

**revision**works for

**LEAVING** CERTIFICATE

**PHYSICS**



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**PHYSICS**

**ORDINARY AND HIGHER** LEVEL

**Pádraig Mac Aodha**



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## CONTENTS

	Introduction	6
<b>Section 1</b>	<b>LIGHT</b>	<b>11</b>
<b>Section 2</b>	<b>MECHANICS</b>	<b>21</b>
<b>Section 3</b>	<b>ELECTRICITY</b>	<b>37</b>
<b>Section 4</b>	<b>MAGNETISM</b>	<b>55</b>
<b>Section 5</b>	<b>MODERN PHYSICS</b>	<b>67</b>
<b>Section 6</b>	<b>WAVES</b>	<b>81</b>
<b>Section 7</b>	<b>HEAT</b>	<b>93</b>
<b>Section 8</b>	<b>OPTION ONE – HIGHER LEVEL:</b> Particle physics	<b>99</b>
<b>Section 9</b>	<b>OPTION TWO – HIGHER LEVEL:</b> Applied electricity	<b>107</b>
<b>Section 10</b>	<b>EXPERIMENTS</b>	<b>115</b>
	<b>WORKED SOLUTIONS TO QUESTIONS</b>	<b>143</b>

# INTRODUCTION

This book is a concise and focused guide to taking the Leaving Certificate Physics exam at both Higher and Ordinary levels.

It contains all the relevant definitions and formulae, a wealth of examples, and exam-style questions addressing all parts of the course. Solutions to the questions are also supplied.

A comprehensive section on mandatory experiments, illustrated with diagrams and graphs, makes learning these experiments much clearer.

The purpose of the book is help you achieve the grade you want in Leaving Certificate Physics, by enabling you to prepare more efficiently and effectively for your examination.

## Exam structure, Higher Level and Ordinary Level

*Time: 3 hours (180 minutes)*

*Marks: 400*

### Structure

**Section A** (120 marks, 30%): Answer three out of four questions. Each question is worth 40 marks.

**Section B** (280 marks, 70%): Answer five out of eight questions. Each question is worth 56 marks.

### Timing

Allow 10 minutes at the start to read through the whole paper.

Allow 20 minutes per question (total: 160 minutes).

Allow 10 minutes at the end to read over your answers.

### Mathematical tables

The mathematical tables are very beneficial to any student sitting the Physics paper because most of the formulae on the syllabus can be found on pages 50–63. The symbols and units are on pages 65–78. Also, take note of the information given on pages 48–49 on the topic of particle physics.

One of the first things you should do in the exam is ask for a copy of the tables.

Be aware of the formulae which are not supplied in the tables; these must be learned.

### Glossary of exam terms

**Calculate:** Here a formula and calculator are needed to work out the numerical problem.

**Define:** This calls for a clear, concise meaning. Sometimes a formula can be used as a definition.

**Derive:** To derive a formula means to prove it. Usually a few lines are needed in the answer. Some derivations need a diagram.

**Describe:** Give a clear account of an apparatus or a method.

**Draw:** Use a pencil and ruler to give a clear, labelled diagram or graph.

**Explain:** To explain something is to give a full,

understandable account of it. A diagram can be a good way of explaining.

**List:** A concise series of points is required here.

**State:** Specify the answer in a sentence or two.

## General guidelines on answering exam questions

### Section A (120 marks, 30%)

Section A examines the 24 mandatory experiments on the syllabus.

Four questions appear in this section, three of which must be answered. Spend 20 minutes answering each question. Most of the experiments have already been asked about at least once so practise doing past exam questions from Section A.

Be able to draw a labelled diagram of the apparatus, including all essential equipment used to obtain the data given in the question. When describing the procedure, use points (no block paragraphs).

Pay special attention to explaining how the variable values given in the table are obtained.

Be able to describe what needs to be adjusted to give a new set of data.

Know two precautions and two sources of error for every experiment. Be specific in your answer; for example, instead of saying 'avoid the error of parallax', a better answer would be 'when measuring the length of the wire with a

metre stick avoid the error of parallax'. Understand the concept of percentage errors and how large values result in smaller percentage errors.

On average, two of the four experiment questions will require a graph to be drawn. When drawing a graph:

- Ask for graph paper.
- Do not plot small graphs. Use at least 75% of the available space on the A4 graph sheet provided.
- Recall the formula that corresponds to the data given. In Physics it is not a case of simply plotting one set of values against the other. Often you may have to square a set of values or find the reciprocal of the data, depending on the relationship stated in the formula. If this is so, make sure any adjustments made to the data are clearly shown in your answer booklet. Marks are awarded for this.
- Choose a scale that is easy to use, where the major grid lines match the natural divisions of the overall scale.
- Draw the graph in pencil so that any mistakes can be erased quickly.
- Label the axes with the names of the variables and include the units.
- Mark each point with a dot surrounded by a small circle.
- If the relationship is a proportional one, expect to get a straight line through the origin. The points may not form a perfect straight line, which is fine. Examiners want to see if students can draw a best-fit line. Use a

long transparent ruler to do this so that any points off the line are clearly visible. The coordinates are checked by examiners so don't plot points on the line just to make it look perfect.

- Some graphs require the student to get the slope and then to use the slope to calculate another quantity. For these it is important to have both variables in SI units. It is also critical to have the variables on the right axis according to the formula  $y = mx$ . It is important to pick two points on the line (not from table) to calculate the slope. The origin (0, 0) is a convenient point to pick if it's on the line.
- Not all graphs will be linear (straight line). Know which ones are not.
- For the graphs that do not require the slope to be calculated, the independent variable should be on the  $x$ -axis and the dependent variable should be on the  $y$ -axis. For example, consider the graph of variation of resistance of a thermistor with temperature. The temperature is the independent variable that is controlled externally, so it goes on the  $x$ -axis. The resistance is the dependent variable because it depends on the temperature, so it goes on the  $y$ -axis.

## Section B (280 marks, 70%)

Answer five out of eight questions.

Approach these questions in a structured way:

- Write down any numerical information you are given.

- Choose and write out the required formulae.
- Fill in the required values into the formula.
- Give your answer in the correct units.

Some students find it useful to draw a diagram of the scenario to visualise it more clearly.

Below are tips specific to particular questions. The remaining questions can be on any topic and have shown no particular pattern in past papers.

### Question 5

- The most popular question – it covers the whole course and is usually answered the best.
- Ten short questions; answer eight.
- Attempt all ten in case you haven't answered a question as well as you think.
- Each short question is worth 7 marks. Often the marks are divided up into 4 + 3, so make sure you make two points in your answer to get the full 7 marks.

### Question 6

- Mechanics-style question.
- Definitions are asked at the beginning.
- The rest of the question is quite mathematical.
- Topics such as linear motion, Newton's laws, momentum, forces and work are popular here.
- A good understanding of the fundamental concepts of physics is essential to do well in this question.
- Students who study Applied Mathematics have a good grasp of this question.

**Question 10**

- Option question (Honours students only): answer part (a) Particle physics or part (b) Applied electricity.
- The option has appeared here every year since 2002 (except in 2005 when it appeared in Q 11).
- There is no rule to say that this topic must come up every year but it always has so don't avoid it.
- There are no options on the syllabus for Ordinary level.

**Question 11**

- Question on science, technology and society.
- This usually consists of a short scientific article (e.g. a newspaper report) followed by eight questions, each worth 7 marks.
- This question tends to be easy to answer at the start, but becomes very difficult quite quickly.
- Questions can also be vague, so it is difficult to get top marks.
- In Ordinary level many of the answers can be found in the article.
- In Higher level the article sets the scene for the question; few or no answers can be obtained from the article itself.

**Question 12**

- This has four parts: (a), (b), (c), (d). Answer two of the parts.
- Any topics in the syllabus can appear here.
- This is a very popular question and is usually answered well.

**Exam tips****Difference between Higher and Ordinary levels**

- The structure and timing of both papers are the same. There is no option question on the Ordinary level paper.
- The questions in both Higher and Ordinary level papers are very specific but the Higher level questions are more challenging.

**Where students lose marks**

- The Physics paper does not have full numbering within most of the questions. This can lead to students accidentally leaving out a part. Read all questions carefully to avoid this mistake.
- Students are deducted one mark every time they omit units. Double-check that all your answers include units.
- For arithmetical slips in calculations, one mark is deducted.
- Examiners have noted a tendency on the part of some students to give a minimum of detail in their answers. Students should elaborate more in their answers. Explain everything fully in a logical fashion.
- Display all your work clearly and neatly. If your answer is illegible then the examiner may not be able to award you the marks even if you knew the answer.



**1**  
**SECTION**



# LIGHT

- Optics – an introduction
- Spherical mirrors
- Refraction of light
- Lenses



# 1 LIGHT

## Optics – an introduction

**Light** A form of energy. It travels at  $300\,000\,000\text{ m s}^{-1} = 3 \times 10^8\text{ m s}^{-1}$ .

**Reflection** The bouncing of rays of light off objects.

**The laws of reflection**

- The incident ray, the normal at the point of incidence and the reflected ray all lie in the same plane.
- The angle of incidence is equal to the angle of reflection ( $i = r$ ).

**Real image** Image formed by the actual intersection of light rays. The image can be formed on a screen.

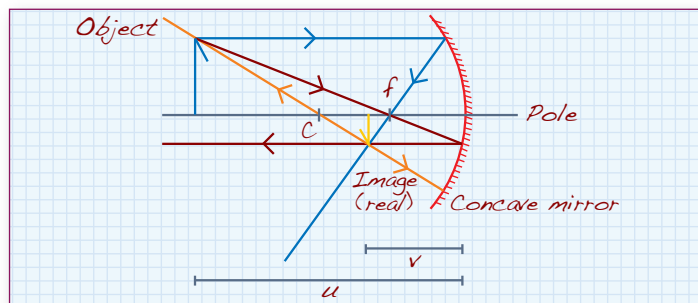
**Virtual image** Image formed by the apparent intersection of light rays. The image can never be formed on a screen.

**Parallax** The relative movement of two objects due to the motion of the observer.

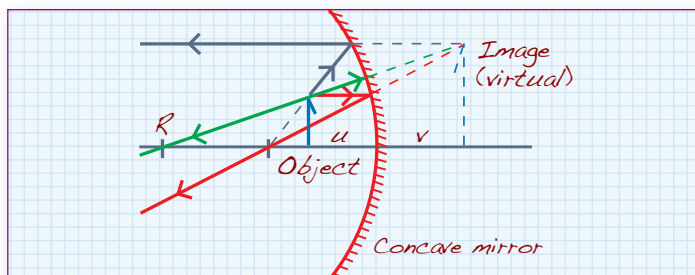
- Experiments:**
1. Locate an image in a plane mirror using the method of no parallax.
  2. Show that light travels in straight lines.

## Spherical mirrors

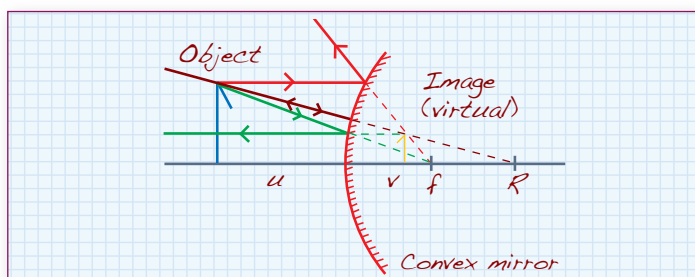
**Concave** If the object is outside the focus, the image will be real and will be located in front of the mirror.



**Concave** If the object is inside or at the focus, the image will be virtual and will be located behind the mirror.



**Convex** The image is always virtual and located behind the mirror. The image is always diminished. The nearer the object is to the mirror the bigger the image will be.



**Mirrors formula** The formula for concave and convex mirrors is:

$$1/u + 1/v = 1/f$$

where  $u$  is the distance of the object from the mirror,  $v$  is the distance of the image from the mirror, and  $f$  is the focal length.



- $u$ : always positive (+ve)
- $v$ : +ve for real image
- $v$ : -ve for virtual image (*convex is always virtual*)
- $f$ : +ve for concave mirror
- $f$ : -ve for convex mirror

To find the magnification use the formula  $m = v/u$ .

**EXAMPLE:**

A concave mirror has a focal length of 50 cm and forms a real image which is five times the height of the object. How far from the mirror is the object?

**Answer:**

Use  $m = v/u$ .

$$5 = v/u, \text{ so } 5u = v$$

Now use  $1/u + 1/v = 1/f$ .

$$1/u + 1/5u = 1/50$$

$$6/5u = 1/50$$

$$6/5u = 1/50$$

$$\text{So } u = 60 \text{ cm}$$

**EXAMPLE:**

A convex mirror of focal length 20 cm forms an image that is one fifth the size of the object. Find the positions of the image and the object.

**Answer:**

Use  $m = v/u$ .

$$1/5 = v/u, \text{ so } 5v = u$$

Now use  $1/u + 1/v = 1/f$ .

$$1/u - 1/v = -1/f$$

$$1/5v - 1/v = -1/20$$

$$\text{gives } v = 16 \text{ cm}$$

$$5v = u \text{ gives } u = 80 \text{ cm}$$

# 1 LIGHT

## Refraction of light

**Refraction** The way in which rays of light bend as they pass from one medium to another.

When light travels from a rarer to a denser medium it is refracted towards the normal. The opposite is also true.

**The laws of refraction**

1. The incident ray, the normal at the point of incidence and the refracted ray all lie in the same plane.
2. The ratio of the sine of the angle of incidence,  $i$ , to the sine of the angle of refraction,  $r$ , is a constant:  $\sin i \div \sin r = n$   
This is **Snell's law**.

**Refractive index of a medium** The ratio of the sine of the angle of incidence to the sine of the angle of refraction when light travels from a vacuum into that medium.

**Refractive index between two media** The ratio of the sine of the angle of incidence to the sine of the angle of refraction when light travels from one of those media to the other.

For any two media A and B:  ${}_A n_B = 1 / {}_B n_A$

**Finding the refractive index** To find the refractive index of a liquid, divide the real depth of a submerged object by the apparent depth.

**Refractive index of medium = Real depth  $\div$  Apparent depth**

To find the refractive index of a medium, divide the speed of light in a vacuum,  $c_1$ , by the speed of the light in the medium,  $c_2$ .

**Refractive index =  $c_1 \div c_2$**

**Critical angle** When light travels from a dense to a less dense medium, the angle of incidence that produces a  $90^\circ$  angle of refraction is called the critical angle,  $C$ .

**Refractive index  $n = 1 / \sin C$**   
where  $C$  is the critical angle.

### EXAMPLE:

A ray of light enters glass from air. The angle of incidence is  $30^\circ$  and the angle of refraction is  $20^\circ$ .

Find the refractive index of the glass.

**Answer:**  $\sin 30 / \sin 20 = 1.46$

### EXAMPLE:

The refractive index between water and glass is 1.15. What is the refractive index between glass and water?

**Answer:** Use  ${}_A n_B = 1 / {}_B n_A$ .  
 $1.15 = 1/n$   
 $1.15n = 1$   
 So  $n = 1/1.15 = 0.869$

### EXAMPLE:

The refractive index between air and glass is 1.5 and the refractive index between air and water is 1.33. Find the refractive index between glass and water.

**Answer:**  $1/1.5 = 0.667$   
 $0.667 \times 1.33 = 0.89$

### EXAMPLE:

The critical angle for a certain medium is  $62^\circ$ . What is its refractive index?

**Answer:**  
 Use  $n = 1 / \sin C$ :  
 $n = 1 / \sin 62$   
 $n = 1 / 0.8829 = 1.13$  (2 d.p.)

**Total internal reflection** When light attempts to pass from a dense to a less dense material, if it strikes the second material with an angle greater than the critical angle, it will not leave the first material but will be reflected back into the first material.

**Applications:** Fibre optics; information transfer.

## Lenses

**For a convex (converging) lens** If the object is outside the focus, the image is real and is located at the opposite side of the lens to the object. It is inverted.

If the object is inside the focus, the image is virtual and is located at the same side of the lens as the object. The image is erect.

**For a concave (diverging) lens** The image is always virtual and located on the same side of the lens as the object. The image is always diminished, but does get larger the nearer to the lens it gets.

### Lens formulae



$$1/u + 1/v = 1/f$$

- $u$ : always positive
- $v$ : +ve for real image
- $v$ : -ve for virtual image
- $f$ : +ve for convex lens
- $f$ : -ve for concave lens

$$\text{Magnification: } m = v / u$$

$$\text{Power of a lens: } P = 1 / f$$

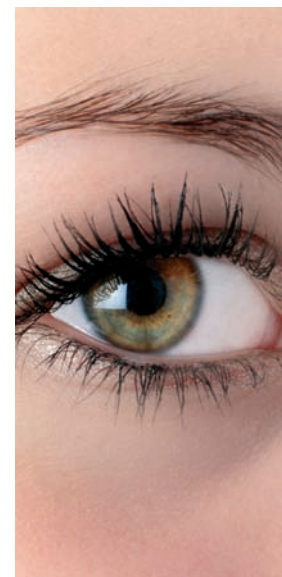
Unit of lens power: per metre,  $\text{m}^{-1}$

Total power of two lenses in contact:

- with power  $P_1$  and  $P_2$ :  $P = P_1 + P_2$
- with focal length  $f_1$  and  $f_2$ :  $P = 1/f_1 + 1/f_2$

**Eye** Accommodation: nearest and farthest objects the eye can focus on.

**Eye diagram** Include:  
lens – retina – iris – ciliary muscle – pupil – optic nerve



### EXAMPLE:

An object is placed 12 cm in front of a convex lens of focal length 22 cm.

**(i)** Find the position, nature and magnification of the image. **(ii)** If the object is 6 cm high, what is the height of the image?

### Answer:

**(i)** Use  $1/u + 1/v = 1/f$ .

$$1/12 + 1/v = 1/22$$

$$1/v = 1/22 - 1/12 = -10/264$$

$$v = -26.4, \text{ -ve so virtual}$$

Use  $m = v/u$ .

$$m = 26.4/12 = 2.2$$

**(ii)** Size of image =  $2.2 \times 0.06 = 13.2 \text{ cm}$

## Questions on light *(Answers on page 144)*

- Q1.** **Define:** light; reflection; real image; virtual image; parallax; refraction; critical angle; total internal reflection; accommodation of the eye.
- Q2.** **State:** Snell's law; the laws of reflection and refraction.
- Q3.** A man stands 2 m front of a plane mirror. **(i)** How far away from him is his reflection? **(ii)** Where must he stand in order to have his reflection 1.5 m from him?
- Q4.** An object is placed 25 cm in front of a concave mirror and produces an image that is 40 cm from the mirror. Calculate the focal length of the mirror.
- Q5.** An object is placed 40 cm in front of a concave mirror that has a focal length of 15 cm. Find the position, nature and magnification of the image.
- Q6.** An incident angle of  $24^\circ$  is made by a ray of light as it passes from air into glass. A refracted angle of  $16.5^\circ$  is produced. Find the refractive index of the glass. Find also the critical angle of the glass.
- Q7.** The refractive index between water and glass is given as 1.14. What is the refractive index between glass and water?
- Q8.** The refractive index of water is given as 1.33. If the water is 5 m deep, what is the apparent depth of the water?
- Q9.** Find the speed of light in water if its refractive index is 1.33.
- Q10.** If the critical angle for diamond is  $24.5^\circ$ , what is its refractive index?

## QUESTIONS

- Q11.** An object is placed 40 cm in front of a convex lens and an image is produced 20 cm from the lens. Find the focal length of the lens. Is the image real or virtual, why?
- Q12.** An image which is twice the height of the object is produced in a convex lens with focal length 50 cm. Find two positions where the image could be produced.
- Q13.** Find the power of a convex lens with focal length 25 cm.
- Q14.** Two convex lenses of power  $7 \text{ m}^{-1}$  and  $9 \text{ m}^{-1}$  are placed in contact. Find the power of the combination and the focal length of the pair.
- Q15.** A concave lens of power  $15 \text{ m}^{-1}$  and a diverging lens of power  $10 \text{ m}^{-1}$  are placed in contact. What is the power of the combination? Find the focal length of the pair.
- Q16.** Draw a ray diagram to show the formation of an image in a convex mirror.
- Q17.** Fibre optic cable is used to transfer information using what principle? The power of a signal in a fibre optic cable decreases by half every 2 km. If the initial power of the signal is 20 W, what will its power be when it has travelled 6 km through the cable?
- Q18.** Why is a fluorescent tube a more efficient source of light than an incandescent bulb?
- Q19.** Two converging lenses of focal length 15 cm are placed in contact. What is the power of the lens combination?

- Q20.** Why are fibre optic cables better than copper conductors for the transmission of signals?
- Q21.** Find the speed of light in a fibre optic cable with a refractive index of 1.55.
- Q22.** How does the human eye focus on objects?
- Q23.** A concave lens of focal length 15 cm forms an image 5 cm from the lens. Find the position of the object.
- Q24.** Give some practical applications of concave mirrors and convex mirrors.
- Q25.** Give some practical applications for converging and diverging lenses.
- Q26.** A scuba diver is at a depth of 10 metres in the water. She looks up and sees a bright circle above her known as Snell's window. **(i)** What causes this phenomenon?  
**(ii)** What is the radius of the circle she sees given that the refractive index of water is  $\frac{4}{3}$ ?
- Q27.** What is the structure of a fibre optic cable?
- Q28.** What is short sight and how can it be corrected?
- Q29.** What is long sight and how can it be corrected?
- Q30.** What is the function of the following structures in the eye?
- The iris
  - The cornea and the crystalline lens
  - The retina

# QUESTIONS



# 2

SECTION



# MECHANICS

- Vectors
- Linear motion
- Force and momentum
- Density and pressure
- Gravity and moments
- Work, energy and power
- Circular motion
- Simple harmonic motion and Hooke's law

# 2 MECHANICS

## Vectors

**Vector quantity** A quantity with magnitude and direction.  
**Example:** velocity.

**Scalar quantity** A quantity with magnitude but no direction.  
**Example:** volume.

**Combining vectors** The **resultant** of two vectors is the result of the two vectors being combined.

If the vectors point in the same direction they can simply be added.  
If they point in opposite directions they must be subtracted.

**Parallelogram law** To find the resultant of two or more vectors, use the parallelogram law:  
If two vectors are drawn tail to tail they form the adjacent sides of a parallelogram. The resultant of these two sides is the resultant of the two vectors. In this course we will use Pythagoras' theorem to find the resultant.

**Experiment Finding the resultant of any two vectors**  
Use three newton-balances. Connect the three together at the hooked end. Adjust the size and direction of the forces until the junction (the point at which they are connected to each other) of the three balances remains at rest. The magnitude (resultant) of any two of the forces will be the reading on the third balance.

**Perpendicular components** All resultants can be broken down into two vectors which are perpendicular to each other. When we are *only given the resultant* of two vectors, we can use this method to calculate the magnitude of the two vectors that went to make up the given resultant.

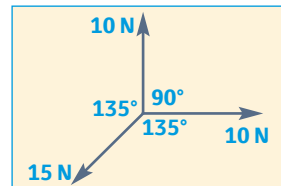
**Formula** If a vector of magnitude  $V$  has two perpendicular components  $X$  and  $Y$ , and  $V$  makes an angle  $\theta$  with component  $X$ , then the magnitudes of the components are:



$$X = V \cos \theta \quad Y = V \sin \theta$$

### EXAMPLE:

Find the resultant. In what direction is the resultant of the three vectors?



**Answer:**  
Use Pythagoras.  
 $\sqrt{(10^2 + 10^2)} = 14.14 \text{ N}$   
Resultant =  $15 - 14.14$   
= **0.86 N** in same direction as the 15 N vector

### EXAMPLE:

A stone weighing 70 N rests on a disabled access ramp. The ramp is inclined at  $15^\circ$  to the horizontal. Find the perpendicular components of the stone's weight.

**Answer:**  
 $X = 70 \sin 15 = 18.12 \text{ N}$   
 $Y = 70 \cos 15 = 67.61 \text{ N}$



## Linear motion

### Scalar and vector quantities

Time, distance and speed are scalar quantities, but velocity and displacement are vector quantities as they have both magnitude and direction.

### Average speed

**Average speed = Distance traveled ÷ Time taken**

Distance unit: metres, m Time unit: seconds, s Speed unit:  $\text{m s}^{-1}$

### Displacement

Change in position in a given direction.  
Displacement unit: metres, m

### Velocity

The rate of change of position with respect to time.

**Average velocity**

$$= (\text{Final position} - \text{Initial position}) \div \text{Time taken}$$

$$v = s \div t \quad \text{Unit of velocity: } \text{m s}^{-1}$$

### Acceleration

The rate of change of velocity with respect to time.

**Average acceleration**

$$= (\text{Final velocity} - \text{Initial velocity}) \div \text{Time taken}$$

$$a = (v - u) \div t \quad \text{Unit of acceleration: } \text{m s}^{-2}$$

### Proofs of equations of motion

**Equation 1:  $v = u + at$**

$$a = (v - u) \div t \quad \text{Cross-multiply: } at = v - u$$

$$\text{So: } v = u + at \quad \text{Q.E.D.}$$

**Equation 2:  $s = ut + \frac{1}{2}at^2$**

$$\text{Average velocity} = (u + v)/2$$

$$\text{Average velocity} = \text{Displacement} \div \text{Time}$$

$$\text{So: } \text{Displacement} = \text{Average velocity} \times \text{Time}$$

$$\text{or: } s = [(u + v)/2] \times t$$

Substitute  $v = u + at$  (equation 1), for  $v$ .

$$s = [(u + u + at)/2] \times t = [(2u + at)/2] \times t = (2ut + at^2)/2$$

$$\text{So: } s = ut + \frac{1}{2}at^2 \quad \text{Q.E.D.}$$

**Equation 3:  $v^2 = u^2 + 2as$**

Square both sides of equation 1:

$$v^2 = (u + at)^2 = u^2 + 2uat + a^2t^2 = u^2 + 2a(ut + \frac{1}{2}at^2)$$

But  $s = ut + \frac{1}{2}at^2$  (equation 2).

$$\text{So: } v^2 = u^2 + 2as \quad \text{Q.E.D.}$$

### EXAMPLE:

A car travels a distance of 1 km in 1 minute. What is its average speed?

**Answer:**

Use  $\text{Speed} = \text{Distance} \div \text{Time}$ .

$$\text{Average speed} = 1000/60$$

$$= 16.67 \text{ m s}^{-1}$$

### EXAMPLE:

A path connects two points X and Y. The length of the path is 60 m. The distance from X to Y in a straight line is 30 m.

A man runs the length of the path in 10 seconds. What is his average velocity? What is his speed?

**Answer:**

The distance the man runs is 60 m but his displacement is 30 m.

$$\text{Average velocity} = 30/10$$

$$= 3 \text{ m s}^{-1}$$

$$\text{Average speed} = 60/10$$

$$= 6 \text{ m s}^{-1}$$

### EXAMPLE:

A car slows from a velocity of  $100 \text{ m s}^{-1}$  to  $10 \text{ m s}^{-1}$  in a time of 25 seconds. What is the car's deceleration?

**Answer:**

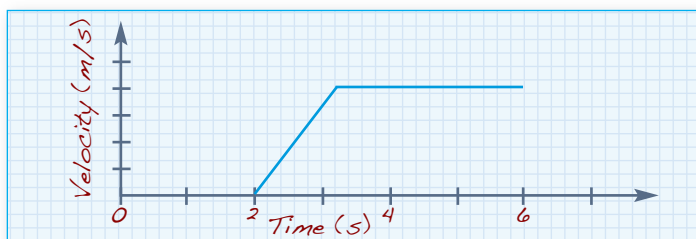
$$\text{Use } a = (v - u) \div t.$$

$$a = (10 - 100) \div 25$$

$$\text{So } a = -3.6 \text{ m s}^{-2}$$

## 2 MECHANICS

### Velocity–time graphs



### Description of motion above

The particle does not move for the first 2 seconds, then undergoes a constant acceleration. At 3.2 seconds it starts to maintain a constant velocity.

**Area under graph = Displacement**

**Slope of graph = Acceleration**

## Force and momentum

### Newton's laws of motion

- Every body will remain in a state of rest or travelling with a constant velocity unless an unbalanced external force acts on it.
- When an unbalanced force acts on a body, the rate of change of the body's momentum is directly proportional to the force and takes place in the force's direction.
- When one body exerts a force on another, the second body exerts an equal and opposite force on the first (action–reaction pair).

**Force** A force is that which can cause acceleration.

**Force = Mass × Acceleration**

$$F = ma$$

Unit of force: newton, N

**Newton** 1 N is the force that gives a mass of 1 kg an acceleration of 1 m s<sup>-2</sup>.

**Mass** A measure of the amount of matter in an object and how difficult it is to accelerate this matter. Unit of mass: kilogram, kg.  
Acceleration is inversely proportional to mass ( $a \propto 1/m$ ).

**Momentum** **Momentum = Mass × Velocity =  $mv$**  Unit: kg m s<sup>-1</sup>

**Force and momentum** Force is equal to the rate of change of momentum:  
 **$F = (mv - mu) \div t$**

### EXAMPLE:

The speed of a go-cart increases uniformly from 3 m s<sup>-1</sup> to 13 m s<sup>-1</sup> as it travels a distance of 60 m. Find the go-cart's acceleration and the time taken to travel the distance.

### Answer:

First use  $v^2 = u^2 + 2as$ .

$$13^2 = 3^2 + 2a(60)$$

$$169 = 9 + 120a$$

$$\text{So } a = 160/120 = \mathbf{1.33 \text{ m s}^{-2}}$$

Now use  $v = u + at$ .

$$13 = 3 + 1.33t$$

$$t = 10 \div 1.33 = \mathbf{7.52 \text{ seconds}}$$

### EXAMPLE:

A 50 N force acts on a body, giving it acceleration of 5 m s<sup>-2</sup>. Find the body's mass.

### Answer:

Use  $F = ma$ .  $50 = m \times 5$

$$\text{So } m = 50 \div 5 = \mathbf{10 \text{ kg}}$$

### EXAMPLE:

Find the acceleration of the mass and its direction.



**Answer:** Use  $F = ma$ .

Left:  $10 = 80a$

$$\text{So } a = 0.125 \text{ m s}^{-2} \text{ left}$$

Right:  $13 = 80a$

$$\text{So } a = 0.1625 \text{ m s}^{-2} \text{ right}$$

$$0.1625 - 0.125 = 0.0375$$

So the mass will accelerate  $\mathbf{0.0375 \text{ m s}^{-2}}$  to the right.

**Friction** The force that opposes an object's motion.

**Principle of conservation of momentum** In any interaction between two or more bodies, the total momentum between the bodies before the interaction is equal to the momentum after the interaction, so long as no resultant force acts on the system.

For two bodies:  $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$   
where  $m$  = mass,  $u$  = initial velocity,  $v$  = final velocity

## Density and pressure

**Density** **Density = Mass ÷ Volume**  
 $\rho = m/v$  Unit of density:  $\text{kg m}^{-3}$

**Pressure** **Pressure = Force per unit area**  
 $P = F/A$  Unit of pressure: pascal, Pa

**Pressure in a liquid =  $\rho gh$**   
where  $\rho$  = liquid density,  $g$  = acceleration due to gravity,  $9.8 \text{ m s}^{-2}$ ,  
 $h$  = depth

**Archimedes' principle** When an object is partially or wholly submerged in a fluid, it experiences an upthrust that is equal to the weight of the fluid it displaces.

