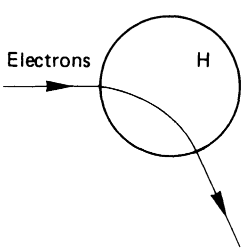
(b)



The sign of the charge may be deduced from the direction of the deflection. If the beam is repelled from the negatively charged plate then the beam is negatively charged.

Example 14.2

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only



The diagram shows the path of a beam of electrons deflected by a magnetic field in the region H, the field being perpendicular to the plane of the paper. The path would be more curved if

1 the field were stronger
2 the electrons were moving faster
3 the electrons were positively charged with an equal charge **(AEB)**

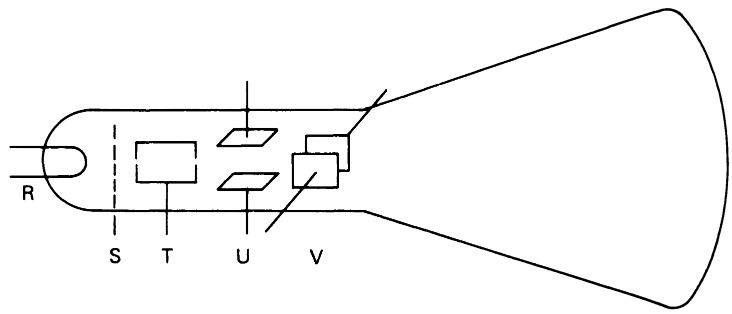
Solution 14.2

[The curvature does not depend on the sign of the charge but only on the magnitude of the charge. If the electrons were moving faster they would be in the field for a shorter time and would be deflected less.]

Answer D

Example 14.3

(a)



The diagram above shows some of the important features of a cathode-ray tube. State *two* other important features, not indicated, which are necessary if a cathode-ray beam is to be produced and observed.

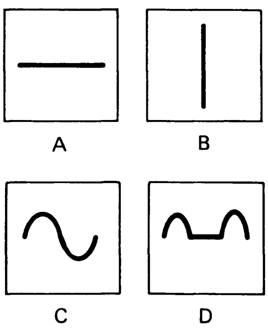
Which part of the tube is known as the *electron gun*? Suggest a reason why it is so called. **(4 marks)**

Explain

(i) the purpose of S, and how this purpose is achieved,

(ii) why T is maintained at a high positive potential relative to R,

(iii) what you would do and expect to observe when using the plates U to determine the sign of the charge on the particles emitted by R. **(8 marks)**



(b) A student centralises the beam of a cathode-ray oscilloscope and, with the time base switched *off*, then applies certain potential differences to the instrument. The traces obtained are shown at A and B.

In each case, describe the nature of the potential difference applied and state whether it was applied to the U or the V plates of the tube shown in part (a).

With the time base switched *on*, the student applies potential differences to the instrument. The traces obtained are shown at C and D.

In each case, describe the nature of the potential difference applied and state whether it was applied to the U or the V plates of the tube. **(8 marks)**

(L)

Solution 14.3

(a) A fluorescent screen is needed. The tube is evacuated. [Power supplies are needed (about 6 V across R and a few thousand volts between T and R).] The left-hand end of the diagram of the tube is the electron gun because it 'shoots out' a beam of electrons.

(i) S controls the number of electrons and hence the brightness. When it is made negative it repels the electrons leaving R. The more negative S is made the dimmer the beam becomes since fewer electrons reach T.

(ii) T must accelerate the electrons that leave R.

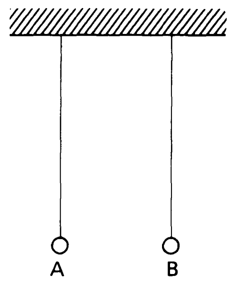
(iii) Connect a potential difference across the U-plates. If the top plate is positive then the beam will be deflected upwards indicating that the beam is negatively charged.

(b) In A, an alternating potential difference was applied across the V plates. In B, an alternating potential difference was applied across the U-plates.

In C, an alternating potential difference was applied across the U-plates (for example, the output of a transformer). In D a half-wave rectified a.c. is applied across the U-plates (for example, the potential difference across a resistor in series with a diode when an a.c. supply is connected across them).

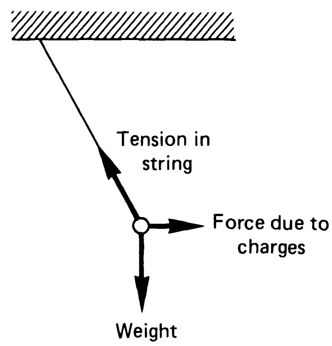
Example 14.4

Two small balls coated with metallic paint are suspended by insulating threads as shown in the diagram. Describe what you would observe if both balls were given a positive charge. How does the effect depend on the distance AB?
Draw a diagram showing all the forces acting on one of the balls. **(6 marks)**



Solution 14.4

The balls would repel each other and both threads would be at an angle to the vertical. The smaller the distance between the threads the greater is the angle the threads make with the vertical.

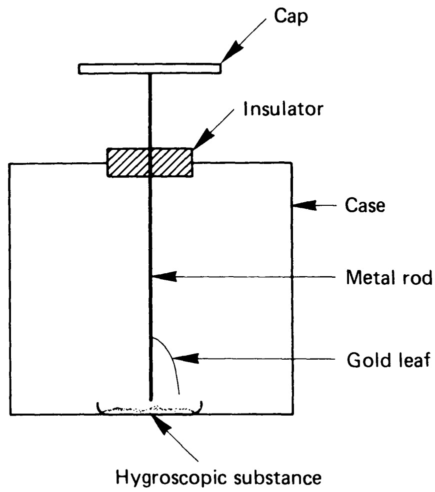


Example 14.5

(a) Draw a labelled diagram of a gold leaf electroscope. **(5 marks)**
(b) Two electroscopes are each given a negative charge. Describe what you would observe and explain your observation when
  (i) a negatively charged polythene rod is brought up to the cap of one of them until it touches it, **(5 marks)**
  (ii) you bring your hand up to the cap of the other one and touch it. **(5 marks)**
(c) In order to reduce the noise level of his machinery a manufacturer of nylon thread put rubber matting on the floor underneath his machinery. Small bits of fluff were found to stick to the nylon thread. Explain the reason for this. Someone suggested that the problem could be overcome by installing a humidifier to keep the air moist. Explain whether you think this was a reasonable suggestion. **(5 marks)**

Solution 14.5

(a)



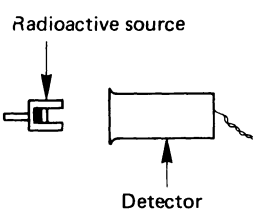
(b) (i) The negatively charged rod will repel electrons from the cap, to the leaf and the bottom of the rod. The leaf will diverge further. As the rod comes closer to the cap the leaf will diverge further still as more electrons are repelled onto it. When the rod touches the cap the leaf still remains diverged.

(ii) As your hand approaches the cap, the negative charge on the cap will induce a positive charge on your hand. As a result of the positive charge on your hand, some electrons will be attracted off the leaf up to the cap. This will reduce the negative charge on the leaf and the leaf will begin to collapse. The effect will be greater the closer the hand gets to the cap. The moment your hand touches the cap the leaf will collapse completely. This is because electrons from Earth will go to the leaf and neutralise the charge on it.

(c) Friction during the manufacture of the thread will cause the thread to become charged. If the charge on the thread is negative bits of fluff close to it will have a positive charge induced on the side nearest to the thread. The unlike charges attract and the fluff sticks to the thread.

Dry air is a good insulator but damp air is quite a good conductor. Moist air in contact with the thread would enable the charge to leak away, so the suggestion is a reasonable one.

Examples 14.6 and 14.7



A detector of radioactivity is placed opposite a radioactive source as shown in the diagram. It is found that radiation from the source is detected only if the distance between the source and the detector is less than 5 cm.

14.6 The source is probably emitting

A alpha radiation only
B beta radiation only
C gamma radiation only
D alpha and beta radiation only
E alpha, beta and gamma radiation

14.7 The source is changed. A sheet of paper placed between the new source and the detector is found to reduce the count rate. A sheet of aluminium is found to stop it completely. The source is emitting

A gamma radiation only
B beta and gamma radiation only

C alpha and gamma radiation only
D alpha and beta radiation only
E alpha, beta and gamma radiation (L)

Solution 14.6

[β- and γ-radiation travel much more than 5 cm in air.]

Answer A

Solution 14.7

[α's would be stopped by a sheet of paper and β's by the sheet of aluminium. γ rays would penetrate the aluminium.]

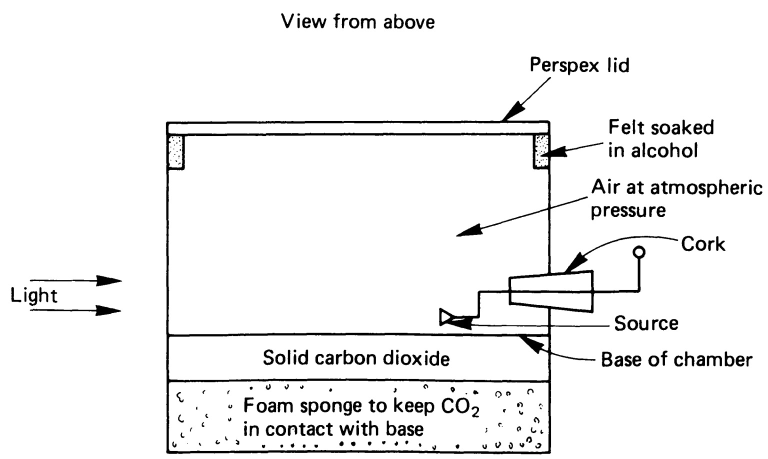
Answer D

Example 14.8

(a) Draw a labelled diagram of a cloud chamber and describe how it works. **(10 marks)**
(b) Compare and contrast the ionising properties and the penetrating properties of α-, β- and γ-radiations. **(6 marks)**
(c) Briefly outline *two* uses of radioactivity. **(4 marks)**

Solution 14.8

(a) The solid carbon dioxide keeps the base at a low temperature. The alcohol evaporates and diffuses downwards towards the base of the chamber. Just above the base the alcohol vapour is supersaturated (its saturated vapour pressure is above the normal saturated vapour pressure at the temperature just



above the base). In this state the vapour condenses on the ions produced by the passage of a radioactive particle and the path of the particle is revealed by the trail of droplets of alcohol. The chamber should be levelled to reduce the effects of convection currents.
(b) α's cause intense ionisation, β's much less and γ's cause very little ionisation. On the other hand, γ's have the greatest penetrating power and it needs 50 cm

of aluminium to reduce the intensity to 1/10th of its original value. β's are stopped by about 2 mm of aluminium and α's by a sheet of paper.