**Law of floatation** The weight of a floating body equals the weight of fluid displaced.

**Proof:** Place an object on a spring balance. Lower the object into a water-filled overflow can until it floats. Find the weight of the displaced water. Its weight is equal to the weight of the object.

**Experiment** **Demonstration of atmospheric pressure:** Place a small amount of water at the bottom of a sealable metal can. Heat the water until steam is observed leaving the top of the can. Remove the heat and seal the can. Put the can under a running cold tap (*this causes the steam to condense*). The can collapses.

**Boyle's law** At a constant temperature the volume of a fixed mass of gas is inversely proportional to its pressure:  $P \propto 1/V$

### EXAMPLE:

Find the momentum of a car which has mass  $2500 \text{ kg}$  and velocity  $2 \text{ m s}^{-1}$ .

**Answer:**  
Momentum = Mass  $\times$  Velocity  
 $= 2500 \times 2 = 5000 \text{ kg m s}^{-1}$

### EXAMPLE:

One body (mass  $10 \text{ kg}$ , velocity  $10 \text{ m s}^{-1}$ ) collides with another (mass  $15 \text{ kg}$ , velocity  $8 \text{ m s}^{-1}$ ). Prior to impact the bodies are travelling in opposite directions, and on impact they stick together. Find the velocity and direction with which they move after the collision.

**Answer:** Let  $v$  = final velocity  
Mom. before  
 $= 10 \times 10 + 15 \times (-8) = -20$   
Mom. after =  $25v$   
Mom. before = Mom. after, so  
 $25v = -20$ , i.e.  $v = 0.8 \text{ m s}^{-1}$ , in direction of  $15 \text{ kg}$  mass.

### EXAMPLE:

A rectangular block ( $H 15 \text{ cm}$ ,  $L 22 \text{ cm}$ ,  $B 37 \text{ cm}$ ) is placed with its upper surface at a depth of  $2 \text{ m}$  in water of density  $1000 \text{ kg m}^{-3}$ . Find the pressure due to the water on the upper and lower surfaces of the block.

**Answer:** Use  $P = \rho gh$ .  
Upper =  $1000 \times 9.8 \times 2$   
 $= 19\,600 \text{ Pa}$   
Lower =  $1000 \times 9.8 \times 2.15$   
 $= 21\,070 \text{ Pa}$

## 2 MECHANICS

### Gravity and moments

#### Universal law of gravitation

Any two point masses attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F = GM_1M_2 \div d^2$$

$G$  is the gravitational constant;  $G = 6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

The acceleration due to gravity at any point above the Earth's surface is

$$g_d = GM \div d^2$$

where  $G$  = gravitational constant,  $M$  = mass of Earth, and  $d$  = distance from the Earth's centre to the point

#### Lever

A system in which a rigid body is free to rotate about a fixed point (a fulcrum).

#### Moment

**Moment of force = Force  $\times$  Perpendicular distance** Unit: N m

#### Equilibrium

Occurs when the sum of the moments of the external forces acting on a body about any axis is zero.

#### Couple

Two forces with the same magnitude acting in opposite directions. Moment of couple (torque):

$$T = Fd$$

where  $d$  = distance between the equal forces of magnitude  $F$

### Work, energy and power

#### Work

**Work = Force  $\times$  Displacement**

$$W = Fd \quad \text{Unit: joule, J}$$

#### Energy

The ability to do work. Unit: joule, J

#### The principle of conservation of energy

Energy cannot be created or destroyed; it can only be changed from one form to another.

#### EXAMPLE:

Find the gravitational attraction between a man of mass 80 kg and the Moon, when the man is standing on the surface of the Moon. (Moon radius =  $1.7 \times 10^6 \text{ m}$ , Moon mass =  $7 \times 10^{22} \text{ kg}$ )

$$\begin{aligned} \text{Answer: } F &= Gm_1m_2 \div d^2 = \\ &= [(6.7 \times 10^{-11}) \times (7 \times 10^{22}) \times 80] \\ &\quad \div (1.7 \times 10^6)^2 = \mathbf{129.8 \text{ N}} \end{aligned}$$

#### EXAMPLE:

Find  $g$ , the acceleration due to gravity, at 100 km above the Earth's surface. (Earth radius =  $6.4 \times 10^6 \text{ m}$ , Earth mass =  $6 \times 10^{24} \text{ kg}$ )

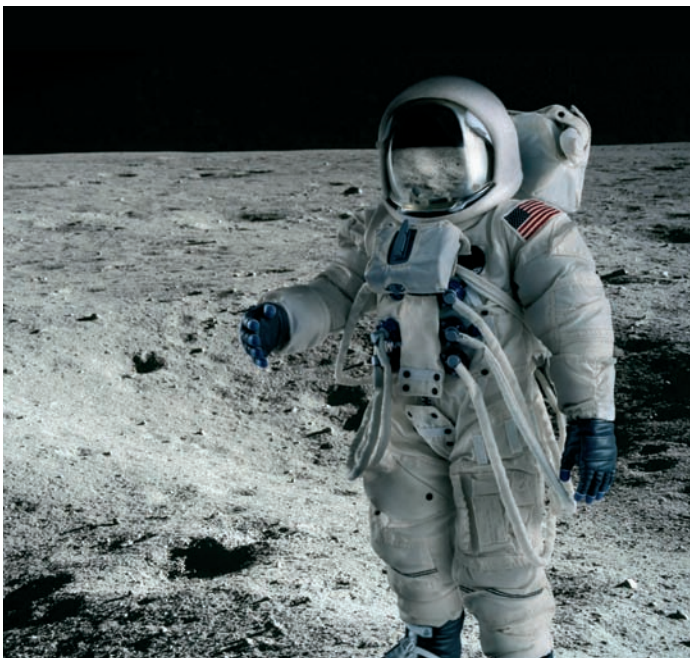
$$\begin{aligned} \text{Answer: } g &= GM \div d^2 \\ &= [(6.7 \times 10^{-11}) \times (6 \times 10^{24})] \\ &\quad \div [100\,000 + 6.4 \times 10^6]^2 \\ &= \mathbf{9.5 \text{ ms}^{-2}} \end{aligned}$$

#### EXAMPLE:

A man carries a 70 kg block up a ladder at a steady speed. He raises the block through a vertical height of 25 m. He exerts an upward force on the block equal to its weight. What is the work done by the man on the block?

#### Answer:

$$\begin{aligned} \text{Force applied} &= \text{block weight} \\ &= 70 \times 9.8 = 686 \text{ N} \\ \text{Use } W &= Fd. \\ W &= 686 \times 25 = \mathbf{17\,150 \text{ J}} \end{aligned}$$



**Kinetic energy ( $E_k$ )** The energy a body has due to its motion.  
 $E_k = \frac{1}{2}mv^2$  where  $m$  = mass,  $v$  = speed

**Potential energy ( $E_p$ )** The energy a body has due to its position.  
 $E_p = mgh$  where  $m$  = mass,  $g = 9.8 \text{ m s}^{-2}$ ,  $h$  = height

Both  $E_k$  and  $E_p$  are available on the applied maths page of the book of maths tables.

**Momentum and  $E_k$**  In collisions momentum is always conserved but there is usually a loss in kinetic energy.

**Power** The rate at which work is done. Unit: watt, W

$$\text{Power} = \text{Work done} \div \text{Time taken} \quad P = W/t$$

$$\text{Power} = \text{Energy converted} \div \text{Time taken} \quad P = E/t$$

**EXAMPLE:**

An object of mass 5 kg is dropped over a 400 m cliff. Find its kinetic energy and speed just before it reaches the bottom.

**Answer:** At top,  $E_k$  is zero, and  $E_p = 5 \times 9.8 \times 400 = 19\,600 \text{ J}$ .  
 As the object falls,  $E_p$  is converted to  $E_k$  so final  $E_k = \text{initial } E_p$ .  
 Final  $E_k = 19\,600 \text{ J}$   
 Use  $E_k = \frac{1}{2}mv^2$ .  
 $\frac{1}{2} \times 5 \times v^2 = 19\,600$   
 $v^2 = 7840$   
 $v = 88.5 \text{ m s}^{-1}$

**EXAMPLE:**

A mass of 2 kg and velocity  $10 \text{ m s}^{-1}$  collides and sticks to a mass of 10 kg which is at rest. Find the velocity and kinetic energy of the combined mass after the collision.

**Answer:**  
 Mom. before = Mom. after  
 $2 \times 10 + 10 \times 0 = 12v$   
 $v = 1.66\dots = 1.67 \text{ m s}^{-1}$

$$E_k \text{ after} = \frac{1}{2} \times 12 \times (1.66\dots)^2 = 16.73 \text{ J}$$

**EXAMPLE:**

A man raises a mass of 50 kg through a vertical height of 10 m in 5 seconds. Find average power.

**Answer:**  $P = E/t$   
 $P = (50 \times 9.8 \times 10) \div 5$   
 $= 980 \text{ W}$

## 2 MECHANICS

**Percentage efficiency** % Efficiency = (Power output ÷ Power input) × 100

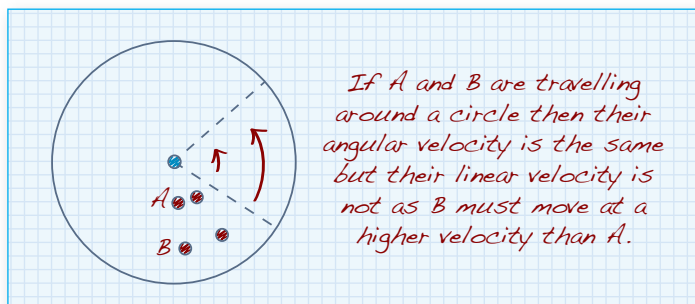
**Renewable energy source** An energy source that does not get used up.  
**Example:** wind and solar radiation.

### Circular motion

**Angle in radians** Arc length ÷ Radius  $\theta = s / r$   
 $180^\circ = \pi = 3.14159 \text{ rad}$   $50^\circ = 50\pi \div 180 = 0.8726 \text{ rad}$

**Angular velocity** Rate of change of an angle  
 $\omega = \theta / t$  or  $\theta = \omega t$  Units:  $\text{rad s}^{-1}$

**Relationship between linear speed and angular velocity**



**Proof of the relationship between angular and linear velocity:**

$$\theta = s / r$$

Divide both sides by time:  $\theta/t = (s/t) \times (1/r)$

But  $\theta/t = \omega$  and  $s/t = v$ , so:  $\omega = v / r$

**Centripetal force** The force acting towards the centre of a circle to keep an object moving in that circle.

To keep a body of mass  $m$  moving at a constant speed  $v$  in a circle of radius  $r$ , a force  $F$  acting toward the centre of the circle is needed.  $F$  is given by:

$$F = mv^2/r \text{ or } F = mr\omega^2 \text{ where } \omega = \text{angular velocity.}$$

**EXAMPLE:**

A machine has an input power of 5000 W and a useful output power of 4000 W. What is the percentage efficiency of the machine?

**Answer:**

$$\begin{aligned} &(4000 \div 5000) \times 100 \\ &= 400 \div 5 \\ &= \mathbf{80\% \text{ efficient}} \end{aligned}$$

**EXAMPLE:**

Find the arc length that has an angle at the centre of a circle of  $49^\circ$  and radius 10 m.

**Answer:**

$$\begin{aligned} \theta &= 49^\circ \div 180 = 0.8552 \text{ rad} \\ \theta &= s \div r \text{ so } s = r\theta \\ s &= 10 \times 0.8552 = \mathbf{8.55 \text{ m}} \end{aligned}$$

**EXAMPLE:**

A mass of 10 kg moves in a circular path of radius 50 cm with constant linear speed  $5 \text{ m s}^{-1}$ . Find the particle's angular velocity, centripetal acceleration, and the force acting on it.

**Answer:**

$$\begin{aligned} \text{Use } \omega &= v/r, \\ \omega &= 5/0.5 = \mathbf{10 \text{ rad s}^{-1}} \\ \text{Use } a &= r\omega^2, \\ a &= 0.5 \times 10^2 = \mathbf{50 \text{ m s}^{-2}} \\ \text{Use } F &= mv^2/r, \\ F &= (10 \times 5^2)/0.5 = \mathbf{500 \text{ N}} \end{aligned}$$

**Centripetal acceleration**

The acceleration towards the centre of a circle, of an object moving in a circle:

$$a = v^2 / r \quad \text{or} \quad a = r\omega^2 \quad \text{where } \omega = \text{angular velocity}$$

**Planetary motion**

The centripetal force that keeps the planets moving in circular orbits is the force of gravity. This force of attraction is given by the universal law of gravitation:  $F = Gm_1m_2/d^2$ .

That is, centripetal force = gravity.

$$\text{Since } mv^2/r = GMm/r^2, \text{ then } v^2 = GM/r$$

where  $M$  = mass of body being orbited,  $m$  = mass of orbiting body,  $r$  = radius of orbit,  $v$  = velocity

**Period of an orbit**

Time taken (period,  $T$ ) for satellite to go once round central body:

$$T = 2\pi r / v \quad \text{or} \quad T^2 = 4\pi^2 r^3 / GM$$

**EXAMPLE:**

An artificial satellite is orbiting the Earth 10 000 km above the Earth's surface. What is its speed?

( $G = 6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$ ,  
Earth radius =  $6.4 \times 10^6 \text{ m}$ ,  
Earth mass =  $6 \times 10^{24} \text{ kg}$ )

**Answer:** Radius of orbit:

$$6.4 \times 10^6 + 10 \times 10^6 \\ = 1.64 \times 10^7 \text{ metres}$$

Use  $v^2 = GM/r$ .

$$v^2 = [(6.7 \times 10^{-11}) \times (6 \times 10^{24})] \\ \div (1.64 \times 10^7)$$

$$= 2.45 \times 10^7$$

$$\text{So } v = 4950 \text{ m s}^{-1}$$



## 2 MECHANICS

### Simple harmonic motion and Hooke's law

#### Elastic substance

If a substance can be stretched under a force and returns to its original state when the force is removed it is said to be elastic.

#### Elastic limit

If a substance is stretched beyond its elastic limit it loses its elasticity and does not return to its original shape.

#### Amplitude

The greatest displacement of an object.

#### Hooke's law

When an object is bent, stretched, compressed or deformed by a displacement  $s$ , the restoring force  $F$  is proportional to the displacement, so long as the elastic limit is not reached.

**Restoring force = Elastic constant  $\times$  Displacement**

$$F = -ks$$

The negative sign indicates that the displacement and restoring forces are in opposite directions.

#### Simple harmonic motion

SHM is where the acceleration,  $a$ , of a body towards a particular point is proportional to its displacement  $s$  from that point.

**Acceleration =  $-(\text{Constant})^2 \times$  Displacement**

$$a = -\omega^2 s$$

Acceleration and displacement are in opposite directions.

#### Examples of SHM

Vibration of each prong of a tuning fork; mass moving up and down on a spring; a pendulum swinging with an angle of less than  $5^\circ$ .

#### Frequency of SHM

Frequency = cycles per second. Unit: hertz, Hz

$$T = 1/f \text{ and } f = 1/T$$

where  $T$  = period (time for one oscillation), and  $f$  = frequency (number of oscillations per second)

#### Energy of a body in SHM

As a body moves in simple harmonic motion its energy is constantly changing from potential to kinetic.

#### Period of SHM

If a particle moves with simple harmonic motion whose equation is  $a = -\omega^2 s$  then the period  $T$  of the motion is given by  $T = 2\pi/\omega$

#### EXAMPLE:

A spring obeying Hooke's law has an elastic constant ( $k$ ) of  $2550 \text{ N m}^{-1}$ . Find the force when the displacement is 5 cm.

#### Answer:

$$F = 2550 \times 0.05 = 127.5 \text{ N}$$

We can ignore the negative sign.



**Terms used to describe SHM**

- Oscillation
- Cycle
- Period
- Frequency



## Questions on mechanics *(Answers on page 146)*

- Q1. Define:** scalar; vector; distance; displacement; velocity; acceleration; force; mass; friction; work; energy; kinetic energy; potential energy; renewable energy; power; density; pressure; equilibrium; a lever; a couple; the elastic limit of a substance; simple harmonic motion; amplitude; angular velocity; centripetal force; centripetal acceleration.
- Q2. State:** Newton's laws of motion; the principle of conservation of momentum; Archimedes' principle; the law of floatation; Boyle's law; universal law of gravitation; the principle of conservation of energy; Hooke's law.
- Q3. Prove:** Newton's equations of motion; the relationship between linear speed and angular velocity.
- Q4.** A car with an initial speed of  $15 \text{ m s}^{-1}$  is given an acceleration of  $3 \text{ m s}^{-2}$ . What is the speed of the car after 11 seconds?
- Q5.** A stone is dropped from the top of a vertical cliff and reaches the water at the foot of the cliff in 3 seconds. Find the height of the cliff.
- Q6.** A motorbike starting from rest is given an acceleration of  $3 \text{ m s}^{-2}$ . Find the velocity of the bike after 4 seconds.
- Q7.** A stone is thrown vertically upward with initial velocity of  $90 \text{ m s}^{-1}$ . Find the greatest height reached by the stone. Find also the time it takes the stone to reach its maximum height.
- Q8.** State which of the following are vectors and which are scalars: time; pressure; velocity; momentum; area; temperature; force.

- Q9.** At a certain point, a pendulum creates an angle of  $35^\circ$  to the vertical. The pendulum bob has a weight of 150 N. Resolve the force on the pendulum into its perpendicular components.
- Q10.** A stone sits on a roof. The stone weighs 20 N. The roof is inclined at an angle of  $35^\circ$ . Resolve the forces on the stone into their perpendicular components.
- Q11.** A stone of mass 2 kg is projected vertically upward through a vertical height of 750 m. Find the increase in potential energy.
- Q12.** A car of mass 800 kg has a velocity of  $20 \text{ m s}^{-1}$ . Find the car's kinetic energy.
- Q13.** A man raises a 50 kg mass through 75 cm, 50 times in half a minute. Find the average power developed by the man.
- Q14.** A horizontal force of 250 N is exerted on a car and pushes it horizontally through a distance of 50 m. Calculate the work done by the force.
- Q15.** A car of mass 950 kg accelerates from 0 to 85 km/h in 30 seconds. Find the work done.
- Q16.** A mass of 10 kg, moving at  $10 \text{ m s}^{-1}$ , collides and sticks to a 5 kg mass which is at rest. Find the velocity of the combined mass. Find also the loss in kinetic energy.
- Q17.** An engine has an input power of 4750 W. The useful output power is found to be 3200 W. Calculate the power efficiency of the engine.

- Q18.** A basketball of mass 700 g, which is initially resting on the hoop, falls to the ground 3.76 m below.
- Find the maximum kinetic energy of the ball.
  - When the ball bounces it loses 7.5 joules of energy. Where does this energy go?
  - Calculate the height of the first bounce.
- Q19.** A satellite sends a radio signal to Earth. At the time of the transmission it is  $1.3 \times 10^{12}$  m from Earth. How long does it take the signal to reach Earth?
- Q20.** A girl swings a ball on a string in a vertical plane. The ball traces out a circle of radius 70 cm. The ball has an angular velocity of  $10 \text{ rad s}^{-1}$ . What is the linear velocity of the ball? How long does it take the ball to complete one revolution?
- Q21.** A spring is stretched 20 cm beyond its natural length; the restoring force is 75 N. The spring obeys Hooke's law. Find the restoring force when the extension is 15 cm.
- Q22.** A particle is moving with simple harmonic motion. It makes 12 full oscillations in 4 seconds. Find the period and the frequency of the motion.
- Q23.** A body moving with simple harmonic motion has a period of 2.5 seconds. What is its acceleration when it is 17 cm from the equilibrium point?
- Q24.** When the displacement of a particle executing simple harmonic motion is 15 cm its acceleration is  $2.5 \text{ m s}^{-2}$ . What is the period of the motion?

- Q25.** Two cars moving in the same direction collide. Car A has mass 1300 kg and velocity  $20 \text{ m s}^{-1}$ , while car B has mass 1500 kg and speed  $10.5 \text{ m s}^{-1}$ . The cars stick together on impact. Find their combined speed after the collision.
- Q26.** A stretched string obeys Hooke's law. When a small mass of 300 g is attached a spring of length 200 mm, its length increases to 285 mm. Calculate the spring constant.
- Q27.** An aircraft, which was flying at  $70 \text{ m s}^{-1}$ , lands and takes 2.5 minutes to come to a halt. Calculate the average acceleration of the aircraft when coming to a stop.
- Q28.** A man of mass 80 kg steps off a boat onto a pier. The man is walking with velocity of  $3 \text{ m s}^{-1}$ . If the boat has a mass of 100 kg, calculate its velocity away from the pier. The effects of the water can be ignored.
- Q29.** A bullet of mass 10 g is fired with an initial velocity of  $105 \text{ m s}^{-1}$ . If the gun has a mass of 20 kg, calculate its recoil velocity.
- Q30.** What is the force of attraction between two masses of  $1 \times 10^6 \text{ kg}$ , lying 5 m apart?
- Q31.** Calculate the acceleration due to gravity on the Earth.
- Q32.** Calculate the acceleration due to gravity at 200 km above the Earth's surface.  
Mass of Earth =  $6 \times 10^{24} \text{ kg}$   
Radius of Earth =  $6.4 \times 10^6 \text{ m}$



SECTION  
**3**



# ELECTRICITY

- Static
- Voltage and capacitance
- Current electricity
- Electromotive force (emf; voltage)
- Resistance
- Electrolysis
- Current–voltage relationships
- Semiconductors

ELECTRICITY

# 3 ELECTRICITY

## Static

**Charge** An indication of a body's excess or deficiency of electrons. The symbol for charge is  $Q$ . The unit of electric charge is the coulomb (C).

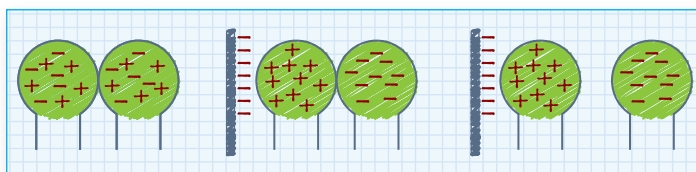
**Static** Static is charge on an insulator.

A negatively charged particle has gained electrons.  
A positively charged particle has lost electrons.

**Insulator** A substance that current **cannot** flow through easily.

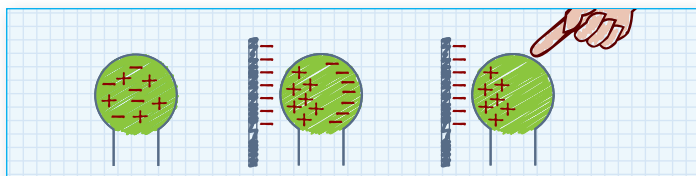
**Conductor** A substances that current **can** flow through easily.

### Separation of charges by induction

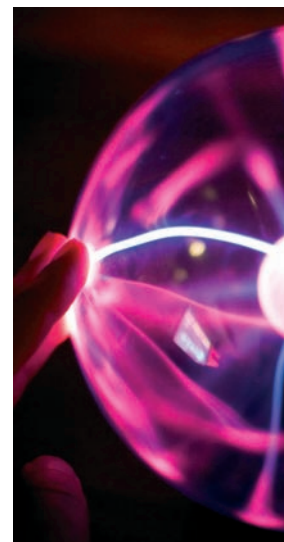


Bring together two spheres of mixed charge. Place a negatively charged rod close to but not touching one of the spheres. The charges separate with the positive going towards the rod and the negative going away from it. Separate the spheres.

### Charging a single object by induction

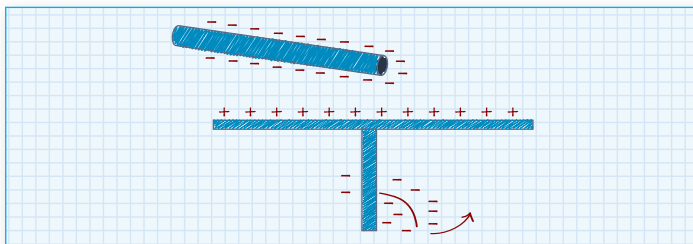


Take a mixed charge sphere. Bring a negatively charged rod close to but not touching the sphere. The charges on the sphere separate: the negative charge is repelled by the negative rod; the positive charge is attracted to the rod. Tap the sphere on the side opposite to the rod. The negative charge discharges into the finger, leaving only positive charge on the sphere.



**Point discharge** Static charge on a conductor tends to accumulate where the conductor is most pointed. The result of this is the **point discharge**. The charge builds up on a point of a conductor until the force of repulsion becomes too strong. Eventually the charge jumps to the nearest object. This occurs with lightning. The cloud builds up huge amounts of charge and eventually this charge jumps to the nearest object such as a building. Hence conduction rods are used which reroute charge to earth.

**Gold leaf electroscope** **Uses:** to detect charge; to give the approximate size of charge; to test sign of charges.



**Permittivity** A property that affects the force between charges. Charges are attracted or repulsed by each other best in a vacuum. In all other media the force between them is weaker. Unit: farads per metre

The permittivity of free space  $\epsilon_0$  is  $8.9 \times 10^{-12} \text{ F m}^{-1}$ .

The permittivity  $\epsilon$  of all other materials can be represented as a multiple  $\epsilon_r$  of the permittivity of free space:  $\epsilon = \epsilon_r \epsilon_0$ .

**Coulomb's law** The electrostatic force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

**Formula** The force between two electrostatic charges is given by the formula:

$$F = Q_1 Q_2 / 4\pi\epsilon d^2$$

where  $F$  = force,  $d$  = the distance between the charges, and  $Q_1, Q_2$  = the size of the charges



*This is an inverse square law: if the distance between the charges is doubled, the force between them is four times smaller.*

**EXAMPLE:**

The relative permittivity  $\epsilon_r$  of a liquid solution is 2.55. What is the permittivity  $\epsilon$  of the solution?

**Answer:**

$$\begin{aligned} \epsilon &= 2.55 \times (8.9 \times 10^{-12}) \\ &= 2.2695 \times 10^{-11} \text{ F m}^{-1} \end{aligned}$$



# 3 ELECTRICITY

**Electric fields** Any region of space where a static charge experiences a force other than the force of gravity. An electric field line is a line along which a positive charge would move if placed in the electric field.

**Experiment:** To show electric field patterns, take some high voltage source plates and place them in a container of cooking oil containing semolina. Connect the plates to the high voltage source. The semolina lines up showing the direction of the electric field.

**Electric field strength** The force experienced by a charge in an electric field. Formula:  $E = F / Q$

where  $E$  = field strength,  $F$  = force and  $Q$  = charge size  
Unit: newton per coulomb,  $N C^{-1}$

**Formula** To find the electric field strength at a distance:



$E = Q / 4\pi\epsilon d^2$   
where  $E$  = field strength,  $\epsilon$  = permittivity,  
 $d$  = distance from charge

## Voltage and capacitance

**Potential difference** The **potential difference** (PD) or **voltage** between two points in an electric field is the work done in bringing a charge of one coulomb from one point to another.

The unit for PD is the joule per coulomb ( $J C^{-1}$ ) or volt (V).

**Volt** The PD between two points is one volt if one joule of work is done in bringing one coulomb of charge from one point to another.

**PD is a scalar quantity:** it has magnitude but no direction.

**Work and PD** The amount of work done in bringing a charge from one point to another is given by

$W = QV$   
where  $W$  = work,  $Q$  = charge,  $V$  = voltage

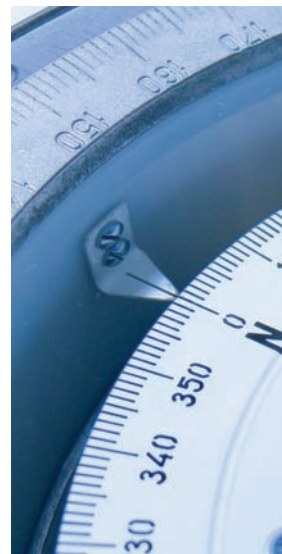
If the electric field strength is weak, then the PD between the poles of the field will be small. The reverse is also true.

### EXAMPLE:

Calculate the electric field strength when a charge of 6.5 micro-coulombs experiences a force of 10 N.

### Answer:

Use  $E = F/Q$ .  
 $E = 10 \div (6.5 \times 10^{-6})$   
 $= 1.54 \times 10^6 N C^{-1}$



**Capacitance** The ratio of charge to potential on a conductor.

**Capacitance**  $C = Q/V$  Unit: farad, F

The amount of charge on a conductor and its potential are directly proportional.

A conductor has a capacitance of one farad if placing a charge of one coulomb on it raises its potential by one volt.

**Parallel plate capacitor** Two parallel plates separated by an insulator (dielectric). It stores charge. The capacitance depends on how much the plates overlap, the distance between them and the permittivity of the dielectric.

Capacitance on parallel plate capacitor:

$C = Q/V$  or  $C = \epsilon A/d$

where  $\epsilon$  = permittivity of dielectric,  $A$  = area of plate overlap,  
 $d$  = distance between plates

Energy stored by capacitor:

$W = \frac{1}{2}CV^2$

## Current electricity

**Three effects of electric current** **Heating:** Heat is produced in all parts of a circuit. For example, a bulb heats up.

**Magnetic:** A compass needle deflects in the presence of an electric field.

**Chemical:** Electrolysis – a current splits water into hydrogen and oxygen.

**Electric current** Atoms contain positive protons and negative electrons. An **electric current** is these particles on the move. The force of attraction or repulsion between molecules made of atoms is an electrostatic force (a fundamental force of nature).

### EXAMPLE:

Calculate the work done in bringing a 6.6 coulomb charge from one point to another when the PD between the two points is 12 V.

**Answer:**

Use  $W = QV$ .

$W = 6.6 \times 12 = 79.2 \text{ J}$

### EXAMPLE:

A conductor has a potential of 10 V when a charge of 10 micro-coulombs is placed on it. Find the capacitance of the conductor.

**Answer:**

Use  $C = Q/V$ .

$C = (10 \times 10^{-6})/10$

$= 0.000\ 001$

$= 1 \text{ micro-farad}$

### EXAMPLE:

A capacitor of capacitance 4.5 F is charged to a PD of 60 V. What is the energy stored?

**Answer:**

Energy =  $\frac{1}{2}CV^2$

$= (\frac{1}{2})(4.5)(60)^2$

$= 8100 \text{ J}$

# 3 ELECTRICITY

**Size of electric current** The amount of charge passing any point on a conductor per second. The unit of electric current is the **ampere** (A or amp).  
One amp = one coulomb per second

The amount of charge  $Q$  passing a point with a steady current  $I$  over time  $t$  is  
 **$Q = It$**

**Work**  **$W = I^2Rt$**   
where  $W$  = work,  $I$  = current,  $R$  = resistance,  $t$  = time

**Power**  **$P = I^2R$  or  $P = IV$**   
where  $P$  = power,  $I$  = current,  $R$  = resistance,  $V$  = voltage

**Power transmission** Power is delivered to the home under high voltage and low current. If it were in high current form, there would be a lot of energy lost via heat (the heating effect of current). It is converted to high current after it enters the home.

## Electromotive force (emf; voltage)

**Potential difference** The PD between two points in a circuit is the energy lost by one coulomb as it moves from one point to another.

**$V = W / Q$**  Unit: joule per coulomb ( $\text{J C}^{-1}$ ) or volt (V)  
where  $V$  = voltage,  $W$  = work,  $Q$  = charge

**Power dissipated** The power dissipated between two points is  
 **$P = IV$**   
where  $P$  = power dissipated,  $I$  = current,  $V$  = voltage

**Voltages in series** If voltages are connected in series add the voltages:  
 **$V = V_1 + V_2 + V_3$**

**Voltages in parallel** If voltages are connected in parallel then:  
 **$V = V_1 = V_2 = V_3$**

**Voltmeter** A voltmeter reads voltage. It is always connected in parallel to a circuit.

### EXAMPLE:

The PD between X and Y is 36 V. 22 coulombs of charge pass a point in a certain time. How much energy is converted between X and Y?

### Answer:

Use  $V = W / Q$ , so  $W = QV$ :  
 $W = 22 \times 36 = \mathbf{792 \text{ J}}$

### EXAMPLE:

What current flows through a 10 watt CFL bulb when it is connected to the mains voltage of 230 V?

### Answer:

Use  $P = VI$ , so  $I = P / V$   
 $I = 10 / 230$   
 $= \mathbf{0.0435 \text{ A}}$

**Electromotive force (emf)** To maintain a current in a circuit there must be a PD between the ends of the circuit. Therefore an electromotive force (emf) is a voltage that is applied to a circuit. Unit: volt, V

**Sources of emf** **Simple cells** consist of two different metals in an acid. They react chemically such that one metal becomes positively charged and one negatively charged. The chemicals get used up and this type of cell cannot be recharged.

**Primary cells** are the dry batteries we use in small everyday electronic equipment. They are usually zinc-carbon based. In some of these the chemical reaction can be reversed.

**Secondary cells** can be recharged many times (e.g. car battery). The most common is the lead-acid type, but the efficient and durable zinc-ion battery could power electric cars.

**Electric cells** convert chemical to electric energy. They consist of two different metals (electrodes) immersed in an electrolyte (liquid or gel solution). A group of these cells (each with a voltage of 2 V typically) together in series is known as a **battery**.

**Mains electricity:** The mains voltage is 230 V.

**Thermocouple:** If two metals that are stuck together in a circuit are held at different temperatures, a small emf will appear between the metals and a small current will flow. The emf is typically only a few millivolts.

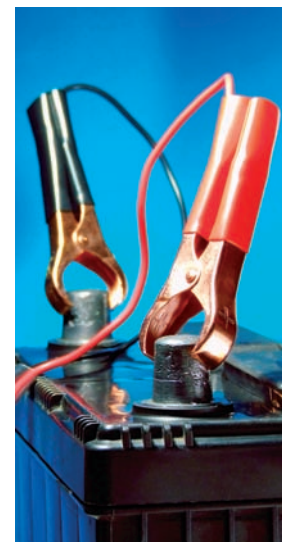
## Resistance

**Resistance** The resistance  $R$  of a conductor is the ratio of the PD  $V$  across it to the current  $I$  flowing through it:

$$R = V / I \quad \text{Unit: ohm, } \Omega$$

where  $R$  = resistance,  $V$  = potential difference,  $I$  = current

**Ohm ( $\Omega$ )** The resistance of a conductor is one ohm if the current flowing through it is one amp when the PD is one volt.



# 3 ELECTRICITY

**Ohm's law** Conductors whose resistance stays constant as the voltage across them changes are known as **ohmic conductors** and they obey Ohm's law:

$$V / I = \text{constant}$$

The constant of proportionality is resistance ( $R$ ).

**Measuring resistance** Use an ammeter in series in the circuit to get current; use a voltmeter in parallel with the circuit to get the voltage. Use  $R = V / I$  to calculate resistance.

**Resistors in series** Resistors connected in series are added together.  
 $R = R_1 + R_2 + R_3$

**Proof:**

$$V = IR$$

$$V_1 = IR_1, \quad V_2 = IR_2, \quad V_3 = IR_3$$

$$\text{So } V_1 + V_2 + V_3 = I(R_1 + R_2 + R_3)$$

$$\text{Hence } V = IR = I(R_1 + R_2 + R_3)$$

$$\text{So } R = R_1 + R_2 + R_3$$

**Resistors in parallel** Resistors connected in parallel can be calculated using  
 $1/R = 1/R_1 + 1/R_2 + 1/R_3$

**Proof:**

$$I_1 = V/R_1, \quad I_2 = V/R_2, \quad I_3 = V/R_3$$

$$I = V/R_1 + V/R_2 + V/R_3 = V(1/R_1 + 1/R_2 + 1/R_3)$$

$$\text{From Ohm's law, } I = V/R$$

$$\text{So } V/R = V(1/R_1 + 1/R_2 + 1/R_3)$$

Canceling  $V$  on both sides gives

$$1/R = 1/R_1 + 1/R_2 + 1/R_3$$

**Factors that affect resistance** Temperature  
 Length  
 Cross-sectional area  
 The material that makes up a substance



**Metallic conductors** The resistance of metallic conductors increases as temperature increases. As the temperature increases the metal atoms vibrate which causes more collisions between the electrons trying to flow through. The resistance changes linearly with temperature.

**Insulators and semiconductors** These resistances decrease as temperature increases. As temperature increases, more electrons break loose from the material that the current is flowing through, allowing more current to flow. A **thermistor** is a semiconductor.

**Resistivity ( $\rho$ )** If a conductor of length  $L$  and cross-sectional area  $A$  has a resistance  $R$ , the resistivity  $\rho$  is given by  

$$\rho = RA/L$$

## Electrolysis

**Electrolysis** Chemical effect of electric current.  
**Applications:** Electroplating; purifying metals; splitting water molecules.

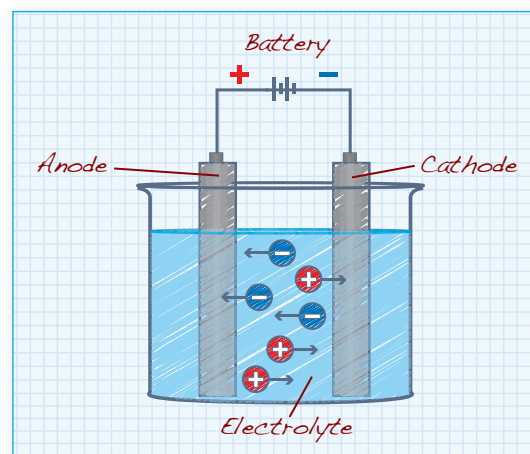
**Electrolyte** Liquid where chemical reaction takes place.

**Electrodes** Rods or plates dipped into electrolyte. If they take part in the reaction they are said to be active electrodes; if they do not they are said to be inactive electrodes.

**Anode** Connected to positive power terminal.

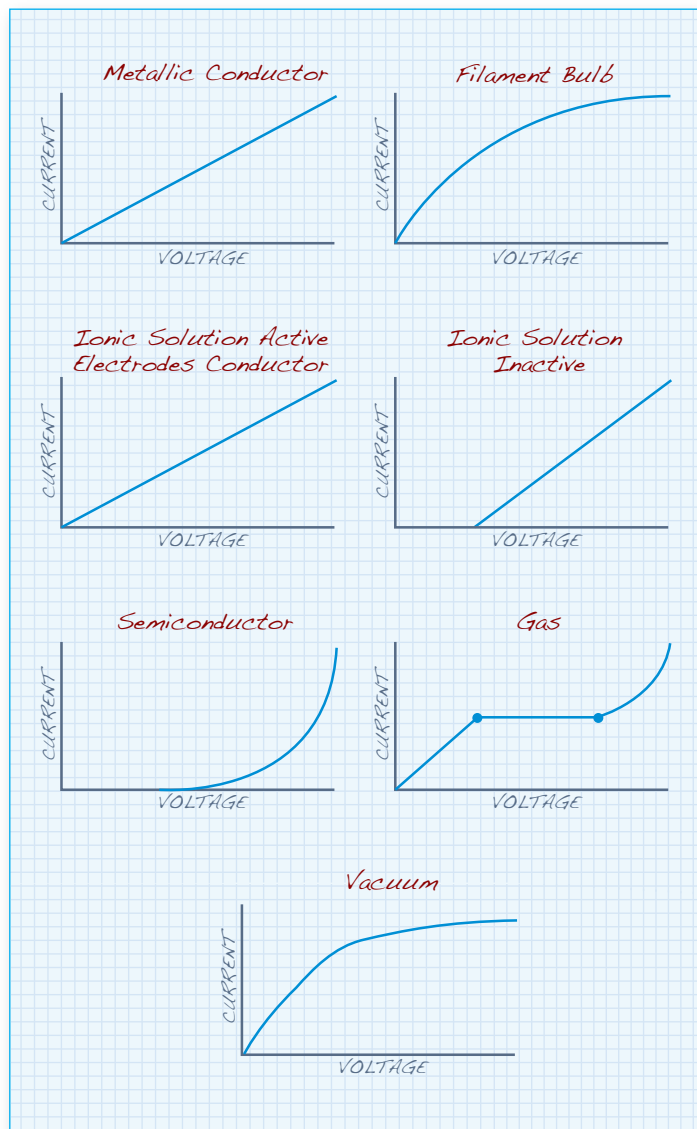
**Cathode** Connected to negative power terminal.

**Ion** Charged atom or group of atoms; that is, atoms having gained or lost electrons. Ions are the charge carriers in an electrolyte.



# 3 ELECTRICITY

## Current-voltage relationships



At constant temperature a **metallic conductor** obeys Ohm's law,  $V = IR$ , such that the graph is a straight line with slope equal to resistance and  $y$ -intercept zero.

In a **filament bulb**, initially voltage increases as current increases. As the filament gets hotter and hotter the resistance increases due to electron collisions, so even if the voltage is increased further the current does not increase so much.

**Ionic solutions with active electrodes** follow Ohm's law.

In **ionic solutions with inactive electrodes**, the electrodes act like a simple cell and produce a back emf in the opposite direction to the voltage. So a current will only start to flow when the voltage is greater than the emf, after which the solutions obey Ohm's law.

In a **semiconductor**, as voltage increases, the current increases. As this happens the semiconductor gets heated due to the current producing extra conduction electrons. This in turn reduces the resistance of the semiconductor, so current increases further.

**Gases** have ions in them which can conduct current. If a voltage is put across a discharge tube, the positive ions will go to the negative terminal and the negative ions will move to the positive terminal, i.e. a current flows. Eventually all the ions are used up and the current stops flowing. However, if the voltage continues to increase the gas can produce further ions by collisions and the current will start to increase again.

A **vacuum** doesn't carry electricity as there is nothing there to carry a charge.

However, if a metal is heated (at the cathode end of a vacuum), thermionic emission occurs and electrons begin to leave the metal and travel to the anode. As the voltage increases, so does the current until maximum thermionic emission is reached. Increasing the voltage after this point will not increase current flow.



# 3 ELECTRICITY

## Semiconductors

Semiconductors are materials whose resistivity is between that of a good conductor and an insulator. The resistivity of a semiconductor decreases as its temperature increases.

Silicon (Si) at almost zero kelvin does not conduct electricity. As its temperature rises some electrons have enough energy to break the covalent bonds that hold it together; this makes electrons available for conduction.

When an electron breaks free from its covalent bond, it leaves behind a gap in the atom from which it came. The gap which is left is positively charged and is called a **hole**. The hole is positive because the atom has lost an electron. A valence electron from another atom can move into this hole, leaving behind another hole.

### Intrinsic conduction

The movement of charge through a pure semiconductor.

### Increased temperature

Increasing temperature leads to increased semiconductor conductivity; that is, it results in more electrons having energy to break the bond. **Example:** the thermistor.

### Shining a light

Shining a light on some semiconductors increases conductivity. This type of conductor is known as a **light-dependent resistor (LDR)**. **Example:** cadmium sulphide.

### Doping

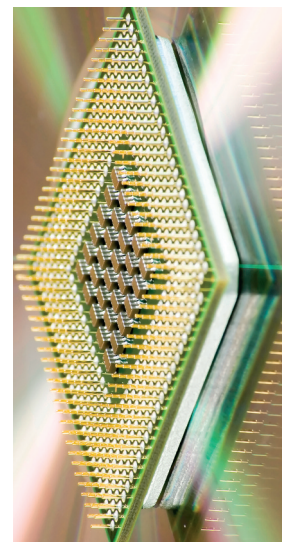
The addition of a small amount of another element to a pure semiconductor. Doping results in two types of semiconductors: n-type and p-type.

### N-type

The impurity added produces more free electrons which are available for conduction. **Example:** phosphorous in silicon.

### P-type

The impurity added produces extra holes which are available for conduction. **Example:** boron in silicon.



**Extrinsic conduction** The increase in conductivity of a semiconductor as a result of the addition of impurities (doping).

**P-N junction** A semiconductor with part of it doped p-type and the rest doped n-type (also known as a p-n diode or semiconductor diode). The n-type has spare electrons while the p-type has spare holes.

**Depletion layer** In a p-n junction, free electrons from the n-type material move to the p-type. Here they meet holes and fill them. Both holes and electrons are no longer free for conduction. Thus a layer builds up that contains virtually no free majority carriers. This results in a depletion layer, a region on both sides of a p-n junction that contains no majority charge carriers and therefore acts as an insulator.

In building up this depletion layer electrons moved from the n-type material, making it positive, and holes moved out of the p-type, making it negative. Due to this a voltage appears across the junction which is then referred to as a **voltage junction**.



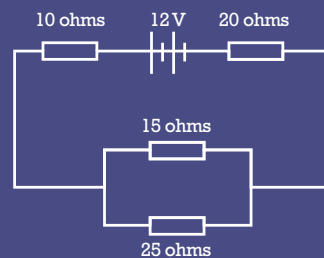
## Questions on electricity *(Answers on page 148)*

- Q1. Define:** static; insulator; conductor; electric field; potential difference; capacitance; electric charge; electromotive force; resistance; work; power; doping.
- Q2. Prove:** the formula for resistors in series; the formula for resistors in parallel.
- Q3. Describe:** how you would separate charges by induction; how you would charge a single object by induction; the uses of a gold leaf electroscope; how you would show electric field patterns experimentally; the setup of some emf sources.
- Q4. Explain** the current–voltage relationship for: a metallic conductor; a filament bulb; an ionic solution with active electrodes; an ionic solution with inactive electrodes; a semiconductor diode; a gas; a vacuum.
- Q5.** Calculate the force that a charge of 4 C exerts on a charge of 7 C placed 3 m from it in a vacuum.
- Q6.** Two point charges of 3 micro-coulombs and –2 micro-coulombs are 60 cm apart. Find the force acting on the charges when under water. ( $H_2O$  relative permittivity = 81)
- Q7.** What is the force on a charge of 3 micro-coulombs in an electric field strength of  $4 \times 10^3 \text{ N C}^{-1}$ .
- Q8.** Find the magnitude of the electric field strength at a distance of 5 m from a charge of 5 micro-coulombs.
- Q9.** A conductor has a potential of 30 V when a charge of 20 micro-coulombs is placed on it. What is its capacitance?

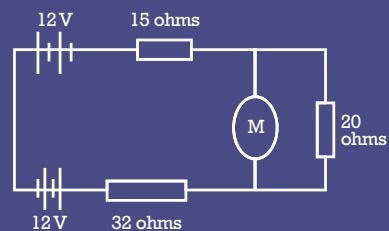
- Q10.** The potential difference between two points is 1500 V. An electron is released at one of the points and moves towards the other end under the action of the field. Find its speed when it reaches the second point.
- Q11.** A capacitor of capacitance 3 micro-farads is charged to a potential difference of 370 V. Find the energy stored.
- Q12.** How much charge passes a point in a circuit in which a steady current of 8 A flows for 2 hours?
- Q13.** Find the number of electrons passing any point in a circuit in one second, if there is a current of 11 A flowing.
- Q14.** How long does it take a current of 7.5 A to transfer a charge of 45 500 C?
- Q15.**  $4 \times 10^2$  electrons pass a point in a circuit every second. What is the current flowing in the circuit?
- Q16.** How much heat energy is produced if there is a potential difference of 15 V between points X and Y and a charge of 30 C passes?
- Q17.** What is the current flowing through a 75 W bulb when it is connected to the 230 V main electricity supply?
- Q18.** Find the voltage across a wire which produces 350 J of heat due to a charge of 65 C passes through it.
- Q19.** The current through a conductor is 7 A when the potential difference across it is 25 V. Calculate the resistance of the conductor.

- Q20.** What is the total resistance in a circuit when  $5\ \Omega$ ,  $8\ \Omega$  and  $10\ \Omega$  resistors are placed in series?
- Q21.** What is the total resistance in a circuit when  $10\ \Omega$ ,  $20\ \Omega$  and  $30\ \Omega$  resistors are placed in parallel?
- Q22.** A circuit has a current of  $6\ \text{A}$  flowing through it. If two resistors, one with resistance  $8\ \Omega$  and the other with resistance  $10\ \Omega$ , are placed into the circuit in series, find the voltage being supplied.
- Q23.** Look at the following schematic circuit diagrams and then answer the questions.

(A)



(B)



- Find the total resistance of the two circuits.  
The motor has resistance  $40\ \Omega$ .
- What is the total potential in circuit B?
- Calculate the current flowing through circuits A and B.
- What is the current flowing through the  $25\ \Omega$  resistor in circuit A?
- If the motor in circuit B has a  $40\ \Omega$  resistance, calculate the current flowing through it.

## QUESTIONS

- Q24.** A wire has a length of 84.9 cm, a diameter of 0.26 mm and a resistance of 27.9  $\Omega$ . Calculate its resistivity.
- Q25.** A Wheatstone bridge is balanced.  $R_1 = 10 \Omega$ ,  $R_2 = 25 \Omega$ ,  $R_3 = 32 \Omega$ . Find the resistance on the  $R_4$  branch of the bridge.
- Q26.** 370 J of heat are produced in a wire when a charge of 60 C passes through it. What is the voltage across the wire?
- Q27.** A current of 5 A flows through a bulb. How much charge would flow through the bulb in 10 minutes?
- Q28.** How long does it take a current of 10 A to transfer a charge of 18 kC?
- Q29.** Find the relative permittivity of a medium if the capacitance is found to be  $1.25 \times 10^{-10}$  F between two plates that are 1 mm apart and the area shared by the plates is 20 cm<sup>2</sup>.



# 4

SECTION

# MAGNETISM

- Magnetic fields and current
- Electromagnetism

MAGNETISM

# 4 MAGNETISM

## Magnetic fields and current

**Magnetic field** Any region of space where magnetic force can be felt.

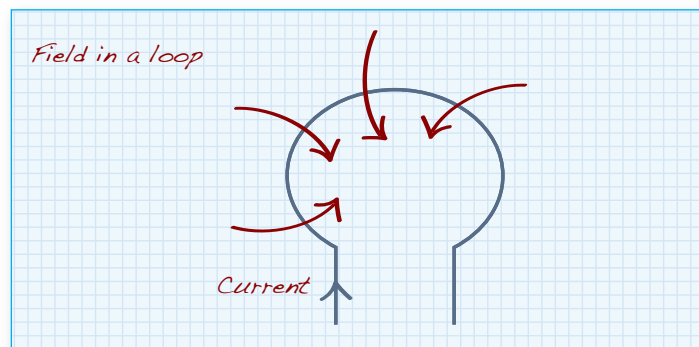
**Magnetic field line** A line along which magnetic north would move if free to do so. The magnetic field lines can be viewed by placing a magnet under a piece of paper and sprinkling some iron filings on the paper.

**Magnetic effect of current flowing through a conductor** Current flowing through a conductor always has a magnetic effect. If the current is removed so is the magnetic effect. This effect can be seen by bringing a compass close to an open switched circuit. On closing the switch the compass will be seen to deflect.

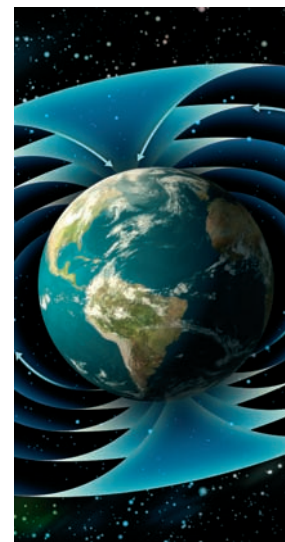
This magnetic field can be plotted by threading a white piece of card through a wire. A compass can then be used to plot the field in the manner used to plot the field lines of a bar magnet.

**The right hand grip rule** If the right hand clasps a conductor with the thumb pointing in the direction of the current (i.e. from positive to negative) then the fingers give the direction of the magnetic field.

**Magnetic field of a loop** The direction of the field can be found using the right hand grip rule.

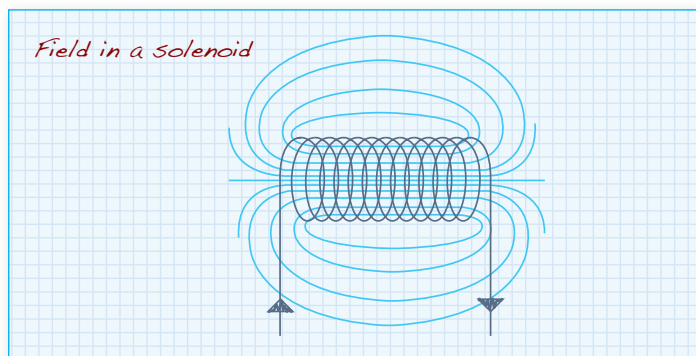


**Magnetic field of a coil** The magnetic field in a coil is stronger than the field in a similar sized loop. The field's direction can be found using the right hand grip rule.



**Magnetic field of a solenoid**

A field is produced from one end to the other.

**Electromagnet**

Soft iron core inside a solenoid with current passing through it. No current, no magnetism. **Application:** scrapyards lifting device.

**Earth's magnetic field**

Earth has a soft iron core and this behaves as a bar magnet. The magnetic poles go from geographical south to north. Many of the highly energetic particles from the Sun which would be carcinogenic to humans are deflected into the poles of the Earth where there are very few people. These particles cause the aurora borealis and the aurora australis (the northern and southern lights) as they enter the Earth's atmosphere. If the magnetic field did not exist this phenomenon would be visible in all parts of the sky over the Earth.

**Current in a magnetic field**

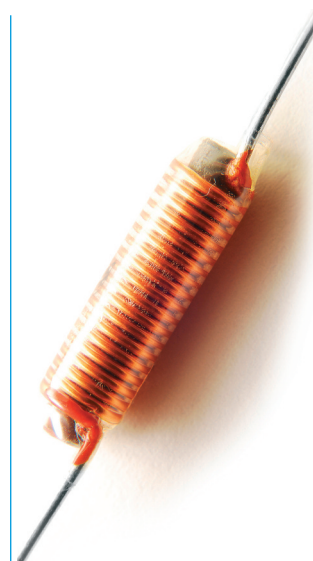
Current in a magnetic field experiences a force unless the conductor is parallel to the magnetic field. The force is always perpendicular to the current and the magnetic field. Electric motors and loudspeakers are based on this fact.

**Fleming's left hand rule**

This gives the direction of a force in a current-carrying conductor in a magnetic field.

If the thumb is placed in the direction of the force, then the index finger shows the direction of the magnetic field and the middle finger shows the direction of the current.

You must be able to apply this rule to different situations.



# 4 MAGNETISM

**Size of force** The size of the force in a current-carrying conductor in a magnetic field depends on the current size, the conductor length and the magnetic field strength.

If a conductor of length  $L$  carrying a current  $I$  is placed at right angles to a magnetic field of flux density  $B$  it experiences a force  $F$  given by:

$$F = ILB$$

**Magnetic flux density ( $B$ )** A measure of the strength of a magnetic field. Unit: tesla, T

The magnetic flux density is 1 tesla if a conductor of length 1 m carrying a current of 1 A experiences a force of 1 N when placed perpendicular to the field.

**Force on a moving charge inside a magnetic field** If there is a flow of positive or negative (electrons) charge, this flow still follows Fleming's left hand rule.

If a charge of  $q$  coulombs is moving with a speed of  $v$  metres per second at right angles to a magnetic field of flux density  $B$  tesla, then there is a force  $F$  newtons on it given by:

$$F = qvB$$

**Derivation of  $F = qvB$**  In a conductor of length  $L$  containing  $n$  charges per unit length with speed of  $v$  and charge size  $q$ , the charge passing in time  $t$  is  $qnvt$ .

Time  $t =$  Amount of charge passing any point in length  $vt$

$I =$  Charge passing  $\div$  Time taken  $= qnvt \div t = qnv$

Force on length  $L$  metres  $= ILB = nvqLB$

Force per unit length (1 m)  $= nvqB$

Force on one moving charge  $= qvB$

**Charged particle in a magnetic field** If a charged particle moving at a constant speed enters a uniform magnetic field, with the force working perpendicularly to the field, the particle moves in a circle.

**Forces between current-carrying conductors** If the current flows in the same direction in two conductors, there is an attractive force between them. If it moves in the opposite direction in the two conductors, there is a repulsive force between them.



## Electromagnetism

<b>Electromagnetic induction</b>	Electromagnetic induction occurs when an emf (electromotive force) appears in a coil due to a change in the magnetic field.
<b>Magnetic flux (<math>\Phi</math>)</b>	A measure of the magnetic field strength through an area.  <b>Magnetic flux through an area = Magnetic flux density <math>\times</math> Area</b> <b><math>\Phi = BA</math></b>  Magnetic flux is a scalar quantity. Unit: weber, Wb
<b>Weber (Wb)</b>	If the magnetic flux density over an area of $1 \text{ m}^2$ is $1 \text{ T}$ then the flux through the area is $1 \text{ Wb}$ .
<b>Faraday's law</b>	The size of the induced emf is directly proportional to the rate of change of flux.
<b>Lenz's law</b>	The direction of an induced current always opposes the change producing it. The energy to produce the emf comes from the motion of the magnet and therefore opposes it. If this was not the case, energy would be created and this cannot happen.  <b>Induced emf (<math>E</math>) = (Final flux – Initial flux) <math>\div</math> Time taken</b> <b>Induced current (<math>I</math>) = Induced emf <math>\div</math> Resistance</b>
<b>Alternating current (AC)</b>	Current that changes direction. Mains current behaves like this. It flows one way for $1/100^{\text{th}}$ of a second and then the other way for $1/100^{\text{th}}$ of a second. It oscillates every $1/50^{\text{th}}$ of a second.  AC voltage is needed to produce AC. If an AC voltage is applied to a pure resistor, the current is found using Ohm's law: <b>Current at an instant = Voltage at that instant <math>\div</math> Resistance</b>
<b>Heating effect of AC</b>	AC like DC has a heating effect. You can calculate this heating effect with regard to the AC's DC equivalent. These equivalent values are known as RMS values.

### EXAMPLE:

The magnetic flux through a coil is reduced from  $0.4 \text{ Wb}$  to zero in  $0.2$  seconds and the coil has  $200$  turns. Find the emf in one turn of the coil. Find also the total emf in the coil.

### Answer:

$$E = (\text{Final} - \text{Induced}) \div \text{Time}$$

$$E = (0 - 0.4) \div 0.2 = -2 \text{ V}$$

= emf in one turn.  
(Ignore the  $-$  sign, which indicates direction only.)

$$\text{Total emf in coil} = 2 \times 200$$

$$= 400 \text{ V}$$

### EXAMPLE:

If the coil in the example above has a resistance of  $100 \text{ ohms}$  calculate the induced current.

### Answer:

$$I = 400/100 = 4 \text{ A}$$

# 4 MAGNETISM

## AC/DC equivalent values

When given an AC value you can find the DC equivalent value using the following formulae:

$$I_{\text{rms}} = I_0 / \sqrt{2}$$

$$V_{\text{rms}} = V_0 / \sqrt{2}$$

$$P = I_{\text{rms}} V_{\text{rms}}$$

$$P = (I_{\text{rms}})^2 R$$

## Mutual induction

When a changing magnetic field in one coil causes an emf to appear in another nearby coil. The size of this induced emf can be increased by bringing the coils closer together, winding both coils on the same soft iron core and increasing the number of turns on each coil.

## Showing mutual induction

Set up two circuits, one with a coil on a soft iron core and a battery in series and the other with a coil on an iron core and a galvanometer in series. Bring the two coils close together. An emf appears in the circuit with the galvanometer even though there is no apparent source of emf. The emf comes from the coil with the battery.

## Showing self-induction

Set up a coil on a soft iron core, battery, switch and bulb in series. When the switch is closed, current flows and so the magnetic field changes. The bulb does not light for a few seconds: this is because as the current flows the magnetic field is forming and increasing. An emf opposes this changing magnetic field.

## AC and inductors

An inductor is a coil. With DC an inductor opposes the flow with its ohmic resistance.

With AC an inductor opposes the flow with its ohmic resistance *and* the back emf induced in it. Inductors are used to level out slight variations in DC in power supply units.

**Uses:** radio tuning circuits; dimmer switches in stage lighting. These are achieved by control of the back emf in the circuit.

## Capacitors and AC

A charged capacitor blocks DC. Current flows until the capacitor is charged and then DC stops flowing. A capacitor conducts AC because this current changes direction and as it does so it charges and then discharges the capacitor.



**Electrical generator** Device that converts mechanical energy to electrical energy.  
**Example:** bike dynamo.

**Transformer** A device used to change the value of an alternating voltage.

Transformers consist of a primary coil and a secondary coil. If the primary coil gets an **AC** voltage applied to it then it can produce a different voltage across the secondary coil.

**Transformer operation** Input voltage in primary coil results in AC in primary coil.

The current causes an alternating magnetic flux in the soft iron core. This alternating flux passes through the secondary coil and causes an emf and this emf is the output voltage. The emf size depends on the number of turns  $N_s$  in the secondary coil.

Step-up transformer:            If  $N_s > N_p$  then  $V_o > V_i$

Step-down transformer:        If  $N_s < N_p$  then  $V_o < V_i$

Formulae:                         $V_i / V_o = N_p / N_s$

Power remains the same so:    $V_i I_p = V_o I_s$

where:

$N_p$  = turns in primary coil,  $N_s$  = turns in secondary coil,

$I_p$  = current in primary coil,  $I_s$  = current in secondary coil,

$V_i$  = input voltage,  $V_o$  = output voltage.



## Questions on magnetism *(Answers on page 149)*

- Q1. Define:** magnetic field; magnetic field lines; electromagnet; magnetic flux density; magnetic flux; electromagnetic induction; the weber; an electrical generator; alternating current; a transformer.
- Q2. State:** Faraday's law; Lenz's law; the right hand grip rule; Fleming's left hand rule.
- Q3. Describe:** mutual induction; self-induction.
- Q4.** An electron enters a uniform magnetic field of flux density  $3 \times 10^{-2}$  T, travelling with a velocity of  $550 \text{ m s}^{-1}$ . Find the radius of the path it follows.
- Q5.** A straight wire 3 m long carrying a current of 5 A is placed perpendicular to a magnetic field of flux density 3 T. What is the force on the wire?
- Q6.** A straight wire of length 5 m carrying a current of 4 A experiences a force of 20 N. Calculate the magnetic flux density of the magnet.
- Q7.** A charge of 3 C moves at a speed of  $15 \text{ m s}^{-1}$  at right angles to a magnetic field of flux density 2.5 T. What is the force on the charge?
- Q8.** What is the force on an electron travelling at  $370 \text{ m s}^{-1}$  at right angles to a magnetic field of flux density 5.5 T.
- Q9.** A square coil of side 20 cm carrying a current of 5 A is free to rotate about an axis located at its centre. It is in a uniform magnetic field of magnetic flux density 0.8 T.
- Find the magnitude of the force acting on the side of the coil when it is perpendicular to the magnetic field.