(c) *Sterilisation.* γ-rays are used to kill bacteria in hospital blankets and foods. *Thickness control.* In paper mills the thickness of paper can be controlled by measuring how much β-radiation is absorbed by the paper. The source is placed on one side of the paper and a Geiger–Müller tube on the other side. The reading on the Geiger–Müller tube is used to adjust the rollers which determine the thickness of the paper.

Example 14.9

The element X has an atomic mass number of 238 and an atomic number of 92. It emits an alpha particle forming an element Y. Y can be represented by

A $^{234}_{90}Y$ **B** $^{236}_{90}Y$ **C** $^{235}_{91}Y$ **D** $^{238}_{92}Y$ **E** $^{238}_{93}Y$ (AEB)

Solution 14.9

[See section 14.3(g).]

Answer A

Example 14.10

An element P has an atomic mass of 239 and an atomic number of 92. It emits a β-particle forming an element Q. Q can be represented by

A $^{239}_{91}Q$ **B** $^{239}_{92}Q$ **C** $^{239}_{93}Q$ **D** $^{238}_{92}Q$ **E** $^{235}_{90}Q$

Solution 14.10

[See section 14.3(g).]

Answer C

Example 14.11

Directions summarised				
A **1, 2, 3** correct	**B** **1, 2** only	**C** **2, 3** only	**D** **1** only	**E** **3** only

The half-life of a radioactive substance is 10 hours. The original activity of a sample is measured and found to be 1200 counts per minute. Which of the following is/are correct?

1 After 10 hours the count rate will be 600 counts per minute
2 After 20 hours the count rate will be 300 counts per minute
3 After 40 hours the count rate will be 150 counts per minute

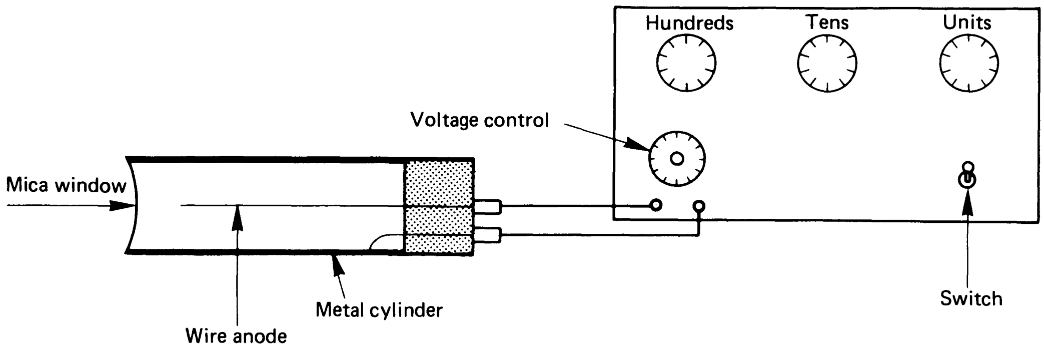
Solution 14.11

[The activity halves every 10 hours. So
after 10 hours the activity will be 600 counts per minute
after 20 hours the activity will be 300 counts per minute
after 30 hours the activity will be 150 counts per minute
after 40 hours the activity will be 75 counts per minute.]

Answer **B**

Example 14.12

Summarised directions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)



The diagram shows a Geiger-Müller tube connected to a scaler. Which of the following statements is/are true?

(1) The inside of the tube contains an inert gas
(2) The voltage control is usually set at about 6 V
(3) Geiger-Müller tubes can never be used to count α-particles because the α-particles cannot penetrate the mica window

Solution 14.12

[The inside of the tube contains a gas such as argon at about half atmospheric pressure. When an ionising radiation enters the tube the argon is ionised and the ions produce a pulse of current. The voltage across the tube is usually about 450 V. In most tubes the mica window is made so thin that α-particles can penetrate it.]

Answer **A**

Example 14.13

PART I
Start a new page

(a) Name *three* types of radiation emitted by radioactive sources. **(1 mark)**
(b) State, justifying your choice in each case, which of the radiations named in (a)
    (i) carries a negative charge

(ii) is similar to X-rays
(iii) is most easily absorbed
(iv) travels with the greatest speed
(v) is not deflected by a magnetic field
(vi) is emitted when $^{238}_{92}U$ decays to $^{234}_{90}Th$
(vii) is similar in nature to cathode rays **(7 marks)**

PART II

Start a new page

(c) Carbon-14 ($^{14}_{6}C$) is an *isotope* of carbon. It is radioactive, decaying to nitrogen-14 ($^{14}_{7}N$).
(i) What is the meaning of the term *isotope*?
(ii) Write an equation for the decay of carbon-14. **(3 marks)**

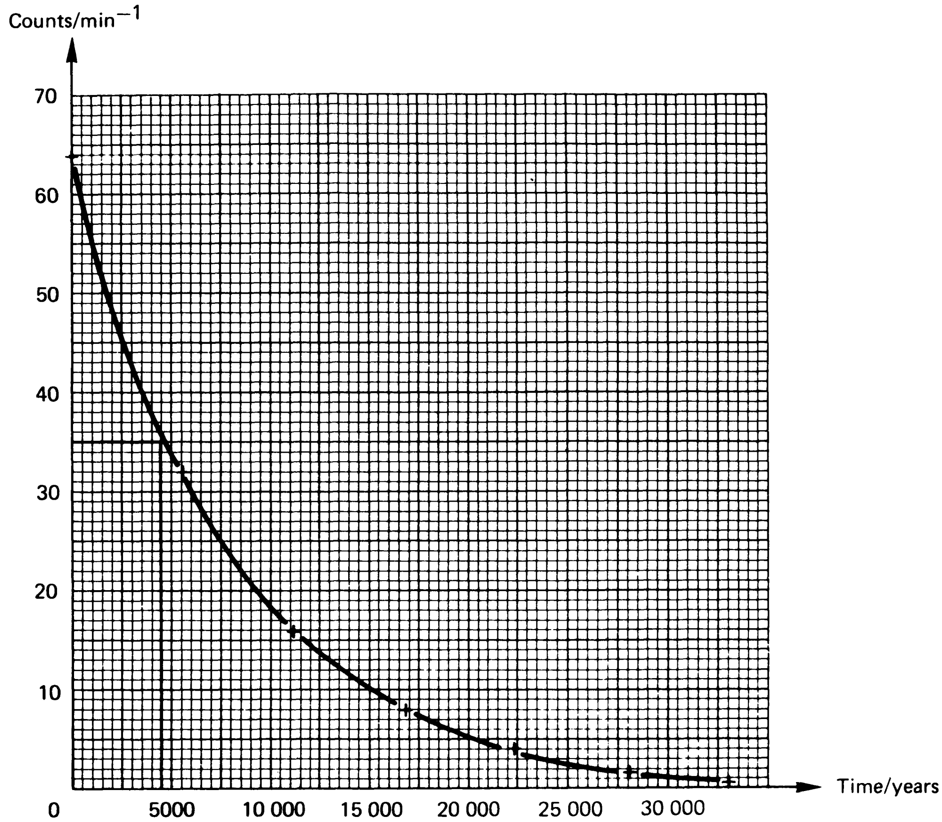
(d) Carbon-14 has a half-life of 5600 years.
(i) What is the meaning of the term *half-life*?
(ii) Draw a graph to show the decay of carbon-14 from an initial activity of 64 counts per minute. **(7 marks)**

(e) While trees and plants live they absorb and emit carbon-14 (in the form of carbon dioxide) so that the amount of the isotope remains constant.
(i) What happens to the amount of carbon-14 after a tree dies?
(ii) A sample of wood from an ancient dwelling gives 36 counts per minute. A similar sample of living wood gives 64 counts per minute. From your graph deduce the approximate age of the dwelling. **(3 marks)**

(AEB)

Solution 14.13

(a) Alpha-, beta- and gamma-radiation.
(b) (i) β-radiation is normally negatively charged (although positive β-particles are sometimes emitted).
(ii) γ-radiation and X-rays are both electromagnetic radiation.
(iii) α-radiation will not pass through a sheet of paper. The others easily penetrate a piece of paper.
(iv) γ-radiation like all electromagnetic radiation travels at the speed of light.
(v) γ-radiation. Both α and β radiation are charged and deflected by a magnetic field.
(vi) α-radiation. It is a helium nuclei $^{4}_{2}He$.
(vii) β-radiation. Cathode rays and β-radiation are both fast moving electrons.
(c) (i) Isotopes are atoms of a given element which differ only in the number of neutrons in the nucleus. Isotopes therefore have the same proton number but a different nucleon number.
(ii) $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$
(d) The half-life is the time for the activity to halve. Thus in 5600 years the activity will halve. In 11200 years it will have become a quarter of its original value.



(e) (i) The carbon-14 decays and every 5600 years the activity will halve.
(ii) 4500 years.

Example 14.14

In an experiment to determine the half-life of radon-220 ($^{220}_{86}Rn$) the following results were obtained, after allowing for the background count:

Time/s	0	10	20	30	40	50	60	70
Count rate/s^{-1}	30	26	23	21	18	16	14	12

(a) By plotting the count rate (vertically) against the time (horizontally), determine the half-life of $^{220}_{86}Rn$. Show clearly on your graph how you obtain your answer. **(6 marks)**

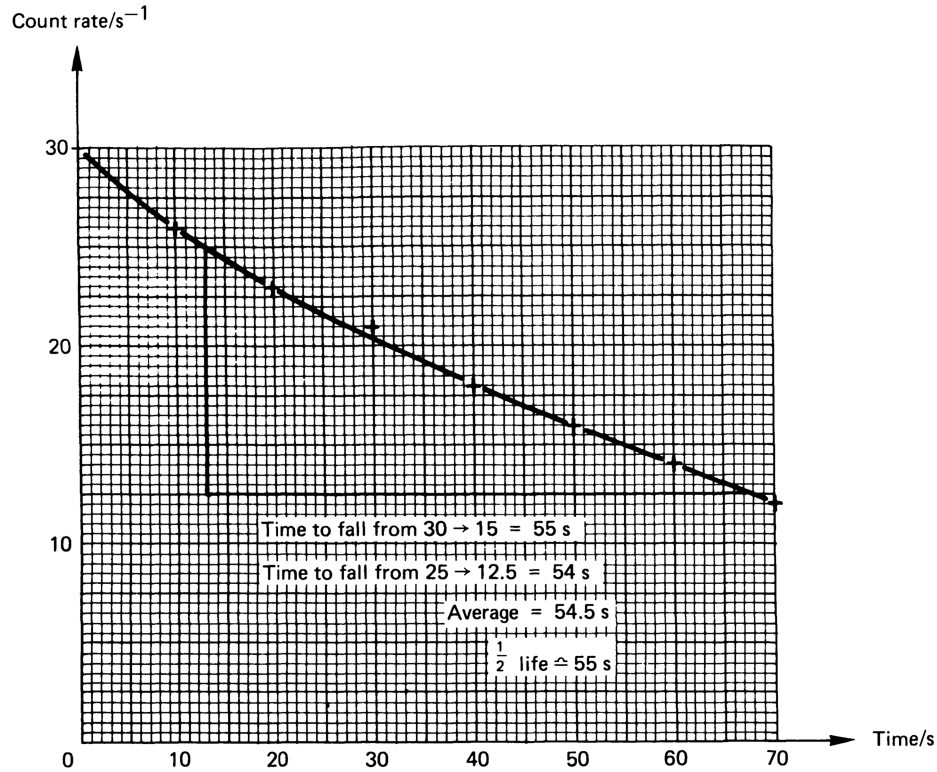
(b) (i) What is the origin of the background count? **(2 marks)**
(ii) How is the background count determined? **(3 marks)**