- Find the moment of force about the axis.
- Why would the moment of force decrease as the coil rotates?
- Will the moment of force ever be zero? Why?

- Q10.** A coil is free to rotate about its axis. The coil loop is in the shape of a square of side 30 cm. The magnetic flux density of the magnet is 2 T and a current of 3 A flows through it. Find the force on the loop if it enters the magnetic field at an angle of  $40^\circ$  to the perpendicular.
- Q11.** The magnetic flux density in a system is 0.3 T. The magnetic flux passing through a coil is 0.5 Wb when placed at right angles. What is the area of the coil?
- Q12.** The plane of a coil of area  $0.3 \text{ m}^2$  makes an angle of  $40^\circ$  to the perpendicular with a magnetic field of flux density 5 T. Calculate the flux in the coil.
- Q13.** A transformer has 200 turns in the primary coil and 6000 turns in the secondary coil. It is connected to a standard 230 V AC supply. Find the voltage across the secondary. No energy losses occur in the transfer.
- Q14.** A rectangular coil of one turn and dimensions  $6 \text{ cm} \times 10 \text{ cm}$  enters a uniform magnetic field of flux density 3 T which is perpendicular to the plane of the coil. The coil moves at  $5 \text{ m s}^{-1}$  parallel to the 10 cm side of the coil and has resistance of 6 ohms. Find the emf induced in the coil and the force that must be exerted on the coil to keep it moving at that speed.
- Q15.** The rms value of an AC voltage is 30 V. Calculate the peak value.

- Q16.** The domestic AC voltage is 230 V. What is the maximum value that this voltage has in a cycle?
- Q17.** What is the peak voltage for a 110 volt rms electricity supply?
- Q18.** A particular galvanometer has a resistance of  $10\ \Omega$  and deflects fully when a current of 15 mA passes through it. What resistor would have to be connected in series to allow this galvanometer to measure a 9 V voltage?
- Q19.** A current is given as 5 A. Find its rms value.
- Q20.** What is the average emf induced in a coil of 30 turns when the magnetic flux cutting it decreases from 2.0 Wb to 1.5 Wb in 0.5 seconds?
- Q21.** A current-carrying conductor is placed in a magnetic field. Give two factors that affect the force which the conductor experiences in the field.
- Q22.** A step-down transformer converts 15 kV to 230 V. If the primary coil contains 2500 turns, how many turns are in the secondary coil?

# QUESTIONS



SECTION  
**5**



# MODERN PHYSICS

- The electron
- Atoms and radioactivity
- Nuclear fission, fusion and energy

MODERN PHYSICS

# 5 Modern physics

## The electron

### Properties of electron

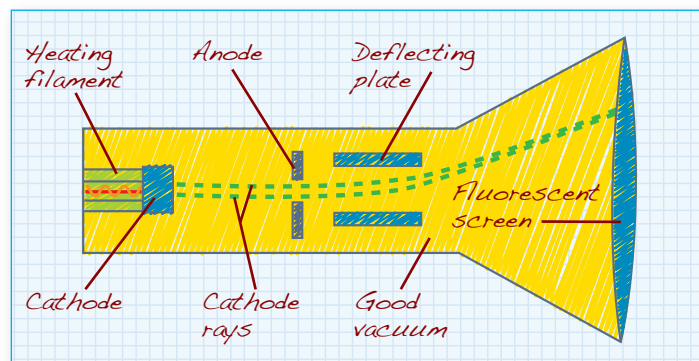
Orbits the nucleus; very small mass; negative charge.

Named by G. J Stoney; charge value discovered by Millikan.

### Thermionic emission

Giving off of electrons from a hot metal.

### Cathode ray tube (CRT)



### Operation of CRT

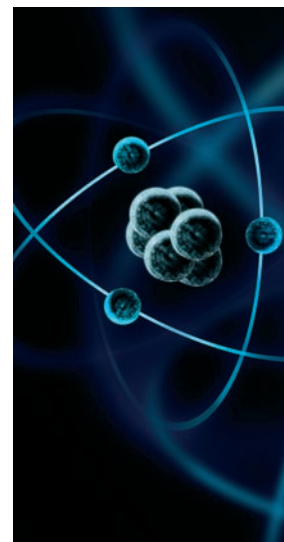
Low voltage is applied to a filament and this heats the cathode. Thermionic emission occurs at the cathode. There is high voltage between the cathode and the anode and this accelerates the electrons. The tube itself is a good vacuum so accelerated electrons do not collide with gas particles (as there are none) but pass unhindered to the screen. The kinetic energy of the accelerated electrons is changed to light. The point at which the electrons hit the screen is controlled by deflecting coils (deflecting plates). The plates are charged positively and negatively (electrons are negatively charged), so the beam direction can be controlled.

### Applications of CRTs

Non-flatscreen TVs and computer monitors; oscilloscopes; electrocardiograms

### Cathode rays

Streams of high speed electrons moving from a cathode. Their properties include travelling in fairly straight lines, making certain substances give out light, having kinetic energy and are deflected in electric or magnetic fields. They are also invisible.



**Electron-volt (eV)** 1 eV is the amount of energy gained or lost by an electron when it moves through a PD of 1 V. Since  $W = eV = e \times 1 = (1.6 \times 10^{-19}) \times 1$ , 1 eV =  $1.6 \times 10^{-19}$  joules. Charge  $\times$  Voltage =  $E_k$ , so  $eV = \frac{1}{2}mv^2$ .

**Electron beam** A beam of electrons at right angles to a magnetic field travels in a circle.

**Photoelectric effect** Emission of electrons from the surface of a metal by electromagnetic radiation of a suitable frequency.  
**Example:** UV light on zinc.

**Photoelectric cell (photocell)** Device which conducts electricity when light of a certain frequency shines on it. The more intense the light, the higher the current flow will be.

**Threshold frequency** For a given metal, the frequency below which photoemission will not occur. Light with frequency above the threshold frequency will result in photoemission.

**Work function ( $\Phi$ )** The minimum energy needed to remove the loosest electron from the surface of a metal.  
**Work function = Planck's constant  $\times$  Threshold frequency**  
 $\Phi = hf_0$

**Photon** A packet or quantum of electromagnetic energy. The energy of a photon is given by  $E = hf$  where  $f$  is the frequency of the light and  $h$  is Planck's constant.

**Photoelectric law (Einstein's)** The velocities of the photoelectrons emitted by the light of a frequency above the threshold frequency range from zero up to a definite maximum velocity. The maximum velocity and therefore the maximum kinetic energy of the emitted electron increases with the frequency of the light but does not depend on light intensity.

The kinetic energy of the fastest electron is the energy of the photon minus the work function:

$$\frac{1}{2}mv^2 = hf - \Phi$$

Therefore:  $hf = \frac{1}{2}mv^2 + \Phi$  Einstein's photoelectric law

**Applications:** Alarms; automatic doors; conveyor belts.

#### EXAMPLE:

An electron passes through 4000 V. Find the potential energy lost, the kinetic energy gained and the speed the electron acquires.

#### Answer:

$$\begin{aligned} E_p &= E_k = eV \\ &= 1.6 \times 10^{-19} \times 4000 \\ &= \mathbf{6.4 \times 10^{-16} \text{ J}} \\ E_k &= \frac{1}{2}mv^2 = \frac{1}{2}(9.1 \times 10^{-31})v^2 \\ v^2 &= (6.4 \times 10^{-16}) \div \frac{1}{2}(9.1 \times 10^{-31}) \\ \text{So } v &= \mathbf{37\,504\,578 \text{ m s}^{-1}} \end{aligned}$$

#### EXAMPLE:

What is the force on an electron moving with a velocity  $5 \times 10^6 \text{ m s}^{-1}$  at right angles to a magnetic field of flux density  $2 \times 10^{-2} \text{ T}$ ?

#### Answer:

The force on the electron is  $F = qvB$ , that is, the force on a charge in a magnetic field.

The force on the electron is also  $F = mv^2/r$ , which is the force towards the centre of the circle, keeping it moving in the circle.

$$\begin{aligned} \text{So: } mv^2/r &= qvB \\ \text{or: } r &= mv^2/qvB = mv/qB \\ mv &= (9.1 \times 10^{-31})(5 \times 10^6) \\ qB &= (2 \times 10^{-2})(1.6 \times 10^{-19}) \\ \text{So } r &= \mathbf{0.0014 \text{ m}} \end{aligned}$$

# 5 Modern physics

**X-rays** High-frequency electromagnetic radiation produced when high-speed electrons in a cathode ray tube strike a metal target (usually lithium) with a high melting point.

## Atoms and radioactivity

**Atoms** These are the smallest part of an element that can exist on its own. They consist of a positive nucleus which contains the positive protons and neutral neutrons. The atom has particles called electrons which are negatively charged orbiting around the nucleus. Rutherford discovered that the atom is mostly empty space.

**The Rutherford experiment** Rutherford bombarded a thin piece of gold leaf with alpha particles (helium nuclei). He found that most of the alpha particles went straight through the gold foil. Some were deflected at small angles and very few were deflected or turned with angles greater than  $90^\circ$ . He concluded that the atom was mostly empty space and that this is why most of the alpha particles went straight through.

If an alpha particle comes close to the nucleus, it is deflected at an angle as the positive nucleus repels the positive alpha particle. If an alpha particle is on a collision course with the nucleus then it is deflected at a large angle away from the nucleus.

**Atomic number (Z)** The atomic number (Z) of an element is the number of protons in the nucleus of an atom of that element.

**Mass number (A)** The mass number (A) of an atom is the total number of protons and neutrons in the nucleus of that atom.

**Neutrons in nucleus** **Number of neutrons in nucleus**  
= Mass number (A) – Atomic number (Z)

**Atomic mass** Hydrogen is the smallest atom so it was said to be one unit of atomic mass. For example lithium, number 3 on the periodic table, has a mass 7 times that of hydrogen. Later the atomic mass unit (u) came to be  $1/12^{\text{th}}$  of the mass of a carbon atom. This is because carbon has mass number 12 and appears as number 6 on the periodic table.



**Isotopes** Atoms of the same element that have the same number of protons but not the same number of neutrons in their nucleus.

**Emission spectrum** When light from a luminous source undergoes dispersion the resulting pattern is called an emission spectrum. There are two types:

**Continuous spectrum:** Produced by incandescent solid or liquid. This type is not individual to the material producing it.

**Line spectrum:** If atoms of a gaseous element are given enough energy they will give out light. The colour of the light given out is individual to the element producing it. If this light is passed through a prism a distinct pattern of coloured light, a line spectrum, is produced. Each element has an individual line spectrum.

**Spectroscopy** This is the study of line spectra. Because the line spectrum for each element is different, scientists are able to tell the elemental composition of celestial bodies many light years away. The line spectrum acts like a fingerprint for that element.

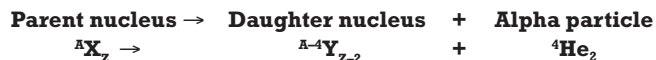
**Radioactivity** The emission of one or more types of radiation caused by the disintegration or decay of the nuclei of certain atoms. There are three types of radiation:

**Alpha radiation ( $\alpha$ ):** Fast-moving helium nuclei ejected from the nucleus of radioactive atoms.

**Beta radiation ( $\beta$ ):** High-speed electrons ejected from the nuclei of radioactive atoms.

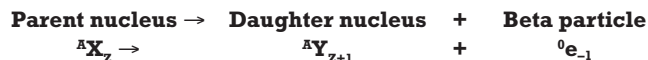
**Gamma radiation ( $\gamma$ ):** High-frequency electromagnetic radiation (frequency greater than that of X-rays) emitted from the nucleus of radioactive atoms.

**Alpha emission** When alpha emission occurs a helium nucleus which contains two protons is ejected from the nucleus of the radioactive atom. Thus the daughter nucleus is two places to the left of the parent nucleus on the periodic table. In general:



# 5 Modern physics

**Beta emission** When beta emission occurs an electron is ejected from the nucleus of the radioactive atom. A neutron splits and produces an electron and a proton. The proton stays in the nucleus while the electron is fired out at high velocity. There is now another proton in the nucleus so the daughter nucleus appears one place to the right of the parent nucleus on the periodic table. In general:



**Gamma radiation** High-frequency radiation from the nuclei of radioactive atoms. When ejected there is no change in the mass of the atom. The atom does lose some energy which makes it more stable. Usually, gamma emission only occurs after either an alpha or beta particle has already been released.

**Energy levels** Electrons orbit the nucleus in certain orbits and they continue to follow the same path unless they are given energy. If they get energy (for example, by being heated) then they can jump to a higher energy level (from energy level  $E_1$  to energy level  $E_2$ ). They remain at energy level  $E_2$  for a very short period of time before losing the gained energy as light and dropping back to energy level  $E_1$ . This light goes toward making the individual line spectrum for that element.

The energy given out by the electron in changing from  $E_1$  to  $E_2$  is given by:

$$hf = E_2 - E_1$$

where  $h$  = Planck's constant and  $f$  = frequency of the light

**Activity (A)** The activity of a substance is the number of nuclei of that substance that are decaying per second. Unit: becquerel, Bq

1 Bq = One radioactive disintegration per second

**The law of radioactive decay** The number of nuclei decaying per second (activity) is directly proportional to the number of nuclei undecayed.

$$\text{Rate of decay} = \lambda N$$

where  $\lambda$  = decay constant and  $N$  = number of undecayed atoms

**Half life** The half life  $T_{1/2}$  of a radioactive isotope is the time taken for half of the undecayed atoms to undergo decay. It is also the time taken for its activity to decrease by half.

Relationship between half life and decay constant:

$$T_{1/2} = \ln 2 / \lambda = 0.693 / \lambda$$

**Detecting nuclear radiation** **The Geiger Muller tube:** Detection is made by measuring ionization produced. This ionization occurs when radiation ionizes material it is passing through by knocking electrons off it. Radiation passes through the mica window into low-pressure argon gas. The radiation ionizes some of the gas. Ions and electrons are produced which cause further ionization in the tube due to the voltage. The ions and electrons cause pulses in the circuit which can be counted and used to measure the quantity of radiation from a source.

**The solid-state detector:** This is a reverse bias P-N junction connected to a counter. When the radiation hits the depletion layer some electron hole pairs are formed there. A small current pulse is formed and then amplified.

**Artificial isotopes** These can be made radioactive by bombarding them with neutrons. The neutrons are captured by the nucleus of the atom. These isotopes are often used in medicine and in industry.

**Uses of radioactive isotopes** Gamma rays are used to sterilize food by irradiation. They are used in industry to check the thickness of objects. They are used in medicine to kill cancer cells.

## Nuclear fission, fusion and energy

**Nuclear fission** The splitting up of a large nucleus into two smaller nuclei of approximately the same atomic mass.

**Uranium fission** Natural uranium is 99.3%  $U^{238}$  and 0.7%  $U^{235}$ . When bombarded with neutrons uranium undergoes fission. If this happens slowly it is more effective – that is, if the neutrons move with kinetic energy equal to that of the surrounding atoms.



## 5 Modern physics

Uranium splits into fission fragments that are often radioactive as well and their masses are roughly similar. They also eject a neutron. If these neutrons go on to split other uranium atoms, a chain reaction occurs. For this to happen the radioactive sample has to be of critical size. Substances that can undergo fission are said to be **fissile**.

**Nuclear reactor**  $U^{238}$  absorbs fast neutrons without undergoing fission. Uranium is mostly  $U^{238}$ .  $U^{235}$  undergoes fission with fast neutrons but the ejected neutrons are absorbed by the surrounding  $U^{238}$  and no chain reaction will occur. Thus in a sample of pure uranium a chain reaction cannot occur.

If the bombardment neutrons can be slowed down, they can produce further fission in  $U^{235}$  rather than being absorbed by the  $U^{238}$  so that a chain reaction can occur. This is done with a reactor that has the following.

**Fuel:** Natural uranium or slightly enriched with  $U^{235}$ .

**Moderator:** Graphite (this slows down the neutrons).

**Control rods:** Usually steel with boron (placing these into the core slows the reaction).

**Shielding:** Stops the escape of radiation.

**Coolant:** Takes the heat from the core to the heat exchanger.

**Heat exchanger:** Heats water and produces steam.

**Environmental factors** Radioactive waste remains a problem for a long time after it is produced. Mining uranium ore is carcinogenic. There are also problems with the removal and disposal of used fuel rods.

**Atomic bomb** Two or more fissile materials of subcritical mass brought together in an uncontrolled chain reaction.

**Nuclear fusion** The joining together of two small nuclei to form a larger nucleus, such as two heavy hydrogen nuclei (deuterium) to form helium, resulting in the release of a large amount of energy:

$${}^2\text{H}_1 + {}^2\text{H}_1 = {}^3\text{He}_2 + {}^1\text{n}_0$$

This can only happen if the force bringing them together is larger than the Coulomb force of repulsion between the two atoms. This is done using very high temperatures resulting in very high speeds. Once started energy is released which maintains the reaction.



The Sun converts hydrogen to helium using nuclear fusion. Nuclear fusion produces less radioactive waste than fission and the fuel (deuterium) is cheap as it is plentiful in the oceans.

**Mass–energy** Mass can be made into energy and vice versa. If natural gas and oxygen are put into a sealed container and burned the mass of the container would be reduced. The reduction in mass cannot be measured by an instrument as it is very small.

Einstein's formula:  $E = mc^2$

Change in energy = Change in mass  $\times$  Speed of light squared

**Mass–energy conversions and nuclear reactions** In a reaction, energy is either given out or taken in and converted to mass.  
If mass of products  $>$  mass of reactants, then energy is supplied.  
If mass of reactants  $>$  mass of products, then energy is released.

**Health hazards of ionizing radiation** Ionizing radiation is radiation capable of knocking electrons off atoms, turning them into ions. Alpha, beta and gamma radiation, X-rays and neutrons are all ionizing and harmful to human tissue. The harm done depends on the radiation type, source activity, exposure duration and the tissue being acted upon. Damage caused can include skin burns, cancer and genetic defects. In cells radiation gives rise to free radicals which disrupt cell function.

**Natural radiation** We are all exposed to natural radiation. Radiation reaches us from space in the form of cosmic rays and from radioactive rocks in the Earth's crust that contain uranium and give off radon gas.

**Precautions** Wear appropriate protective clothing; minimize the dose; do not ingest.

**Measuring background radiation** **Experiment:** This is done using a GM tube. Switch the tube to high voltage and allow it to heat up. Set to measuring voltage. It is seen that background radiation has a random nature.



## Questions on modern physics *(Answers on page 151)*

- Q1. Define:** thermionic emission; cathode rays; the electron volt; photoelectric effect; photocell; threshold frequency; work function; the photon; X-rays; the atom; atomic number; mass number; emission spectra; continuous spectra; line spectra; alpha radiation; beta radiation; gamma radiation; half life; artificial isotopes; nuclear fission; nuclear fusion.
- Q2. Explain:** the operation of the cathode ray tube; Einstein's photoelectric law; the Rutherford experiment and his conclusions; the operation of the Geiger Muller tube; the operation of the solid-state detector; the functions of the different parts of a nuclear reactor; the health hazards of ionizing radiation.
- Q3.** An electron has energy of  $200 \times 10^{-18}$  J. Express this energy in keV.
- Q4.** What is the speed of an electron that experiences a force of  $3.2 \times 10^{-12}$  N as it enters a magnetic field of magnetic flux density 5 T at right angles?
- Q5.** An electron enters a magnetic field of flux density  $1.39 \times 10^2$  T at right angles to the field. It enters with a speed of  $4 \times 10^6$  m s<sup>-1</sup>. Calculate the radius of the path it takes.
- Q6.** An electron is accelerated from rest through a voltage of 11 500 V. Find the speed it reaches.
- Q7.** What is the frequency and wavelength of a photon with energy 5.2 eV?
- Q8.** An electron starts from rest and moves through a potential difference of  $1 \times 10^4$  V. Find its velocity when it leaves this high voltage.

## QUESTIONS

- Q9.** An electron reaches a velocity of  $720 \text{ m s}^{-1}$  in high voltage. Express the kinetic energy it has in electron-volts.
- Q10.** A light wave has a wavelength of  $5.5 \times 10^{-7} \text{ m}$ . What is the energy of the wave?
- Q11.** A photon has energy of 6 eV. Find its wavelength.
- Q12.** Light is passed through a diffraction grating with 500 lines per mm. The angle between the second order fringe to the right and the second order fringe to the left is  $44.4^\circ$ . Find the energy of the light.
- Q13.** The energy of the light from Q12 falls on a metal with a work function of 3 eV. Does photoemission occur? If so, what is the kinetic energy of the emitted electrons?
- Q14.** Complete the following nuclear decay processes:
- $${}^{220}\text{Rn}_{86} \rightarrow \alpha + \text{---}$$
- $${}^{14}\text{C}_6 \rightarrow \text{---} + \beta$$
- $${}^1_0\text{n} \rightarrow {}^1_1\text{p} + \text{---}$$
- Q15.** Calculate the number of alpha and beta particles emitted in the decay of  ${}^{238}\text{U}_{92}$  to  ${}^{226}\text{Ra}_{88}$ .
- Q16.** Calculate the number of alpha and beta particles emitted in a decay of  ${}^{238}\text{U}_{92}$  to  ${}^{230}\text{Th}_{90}$ .
- Q17.** Write out the radioactive decay series of  ${}^{232}\text{Th}_{90}$  when it loses an alpha particle followed by two beta particles and finally another alpha particle.

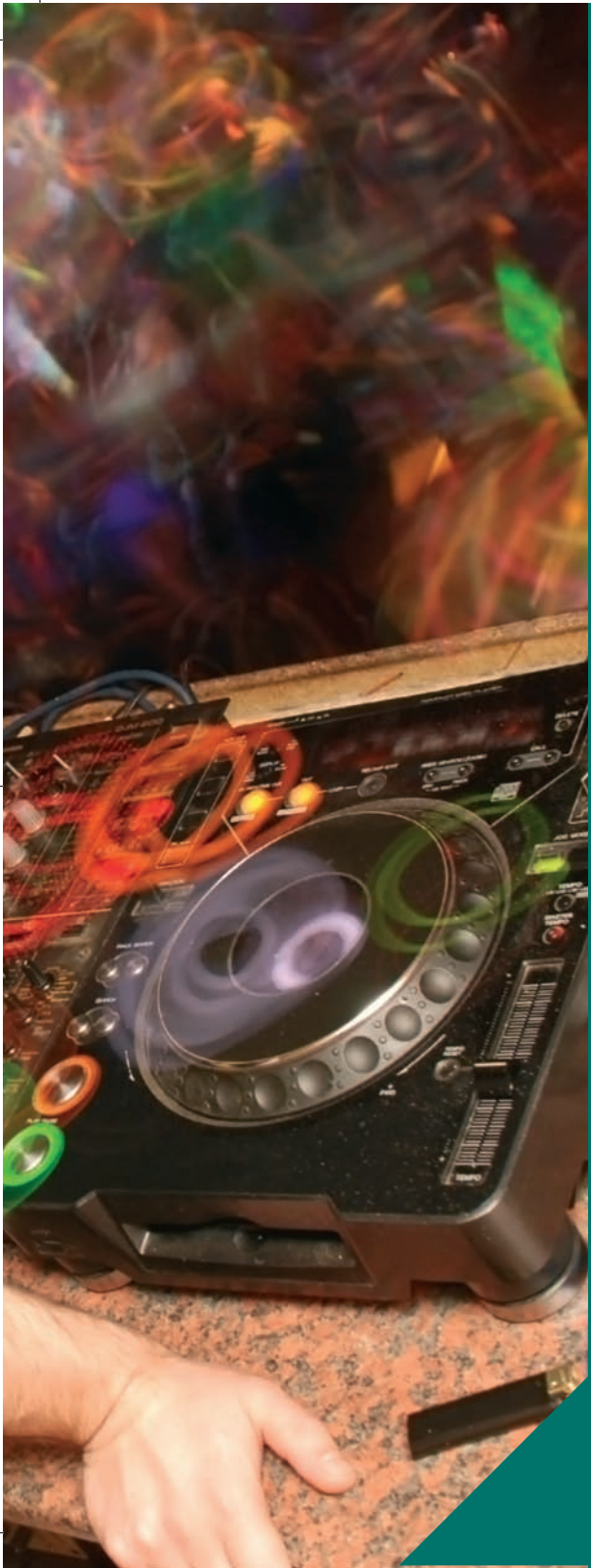
- Q18.** The half-life of a radioactive isotope is 3 years.  
What fraction of it will remain after  
3 years  
9 years  
81 years?
- Q19.** The half-life of a radioactive isotope is 50 years. What fraction of the isotope will have decayed after 250 years?
- Q20.** A radioactive isotope has a half-life of 125 seconds. Calculate its decay constant.
- Q21.** The decay constant of a radioactive isotope is  $5 \times 10^{-3} \text{ s}^{-1}$ . Find its half-life.
- Q22.** The decay constant of a radioactive isotope is  $2.3 \times 10^{-3} \text{ s}^{-1}$ . Find its half-life.
- Q23.** The decay constant of a certain isotope is  $8.8 \times 10^{-8} \text{ s}^{-1}$ . A sample of the isotope undergoes  $3.3 \times 10^3$  disintegrations per second. Find the number of undecayed atoms in the sample.
- Q24.** The decay constant of a certain isotope is  $9.3 \times 10^{-7} \text{ s}^{-1}$ . A sample of the isotope undergoes  $4.1 \times 10^2$  disintegrations per second. Find the number of undecayed atoms in the sample.

# QUESTIONS



# 6

SECTION



# WAVES

- Waves
- Vibrations and sound
- Wave nature of light

WAVES

# 6 WAVES

## Waves

**Mechanical waves** Waves passing through substances via vibrations being passed from one molecule to another. They need a medium in which to travel. **Examples:** waves on rope or a spring; sound waves in air.

**Electromagnetic waves** Waves that do not require a medium in which to travel. They travel fastest in a vacuum, at  $3 \times 10^8 \text{ m s}^{-1}$ .

**Examples:** X-rays, gamma rays.

**Travelling waves** Travelling waves carry energy through a medium without any overall movement of the medium. They can be mechanical or electromagnetic and always travel from the source producing them, transferring energy to other places through which they pass. There are two types: transverse and longitudinal.

**Transverse wave:** A wave whose direction of vibration is perpendicular to the direction in which the wave travels.

**Example:** wave on rope.

**Longitudinal wave:** A wave whose direction of vibration is parallel to the direction in which the wave travels.

**Example:** Compression wave on a spring.

**Wave terms explained** **Cycle (oscillation):** Disturbance produced by one complete vibration.

**Amplitude:** The maximum distance of any particle from its undisturbed position.

**Wavelength:** Distance from any one point on a cycle to its corresponding point on the next cycle.

**Frequency:** The number of cycles passing any point in one second.  
Unit: hertz, Hz

If a periodic wave has a frequency  $f$ , wavelength  $\lambda$  and velocity  $c$ :  
 $c = f\lambda$

### EXAMPLE:

A wave has a frequency of 35 Hz. How many full cycles pass per second? How long does it take for one cycle to pass?

### Answer:

$35 \text{ Hz} = 35 \text{ cycles per second}$   
Time for one cycle =  $1/35$   
=  **$0.0286 \text{ s}$**

### EXAMPLE:

Wavelength of visible light varies from  $3.7 \times 10^{-7}$  to  $7.0 \times 10^{-7} \text{ m}$ . Find the highest frequency an electromagnetic wave can have and still be in the visible range.

### Answer:

As  $c = f\lambda$  it follows that frequency is highest when  $\lambda$  is lowest, so use  $3.7 \times 10^{-7}$ .

Maximum  $f = c/\lambda$   
=  $3 \times 10^8 / 3.7 \times 10^{-7}$   
=  **$8.1 \times 10^{14} \text{ Hz}$**

<b>Wave properties</b>	<b>Reflection:</b> The bouncing of waves off obstacles in their path.
	<b>Refraction:</b> The change in direction of a wave when it enters a region that causes its speed to change.
	<b>Diffraction:</b> The sideways spread of waves into regions beyond a gap or around an obstacle.
	<b>Interference</b> This occurs when waves from two different sources meet. The displacement produced at any point of interference is the algebraic sum that each wave would produce on its own.
	<b>Interference pattern:</b> This is the pattern formed when waves from two different sources meet.
	<b>Constructive interference:</b> When two wave sources meet and the amplitude of the resulting wave is greater than either individual wave.
	<b>Destructive interference:</b> When two waves meet and the amplitude of the resulting wave is smaller than the amplitude of either individual wave.
<b>Coherent sources</b>	Sources producing two waves that are in phase, or have a constant phase difference between them.
<b>Polarisation</b>	Only transverse waves can be polarised. The plane in which the wave is vibrating is the plane of polarisation.
<b>Stationary waves</b>	When two waves of the same frequency and amplitude moving in opposite directions meet, they interfere with each other and the resulting wave form is a stationary wave.
<b>The Doppler effect</b>	The apparent change in the frequency of waves due to the motion of the source and the observer. As the source or the observer move closer together the frequency seems to become higher. As they

**EXAMPLE:**

A stationary wave is set up and the distance between two consecutive nodes is 4 m. The wave is traveling at a speed of  $12 \text{ m s}^{-1}$ . Find the frequency of the wave.

**Answer:**

The distance between a node and another node is  $\lambda/2$ .

$$4 = \lambda/2, \text{ so } \lambda = 8 \text{ m}$$

$$\text{Use } c = f\lambda.$$

$$12 = f \times 8$$

$$f = 12/8$$

$$= 3/2 \text{ or } \mathbf{1.5 \text{ Hz}}$$

**EXAMPLE:**

A stationary wave is set up with the distance between the 3rd and 9th node being 20 m. It is a sound wave so its speed is  $340 \text{ m s}^{-1}$ . Find the frequency of the wave.

**Answer:**

The distance between two adjacent nodes is  $\lambda/2$ . So the distance between the 3rd and 9th nodes is  $6\lambda/2 = 3\lambda$ .

$$3\lambda = 20 \text{ m}$$

$$\text{So } \lambda = 20/3 = 6.666 \text{ m}$$

Now use  $c = f\lambda$ .

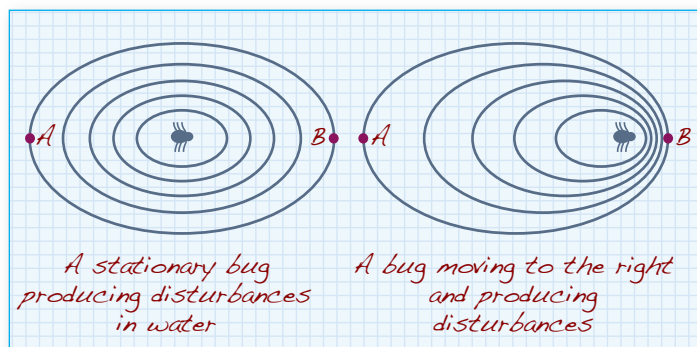
$$340 = f \times 6.666$$

$$f = \mathbf{51 \text{ Hz}}$$

# 6 WAVES

become farther apart the frequency seems to become smaller. This occurs because the sound waves being produced are travelling at the same speed therefore as the source is moving it is catching up with its own sound waves. This makes the crests of these sound waves closer together and thus shortens the wavelength of each wave.