(c) $^{220}_{86}Rn$ emits α-particles.
(i) What is an α-particle? **(2 marks)**
(ii) When $^{220}_{86}Rn$ emits an α-particle it becomes an isotope of the element polonium (Po). Write an equation to represent this change. **(2 marks)**

(d) When carrying out experiments with radioactive sources, students are instructed that
(i) the source should never be held close to the human body,
(ii) no eating or drinking is allowed in the laboratory.
Why is it important to follow these instructions? **(5 marks)**
(L)

Solution 14.14

(a) [The half-life is the time for the count rate to halve no matter where it starts. You should always take a number of different starting points and take the average value for the half-life. In this case only two were taken because the



readings stopped soon after the count rate halved. Normally at least three values would be calculated.]

(b) (i) The background count is always present in the atmosphere. It arises from cosmic rays entering the atmosphere, radioactive materials on the surface of the Earth, radon in the atmosphere and X-rays from television screens.

(ii) In the above experiment the detector is removed from the radon source and left in the atmosphere. The count is taken over a period of say a minute and the count rate per second determined by dividing by 60. The average of about 10 counts would be taken.

(c) (i) An α-particle is a helium nucleus, ${}^{4}_{2}He$. It has a charge of +2 and a nucleon number of 4.

(ii) ${}^{220}_{86}Rn = {}^{216}_{84}Po + {}^{4}_{2}He$

(d) Radiation is dangerous because it can harm living cells.

(i) The intensity of radiation falls off rapidly as the distance increases, so the further the source is from the human body the less is the risk.

(ii) α-radiation cannot penetrate the skin so the greatest risk comes from swallowing minute traces. Indeed any radiation is more dangerous if it is inside the body, hence eating and drinking should never take place in the vicinity of radioactive materials.

Harm to the body could result if these instructions were not followed.

Example 14.15

A student suggests that a stable isotope of an element X should be represented by the form ${}^{7}_{3}X$. Another student suggests the form ${}^{4}_{3}X$ for another stable isotope.

(a) State why these two forms represent isotopes of the element X.

(b) How many neutrons are there in an atom of
(i) ${}^{4}_{3}X$, (ii) ${}^{7}_{3}X$?

(c) Which is likely to be the form of the stable isotope? Give a reason for your answer.

(6 marks)

(L)

Solution 14.15

(a) They have the same proton number, 3, and hence the same number of protons, the same number of electrons and the same chemical properties. They have different numbers of neutrons in the nucleus.

(b) (i) 1, (ii) 4.

(c) Light elements are stable if the number of protons and neutrons are approximately equal. $^{7}_{3}X$ is likely to be more stable because it has 3 protons and 4 neutrons.

14.5 Have You Mastered the Basics?

1. Can you describe an apparatus to produce a beam of electrons and describe the path of the beam as it passes through an electric and magnetic field?
2. Can you describe a cathode-ray oscilloscope?
3. Can you describe what happens to the leaf of a charged gold leaf electroscope when a charged rod is brought up to the cap?
4. Can you explain the principles of operation of a cloud chamber and a Geiger-Müller tube?
5. Can you state the nature, charge and properties of α-, β- and γ-radiation?
6. Can you state the law of radioactive decay and explain the meaning of half-life?
7. Can you explain the meaning of proton number, nucleon number and isotope?
8. Can you describe some uses of radioactivity and the safety precautions necessary when using them?
9. Can you write equations to illustrate α and β decay?
10. The half-life of a radioactive isotope which emits β particles is 24 days. It has a mass of 1 kg and its activity is found to be 2000 counts/min.
    (a) What is the activity after (i) 48 days and (ii) 96 days?
    (b) Has its mass changed significantly after 96 days?