## Waves from stationary source



## Formulae for Doppler effect calculations

Formulae for the apparent frequency  $f'$  of waves from a moving source where

$f$  = actual frequency of the waves from the source,

$u$  = the speed of the source,

$c$  = speed of waves in medium

Source moving toward observer:

$$f' = fc \div (c - u)$$

Source moving away from observer

$$f' = fc \div (c + u)$$

## Vibrations and sound

All sound is produced by vibrations. Any object vibrating with a frequency above 20 Hz will produce a sound audible to humans. Sound always travels as a wave. This is proven by the fact that sound obeys all the properties of waves bar one – reflection, diffraction, refraction and interference – but sound waves cannot be polarised as only transverse waves can be polarised. Sound needs a medium in which to travel.



Sound is a **longitudinal** wave; that is, the vibrations travel parallel to the motion of the wave.

A vibrating object can produce a sound in air by causing the air around it to vibrate. These air molecules then cause a vibration of air molecules around them. It is these vibrations that travel along air molecules until they reach the ear drum. The ear drum then begins to vibrate and these vibrations are interpreted by the brain.

**Noise reduction using destructive interference**

If noise in an area needs to be reduced, a loudspeaker can be used to produce a noise of the same frequency. The troughs of the speaker sound coincide with the crests of the noise and the crests of the noise coincide with the troughs of the speaker sound. The speaker sound and the noise in the area interfere destructively resulting in an area which is nearly silent.

**Overtones**

Multiples of the frequency of a wave. If a wave has a frequency  $f$  then the first overtone occurs at  $2f$  and the second occurs at  $3f$ . (In music these are known as harmonics.)

**Loudness**

The greater the amplitude of a sound wave, the louder the sound will be.

**Pitch**

The pitch of a note depends on frequency.

**Higher frequency = higher pitch**

**Lower frequency = lower pitch**

**Quality**

The quality of a note depends on the number and strength of different overtones.

**Limits of audibility**

Highest and lowest frequencies heard by humans.  
Range: 20 Hz to 20 000 Hz

**Natural frequency**

The frequency at which an object tends to vibrate when free to do so. It is more likely to vibrate at this frequency than others.

**Resonance**

If the frequency of a periodic wave applied to a body is the same as the body's natural frequency, then the body will vibrate with large amplitude.



# 6 WAVES

**Sound intensity** Sound spreads out in the shape of a sphere from the source producing it. The further from the source, the larger the sphere and the lower the sound energy per square metre.

$$\text{Sound intensity} = \text{Power} \div \text{Area} \quad \text{Unit: } \text{W m}^{-2}$$

**Sound intensity level** A smaller and more easily used scale representing sound intensity; measured in decibels, dB. If the sound intensity is doubled, the sound intensity level increases by 3 dB.

**Formula** Formula for the fundamental frequency  $F$  of a stretched string



$$F = \frac{1}{2L} \sqrt{\frac{T}{\mu}}$$

$L$  = string length

$T$  = tension in newtons

$\mu$  = mass per unit length

## Wave nature of light

**What is light?** Light waves are electromagnetic waves.

**Monochromatic light** Monochromatic light is light which consists of only one wavelength and therefore cannot be broken into different colours.

**Example:** Sodium light

**Diffraction grating** To measure the wavelength of light, use a diffraction grating. This consists of a few hundred opaque lines engraved onto a transparent medium.

If a grating has  $n$  lines per mm then:

$$d = 1/n \text{ mm} = 1/(n \times 10^3) \text{ m}$$

**Interference** Interference occurs when wavelengths of light are reflected from different surfaces at different angles and meet.

**Constructive interference** When the wavelength of two light rays are brought into phase at angle  $\theta$  by using a convex lens in a collimator, and sent through a slit, a bright image is formed. This is known as constructive interference.

**EXAMPLE:**

What is the sound intensity of a 400 watt speaker at a distance of 3 m?

**Answer:**

$$\begin{aligned} \text{Sound intensity} &= P/A \\ &= 400/(4\pi \times 3^2) = 3.54 \text{ W m}^{-2} \end{aligned}$$

**EXAMPLE:**

If the sound intensity in the previous example drops to  $1.765 \text{ W m}^{-2}$ , by how much has the sound intensity level dropped?

**Answer:**

The sound intensity has dropped by  $\frac{1}{2}$ , so the sound intensity level drops by **3 dB**.

**EXAMPLE:**

A wire of length 5 m and mass 0.8 kg is stretched between two points so that the tension of the wire is 300 N. Calculate its fundamental frequency.

**Answer:**

$$\begin{aligned} U &= 0.8/5 = 0.16 \text{ kg m}^{-1} \\ F &= [1/(2 \times 5)] \times \sqrt{(300/0.16)} \\ &= 4.33 \text{ Hz} \end{aligned}$$

The first-order diffracted images are formed when the light passes through the slit and bends  $\theta$  degrees from the normal.

### The spectrometer

The spectrometer has four main parts:

#### Collimator (see diagram on page 119)

Made of two tubes: the large tube contains a convex lens; the narrow tube has an adjustable slit at one end. Light leaves the collimator as a parallel beam. 'Collimate' = 'To make parallel'.

#### Turntable

Free to rotate around the vertical axis.

#### Vernier scale measurements

These change with movement of the turntable and allow accurate angular measurements to be taken.

#### Astronomical telescope

Free to rotate with the turntable; part of the vernier scale is attached to the telescope. The scope is used to view the image of the light after it has passed through the slit.

### Spectrometer set up

- Ensure that cross hairs are in focus by moving the eyepiece.
- Focus the telescope on a distant object.
- Focus on the light shining through the slit on the collimator.
- Adjust slit width, level the turntable.

### Spectrometer reading errors

Spectrometer reading errors can occur if the slit on the collimator is too narrow or too wide, if the grating is not at right angles to the light, if the turntable is not level, if the vernier scale has been read incorrectly or if the judgement that the cross hairs are at the centre of the light fringe is inaccurate.

### Calculating wavelength

When  $n = 1$ , image formed = 1st order.  
When  $n = 2$ , image formed = 2nd order.  
 $n\lambda = d \sin \theta$

### Number of refracted images

Calculating the amount of refracted images that can be found at each side of the central image:  
 $n = (d \sin \theta) / \lambda$  (Remember the max. value of  $\sin \theta$  is 1.)  
So:  $n_{\max} = d / \lambda$



# 6 WAVES

**Polarisation** The filtering of light through a polaroid material. Only light that is parallel to the plane of the polaroid material will pass through.  
Use of polarisation: reduces glare.

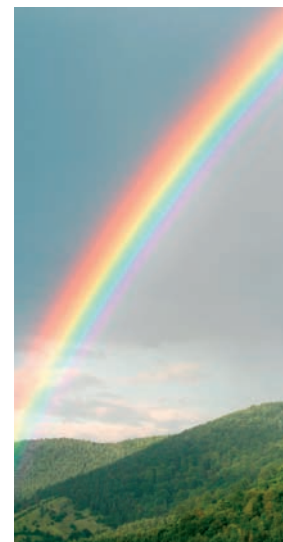
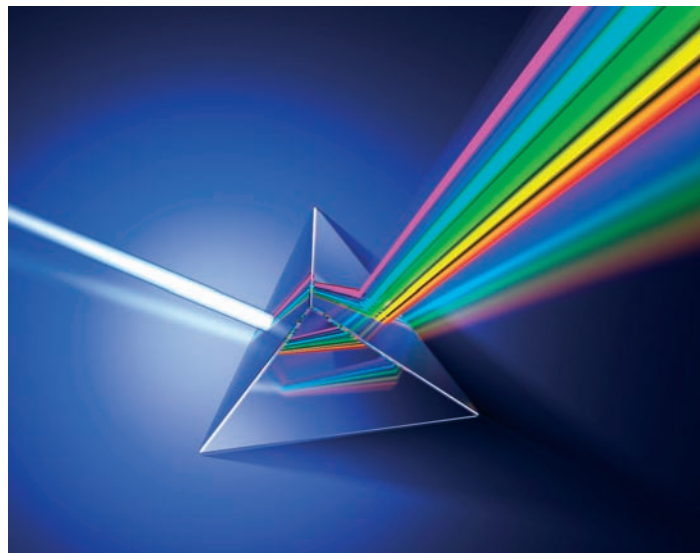
**Colours of light** **Primary colours:** red, green, blue.  
**Secondary colours:** cyan, yellow, magenta.

**Dispersion** The breaking up of white light into its constituent colours.  
Can be done via a prism or a grating. Natural occurrence is a rainbow.

**Electromagnetic spectrum** All the white light wavelengths as well as X rays, gamma rays, radio waves, infrared waves, ultraviolet waves etc.

**Infrared waves:** Produced by all bodies that are above zero kelvin.

**Ultraviolet waves:** The part of light that allows the body to make vitamin D.





## Questions on waves *(Answers on page 152)*

- Q1. Define:** mechanical waves; electromagnetic waves; travelling waves; transverse waves; longitudinal waves; reflection; refraction; diffraction; interference; constructive interference; destructive interference; polarisation; stationary waves; the Doppler effect; natural frequency; resonance; fundamental frequency; monochromatic light; dispersion.
- Q2. Explain:** the parts of a wave; noise reduction by interference; the parts and functions of the spectrometer.
- Q3.** The frequency of a wave in water is 30 Hz. How many cycles pass one second?
- Q4.** A source emits a wave with wavelength 4 m and the wave has a frequency of 10 Hz. What is the speed of the wave?
- Q5.** The distance between a node and an adjacent anti-node in a stationary wave is 2 m. The frequency of the wave is 10 Hz. What is the speed of the wave?
- Q6.** An ice cream van travelling at  $50 \text{ m s}^{-1}$  passes a stationary observer. Its tune emits a note of frequency 2 kHz. What is the frequency heard by the observer as the van approaches and as it moves away from the observer?
- Q7.** A bat emits a wave of frequency 67 kHz and wavelength 4.9 mm towards the wall of a cave. It detects the reflected wave 21 ms later. Calculate the speed of the wave and the distance of the bat from the wall.
- Q8.** Waves on a rope travel at a speed of  $6.5 \text{ m s}^{-1}$ . When a stationary wave is set up on the rope the distance between a node and its nearest anti-node is 65 cm. What is the frequency of the wave?

## QUESTIONS

- Q9.** A car travelling at  $65 \text{ m s}^{-1}$  approaches a stationary observer. As the car passes, its engine is emitting a note with a pitch of  $1500 \text{ Hz}$ . What is the change in pitch observed as the car moves away?
- Q10.** A person walks towards a loudspeaker and the sound intensity increases from  $2 \text{ W m}^{-2}$  to  $4 \text{ W m}^{-2}$ . What is the change in the sound intensity level heard by the person?
- Q11.** A student carries out an experiment in the laboratory and finds the red line emitted by a hydrogen discharge tube has a wavelength of  $650 \text{ nm}$ . The red line in the hydrogen spectrum of a star which is moving is known to be  $715 \text{ nm}$ . Calculate the frequency of the red line of the hydrogen in the tube and star's spectrum. Find also the speed of the star.
- Q12.** A string on a guitar is vibrating at its fundamental frequency of  $555 \text{ Hz}$ . Its length is  $0.75 \text{ m}$  and its mass per unit length is  $0.025 \text{ kg m}^{-1}$ . Find the tension in the string.
- Q13.** A loudspeaker has a power rating of  $300 \text{ W}$ . What is the sound intensity at a distance of  $3 \text{ m}$  from the loudspeaker?
- Q14.** A diffraction grating has  $300$  lines per  $\text{mm}$ . What is the value of  $d$  in the diffraction grating formula  $n\lambda = d \sin \theta$ ?
- Q15.** When a parallel beam of monochromatic light is incident normally on a diffraction grating having  $600$  lines per  $\text{mm}$  on it, the angle between the second-order image and the normal to the grating is  $21^\circ$ . What is the wavelength of the light?



**SECTION**

**7**



# HEAT

- Temperature and heat
- Transfer of heat

HEAT

# 7 HEAT

## Temperature and heat

**Temperature** A measure of the hotness or coldness of a body.  
The SI unit for temperature is kelvin, K.

$$0 \text{ K} = -273.15 \text{ }^{\circ}\text{C}$$

Zero kelvin is also known as **absolute zero**. This is the point at which pressure in an ideal gas is zero. (Hydrogen gas is the closest to being used as an ideal gas.)

**Thermometric property** A property of a substance that changes measurably with temperature. Examples of thermometric properties include resistance (thermistor) and expansion (mercury).

**Heat ( $Q$ )** The energy due to movement within a body.

**Heat capacity ( $C$ )** This is the heat energy needed to change an object's temperature by 1 K (1  $^{\circ}\text{C}$ ):

$$\text{Heat} = \text{Heat capacity} \times \text{Change in temperature}$$

$$Q = C \Delta\theta$$

**Specific heat capacity ( $c$ )** The specific heat capacity ( $c$ ) of a substance is the heat energy needed to change the temperature of 1 kg of that substance by 1 K.  
Unit:  $\text{J kg}^{-1} \text{ K}^{-1}$

$$Q = mc \Delta\theta$$

where  $m$  = mass.

**Latent heat ( $L$ )** The latent heat ( $L$ ) of a substance is the heat energy needed to change its state without a change in temperature.  
Solid to liquid = latent heat of fusion  
Liquid to gas = latent heat of vaporisation

**Specific latent heat ( $l$ )** The specific latent heat ( $l$ ) of a substance is the amount of heat energy needed to change the state of 1 kg of that substance without a change in temperature. Unit:  $\text{J kg}^{-1}$

$$Q = ml$$

### EXAMPLE:

*How much heat energy is needed to raise the temperature of 3 kg of water from 10  $^{\circ}\text{C}$  to 100  $^{\circ}\text{C}$ ?*

### Answer:

$$Q = mc \Delta\theta$$

$$= 3 \times 4180 \times (100 - 10)$$

$$= \mathbf{1\ 128\ 600\ J}$$



**Specific latent heat of fusion** The specific latent heat of fusion of a substance is the amount of heat needed to change 1 kg of that substance from a solid to a liquid without a change in temperature.

**Specific latent heat of vaporisation** The specific latent heat of vaporisation of a substance is heat energy needed to change 1 kg of that substance from a liquid to a gas without a change in temperature.

**Storage heaters** Heat is pumped into bricks with high specific heat capacity and this heat is then released later.

## Transfer of heat

Heat is transferred in three ways:

**Conduction** Movement of heat energy through a substance by passing on of molecular vibration from molecule to molecule. There is no overall movement of the substance.

The **U value** of a substance is the amount of heat energy conducted through 1 m<sup>2</sup> of the substance per second when a temperature difference of one degree is maintained between the ends.

**Radiation** This is the transfer of heat by means of electromagnetic waves.  
**Example:** the Sun.

The **solar constant** is the average amount of the Sun's energy that falls on one square meter of the Earth's surface per second. Its average is 1.35 kW m<sup>-2</sup>.

**Convection** The transfer of heat through a fluid or a gas by means of circulating currents caused by the heat.

### EXAMPLE:

Use the solar constant to find the average energy falling on 2 m<sup>2</sup> of the Earth's surface every year.

#### Answer:

$$1 \text{ year} = 365 \times 24 \times 60 \times 60 \\ = 3.1536 \times 10^7 \text{ seconds}$$

$$E = \text{solar const.} \times \text{time} \times \text{area} \\ = 1.35 \times 10^3 \times 3.1536 \times 10^7 \times 2 \\ = \mathbf{85\,147\,200\,kJ}$$

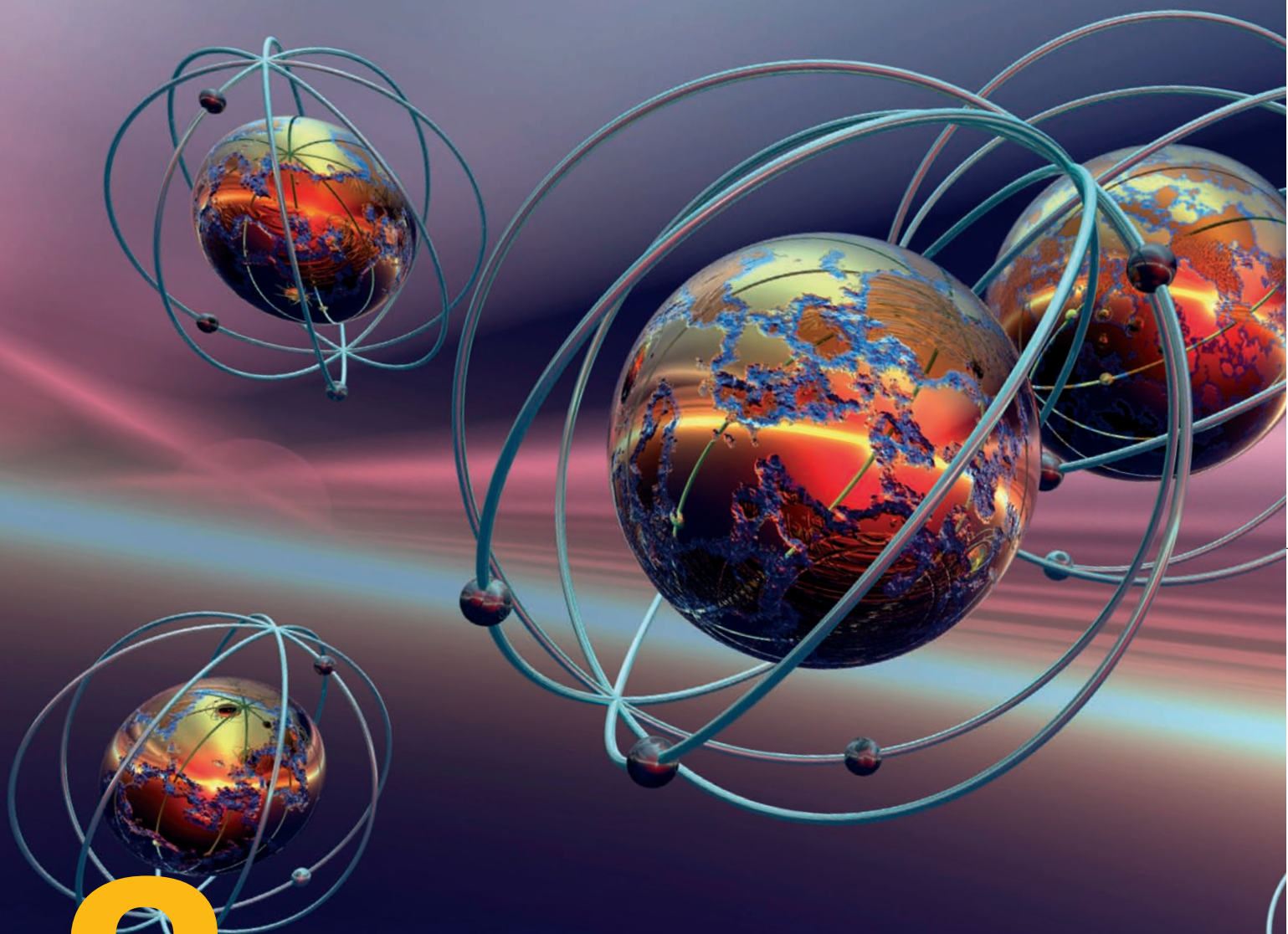


## Questions on heat *(Answers on page 154)*

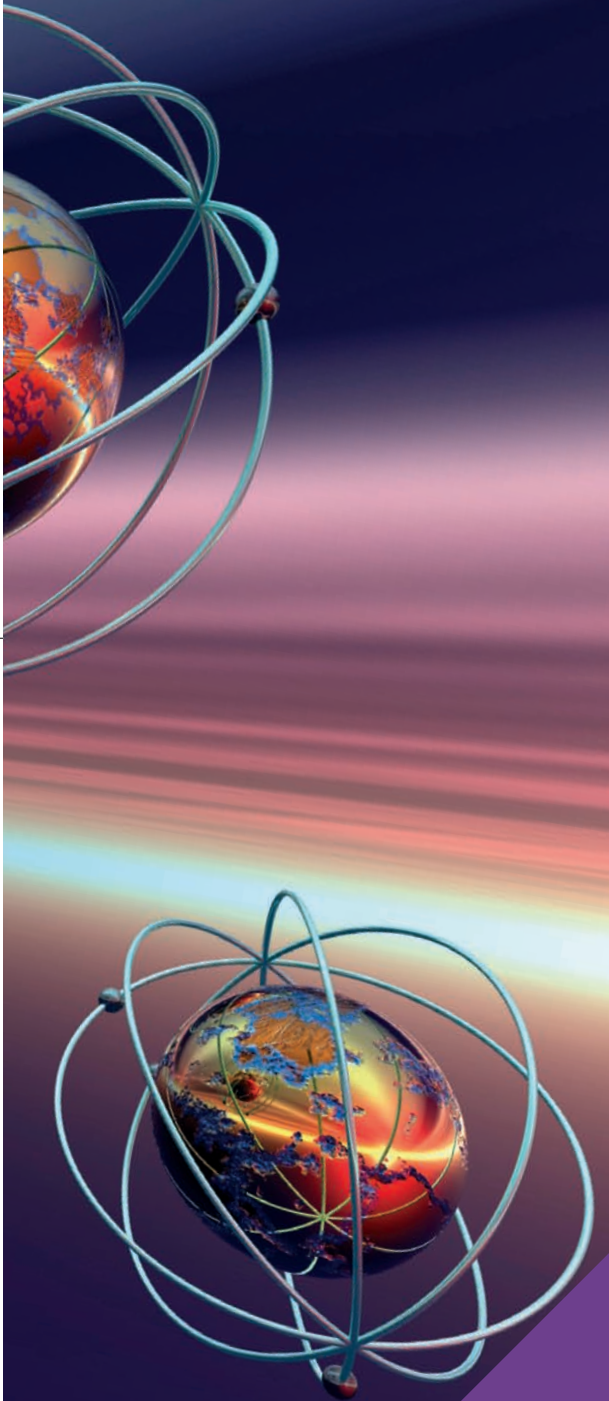
- Q1.** **Define:** temperature; heat; heat capacity; latent heat, specific latent heat; specific latent heat of fusion; specific latent heat of vaporisation; conduction; convection; radiation; the U value; the solar constant; a thermometric property.
- Q2.** Find the boiling point of water in kelvin.
- Q3.** Convert the following to degrees celcius.
- 83 K
  - 95 K
  - 125 K
- Q4.** Convert the following to kelvin.
- 10 °C
  - 0 °C
  - 165 °C
- Q5.** The solar constant for Ireland is 1500 watts per square meter. How much energy falls on an area of 5 square meters in an hour? If you had solar panels which were 30 per cent efficient covering 3 square meters of ground, how much useful energy would you collect in an hour?
- Q6.** How much heat energy has been put into a water filled copper calorimeter if 150 g of water in the calorimeter of mass 90 g is heated from 15 °C to 35 °C?  
(Specific heat capacity of water =  $4200 \text{ J kg}^{-1} \text{ K}^{-1}$ )
- Q7.** 11 kJ of heat is needed to raise the temperature of 1.5 kg of copper from 17 °C to 26 °C. Calculate the specific heat capacity of copper.

# QUESTIONS

- Q8.** 3 MJ of heat are required to heat iron from 10 °C to 300 °C. What is the mass of the iron if the specific heat capacity of iron is  $280 \text{ J kg}^{-1} \text{ K}^{-1}$ ?
- Q9.** 50 g of water at 100 °C is added to 100 g of water at 22 °C. No heat is lost to the surroundings during the process. Find the final temperature of the system.
- Q10.** A 2.5 kW heater heats 8.5 kg of water. This raises the temperature from 25 °C to 83 °C. No heat is lost to the surroundings during the process. How long does the process take if the specific heat capacity of the water is  $4200 \text{ J kg}^{-1} \text{ K}^{-1}$ ?



**8**  
SECTION



# OPTION ONE

HIGHER LEVEL

- Particle physics

# 8 Option one: Particle physics

## Option one: Particle physics

In a nuclear reaction, mass–energy, electric charge and momentum are conserved.

**Conservation of momentum**  $m_1u + m_2v = 0$   
 $m_1u = m_2v$  (Ignore the negative sign.)  
 So:  $m_1/m_2 = v/u$

**Ratio of kinetic energy** Ratio of  $E_k = \frac{1}{2}m_1u^2 / \frac{1}{2}m_2v^2 = m_1u^2/m_2v^2$  (eqn. 1)  
 From above  $m_1/m_2 = v/u$ . Substituting this into eqn. 1 gives:  
 Ratio of  $E_k = (v/u) (u^2/v^2) = u/v$

**Disintegration energy (Q)** When radioactive disintegration takes place spontaneously, kinetic energy is released. This energy is called disintegration energy and its symbol is  $Q$ .

**The neutrino** Usually in the decay process the energy of the products (the results of the reaction) is determined by the change in mass. But when this was done with beta decay, the results were not always predicable. In the case of beta decay, both energy and momentum seemed **not** to be conserved.

Wolfgang Pauli proposed a third particle, called the neutrino ( $\nu$ ), which carries away the missing momentum and energy.

The neutrino only interacts weakly with matter.

**Splitting of the nucleus** The first artificial splitting of the nucleus by accelerated particles was achieved by Ernest Walton and John Cockroft. They bombarded Li with H and got the following reaction:  
 ${}^7\text{Li}_3 + {}^1\text{H}_1 \rightarrow {}^4\text{He}_2 + {}^4\text{He}_2 + \text{Kinetic energy}$

**Workings of first particle accelerator** **High voltage:** Produced by transformers, rectifiers and capacitors.  
**Hydrogen protons:** Accelerated by high voltage and struck Li target at  $45^\circ$ .

**Reaction products:** Emitted at right angles onto a zinc sulphide screen, where they caused a flash.

### EXAMPLE:

In a reaction  ${}^{226}\text{Ra}_{88} \rightarrow {}^{222}\text{Rn}_{86} + {}^4\text{He}_2 + Q$ .  
 $7.8 \times 10^{-13}$  J of energy is released as the kinetic energy of the products. Find the kinetic energy of the alpha particle.

### Answer:

Momentum is conserved so  $m_1/m_2$  is the ratio of the masses.

${}^{222}\text{Rn} / {}^4\text{He} = 222 / 4 = 55.5:1$   
 is the ratio of masses.

Kinetic energy breaks down in the same ratio, 1 : 55.5

So  $1 + 55.5 = 56.5$

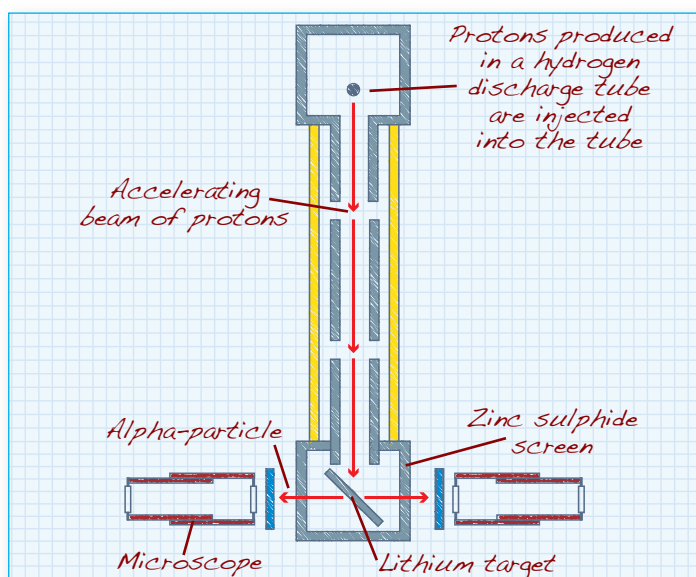
$7.8 \times 10^{-13} / 56.5$   
 $= 1.3805 \times 10^{-14} \times 55.5$   
 $= 7.68 \times 10^{-13}$  J

as most kinetic energy is taken by lighter alpha particle.

Two particles  ${}^4\text{He}_2$  were expected and found.

There was an energy gain in this reaction and it came from the loss of mass. This was the first experiment to verify Einstein's equation  $E = mc^2$ .

### Walton and Cockroft's apparatus



### Antimatter

When finding the energy released in a reaction, find the difference between the mass of the products and reactants. (If masses are given in u, convert to kg:  $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ .) Then use  $E = mc^2$ .

A particle's antiparticle has the same mass as the original particle and it also has the same charge, but the charge has the opposite sign to the original particle.

### The positron

Discovered by Carl David Anderson. He found a particle with the same mass as the electron but with a positive charge (equal but opposite charge to that of electron).

The positron is the antiparticle of the electron.



## 8 Option one: Particle physics

**Pair production** Creation of two particles from energy. In this process a particle and its antiparticle are produced. Momentum and electric charge are conserved.

This was first done by placing a lead plate into a cloud chamber and bombarding it with gamma rays. An electron and a positron were produced.

Pair production occurs when a gamma ray loses its energy ( $hf$ ) and is converted into an electron and a positron; the energy left over is the kinetic energy each particle has:

$$hf = 2mc^2 + E_{k1} + E_{k2}$$

**Pair annihilation** In this process, an electron and a positron that lie close together and are almost at rest join together and are annihilated, producing energy. The matter they are made of disappears.

The momentum of the system before annihilation is zero and so must be zero after the annihilation. Thus two gamma-ray photons are produced and they travel in opposite directions to conserve momentum.

$$\text{Pair annihilation} \rightarrow e^+ + e^- \rightarrow 2hf$$

**Particle accelerators** It was found that when particles were accelerated and then collided with each other, their kinetic energy produced mass in the form of new short-lived particles.

Ernest Lawrence developed the cyclotron, a much larger accelerator than Walton's. It was the first circular accelerator and used magnetic fields to confine the particle beam.

$$\mathbf{P + P + Energy \rightarrow P + P + Additional particles}$$

400 short-lived particles were discovered, usually lasting between  $10^{-6}$  and  $10^{-23}$  seconds.

**Particle families** The higher the energy of colliding particles, the greater the variety of new particles produced and the greater the mass of these particles.

The variety of the produced particles is known collectively as the **particle zoo**.



**The four  
fundamental  
forces of  
nature**

**Gravitational force**

Acts on masses. Always attractive. Infinite range. A weak force.

**Electromagnetic force**

Binds atoms and molecules together (can be attractive or repulsive). Much stronger than the gravitational force between the same particles. Infinite range. Second strongest force.

**Strong nuclear force**

Short range. Binds the nucleus. Electrons do not feel it.  
Strongest force.

**Weak nuclear force**

Force between particles not affected by or subject to the strong force. Beta decay occurs via the weak nuclear force. Short range.  
Stronger than gravitational only.

## Questions on particle physics *(Answers on page 154)*

- Q1.** **Define:** antimatter; the positron; pair production; pair annihilation.
- Q2.**  $^{222}\text{Rn}_{86}$  undergoes a nuclear disintegration and loses an alpha particle.  $7.8 \times 10^{-13}$  J is released as the kinetic energy of the products. Find the kinetic energy of the alpha particle.
- Q3.** 150 MJ of energy is released in a nuclear reaction. Calculate the loss of mass during the reaction.
- Q4.** What is the velocity of a proton when it is accelerated from rest through a potential difference of 800 kV?
- Q5.** What is the nuclear equation that represents the disintegration of a lithium nucleus when bombarded with a proton?
- Q6.** Calculate the energy released in the disintegration of a lithium nucleus when bombarded with a proton.  
(Li mass =  $1.165007 \times 10^{-26}$  kg;  
He mass =  $6.646322 \times 10^{-27}$  kg)
- Q7.** Complete the nuclear equation  ${}^7\text{Li}_3 + {}^1\text{H}_1 \rightarrow \dots$
- Q8.** A proton or an electron can be accelerated in a high voltage. Explain why a neutron cannot.
- Q9.** Explain how the existence of the neutrino can explain the apparently missing momentum and energy in beta decay.