14.6 Answers and Hints on Solutions to 'Have You Mastered the Basics?'

1. See section 14.2 and Example 14.1.
2. See section 14.2 and Example 14.3.
3. See section 14.1 and Example 14.5.
4. See section 14.3(a) and Example 14.8.
5. See section 14.3(b).
6. See sections 14.3(c) and 14.3(d). Also Examples 14.11 and 14.13.
7. See section 14.3(e).
8. See sections 14.3(h) and 14.3(i).
9. See section 14.3(g) and Examples 14.13 and 14.14.
10. After 24 days the count rate is 1000 counts/min.
    After 48 days the count rate is 500 counts/min.
    After 72 days the count rate is 250 counts/min.
    After 96 days the count rate is 125 counts/min.
    (a) (i) 500 counts/min. (ii) 125 counts/min.
    (b) No. The mass of a β particle is *very* small so the mass of the isotope has not changed appreciably. However, the mass of the undecayed isotope is 0.25 kg and 0.75 kg of the isotope has decayed.

14.7 Questions

Question 14.1

(a) Draw a labelled diagram of a gold leaf electroscope. **(5 marks)**

(b) A positively charged acetate strip is brought near to the cap of an uncharged electroscope.

(i) What sort of charge is on the leaf?

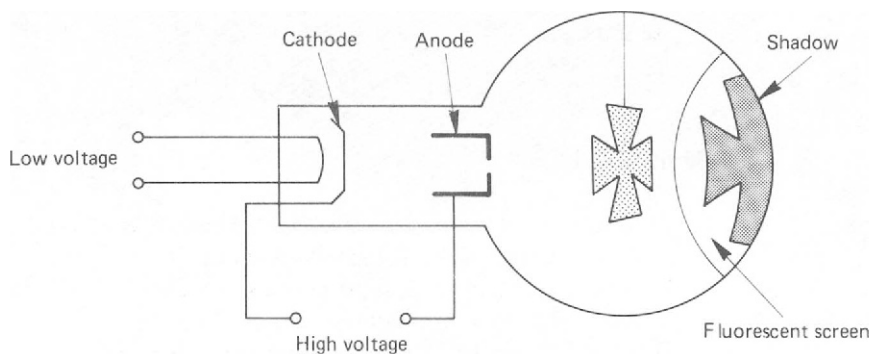
(ii) What happens to the leaf if the cap is touched while the strip is still held in position? Explain your answer by saying what happens to the charge on the leaf.

(iii) If the finger is removed and then the rod what will happen to the leaf? Is there any charge on the leaf? If so, what sort of charge? **(9 marks)**

(c) Describe with the aid of diagrams what will happen if a charged rod is held near to a small pith ball suspended from a nylon thread. Will the effect be different on a damp day? **(6 marks)**

Question 14.2

The diagram shows a simple form of cathode-ray tube (known as a Maltese-Cross tube) which produces a sharp shadow of a cross on a fluorescent screen.



(a) Explain what is meant by cathode rays and how they are produced. **(4 marks)**

(b) State the properties of cathode rays, mentioning similarities and differences compared with light. **(6 marks)**

(c) Draw a diagram to show how two plane circular coils carrying electric current (Helmholtz coils) could be used to deflect the shadow on the screen downwards. By means of labels on your diagrams, or otherwise, explain how the deflection is produced. **(3 marks, 3 marks)**

(d) Describe *two* ways by which the brightness of the screen around the deflected shadow could be increased, and explain what effect each would have on the size of the deflection. **(4 marks)**

(OLE)

Question 14.3

(a) How may a cathode-ray oscilloscope be used to measure

(i) the e.m.f. of a dry cell

(ii) the maximum or peak value of the e.m.f. of a dynamo which is rotating at constant speed. **(12 marks)**

(b) The time base of an oscilloscope is switched on and the switch set to 5 milliseconds per centimetre. The distance across the screen is 12 cm.

Sketch the appearance of the trace on the screen, if an oscillation of frequency 50 Hz is fed to the input. **(6 marks)**

(c) How is the brightness of the spot controlled? **(2 marks)**

Question 14.4

Directions summarised				
A 1, 2, 3 correct	**B** 1, 2 only	**C** 2, 3 only	**D** 1 only	**E** 3 only

The isotopes of any one element
1 have the same chemical properties
2 contain the same number of neutrons in the nucleus
3 contain different numbers of protons in the nucleus (L)

Question 14.5

The symbol $^{235}_{92}U$ denotes an *isotope* of the element uranium of *nucleon number* 235 and *proton number* 92. Explain the meaning of the terms in italics. **(6 marks)**

State the changes which take place in the nucleus of a radioactive element when an alpha particle is emitted. **(4 marks)**

Hence show, using the above symbol notation, the change when radium ($^{226}_{88}Ra$) emits an alpha particle and radon (Rn) is formed. **(2 marks)**

State *two* uses of radioactive isotopes and *one* precaution necessary when using such substances. **(3 marks)**

(SUJB)

Question 14.6

An isotope is said to have a half-life of 6 years. This means that
A After 1 year $\frac{1}{6}$ of the isotope has decayed
B After 1 year $\frac{1}{6}$ of the isotope remains undecayed
C After 12 years $\frac{1}{4}$ of the isotope has decayed
D After 12 years $\frac{1}{4}$ of the isotope remains undecayed
E After 12 years the isotope has completely decayed

Question 14.7

Summarised directions for recording responses to multiple completion questions				
A (1) alone	**B** (3) alone	**C** (1) and (2) only	**D** (2) and (3) only	**E** (1), (2) and (3)

$^{210}_{84}Po$ has a half-life of 124 days and decays into $^{206}_{82}Pb$. Which of the following statements is/are correct?
(1) $^{210}_{84}Po$ emits a α particle
(2) After 248 days $\frac{1}{4}$ of the $^{210}_{84}Po$ will be left undecayed
(3) $^{206}_{82}Pb$ has 82 neutrons in its nucleus

Question 14.8

(a) Compile a table for α, β, and γ radiation which shows (i) their nature, (ii) their relative penetrating powers, (iii) their ionising powers. **(8 marks)**
(b) You are asked to determine the level of shaving cream in an aerosol. Explain how you would do this using a radioactive source and a detector. **(6 marks)**
(c) The half-life of an element is 8 days. How much of it will be left after 24 days? **(6 marks)**

Question 14.9

What is meant by the half-life of a radioactive element? Use the table of readings below to calculate the half-life of the element.

Time/s	0	110	163
Count rate/min^{-1}	2000	500	250

After what time would you expect the count rate to be 125?

Question 14.10

(a) A Geiger-Müller tube attached to a scaler is placed on a bench in the laboratory. Over three consecutive minutes the scaler reads 11, 9 and 16 counts per minute.

When a radioactive source is placed near to the Geiger-Müller tube the counts over three consecutive minutes are 1310, 1270, and 1296 per minute.

When a piece of thick paper is placed between the source and the tube the counts are 1250, 1242, and 1236 per minute.

When the paper is replaced by a sheet of aluminium 2 mm thick the counts are 13, 12 and 11 per minute.

(i) Why is there a reading when no source is present? **(2 marks)**

(ii) Why do the three readings in any one group differ? **(2 marks)**

(iii) What can be deduced about the nature of the emission? Give reasons for your answer. **(5 marks)**

(b) What do you understand by the *half-life* of a radioactive element? **(2 marks)**

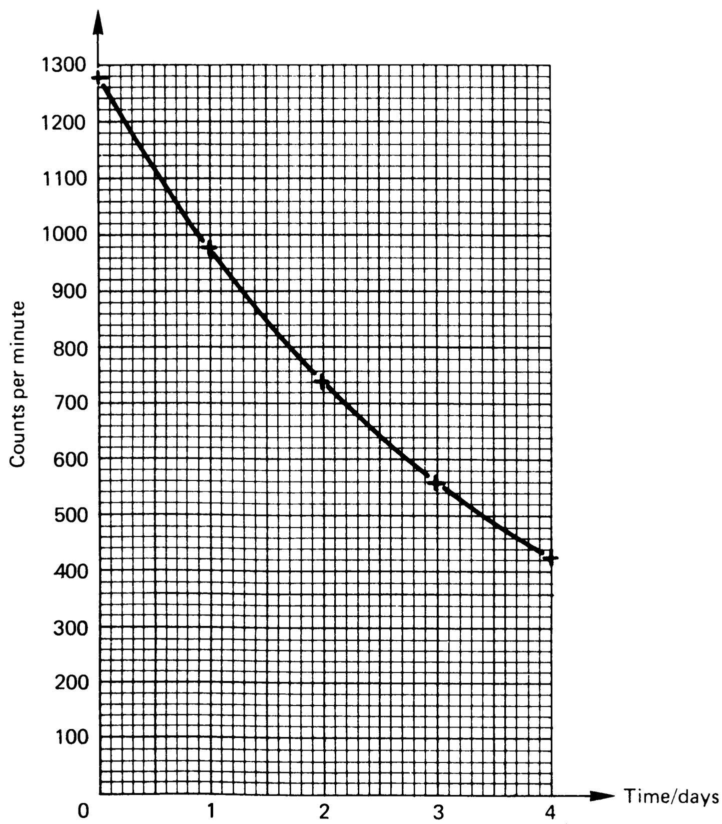
The graph below is plotted from readings taken with a radioactive source at daily intervals.

Use the graph to deduce the half-life of the source. **(2 marks)**

Hence give the count rate after five days, and the time when the count is 160 per minute. **(4 marks)**

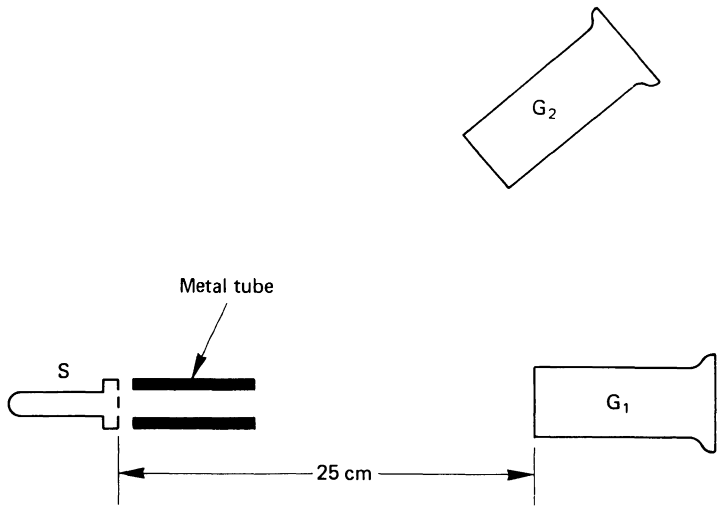
Would you expect the mass of the source to have changed significantly after 4 days? (Give a reason for your answer.) **(3 marks)**

(L)



Question 14.11

(a)



A Geiger counter G_1, placed as shown at a distance of 25 cm from a radioactive source, S, records an average count of 250 per minute. A similar counter G_2 placed above G_1, but also at 25 cm from S, records three successive minute-interval counts of 21, 18 and 23. When a horse-shoe magnet is suitably positioned the count rate of G_1 decreases to approximately half its former value and the count rate of G_2 shows an appreciable increase.