## QUESTIONS

- Q10.** Why is it difficult to detect the neutrino?
- Q11.** Write an equation to represent:
- pair production
  - pair annihilation.
- Q12.** Find the minimum frequency required of a  $\gamma$ -ray photon in order for pair production of an electron and a positron to occur.
- Q13.** If a proton and an antiproton undergo pair annihilation calculate the frequency of the produced photons. How is momentum conserved in this interaction?
- Q14.** Give the quark composition of
- the neutron
  - the proton.
- Q15.** Why do electrons not have a quark composition?
- Q16.** In a circular accelerator, two protons, each with a kinetic energy of 1.5 GeV, travelling in opposite directions, collide. After the collision two protons and three pions are emitted. Calculate the kinetic energy of all the particles after the collision.
- Q17.** What is the quark composition of
- a baryon
  - a meson.
- Q18.** What is a lepton? Name two types of lepton.



# 9

SECTION



# OPTION TWO

HIGHER LEVEL

- Applied electricity



# 9 Option two: Applied electricity

## Option two: Applied electricity

### Electromagnetic relay

A switch in an electric circuit that is turned on or off via an electromagnet.

**Applications:** Switching electric motors on and off; in cars, starter motor and heated rear windows.

### Force on a current-carrying coil in a magnetic field

If a current-carrying coil is in a magnetic field and is free to rotate it will experience a force which will cause it to rotate. This motion follows Fleming's left hand rule. As the coil motion is governed by Fleming's left hand rule, the forces acting on the coil will also cause it to eventually stop rotating, as the coil becomes parallel to the magnetic field.

### Applications

Many devices work because of the force on a current-carrying conductor in a magnetic field:

#### The DC motor

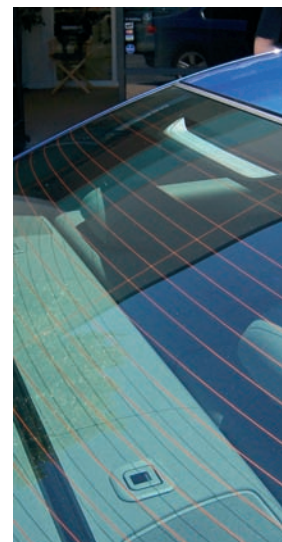
The coil described above can be made to rotate continuously by using a split ring commutator. The split ring commutator contains carbon brushes which are connected to a battery. This arrangement ensures that current always flows through the coil in one direction only even though the coil is rotating.

#### The moving-coil loudspeaker

Consists of a coil of wire wound around a cardboard tube placed in a magnetic field. The cardboard tube extends to a cardboard cone. As the current in the coil changes it produces vibrations which are heard in the cone as sound.

#### The moving-coil galvanometer

Consists of a coil of wire wound around a soft iron core in a magnetic field. The coil is free to rotate and is spring loaded. If a current is applied to the coil it will cause it to rotate against the action of the spring. A pointer is attached to the coil to read an appropriate scale.



### Converting a moving-coil galvanometer into other devices

#### Voltmeter

Connect a multiplier (high resistance) in series with the galvanometer.

#### Ohmmeter

Connect a battery and variable resistor in series with the galvanometer.

#### Ammeter

Connect a shunt (low resistance) in parallel with the galvanometer.

### Electromagnetic induction

In electromagnetic induction, an emf is induced due to a coil in a changing magnetic field.

#### Induction coil

A device used to produce high voltage from a low voltage DC source.

**Application:** High voltage spark plugs in a petrol engine.

### Alternating current

#### AC generator

This is a similar device to the DC motor. The split ring is replaced by slip rings. Now when the coil is rotating in a uniform magnetic field an alternating emf is induced.

#### Induction motor

Consists of stationary magnets and conductors which are free to rotate. It operates by Faraday's law.

### Diodes

#### Light emitting diode

Consists of a pn junction which when in forward biased gives out light.

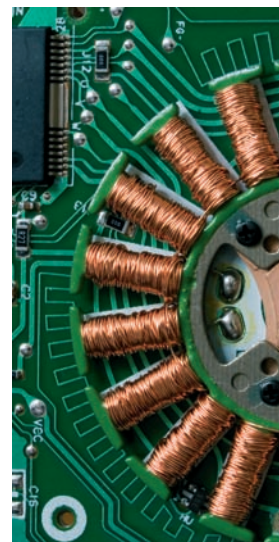
#### Photodiode

A reversed biased pn junction that conducts electricity in the presence of light. The current flow is directly proportional to light intensity.

### Rectification

When diodes are used to change AC to DC.

Two types of rectifier include the half-wave and full-wave rectifier. The half-wave rectifier causes DC to flow in a circuit for half of the AC cycle. The full-wave rectifier causes DC to flow in a circuit for the full AC cycle.



## 9 Option two: Applied electricity

**The transistor** The bi-polar transistor consists of three layers of doped semiconductor material sandwiched together. These are named the emitter, collector and base.

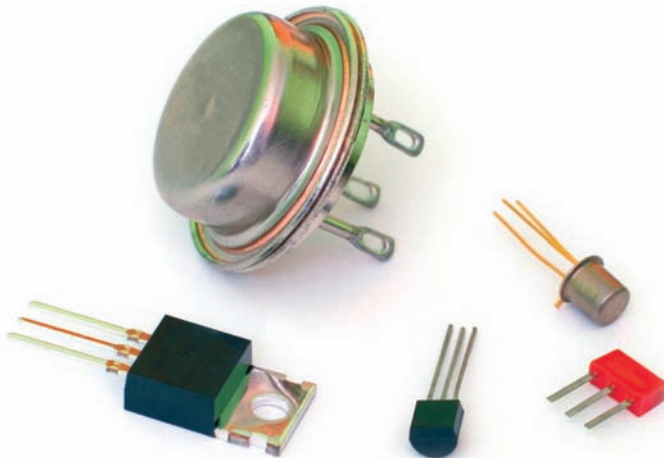
For an npn transistor:

**Emitter:** n type doped semiconductor material.

**Base:** p type doped semiconductor material.

**Collector:** n type doped semiconductor material.

A transistor can be used as a switch. The base current, which is small, can be used to turn the collector current, which is large, on or off.



**Logic gates** These were devised by George Boole.

**AND gate:** If the input voltage on both terminals is high then the gate output voltage will be high. Otherwise the output voltage will be low.

**OR gate:** If either of the input voltages are high then the output voltage will be high. Otherwise the output voltage will be low.

**NOT gate:** If the input voltage is high the output voltage will be low and vice versa.

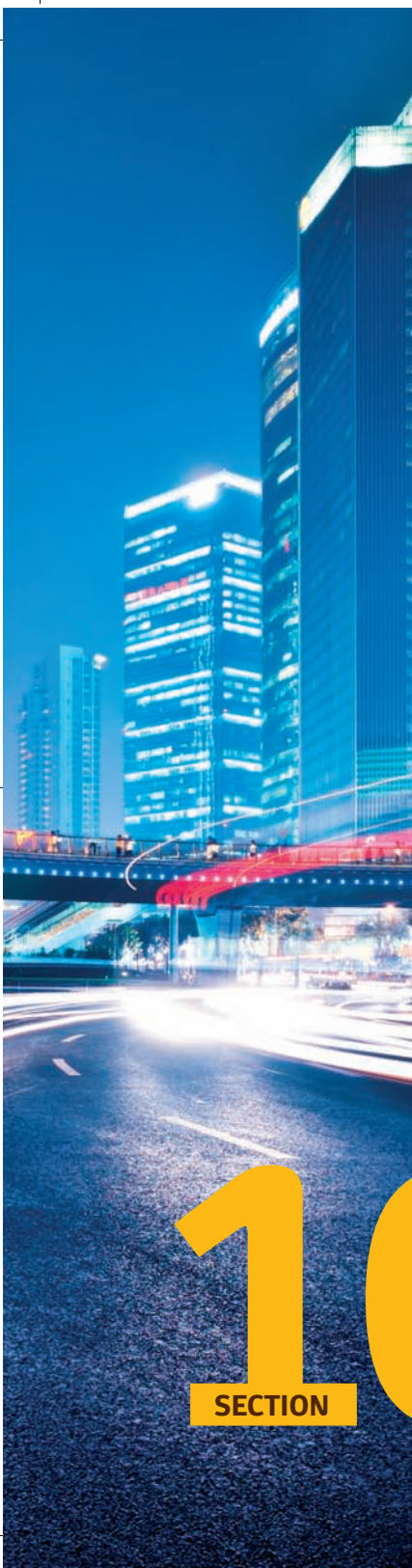


## Questions on applied electricity *(Answers on page 155)*

- Q1.** What is an electromagnetic relay? Give some applications of it.
- Q2.** What rule does the motion of a current-carrying coil in a magnetic field follow?
- Q3.** Explain the workings of:
- a DC motor
  - a moving-coil loudspeaker
  - a moving-coil galvanometer.
- Q4.** Explain how you would convert a moving-coil galvanometer into:
- a voltmeter
  - an ammeter
  - an ohmmeter.
- Q5.** What is electromagnetic induction?
- Q6.** What is an induction coil? Give an application of this device.
- Q7.** Describe the workings of an AC generator.
- Q8.** Describe the workings of an induction motor.
- Q9.** What is rectification of a current? Name two types of rectifier and describe the output current of both.
- Q10.** Describe the structure of a npn transistor. Name the parts of the transistor and give an application of the transistor you have described.

- Q11.** Name three types of logic gate.
- Q12.** For each of the logic gates you have named in Q11, describe how you would ensure that a high output voltage is produced by each.

# QUESTIONS



# 10

SECTION

# EXPERIMENTS

- Light
- Mechanics
- Electricity
- Sound
- Heat

EXPERIMENTS

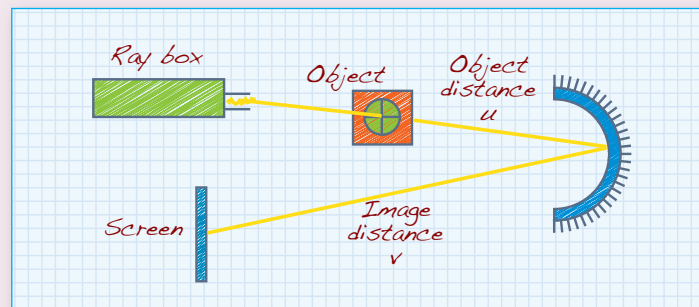


## EXPERIMENTS

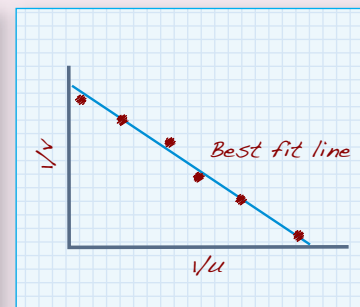
### Light

To find the focal length of a concave mirror

#### Diagram



#### Graph



#### Method

Set up apparatus as shown. Find a sharp image of the object on the screen. Measure  $u$  and  $v$ . Draw a graph of  $1/v$  against  $1/u$ .

#### Formula

$$1/u + 1/v = 1/f$$

where  $u$  = object distance,  $v$  = image distance,  $f$  = focal length.

#### Errors

Ruler accurate to  $\pm 1$  mm. Opinion when image is sharpest.

#### Accuracy

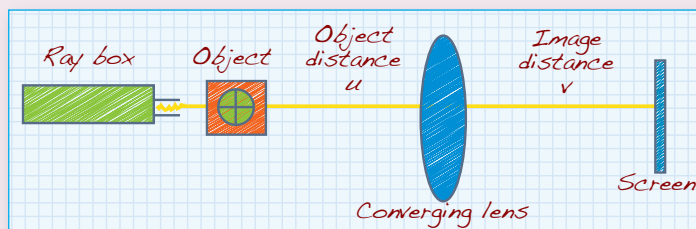
Do the experiment many times and get an average.

Find an approximation of the focal length to ensure the object is placed outside it and hence that a real image is being produced.

The line on the graph should cut the  $x$ -axis and  $y$ -axis at  $1/f$ . So the values where both axes are cut should be approximately equal.

**To find the focal length of a convex lens**

**Diagram**



**Method**

Set up the apparatus as shown. Find a sharp image of the object on the screen. Measure  $u$  and  $v$ .

**Formula**

$$1/u + 1/v = 1/f$$

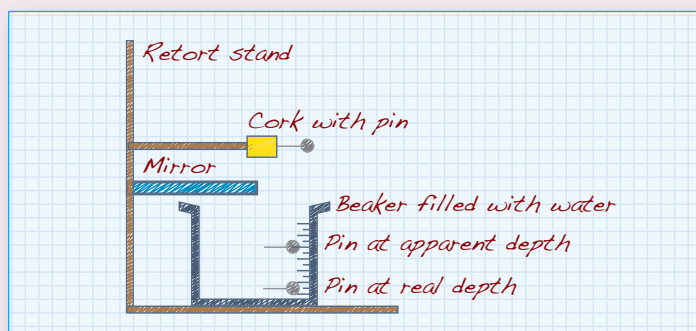
where  $u$  = object distance,  $v$  = image distance,  $f$  = focal length.

**Errors and accuracy**

Errors, accuracy and approximation are the same as for finding the focal length of the concave mirror.

**To find the refractive index of a liquid**

**Diagram**



**Method**

Set up the apparatus as shown. Adjust the cork and pin until its image in the mirror is in no parallax with the apparent depth of the

## EXPERIMENTS

immersed pin. Measure the real and apparent depth (from the back of the mirror to the image of the pin in the cork).

### Formula

**Refractive index = Real depth  $\div$  Apparent depth**

### Notes

This experiment is carried out using the method of no parallax.

**Parallax** is the apparent movement of an object with regard to another object, due to observer motion.

### Errors

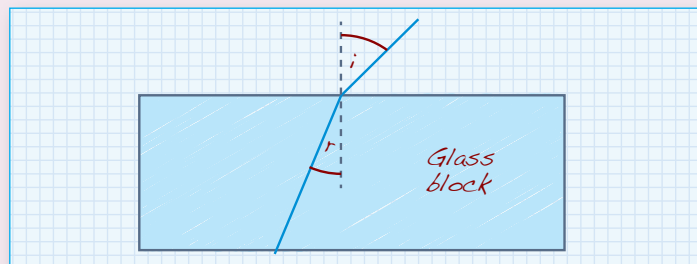
Ensure that parallax error is avoided when using the ruler.

### Accuracy

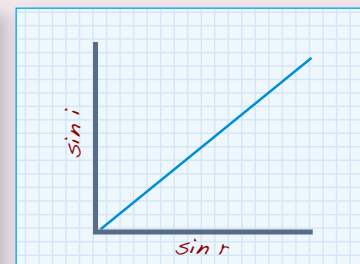
Repeat the process of finding and measuring the point of no parallax and then calculate the average of the apparent depth.

**To verify  
Snell's law**

### Diagram



### Graph



### Method

Set up a ray box so that a ray passes through a glass block as shown. Measure  $i$  and  $r$  using a protractor. Graph  $\sin i$  against  $\sin r$ . A straight line through the origin shows that  $\sin i$  is directly proportional to  $\sin r$  (i.e. verifies Snell's law).

### Formula

$$n = \sin i \div \sin r$$

Finding the slope of the graph will yield the refractive index of the glass.

### Errors

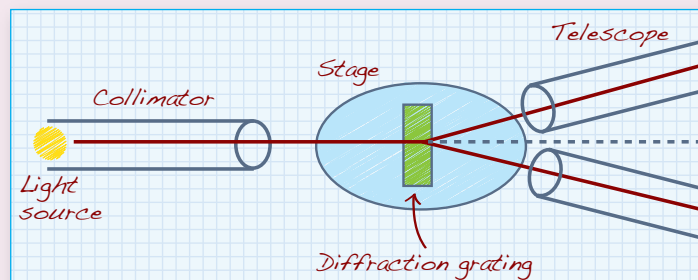
There is an error in the accuracy of the protractor.

### Accuracy

Angles of incidence should be kept over  $20^\circ$  to reduce the percentage error in the protractor. As the refracted angle is always smaller than the incident angle, large incident angles reduce the percentage error on the measurement of refracted angles also. The more points that are plotted on the graph, the more accurate the line of best fit will be.

To find the wavelength of monochromatic light

### Diagram



### Method

Set up the apparatus as shown. Measure the angle from the brightest centre (zero-order) fringe to the first-order fringe using the **vernier** and scale. Calculate the wavelength.

### Spectrometer setup

Focus the telescope on a distant object. Ensure base and stage are level. Adjust the slit width.

### Formulae

$$n\lambda = d \sin \theta$$

where  $\lambda$  = wavelength of light,  $n$  = fringe order,  $d$  = grating constant, and  $\theta$  = angle of diffraction.

To find the maximum number of fringes possible from a diffraction grating use  $n_{\max} = d/\lambda$

## EXPERIMENTS

### Calculating the grating constant $d$

**Example:** Find the grating constant  $d$  if the diffraction grating contains 500 lines per mm.

**Answer:**  $d = 1 \div 500\,000 = 2 \times 10^{-6}$  m

### Errors

Crosshairs not in the centre of the ray.

Error in Vernier scale.

Diffraction grating not completely perpendicular to stage.

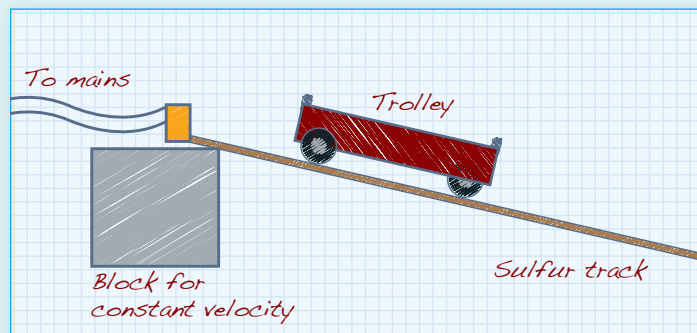
### Accuracy

This can be improved by using a diffraction grating with more lines per mm. This gives a larger angle for  $\theta$  and thus reduces the percentage error when measuring it.

## Mechanics

To find  
velocity and  
acceleration

### Diagram



### Method

Set up apparatus as shown. Measure the distance  $d$  travelled by the trolley with a ruler. Calculate the time  $t$  using the mains, which cycles every 0.02 seconds. A line of sulfur and a gap on the track is 0.02 seconds. Count sulfur lines and gaps to find the time.

### Formulae

**Velocity**  $v = d/t$

**Acceleration**  $a$  is calculated by finding the initial velocity  $u$  and final velocity  $v$  and then dividing the difference between them by the total time taken,  $t$ :  $a = (v - u) \div t$

### Errors

The error on the ruler is  $\pm 1$  mm. Avoid ruler parallax error.  
The error in the calculation of time is  $\pm 0.02$  seconds.

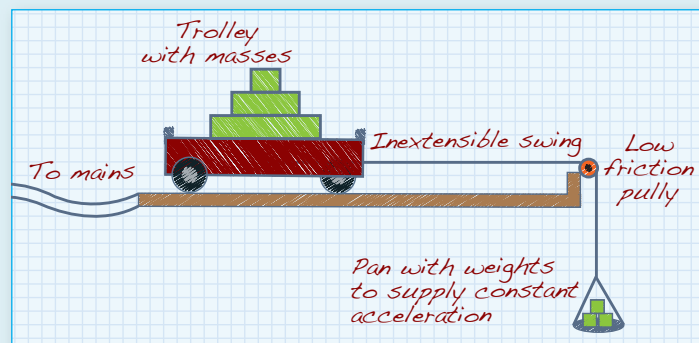
### Accuracy

Use a longer track to reduce the percentage error in distance calculations. Oil the trolley wheels to lower friction and obtain a more accurate result. Carry out the experiment many times and find an average.

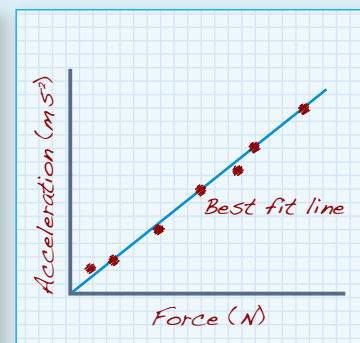
## EXPERIMENTS

To show  
acceleration is  
proportional  
to force

### Diagram



### Graph



### Method

Set up apparatus as shown. Calculate the acceleration as above. Transfer known masses from the trolley to the pan and calculate the acceleration again. Graph the results. A straight line through the origin shows that acceleration is directly proportional to force.

### Errors

The errors in measuring time and distance are the same as the previous experiment. An error exists on the electronic balance used to find the mass of the known masses.

### Accuracy

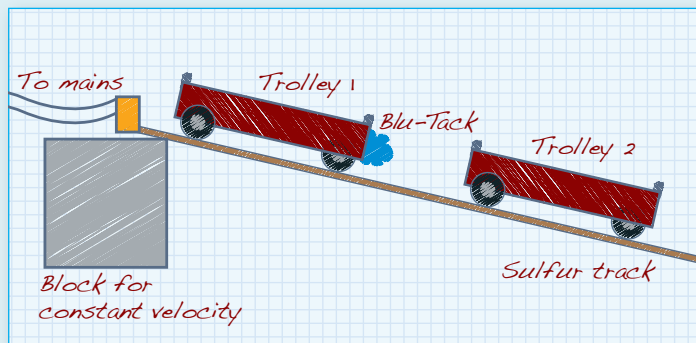
Oil the trolley wheels and the pulley wheel to reduce friction.

The slope of the graph is equal to the mass of the system.

Transferring the known masses from the trolley to the pan ensures that the system is a closed system (that is, no extra external factors are introduced which may affect the results).

Verify the  
principle of  
conservation  
of  
momentum

### Diagram



### Method

Set up the apparatus as shown. Trolley 1 is set in motion with constant velocity. Trolley 2 remains at rest. Trolley 1 then collides with and sticks to trolley 2 via the Blu-Tack. The pair move off together. Calculate the velocity of trolley 1 before the impact. Then calculate the velocity of the pair moving together. Find the masses of the trolleys using an electronic balance.

### Formulae

**Momentum = Velocity × Mass**

The momentum before the crash should be equal to the momentum after the crash:

$$m_1 u_1 + m_2 u_2 = (m_1 + m_2) v$$

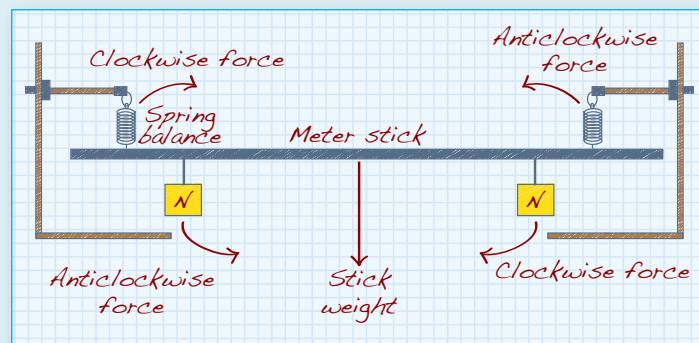
where  $m_1$  and  $m_2$  are the trolley masses,  $u_1$  and  $u_2$  are the initial velocities of trolleys 1 and 2, and  $v$  is the final velocity of the pair.

The calculation of velocity, the errors and the increased accuracy are given in the previous experiments.

## EXPERIMENTS

The laws of equilibrium for a set of coplanar forces

### Diagram



### Method

Set up the apparatus as shown. Use an electronic balance to find the mass of the weights. Ensure the meter stick is in a horizontal position. The clockwise and anticlockwise moments labeled in the diagram are based on the student calculating from the 50 cm mark on the meter stick.

### Formula

**Moment = Perpendicular distance  $\times$  Force** Unit: N m

The sum of the clockwise moments will be equal to the sum of the anticlockwise moments.

### Errors

The spring balance is accurate to  $\pm 0.2$  N.

There is an error associated with the electronic balance.

The spring balances must hang vertically.

### Accuracy

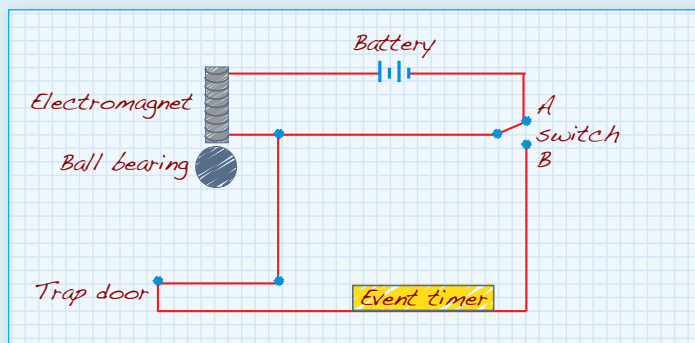
A spirit level can be used to ensure the meter stick is horizontal.

A digital balance is more accurate than the newton balance.

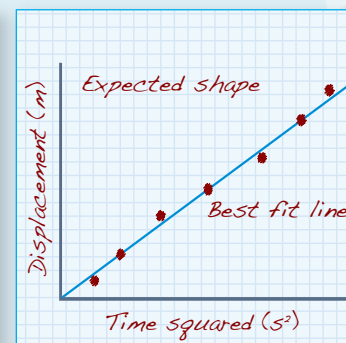
If the spring balances are not in a vertical position, the vertical force they produce can still be found using vector components.

### Measuring acceleration due to gravity using the free fall method

#### Diagram



#### Graph



#### Method

Set up the apparatus as shown. Measure the distance from the bottom of the ball bearing to the trap door. When the switch is thrown the ball bearing falls and the timer starts. When the bearing hits the trap door the timer stops (do this a few times and use the shortest fall time). Graph displacement in meters, against the time squared. A straight line through the origin shows that displacement is directly proportional to the time squared.

#### Formulae

$$g = 2s/t^2$$

where  $g$  = acceleration due to gravity,  $s$  = displacement and  $t$  = time

The graph can also be used to find  $g$ :

$$g = 2 \times \text{slope}$$

#### Errors

The ruler is accurate to  $\pm 1$  mm. There is also an error associated with the event timer.

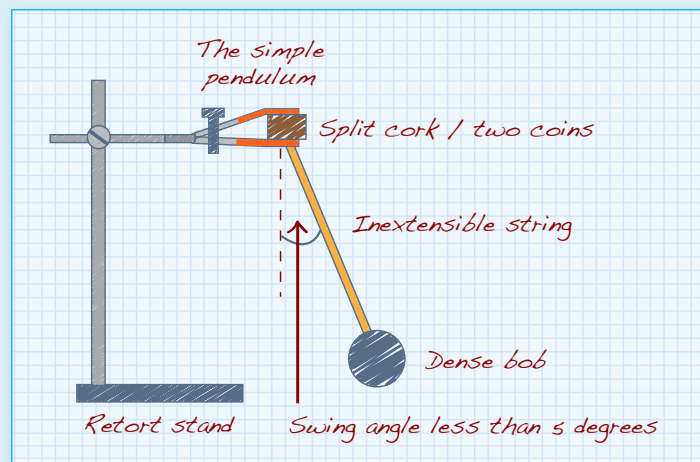
#### Accuracy

If the ball bearing falls over a larger distance the percentage errors associated with the ruler and the event timer are reduced. Do the experiment many times and get an average.

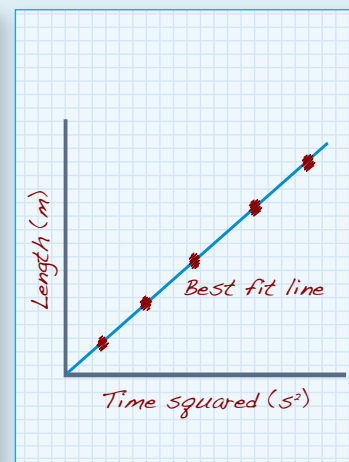
## EXPERIMENTS

### Measuring acceleration due to gravity with a simple pendulum

#### Diagram



#### Graph



#### Method

Set up apparatus as shown. Swing the pendulum with an angle of less than  $5^\circ$ . Record the time for 50 oscillations. Divide your result by 50 to get the time for one oscillation. Record the pendulum length using a ruler. Measure from the split cork to the centre of the pendulum bob. Repeat the procedure for different pendulum lengths. Graph the time squared against the length in meters. A straight line through the origin shows that length is directly proportional to time squared.

#### Formulae

$$g = 4\pi^2(L/T^2)$$

where  $g$  = acceleration due to gravity,  $L$  = pendulum length,

$T$  = time

The graph can be used to find  $g$ :

$$g = 4\pi^2 \times \text{slope}$$

#### Errors

There are percentage errors on both the ruler and the timer.

There is a timing error in starting and stopping the stopwatch.

**Accuracy**

Carry out the experiment many times with each length and get an average for each. Reduce the percentage error on the ruler by using large values for length  $L$ . Calculate the time for one oscillation by using more than 50 oscillations.

A swing angle of less than  $5^\circ$  is used so that you can assume the bob is in simple harmonic motion and to ensure the force causing the acceleration is directly proportional to  $g$ , the acceleration due to gravity.

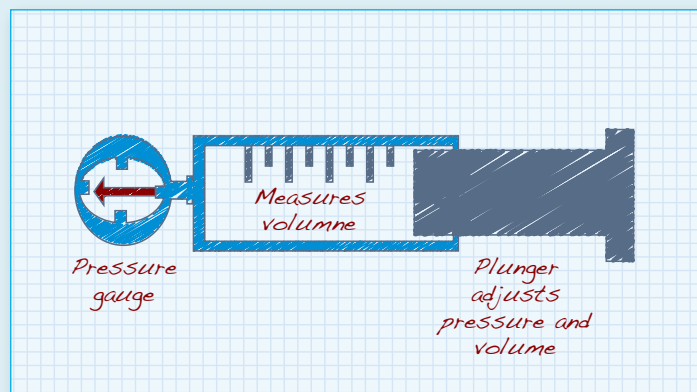
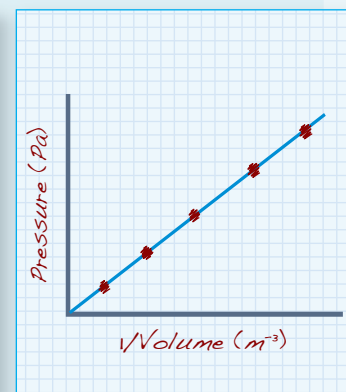
A small dense bob is used to reduce air resistance and to keep the string taut.

An inextensible string is used to ensure the string's length remained constant.

The pendulum must only be allowed to oscillate in one plane. It cannot be allowed to spin.

**Verification of Boyle's law**

Boyle's law states that for a fixed mass of gas, at constant temperature, pressure is inversely proportional to volume.

**Diagram****Graph**

## EXPERIMENTS

### Method

Set up the apparatus as shown. Use the plunger to adjust the volume and pressure. Record the volume and pressure. Release the pressurized air. Leave the apparatus for a few moments. Repeat the procedure for different values of volume and pressure. Graph pressure against  $1/\text{volume}$ . A straight line through the origin shows that pressure is proportional to  $1/\text{volume}$ .