(i) Account for the three successive minute-interval counts recorded by G_2 and explain why these figures are not constant. **(3 marks)**

(ii) Why, in experiments with radioactive sources, is a knowledge of these figures important? Indicate how they are used. **(3 marks)**

(iii) What is the nature of the radiation emitted by S? Give reasons for your answer. **(5 marks)**

(iv) Describe, as exactly as you can, the position of the horse-shoe magnet. (A diagram may help.) **(2 marks)**

(v) State clearly the direction of the magnetic field. **(1 mark)**

(vi) What is the purpose of the metal tube? **(1 mark)**

(b) In a physics textbook the following statement appears: 'Radium-D decays with the emission of a β-particle to form radium-E which then decays with the emission of a β-particle to form radium-F. Radium-F decays with the emission of an α-particle to form lead.' Explain why radium-D is an isotope of lead. **(5 marks)**

(L)

Question 14.12

(a) Describe how a cloud chamber is used to make the tracks of α-particles visible. Your account should include

(i) a labelled diagram of a cloud chamber.

(ii) An account of how the tracks are produced.

(iii) A statement of what you would expect to observe.

(b) A Geiger–Müller tube is fitted through a cork in the top of a beaker so that the end of the tube is in the beaker. The beaker contains a radioactive gas. The Geiger–Müller tube is connected to a ratemeter and the following table shows how the count rate varied with the time.

Time/s	0	30	60	90	120	180	240
Count rate/min^{-1}	200	132	95	63	41	18	10

Plot a graph of count rate against time and use your graph to determine the half-life of the gas.

14.8 Answers and Hints on Solutions to Questions

1. (a) See Example 14.5.
   (b) (i) Positive. (ii) When the cap is touched, electrons from the Earth are 'attracted' to the leaf which is neutralised. The leaf will collapse, but there is still negative charge held on the cap by the positively charged strip. (iii) There is negative charge on the leaf.
   (c) Draw diagrams to show the pith ball will be attracted (see Example 14.4). When it touches the rod it will get some of the rod's charge and be repelled. Charge will leak away on a damp day and the experiment will not work well.
2. (a) Cathode rays are streams of electrons. See section 14.2.
   (b) Both travel in straight lines. Cathode rays are negatively charged particles, light is an electromagnetic wave. Cathode rays may be deflected by electric and magnetic fields. They are detected in different ways. Cathode rays have mass.
   (c) See Example 14.2. The coils must be in planes parallel to the paper and in front of and behind the tube. The direction of the deflection may be found by the left-hand rule (section 13.6). Remember the conventional direction of the current is opposite to that of the electron flow.
   (d) Increase the anode voltage or apply a positive potential to the cross. Both would decrease the size of the deflection.
3. (a) (i) Set the spot in the centre of the screen and connect the cell across the Y-plates (marked 'input'). The knob marked 'volts/cm' should be set at about 1 volt/cm if two or three 1.5 V cells are used, for a greater voltage a different setting would be needed. (ii) A suitable setting is chosen for the volts/cm and the output terminals of the dynamo connected to the input terminals of the oscilloscope.
   (b) One cycle will occupy 4 cm of screen.
   (c) A grid close to the cathode is made more negative to reduce the brightness of the beam.
4. See section 14.3(f).
   <u>Answer D</u>
5. See sections 14.3(e), (f) and (g). $^{222}_{86}Rn$ is formed. See sections 14.3(h) and (i).
6. See section 14.3(d) and Example 14.11.
   <u>Answer D</u>
7. See section 14.3(g) and Example 14.11. It has 82 protons in its nucleus.
   <u>Answer C</u>
8. (a) See section 14.3(b).
   (b) Place a β source on one side of the tin and a G–M tube on the other side directly opposite the source. Keep the source and detector in the same horizontal plane and move them up and down the outside of the tin.
   (c) See Example 14.11 and 'Have you Mastered the Basics' No. 10.
   <u>Answer. $\frac{1}{8}$ of the element will be left.</u>
9. See section 14.3(d) and Example 14.11. Two half-lives is 110 s therefore one half-life is 55 s. One half-life is (163 − 110) s = 53 s. Average is 54 s. About 217 s.
10. (a) (i) See Example 14.14. (ii) Radioactivity is a random process. (iii) No significant reduction with paper; therefore not alpha. Radiation reduced to background count by 2 mm of aluminium and therefore not gamma. Must be beta.
    (b) See section 14.3(d) and Example 14.11. About 2.5 days. After 5 days count rate is 320 counts/min. The count rate will be 160 after 7.5 days.

The mass does not appreciably change when β-particles are emitted, because the mass of the emitted particles is small.

11. (a) (i) Background count (see Example 14.14) and random process of emission. (ii) The average background count must be deducted from all the readings. (iii) β-radiation is deflected into G_2. γ-radiation still enters G_1. (iv) and (v) Just at the end of the metal tube with the N-pole under the paper and the S-pole above the paper. (vi) To collimate the beam.

    (b) The emission is $2\,{}_{-1}^{0}e$ and ${}_{2}^{4}He$; therefore the proton number remains the same.

12. See Example 14.8. The tracks are straight lines of about the same length. Find the time for the count rate to halve for a number of different parts of the graph and take the average value of the half-life. The half-life is about 54 s.

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