### Errors

Avoid parallax error by reading the pressure and volume scales at eye level.

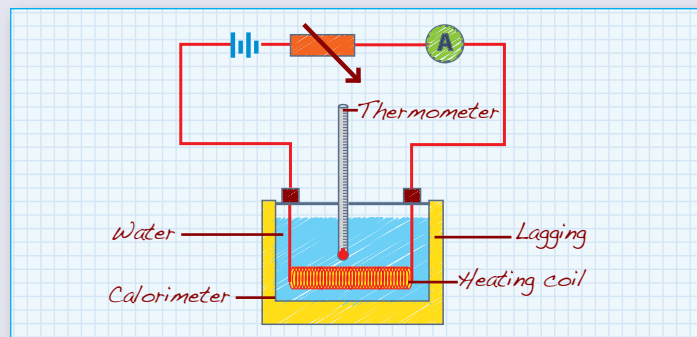
### Accuracy

The apparatus should not be allowed to heat up. Do not leave the apparatus under pressure as this will cause heat due to gaseous collisions. Releasing the pressurized gas slowly will ensure the temperature remains constant. If the ranges of the readings are increased the percentage error associated with them is reduced.

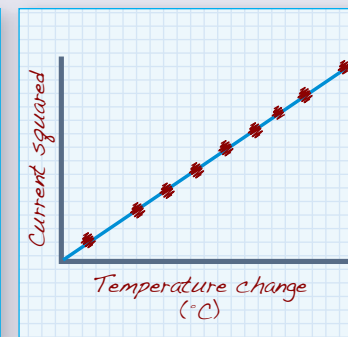
## Electricity

### Verification of Joule's law

#### Diagram



#### Graph



#### Method

Set up the apparatus as shown. Allow a set amount of current to flow for 3 minutes. Record the temperature change. Use the rheostat to adjust the amount of current flowing and repeat the process. Graph the results by squaring the values recorded for current against the temperature changes. A straight line through the origin shows that the current squared is directly proportional to the temperature change.

Each time the procedure is carried out, the water should be replaced with the same volume of cold water. The temperature of the cold water should be just below room temperature so that the heat lost to the environment (when heated) is negated by the energy gained from the environment at the start of the experiment.

#### Errors

There is a percentage error associated with the thermometer and the ammeter. There is also a percentage error associated with the vessel used to measure the volume of water which should be constant. An unavoidable error arises in starting and stopping the timer.

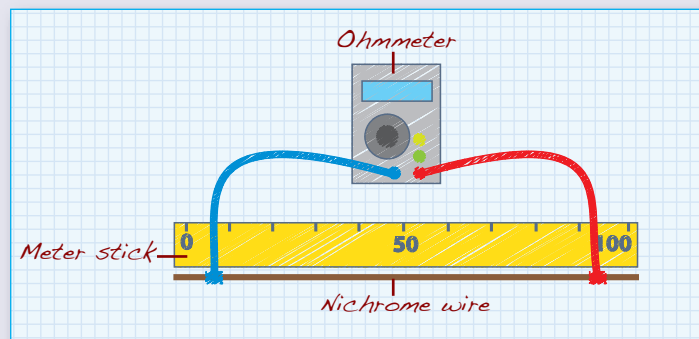
#### Accuracy

The water should not be heated for too long as heat will then be lost to the environment. Do not heat the water for too short a period to reduce percentage error.

## EXPERIMENTS

To measure  
the resistivity  
of a material  
wire

### Diagram



### Method

Set up the apparatus as shown. Use the ohmmeter to measure the resistance of the nichrome wire. Use a meter stick to measure the length of the wire. Use a micrometer to measure the diameter of the wire.

### Formula

$$\rho = R\pi d^2/4L$$

where:  $\rho$  = resistivity,  $R$  = resistance,  
 $d$  = wire diameter,  $L$  = wire length

### Errors

There is a percentage error associated with the ruler, the micrometer and the ohmmeter. Avoid parallax error on the ruler. The leads of the ohmmeter have resistance.

### Accuracy

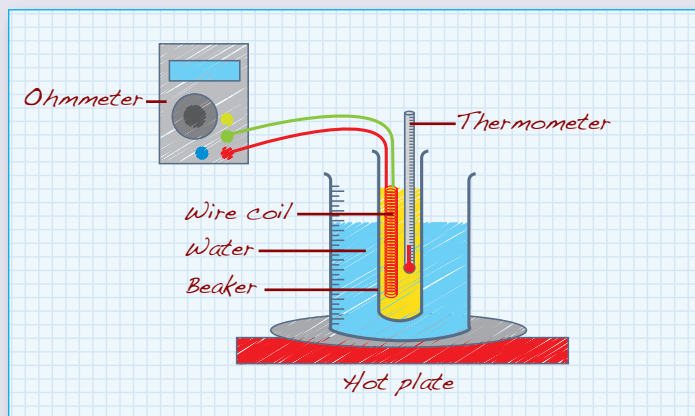
Do not increase the resistance of the wire by holding it. Ensure the wire is straight when measuring its length.

### Using the micrometer

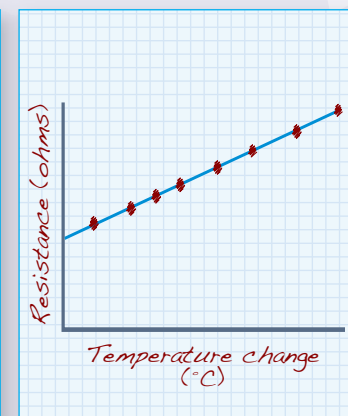
Clamp the wire into the jaws of the micrometer. Use the Vernier and circular scale on the micrometer to measure the wire diameter. If there is a non-zero error on the micrometer this must be added or subtracted. Calculate an average of the wire diameter because the wire is not necessarily a uniform cylinder.

To investigate the variation of the resistance of a metallic conductor with temperature

### Diagram



### Graph



### Method

Set up the apparatus as shown. Record the resistance reading on the ohmmeter at regular temperature intervals as the water is heated. Record and graph the results. There is a linear relationship between resistance and the change in temperature.

### Errors

There is a percentage error associated with the thermometer and the ohmmeter. Avoid the parallax error associated with reading the thermometer.

### Accuracy

Use a digital thermometer to increase accuracy. The more temperature and resistance readings that are taken, the more accurate the graph will be. Ensure that the connections in the circuit are clean.

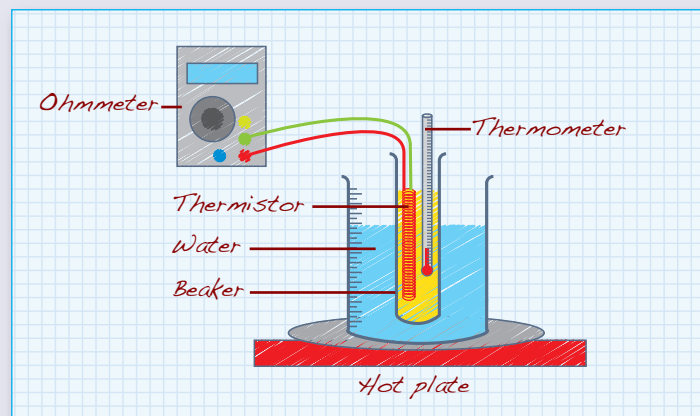
The coil is immersed in glycerol as it makes better thermal contact than water.

**Note:** This experiment can be used as Mandatory experiment 8: The calibration curve of a thermometer using the laboratory mercury thermometer as a standard.

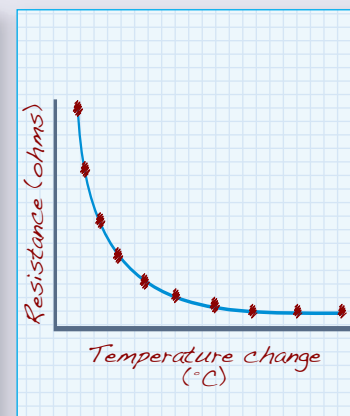
## EXPERIMENTS

To investigate the variation of the resistance of a thermistor with temperature

### Diagram



### Graph



### Method

Set up the apparatus as shown. Record the resistance reading on the ohmmeter at regular temperature intervals as the water is heated. Record and graph the results. As the temperature of a thermistor rises, its resistance decreases.

### Errors

There is a percentage error associated with the thermometer and the ohmmeter. Avoid the parallax error associated with reading the thermometer.

### Accuracy

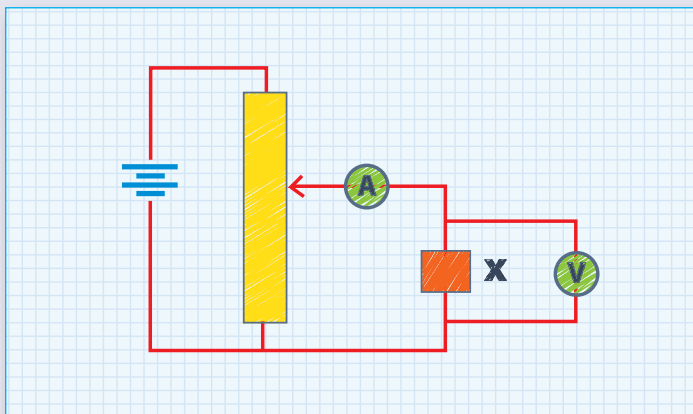
Use a digital thermometer to increase accuracy. The more temperature and resistance readings that are taken, the more accurate the graph will be. Ensure that the connections in the circuit are clean.

The coil is immersed in glycerol as it makes better thermal contact than water with the coil.

The water should be heated slowly to allow the glycerol and the thermistor heat uniformly.

To investigate the variation of current and voltage for a metallic conductor, a bulb, a semiconductor diode (thermistor) and an ionic solution

### Diagram



### Method

Set up the apparatus as shown. Place a metallic conductor, a bulb, a thermistor or an ionic solution at X in the diagram as required. Record the readings on both the ammeter and the voltmeter. Adjust the rheostat increasing the potential difference and the current. Record the readings again. Plot a graph of current against voltage for the results.

For explanations on the shapes of the graphs see page 46.

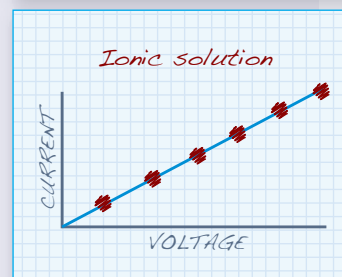
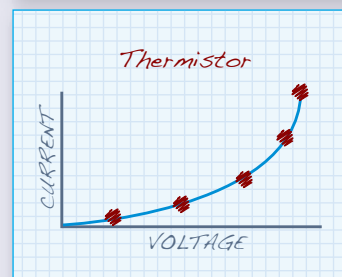
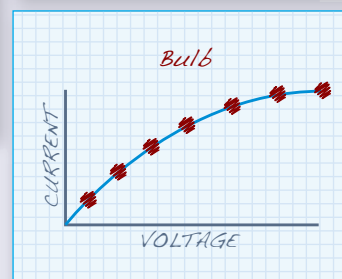
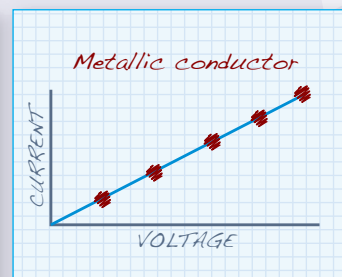
### Errors

There are errors associated with the voltmeter and the ammeter.

### Accuracy

The more readings that are taken during the experiment, the more accurate the graph will be.

### Graphs

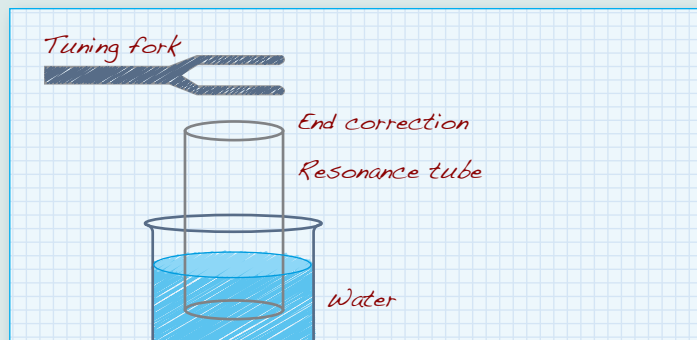


## EXPERIMENTS

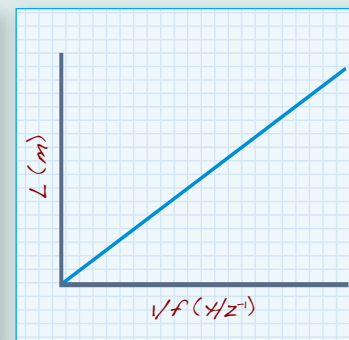
### Sound

To investigate  
the speed of  
sound in air

#### Diagram



#### Graph



#### Method

Set up the apparatus as shown. Strike the tuning fork and hold it over the resonance tube. Starting with the tube at its shortest, increase the length of the tube until a note can be heard in the tube. Measure the length of the resonance tube at this point. Record the frequency of the tuning fork. Measure the diameter of the resonance tube with vernier calipers. Graph length in meters against  $1/f$ , where  $f$  is in hertz. A straight line through the origin shows that length is directly proportional to  $1/f$ .

#### Formula

$$c = 4f(L + 0.3d)$$

where  $c$  = speed of sound,  $f$  = fork frequency,

$L$  = tube length,  $d$  = tube diameter.

The end correction (that is, the distance the sound wave protrudes out of the end of the tube) is taken to be 0.3 of the resonance tube's diameter.

#### Errors

There is the percentage error associated with the ruler used to measure the length of the tube. There is also a percentage error in

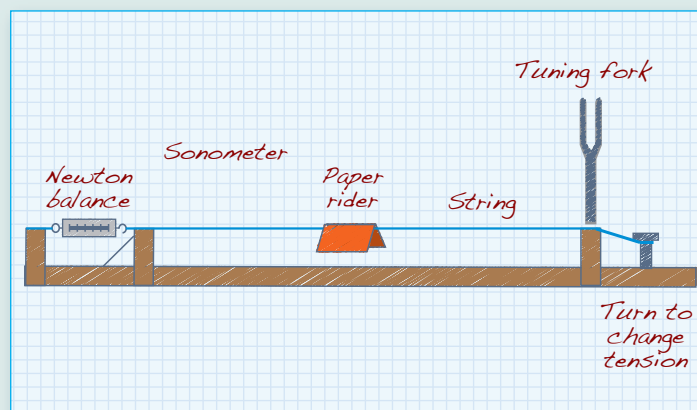
the vernier calipers used to measure the diameter of the resonance tube.

### Accuracy

Avoid the parallax error on the ruler. It can be difficult to find the point where the sound is loudest so this point should be found many times for each tuning fork and the resulting lengths averaged. The need for the estimated end correction figure can be eliminated by finding the length between the first and second points of resonance in the tube (doing this will yield half of the wavelength of the wave).

To investigate  
fundamental  
frequency of  
a stretched  
string

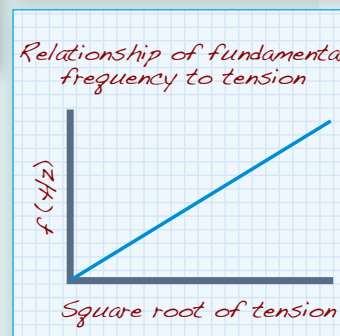
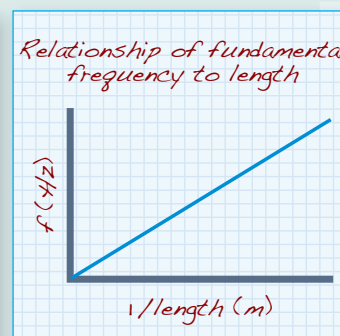
### Diagram



### Method 1

**For length:** Set up the apparatus as shown. Strike the tuning fork. Adjust  $L$ , the length of the string, until the fundamental frequency is reached (the paper rider is thrown off the string). Record the string length and the frequency of the tuning fork. The tension should remain constant throughout the experiment. Graph the results of the frequency against  $1/L$ . A straight line through the origin shows that the frequency is directly proportional to  $1/L$ .

### Graphs



## EXPERIMENTS

### Method 2

**For tension:** Set up the apparatus as shown. Strike the tuning fork. Adjust the tension on the string until the fundamental frequency is reached (the paper rider is thrown off the string). Record the tension on the string by reading the newton balance. Record the frequency of the tuning fork used. The string length should remain constant throughout the experiment. Graph the results of the frequency against the tension squared. A straight line through the origin shows that frequency is directly proportional to the tension squared.

### Errors

**For length:** There is a percentage error associated with the ruler used to measure the string length.

**For tension:** There is a percentage error associated with the newton balance used to measure the tension.

### Accuracy

Avoid parallax error when reading the ruler and the newton balance. The more tuning forks that are used, the more results will be produced and the more accurate the graphs will be.

To ensure you have found the fundamental frequency and not a harmonic of the string:

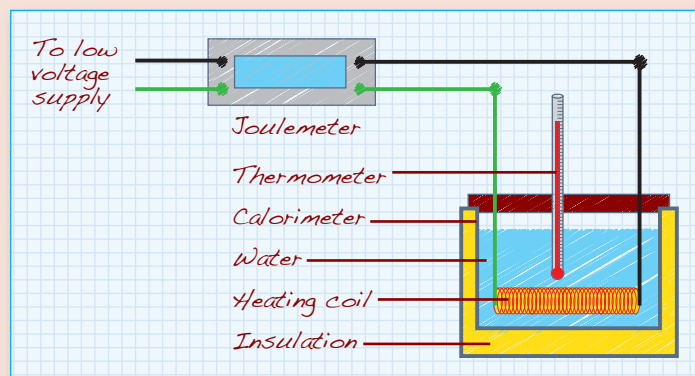
**For length:** Start the experiment with the string at its longest and then make it shorter until the fundamental frequency is found.

**For tension:** Start the experiment with low tension on the string and then increase the tension until the fundamental frequency is found.

## Heat

To measure the specific heat capacity of water by an electrical method

### Diagram



### Method

Set up the apparatus as shown. Set a current flowing through the heating coil immersed in water. The amount of energy transferred to the water and calorimeter is displayed on the joulemeter. Measure the rise in temperature using the thermometer. Knowing the mass of the water, the mass of the calorimeter and the specific heat capacity of copper, the specific heat capacity of water can be calculated.

### Formula

Electrical energy supplied =  
Heat gained by water + Heat gained by calorimeter

That is:

$$Q = M_w C_w (\theta_2 - \theta_1) + M_c C_c (\theta_2 - \theta_1)$$

where:

$M_w$  and  $M_c$  = the mass of the water and the copper calorimeter

$C_w$  and  $C_c$  = the specific heat capacity of water and of copper

$\theta_2$  and  $\theta_1$  = the final and initial temperature

## EXPERIMENTS

### Measurements

**Energy added to the system:** Read the output of the joulemeter.

**Mass of empty calorimeter:** Use an electronic balance.

Convert grams to kilograms.

**Mass of calorimeter and water:** Use an electronic balance.

Convert grams to kilograms.

**Mass of water:** Subtract the mass of calorimeter from the mass of water and calorimeter.

**Initial temperature:** Use a thermometer to measure the water temperature at the start.

**Final temperature:** Use the thermometer to measure the water temperature at the end.

### Errors

There are percentage errors associated with the thermometer and the joulemeter.

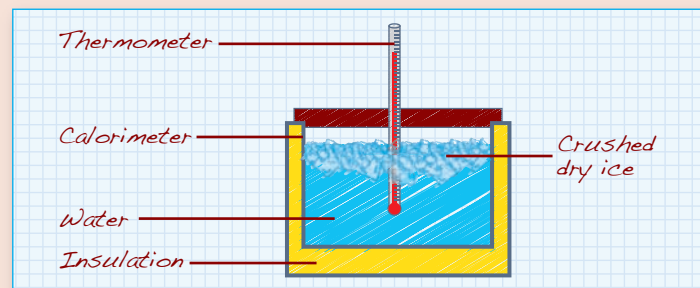
### Accuracy

Use a thermometer and stirrer with a low specific heat capacity to ensure minimal heat is lost to them. Use a digital thermometer.

Allow a greater temperature change to reduce percentage error on the thermometer. Ensure the calorimeter is well insulated and has a lid to reduce heat loss to the environment.

**To measure  
the specific  
latent heat of  
fusion of ice**

### Diagram



**Method**

Set up the apparatus as shown. Add dry crushed ice to the calorimeter containing water with a temperature about 5 °C above room temperature. Allow the ice to melt fully. Continue to add ice until the water reaches about 5 °C below room temperature. Knowing the mass of the calorimeter, water and ice, the specific latent heat of fusion can be calculated.

**Formula**

Heat lost by water + Heat lost by calorimeter =  
Heat needed to melt ice at 0 °C to water at 0 °C  
+ Heat needed to raise temperature of melted ice  
from 0 °C to the final temperature

That is:

$$M_w C_w (\theta_1 - \theta_2) + M_c C_c (\theta_1 - \theta_2) = M_{ice} L + M_{ice} C_w (\theta_2 - 0)$$

where:

$M_w, M_c, M_{ice}$  = mass of the water, copper calorimeter and ice

$C_w, C_c$  = specific heat capacity of water and copper

$\theta_2, \theta_1$  = final and initial temperature

**Errors**

There is a percentage error associated with the thermometer.

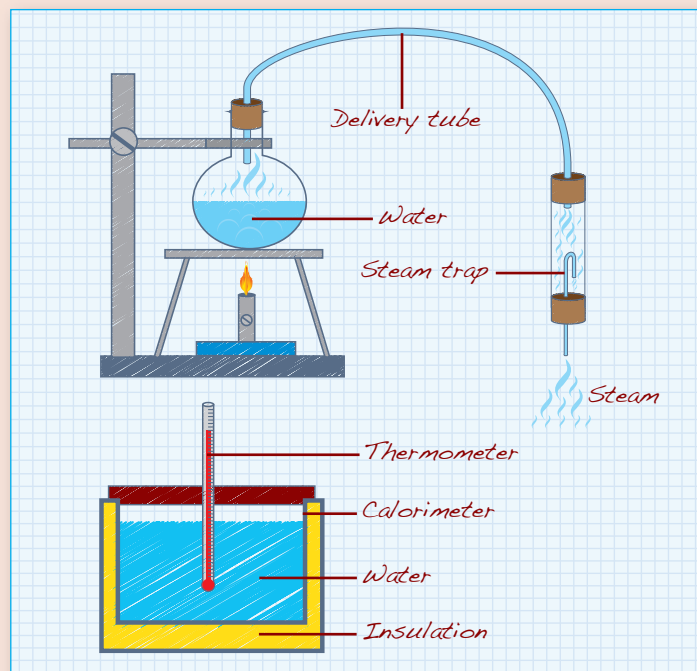
**Accuracy**

Avoid the parallax error when reading the thermometer. Good insulation ensures that heat lost to or gained from the environment is minimized. After taking the ice from the freezer it will be at a temperature below zero degrees so it must be allowed to reach zero degrees by leaving it to stand for a few minutes.

## EXPERIMENTS

To measure  
the specific  
latent heat of  
vaporisation  
of water

### Diagram



### Method

Set up the apparatus as shown. Add steam to the calorimeter.

Measure the rise in the water temperature produced by the steam.

The specific latent heat of vaporisation can be calculated using the formula.

**Formula**

Heat gained by water + Heat gained by calorimeter =  
Heat given out by steam in boiling water at 100 °C  
+ Heat lost by condensed steam cooling from 100 °C  
to the final temperature

That is:

$$M_w C_w (\theta_2 - \theta_1) + M_c C_c (\theta_2 - \theta_1) = M_s L + M_s C_w (100 - \theta_2)$$

where:

$M_w, M_c, M_s$  = mass of the water, copper calorimeter and steam

$C_w, C_c$  = specific heat capacity of water and copper

$\theta_2, \theta_1$  = final and initial temperature

**Errors**

There is a percentage error associated with the thermometer.  
Some water may leak into the calorimeter from the steam trap  
which will have already lost its latent heat.

**Accuracy**

Avoid the parallax error when reading the thermometer. Use a  
digital thermometer. Use a well-insulated calorimeter to avoid  
heat being lost to the environment.



# WORKED SOLUTIONS TO QUESTIONS

SOLUTIONS

## SOLUTIONS

### Answers to light questions

#### Q1 and Q2.

See pages 12–15.

#### Q3.

The reflection is always twice his distance from the mirror.

(i) 4 m (ii)  $1.5/2 = 75$  cm

#### Q4.

Use  $1/u + 1/v = 1/f$ .

$$\begin{aligned} 1/f &= 1/25 + 1/40 \\ &= 40/1000 + 25/1000 \\ &= 65/1000 = 1/15.38 \\ \text{So } f &= 15.38 \text{ cm} \end{aligned}$$

#### Q5.

Use  $1/u + 1/v = 1/f$ .

$$\begin{aligned} 1/40 + 1/v &= 1/15 \\ 1/v &= 1/15 - 1/40 \\ &= 40/600 - 15/600 \\ &= 25/600 = 1/24 \end{aligned}$$

So  $v = 24$  cm; real image

Use  $m = v/u$ .

$$m = 24/40 = 0.6$$

#### Q6.

Use  $n = \sin i \div \sin r$ .

$$\begin{aligned} n &= \sin 24 \div \sin 16.5 \\ &= 0.4067 \div 0.2840 = 1.43 \end{aligned}$$

Use  $n = 1/\sin C$ .

$$\begin{aligned} 1.43 &= 1/\sin C \\ 1.43 \sin C &= 1 \\ \sin C &= 1/1.43 = 0.699 \\ C &= \sin^{-1}(0.699) = 44.37^\circ \end{aligned}$$

#### Q7.

$$\begin{aligned} {}_G n_W &= 1/{}_W n_G \\ {}_G n_W &= 1/1.14 = 0.877 \end{aligned}$$

#### Q8.

$n = \text{Real} \div \text{Apparent depth}$

Let  $a = \text{Apparent depth}$

$$\begin{aligned} 1.33 &= 5/a \\ 1.33a &= 5 \\ a &= 5/1.33 = 3.76 \\ \text{Apparent depth} &= 3.76 \text{ m} \end{aligned}$$

#### Q9.

Use  $n = c_1/c_2$ .

$$\begin{aligned} 1.33 &= (3 \times 10^8)/c_2 \\ c_2 &= (3 \times 10^8)/1.33 \\ \text{So } c_2 &= 2.26 \times 10^8 \text{ m s}^{-1} \end{aligned}$$

#### Q10.

Use  $n = 1 / \sin C$ .

$$n = 1 \div 0.4147 = 2.4$$

#### Q11.

Use  $1/u + 1/v = 1/f$ .

$$\begin{aligned} 1/f &= 1/40 + 1/20 \\ &= 1/40 + 2/40 \\ &= 3/40 = 1/13.33 \\ \text{So } f &= 13.33 \text{ cm} \\ \text{Real as it is positive} \end{aligned}$$

#### Q12.

Use  $m = v/u$ .

$$\begin{aligned} 2 &= v/u \\ 2u &= v \end{aligned}$$

Now use  $1/u + 1/v = 1/f$ .

$$\begin{aligned} 1/u - 1/2u &= 1/50 \\ 1/2u &= 1/50 \\ 2u &= 50 \\ u &= 25 \text{ cm} \end{aligned}$$

Use  $1/u + 1/v = 1/f$  again.

$$\begin{aligned} 1/u + 1/2u &= 1/50 \\ 2/2u + 1/2u &= 1/50 \\ 3/2u &= 1/50 \\ 2u &= 150 \\ u &= 75 \text{ cm} \end{aligned}$$

#### Q13.

Use  $P = 1/f$ .

$$P = 1/0.25 = 4 \text{ m}^{-1}$$

#### Q14.

First use  $P = P_1 + P_2$ .

$$P = 7 + 9 = 18 \text{ m}^{-1}$$

Now use  $P = 1/f$ .

$$\begin{aligned} 18 &= 1/f \\ 18f &= 1 \\ f &= 1/18 \\ \text{So } f &= 0.0556 \text{ m} = 5.56 \text{ cm} \end{aligned}$$

#### Q15.

First use  $P = P_1 + P_2$ .

$$P = 15 - 10 = 5 \text{ m}^{-1}$$

Now use  $P = 1/f$ .

$$\begin{aligned} 5 &= 1/f \\ 5f &= 1 \\ \text{So } f &= 0.2 \text{ m} = 20 \text{ cm} \end{aligned}$$

#### Q16.

See page 13.

#### Q17.

Total internal reflection.

Power is halved every 2 km, so over 6 km it will be halved 3 times: from 20 W to 10 W to 5 W to 2.5 W.

**Q18.**

Less energy is lost via heat.

**Q19.**Use  $P = 1/f$ .

$$P = 1/0.15 = 6.667 \text{ m}^{-1}$$

Now use  $P = P_1 + P_2$ .

$$P = 6.667 + 6.667 = 13.33 \text{ m}^{-1}$$

**Q20.**

They do not lose the signal as quickly. They are flexible.

**Q21.**Use  $n = c_1/c_2$ .

$$c_2 = (3 \times 10^8)/1.55$$

$$\text{So } c_2 = 1.94 \times 10^8 \text{ m s}^{-1}$$

**Q22.**

The ciliary muscle lengthens and shortens the focal length of the lens.

**Q23.**Rearrange  $1/u + 1/v = 1/f$   
to  $1/u - 1/v = -1/f$ .

$$1/u - 1/5 = -1/15$$

$$1/u = -1/15 + 1/5$$

$$= -1/15 + 3/15 = 2/15$$

$$\text{So } u = 7.5 \text{ cm}$$

**Q24.****Concave:**

Dentist mirror

Makeup mirror

**Convex:**

Shop security

Seeing traffic on blind turn

**Q25.****Concave:**

Magnifying glass

Eye glasses

**Convex:**

Contact lenses

Eye glasses

**Q26.**

Total internal reflection

Use  $n = 1/\sin C$ .

$$4/3 = 1/\sin C$$

$$\sin C = 3/4 = 0.75$$

$$C = 48.5^\circ$$

Let  $r$  = radius of circle.Then  $\tan C = r/10$ 

$$r = 10 \tan C = 10 \times 1.13$$

$$\text{Radius} = 11.3 \text{ m}$$

**Q27.**

An inner solid tube of glass coated in a layer of glass of rarer density

**Q28.**

In short sight the focal length of the eye's convex lens is too short to focus light onto the retina. It can be corrected using a diverging (concave) lens in front of the eye.

**Q29.**

In long sight the focal length of the eye's convex lens is too long to focus light onto

the retina. Long sight can be corrected by a converging (convex) lens in front of the eye.

**Q30.****Iris:** controls the amount of light entering the eye**Cornea and lens:** focus light on the retina**Retina:** acts as a screen for images produced by the lens

## SOLUTIONS

### Answers to mechanics questions

#### Q1 to Q3.

See pages 22–31.

#### Q4.

Use  $v = u + at$ .

$$v = 15 + 3 \times 11$$

$$\text{So } v = 48 \text{ m s}^{-1}$$

#### Q5.

Use  $s = ut + \frac{1}{2}at^2$ .

$$s = 0 \times 3 + \frac{1}{2} \times 9.8 \times 3^2$$

$$= \frac{1}{2} \times 9.8 \times 9$$

$$\text{So } s = 44.1 \text{ m}$$

#### Q6.

Use  $v = u + at$ .

$$v = 0 + 3 \times 4$$

$$\text{So } v = 12 \text{ m s}^{-1}$$

#### Q7.

Use  $v^2 = u^2 + 2as$

$$0^2 = 90^2 + 2 \times (-9.8)s$$

$$s = -8100/19.6$$

$$\text{So } s = 413.3 \text{ m}$$

Use  $v = u + at$ .

$$0 = 90 + (-9.8)t$$

$$t = 90/9.8$$

$$\text{So } t = 9.18 \text{ seconds}$$

#### Q8.

**Scalar:** time; pressure; area; temperature

**Vector:** velocity; momentum; force

#### Q9.

Use  $X = V \cos \theta$ .

$$X = 150 \cos 35$$

$$= 122.87 \text{ N}$$

Use  $Y = V \sin \theta$ .

$$Y = 150 \sin 35$$

$$= 86.04 \text{ N}$$

#### Q10.

Use  $X = V \cos \theta$ .

$$X = 20 \cos 35$$

$$= 16.38 \text{ N}$$

Use  $Y = V \sin \theta$ .

$$Y = 20 \sin 35$$

$$= 11.47 \text{ N}$$

#### Q11.

Use  $E_p = mgh$ .

$$E_p = 2 \times 9.8 \times 750$$

$$= 14\,700 \text{ J}$$

#### Q12.

Use  $E_k = \frac{1}{2}mv^2$ .

$$E_k = \frac{1}{2} \times 800 \times 20^2$$

$$= 160\,000 \text{ J}$$

$$= 1.6 \times 10^5 \text{ J}$$

#### Q13.

Use  $E_p = mgh$ .

$$E_p = 50 \times 9.8 \times 0.75$$

For one movement:

$$W = 367.5 \text{ J}$$

For 50 movements:

$$W = 367.5 \times 50$$

$$= 18\,375 \text{ J}$$

Now use  $P = W/t$ .

$$P = 18\,375 / 30$$

$$= 612.5 \text{ watts}$$

#### Q14.

Use  $W = Fd$ .

$$W = 250 \times 50$$

$$= 12\,500 \text{ J}$$

$$= 1.25 \times 10^4 \text{ J}$$

#### Q15.

Change km/h to m s<sup>-1</sup>.

$$85\,000 \div 3600$$

$$= 23.61 \text{ m s}^{-1}$$

Now use  $E_k = \frac{1}{2}mv^2$ .

$$E_k = \frac{1}{2} \times 950 \times 23.61^2$$

$$= 264\,780.25 \text{ J}$$

$$= 2.65 \times 10^5 \text{ J}$$

#### Q16.

Use  $m_1u_1 + m_2u_2 = (m_1 + m_2)v$ .

$$10 \times 10 + 5 \times 0 = (10 + 5)v$$

$$100 = 15v$$

$$v = 100/15$$

$$= 6.667 \text{ m s}^{-1}$$

Use  $E_k = \frac{1}{2}mv^2$ .

$E_k$  before collision:

$$\frac{1}{2} \times 10 \times 10^2 + \frac{1}{2} \times 5 \times 0^2$$

$$= 500 \text{ J}$$

$E_k$  after collision:

$$\frac{1}{2} \times 15 \times (100/15)^2$$

$$= 333.333 \text{ J}$$

So loss in  $E_k = 166.117 \text{ J}$

#### Q17.

Use % Efficiency =

$$(\text{Output/Input}) \times 100.$$

$$(3200/4750) \times 100$$

$$= 67.4\%$$

**Q18.**

$$\begin{aligned}\text{Max. } E_k &= \text{Initial } E_p = mgh \\ &= (700 \times 10^{-3}) \times 9.8 \times 3.76 \\ &= 25.79 \text{ J}\end{aligned}$$

The energy is lost as sound and heat.

$$\begin{aligned}25.76 - 7.5 &= 18.26 \text{ J} \\ \text{Use } E_p &= mgh \\ 18.26 &= (700 \times 10^{-3}) \times 9.8 \times h \\ h &= 18.26/6.86 \\ &= 2.66 \text{ m}\end{aligned}$$

**Q19.**

$$\begin{aligned}\text{Use } v &= s \div t. \\ 3 \times 10^9 &= (1.3 \times 10^{12}) \div t \\ t &= 4333.33 \text{ seconds} \\ &= 72 \text{ minutes} \\ &= 1.2 \text{ hours}\end{aligned}$$

**Q20.**

$$\begin{aligned}\text{Use } \omega &= v/r. \\ 10 &= v/0.7 \\ v &= 7 \text{ m s}^{-1}\end{aligned}$$

$$\text{Use } T = 2\pi r/v.$$

$$\begin{aligned}T &= (2\pi \times 0.7) \div 7 \\ &= 0.628 \text{ seconds}\end{aligned}$$

**Q21.**

$$\begin{aligned}\text{Use } F &= -ks. \\ \text{First find } k. \\ 75 &= k \times 0.2 \\ k &= 75/0.2 \\ &= 375\end{aligned}$$

$$\begin{aligned}F &= 375 \times 0.15 \\ &= 56.25 \text{ N}\end{aligned}$$

**Q22.**

$$\begin{aligned}\text{Frequency} &= 12/4 \\ &= 3 \text{ oscillations per second} \\ &= 3 \text{ Hz} \\ \text{Now use } T &= 1/f. \\ T &= 1/3 \\ &= 0.333 \text{ seconds}\end{aligned}$$

**Q23.**

$$\begin{aligned}\text{Use } T &= 2\pi/\omega. \\ 2.5 &= 2\pi/\omega \\ 2.5\omega &= 2\pi \\ \omega &= 2.51 \text{ rad s}^{-1} \\ \text{Now use } a &= -\omega^2 s. \\ a &= -(2.51)^2 \times 0.17 \\ &= 1.07 \text{ m s}^{-2}\end{aligned}$$

**Q24.**

$$\begin{aligned}\text{Use } a &= -\omega^2 s. \\ 2.5 &= \omega^2 \times 0.15 \\ \omega^2 &= 2.5/0.15 \\ \omega &= 4.0825 \\ \text{Use } T &= 2\pi/\omega. \\ T &= 2\pi/4.0825 \\ &= 1.539 \text{ seconds}\end{aligned}$$

**Q25.**

$$\begin{aligned}m_1 u_1 + m_2 u_2 &= (m_1 + m_2)v \\ 1300 \times 20 + 1500 \times 10.5 \\ &= (1300 + 1500)v \\ 26\,000 + 15\,750 &= 2800v \\ v &= 14.91 \text{ m s}^{-1}\end{aligned}$$

**Q26.**

$$\begin{aligned}\text{Use } F &= -ks. \\ 0.3 \times 9.8 &= -k(0.285 - 0.2) \\ 2.94 &= -k \times (8.5 \times 10^{-2}) \\ -k &= 2.94/(8.5 \times 10^{-2}) \\ &= 34.588\end{aligned}$$

**Q27.**

$$\begin{aligned}\text{Use } v &= u + at \\ 0 &= 70 + 150a \\ \text{So } a &= 0.467 \text{ m s}^{-2}\end{aligned}$$

**Q28.**

$$\begin{aligned}\text{Let } v &= \text{velocity of boat.} \\ 80 \times 3 &= 100v \\ v &= 240/100 = 2.4 \text{ m s}^{-1}\end{aligned}$$

**Q29.**

$$\begin{aligned}\text{Let } v &= \text{recoil velocity.} \\ (10 \times 10^{-3}) \times 105 &= 20v \\ v &= 1.05/20 = 0.0525 \text{ m s}^{-1}\end{aligned}$$

**Q30.**

$$\begin{aligned}\text{Use } F &= Gm_1 m_2 / d^2. \\ F &= [(1 \times 10^6)^2 \times (6.7 \times 10^{-11})] / 5^2 \\ &= 2.68 \text{ N}\end{aligned}$$

**Q31.**

$$\begin{aligned}\text{Use } g &= Gm/d^2. \\ g &= [(6.7 \times 10^{-11})(6 \times 10^{24})] \\ &\quad \div (6.4 \times 10^6)^2 \\ &= (4.02 \times 10^{14}) \div (6.4 \times 10^6)^2 \\ &= 9.8 \text{ m s}^{-2}\end{aligned}$$

**Q32.**

$$\begin{aligned}\text{Use } g &= Gm/d^2. \\ g &= (4.02 \times 10^{14}) \div \\ &\quad (6.4 \times 10^6 + 2 \times 10^5)^2 \\ &= (4.02 \times 10^{14}) \div (4.356 \times 10^{13}) \\ &= 9.2286 \text{ m s}^{-2}\end{aligned}$$

## SOLUTIONS

### Answers to electricity questions

#### Q1 to Q4.

See pages 38 to 49.

#### Q5.

Use  $F = Q_1 Q_2 / 4\pi\epsilon d^2$ .

$$F = (4 \times 7) \div [4\pi(8.9 \times 10^{-12})3^2] \\ = 2.78 \times 10^{10} \text{ N}$$

#### Q6.

$$F = [(3 \times 10^{-6})(2 \times 10^{-6})] \div \\ 4\pi(8.9 \times 10^{-12}) \times 81(60 \times 10^{-2})^2 \\ = 0.0018 \text{ N}$$

#### Q7.

Use  $E = F/Q$ .

$$4 \times 10^3 = F/(3 \times 10^{-6}) \\ F = 0.012 \text{ N}$$

#### Q8.

Use  $E = Q/4\pi\epsilon d^2$ .

$$E = (5 \times 10^{-6}) \div \\ [4\pi \times (8.9 \times 10^{-12}) \times 5^2] \\ = 1788.26 \text{ N C}^{-1}$$

#### Q9.

Use  $C = Q/V$ .

$$C = (20 \times 10^{-6})/30 \\ = 6.667 \times 10^{-7} \text{ F}$$

#### Q10.

Use  $eV = E_k = \frac{1}{2}mv^2$ .

$$(1.6 \times 10^{-19}) \times 1500 \\ = \frac{1}{2}(9.1 \times 10^{-31})v^2 \\ v^2 = (2.4 \times 10^{-16}) \div (4.55 \times 10^{-31}) \\ v = 2.30 \times 10^7 \text{ m s}^{-1}$$

#### Q11.

Use  $W = \frac{1}{2}CV^2$ .

$$W = \frac{1}{2}(3 \times 10^{-6}) \times 370^2 \\ = 0.205 \text{ 35 J}$$

#### Q12.

$$8 \text{ A} = 8 \text{ C s}^{-1}$$

$$2 \text{ hours} = 2 \times 60 \times 60 \\ = 7200 \text{ seconds}$$

$$8 \times 7200 = 57 \text{ 600 C}$$

#### Q13.

$$11 \text{ A} = 11 \text{ C s}^{-1}$$

Number of electrons

$$= 11 \div (1.6 \times 10^{-19}) \\ = 6.875 \times 10^{19}$$

#### Q14.

$$7.5 \text{ A} = 7.5 \text{ C s}^{-1}$$

Time to transfer charge

$$= 45 \text{ 500} \div 7.5 \\ = 6066.67 \text{ seconds} \\ = 1.685 \text{ hours}$$

#### Q15.

$$\text{Current} = 4 \times 10^2 \times 1.6 \times 10^{-19} \\ = 6.4 \times 10^{-17} \text{ A}$$

#### Q16.

Use  $V = W/Q$ .

$$15 = W/30 \\ W = 450 \text{ J}$$

#### Q17.

Use  $P = VI$ .

$$75 = 230I \\ I = 0.326 \text{ A}$$

#### Q18.

Use  $V = W/Q$ .

$$V = 350/65 = 5.385 \text{ volts}$$

#### Q19.

Use  $V = IR$ .

$$25 = 7R \\ R = 25/7 = 3.57 \Omega$$

#### Q20.

$$5 + 8 + 10 = 23 \Omega$$

#### Q21.

Use  $1/R = 1/R_1 + 1/R_2 + 1/R_3$ .

$$1/R = 1/10 + 1/20 + 1/30 \\ = (6 + 3 + 2)/60 = 11/60 \\ = 1/5.455 \\ R = 5.455 \Omega$$

#### Q22.

$$R = 8 + 10 = 18 \Omega$$

Use  $V = IR$ .

$$V = 6 \times 18 \\ = 108 \text{ volts}$$

#### Q23.

Resistance of A:

$$1/R = 1/15 + 1/25 \\ = (25 + 15)/375 \\ = 40/375 = 1/9.375 \\ R = 9.375 \\ \text{Total} = 9.375 + 10 + 20 \\ = 39.375 \Omega$$

Resistance of B:

$$1/R = 1/20 + 1/40 \\ = (2 + 1)/40 = 3/40 \\ R = 13.33 \\ \text{Total} = 15 + 32 + 13.33 \\ = 60.33 \Omega$$

Total potential of B:

$$\text{Use } V = V_1 + V_2.$$

$$V = 12 + 12 = 24 \text{ volts}$$

Total current in A:

$$\text{Use } V = IR$$

$$12 = I \times 39.375$$

$$I = 12/39.375$$

$$= 0.305 \text{ A}$$

Total current in B:

$$24 = I \times 60.33$$

$$I = 24/60.33$$

$$= 0.398 \text{ A}$$

$I$  in 25 resistor:

$$15 + 25 = 40$$

$$0.305/40 = 0.007625$$

$$0.007625 \times 15 = 0.1144 \text{ A}$$

$I$  in motor:

$$40 + 20 = 60$$

$$0.398/60 = 0.00663$$

$$0.00663 \times 20 = 0.1326 \text{ A}$$

**Q24.**

$$\text{Use } \rho = R\pi d^2/4L.$$

$$\rho = [27.9\pi(0.26 \times 10^{-3})^2] \div [4 \times (84.9 \times 10^{-2})]$$

$$= (5.925 \times 10^{-6}) \div 3.396$$

$$= 17.45 \times 10^{-7} \Omega \text{ m}$$

**Q25.**

$$\text{Use } R_1/R_2 = R_3/R_4.$$

$$10/25 = 32/R_4$$

$$10R_4 = 800$$

$$R_4 = 80 \Omega$$

**Q26.**

$$\text{Use } W = QV.$$

$$370 = 60V$$

$$V = 370/60$$

$$= 6.1667 \text{ volts}$$

**Q27.**

$$5 \text{ A} = 5 \text{ C s}^{-1}$$

$$5 \times 60 \times 10 = 3000 \text{ C}$$

**Q28.**

$$10 \text{ A} = 10 \text{ C s}^{-1}$$

$$18 \text{ kC} = 18\,000 \text{ C}$$

$$18\,000 \div 10 = 1800 \text{ seconds}$$

$$1800 \div 60 = 30 \text{ minutes}$$

**Q29.**

$$\text{Use } C = \epsilon A/d.$$

$$1.25 \times 10^{-10} = \epsilon(20 \times 10^{-4})/10^{-3}$$

$$\epsilon = (1.25 \times 10^{-13}) \div (20 \times 10^{-4})$$

$$= 6.25 \times 10^{-11}$$

$$\epsilon_0 = 8.9 \times 10^{-12}$$

$$\text{Now use } \epsilon = \epsilon_r \epsilon_0.$$

$$6.25 \times 10^{-11} = \epsilon_r(8.9 \times 10^{-12})$$

$$\epsilon_r = 7.022$$

$$= 7 \text{ to nearest whole number}$$

## Answers to magnetism questions

**Q1 to Q3**

See pages 56 to 61.

**Q4.**

$$\text{From } F = mv^2/r:$$

$$F = (9.1 \times 10^{-31})550^2/r$$

$$= 2.75275 \times 10^{-25}/r$$

$$\text{From } F = qvB:$$

$$F = (1.6 \times 10^{-19}) \times 550 \times (3 \times 10^{-2})$$

$$= 2.64 \times 10^{-18}$$

$$\text{Since } F = mv^2/r = qvB:$$

$$(2.64 \times 10^{-18})r = 2.75275 \times 10^{-25}$$

$$r = 1.0427 \times 10^{-7} \text{ m}$$

**Q5.**

$$\text{Use } F = BIL.$$

$$F = 3 \times 5 \times 3 = 45 \text{ N}$$

**Q6.**

$$\text{Use } F = BIL.$$

$$20 = B \times 4 \times 5$$

$$B = 1 \text{ T}$$

**Q7.**

$$\text{Use } F = qvB.$$

$$F = 3 \times 15 \times 2.5$$

$$= 112.5 \text{ N}$$

## SOLUTIONS

### Q8.

Use  $F = qvB$ .

$$F = (1.6 \times 10^{-19}) \times 370 \times 5.5 \\ = 3.256 \times 10^{-16} \text{ N}$$

### Q9.

Use  $F = BIL$ .

$$F = 0.8 \times 5 \times (20 \times 10^{-2}) \\ = 0.8 \text{ N}$$

Moment of force:

$$0.8 \times (10 \times 10^{-2}) = 0.08 \text{ N m}$$

It decreases because the coil is not fully perpendicular to the field.

Yes, when the perpendicular distance to the force is zero

### Q10.

$$X = 2 \sin 40 = 1.286 \text{ T}$$

Use  $F = BIL$ .

$$F = 1.286 \times (30 \times 10^{-2}) \times 3 \\ = 1.157 \text{ N}$$

### Q11.

Use  $\Phi = BA$ .

$$0.5 = 0.3A$$

$$A = 0.5/0.3 = 1.667 \text{ m}^2$$

### Q12.

$$X = 5 \sin 40 = 3.2 \text{ T}$$

Use  $\Phi = BA$ .

$$\Phi = 3.2 \times 0.3 = 0.96 \text{ Wb}$$

### Q13.

Use  $V_i/V_o = N_p/N_s$ .

$$230/V = 200/6000$$

$$200V = 1.38 \times 10^6$$

$$V = 6900 \text{ volts}$$

### Q14.

Emf = (Final – Initial) ÷ Time

Initial flux = 0

$$\text{Final flux } \Phi = 3 \times (60 \times 10^{-4})$$

$$= 1.8 \times 10^{-2} \text{ Wb}$$

Find time taken from

$$V = D/T.$$

$$5 = (10 \times 10^{-2})/T$$

$$T = 0.02 \text{ seconds}$$

$$\text{Emf} = [(1.8 \times 10^{-2}) - 0] \div 0.02$$

$$= 0.9 \text{ volts}$$

Now find the force.

First use  $V = IR$ .

$$0.9 = I \times 6$$

$$I = 0.15$$

Now use  $P = VI$ .

$$P = 0.9 \times 0.15 = 0.135$$

Since  $P = W = Fs$

$$0.135 = F \times 5$$

$$F = 0.027 \text{ N}$$

### Q15.

Use  $V_{\text{rms}} = V_o/\sqrt{2}$ .

$$V_o = 30\sqrt{2}$$

$$= 42.43 \text{ volts}$$

### Q16.

Use  $V_{\text{rms}} = V_o/\sqrt{2}$ .

$$230 = V_o/\sqrt{2}$$

$$V_o = 325.3 \text{ volts}$$

### Q17.

Use  $V_{\text{rms}} = V_o/\sqrt{2}$ .

$$110\sqrt{2} = V_o$$

$$V_o = 155.56 \text{ volts}$$

### Q18.

Total resistance  $R = V/I$

$$R = 9 \div (15 \times 10^{-3}) = 600 \Omega$$

The galvanometer has a resistance of  $10 \Omega$ .

So value of resistor =

$$600 - 10 = 590 \Omega$$

A  $590 \Omega$  resistor in series with the galvanometer

### Q19.

Use  $I_{\text{rms}} = I_o/\sqrt{2}$ .

$$I_{\text{rms}} = 5/\sqrt{2} = 3.54 \text{ A}$$

### Q20.

Emf in one turn:

Emf = (Final – Initial) ÷ Time

$$\text{Emf} = (1.5 - 2) \div 0.5$$

$$= -1 \text{ volt}$$

Emf in 30 turns:

$$-1 \times 30 = -30 \text{ volts}$$

The negative sign indicates the direction.

### Q21.

Since  $F = BIL$ , force is

affected by:

magnetic field density;

current size;

conductor length

### Q22.

Use  $N_p/N_s = V_i/V_o$ .

$$2500 \div N = 15\,000 \div 230$$

$$N = 38 \text{ turns}$$

## Answers to modern physics questions

### Q1 and Q2.

See pages 68 to 75.

### Q3.

$$(200 \times 10^{-18}) \div (1.6 \times 10^{-19}) \\ = 1250 \text{ eV} = 1.25 \text{ keV}$$

### Q4.

Use  $F = qvB$ .

$$3.2 \times 10^{-12} = (1.6 \times 10^{-19}) \times v \times 5 \\ v = 4 \times 10^6 \text{ m s}^{-1}$$

### Q5.

Use  $F = qvB$ .

$$F = (1.6 \times 10^{-19}) \times (4 \times 10^6) \times \\ (1.39 \times 10^{-2}) \\ = 8.896 \times 10^{-15}$$

Now use  $F = mv^2/r$ .

$$F = (9.1 \times 10^{-31})(4 \times 10^6)^2/r$$

Since  $F = mv^2/r = qvB$ :

$$(1.456 \times 10^{-17})/r = 8.896 \times 10^{-15} \\ r = (1.456 \times 10^{-17}) \div \\ (8.896 \times 10^{-15}) \\ = 0.00163 \text{ m}$$

### Q6.

$$eV = (1.6 \times 10^{-19}) \times 11\,500 \\ = 1.84 \times 10^{-15} \\ E_k = \frac{1}{2}(9.1 \times 10^{-31})v^2 \\ = (4.55 \times 10^{-31})v^2$$

Since  $eV = E_k$ :

$$1.84 \times 10^{-15} = (4.55 \times 10^{-31})v^2 \\ v^2 = 4.04 \times 10^{15} \\ v = 6.359 \times 10^7 \text{ m s}^{-1}$$

### Q7.

$$E = 5.2 \times (1.6 \times 10^{-19}) \\ = 8.32 \times 10^{-19} \text{ J}$$

Use  $E = hf$ .

$$8.32 \times 10^{-19} = (6.6 \times 10^{-34})f \\ f = 1.26 \times 10^{15} \text{ Hz}$$

Now use  $c = f\lambda$ .

$$3 \times 10^8 = (1.26 \times 10^{15})\lambda \\ \lambda = 2.38 \times 10^{-7} \text{ m}$$

### Q8.

$$eV = (1.6 \times 10^{-19})(1 \times 10^4) \\ = 1.6 \times 10^{-15}$$

Since  $eV = \frac{1}{2}mv^2$ :

$$1.6 \times 10^{-15} = \frac{1}{2}(9.1 \times 10^{-31})v^2 \\ = (4.55 \times 10^{-31})v^2 \\ v^2 = 3.516 \times 10^{15} \\ v = 5.93 \times 10^7 \text{ m s}^{-1}$$

### Q9.

Use  $E_k = \frac{1}{2}mv^2$ .

$$E_k = \frac{1}{2}(9.1 \times 10^{-31}) \times 720^2 \\ = 2.36 \times 10^{-25} \text{ J}$$

Divide by  $1.6 \times 10^{-19}$ .

$$E_k = 14.74 \times 10^{-7} \text{ eV}$$

### Q10.

Use  $c = f\lambda$ .

$$3 \times 10^8 = f \times (5.5 \times 10^{-7}) \\ f = 5.4545 \times 10^{14} \text{ Hz}$$

Now use  $E = hf$ .

$$E = (6.6 \times 10^{-34})(5.45 \times 10^{14}) \\ = 3.6 \times 10^{-19} \text{ J}$$

### Q11.

$$E = 6 \times (1.6 \times 10^{-19}) \\ = 9.6 \times 10^{-19} \text{ J} \\ \text{Use } E = hf. \\ 9.6 \times 10^{-19} = (6.6 \times 10^{-34})f \\ f = 1.4545 \times 10^{15} \text{ Hz}$$

Now use  $c = f\lambda$

$$3 \times 10^8 = (1.45 \times 10^{15})\lambda \\ \lambda = 2.06 \times 10^{-7} \text{ m}$$

### Q12.

$$d = 1 \div 500\,000 = 2 \times 10^{-6} \text{ m} \\ 44.4/2 = 22.2^\circ \\ \text{Use } n\lambda = d \sin \theta. \\ 2\lambda = (2 \times 10^{-6}) \sin 22.2 \\ \lambda = 377 \text{ nm}$$

Now use  $c = f\lambda$

$$3 \times 10^8 = f \times (377 \times 10^{-9}) \\ f = 8.1 \times 10^{14} \text{ Hz}$$

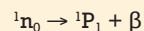
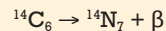
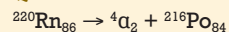
Finally use  $E = hf$ .

$$E = (6.6 \times 10^{-34})(8.1 \times 10^{14}) \\ = 5.346 \times 10^{-19} \text{ J}$$

### Q13.

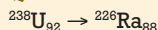
$$\Phi = 3 \times (1.6 \times 10^{-19}) \\ = 4.8 \times 10^{-19} \text{ J} \\ \text{Yes, as } E \text{ available is greater than } \Phi. \\ E_k = (5.346 - 4.8) \times 10^{-19} \\ = 5.46 \times 10^{-20} \text{ J}$$

### Q14.



## SOLUTIONS

### Q15.

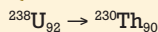


$$238 - 226 = 12$$

$$12 \div 4 = 3 \text{ alpha particles}$$

If 3 alpha particles are gone, then 92 should now be 86, but it is 88. Therefore 2 beta particles must also have been emitted as each particle increases the atomic number by 1.

### Q16.

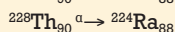


$$238 - 230 = 8$$

$$8 \div 4 = 2 \text{ alpha particles}$$

If 2 alpha particles are gone then the 92 should now be 88, but it is 90. Therefore 2 beta particles must have been emitted.

### Q17.



### Q18.

$$T_{1/2} = 3 \text{ years}$$

$$3/3 = 1 \text{ half-life}$$

$$1/2 \text{ will remain.}$$

$$9/3 = 3 \text{ half-lives}$$

$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 1/8 \text{ will remain.}$$

$$81/3 = 27 \text{ half-lives}$$

$$1/2^{27} = 1/134217728$$

will remain.

### Q19.

$$250/50 = 5 \text{ half-lives}$$

$$1/2^5 = 1/32$$

So 31/32 will have decayed.

### Q20.

$$T_{1/2} = 125 \text{ seconds}$$

$$\text{Use } T_{1/2} = \ln 2 / \lambda.$$

$$125 = 0.693 / \lambda$$

$$\lambda = 0.0055 \text{ s}^{-1}$$

### Q21.

$$\text{Use } T_{1/2} = \ln 2 / \lambda.$$

$$T_{1/2} = 0.693 / (5 \times 10^{-3})$$

$$= 138.6 \text{ seconds}$$

### Q22.

$$T_{1/2} = 0.693 / (2.3 \times 10^{-3})$$

$$= 301.3 \text{ seconds}$$

### Q23.

Let  $N$  = number of undecayed particles.

$$\text{Rate of decay} = \lambda N$$

$$3.3 \times 10^3 = (8.8 \times 10^{-8}) \times N$$

$$N = 3.75 \times 10^{10}$$

### Q24.

$$\text{Rate of decay} = \lambda N$$

$$4.1 \times 10^2 = (9.3 \times 10^{-7}) \times N$$

$$N = 4.4 \times 10^8$$

## Answers to wave questions

### Q1 and Q2

See pages 82 to 89.

### Q3.

30, because 1 Hz is one cycle per second.

### Q4.

$$\text{Use } c = f \lambda.$$

$$c = 10 \times 4 = 40 \text{ m s}^{-1}$$

### Q5.

Distance from node to anti-node is  $\lambda/4$ .

$$2 \times 4 = 8 \text{ m} = \lambda$$

$$c = 10 \times 8 = 80 \text{ m s}^{-1}$$

### Q6.

$$f' = fc \div (c - u) \quad (\text{toward})$$

$$f' = (2000 \times 340) \div (340 - 50)$$

$$= (68 \times 10^4) \div 290 = 2344.8 \text{ Hz}$$

$$f' = fc \div (c + u) \quad (\text{away})$$

$$f' = (68 \times 10^4) \div (340 + 50)$$

$$= 1743.59 \text{ Hz}$$

### Q7.

$$c = f \lambda$$

$$c = (67 \times 10^3)(4.9 \times 10^{-3})$$

$$= 328.3 \text{ m s}^{-1}$$

$$\text{Total distance} =$$

$$328.3(21 \times 10^{-3}) = 6.8943 \text{ m}$$

$$\text{Distance to wall} =$$

$$6.8943/2 = 3.447 \text{ m}$$

**Q8.**

$$\lambda = 0.65 \times 4 = 2.6 \text{ m}$$

$$\text{Use } c = f\lambda.$$

$$6.5 = f \times 2.6$$

$$f = 2.5 \text{ Hz}$$

**Q9.**

$$f' = fc \div (c - u)$$

$$f' = (1500 \times 340) \div (340 - 65)$$

$$= (51 \times 10^4) \div 275$$

$$= 1854.545 \text{ Hz}$$

$$f' = fc \div (c + u)$$

$$f' = (1500 \times 340) \div (340 + 65)$$

$$= (51 \times 10^4) \div 405$$

$$= 1259.259 \text{ Hz}$$

Frequency change

$$= 1854.545 - 1259.259$$

$$= 595.286 \text{ Hz}$$

**Q10.**

When sound intensity doubles, the sound intensity level increases by 3 db.

$$4/2 = 2. \text{ It has doubled.}$$

So the sound intensity level increase is 3 db.

**Q11.**

$$\text{Use } c = f\lambda, \text{ i.e. } f = c/\lambda.$$

In laboratory:

$$f = (3 \times 10^8) / (650 \times 10^{-9})$$

$$= 4.62 \times 10^{14} \text{ Hz}$$

For star:

$$f' = (3 \times 10^8) / (715 \times 10^{-9})$$

$$= 4.2 \times 10^{14} \text{ Hz}$$

Use  $f' = fc \div (c + u)$ , where  $u$  is the speed of the star.

$$fc = (4.62 \times 10^{14})(3 \times 10^8)$$

$$= 1.386 \times 10^{23}$$

$$\text{So } 4.2 \times 10^{14}$$

$$= (1.386 \times 10^{23}) \div [(3 \times 10^8) + u]$$

$$(4.2 \times 10^{14})[(3 \times 10^8) + u]$$

$$= 1.386 \times 10^{23}$$

$$(4.2 \times 10^{14})u$$

$$= 1.386 \times 10^{23} - 1.26 \times 10^{23}$$

$$= 1.26 \times 10^{22}$$

$$u = 3 \times 10^7 \text{ m s}^{-1}$$

**Q12.**

$$\text{Use } F = (1/2L) \times [\sqrt{(T/U)}].$$

$$555$$

$$= [1/(2 \times 0.75)] \times [\sqrt{(T/0.025)}]$$

$$= [1/1.5] \times [\sqrt{T}/\sqrt{0.025}]$$

$$= \sqrt{T} \div (1.5\sqrt{0.025})$$

$$= \sqrt{T} \div 0.2372$$

$$\sqrt{T} = 555 \times 0.2372 = 131.63$$

$$T = 17\,326.4 \text{ N}$$

**Q13.**

$$\text{Sound intensity} = P/A$$

Sound moves from the source producing it as a sphere. The area of this sphere is  $A$  in the formula. The area of a sphere is given by  $4\pi r^2$ .

$$\text{So } A = 4\pi \times 3^2 = 113.1 \text{ m}^2$$

$$\text{Intensity} = 300/113.1$$

$$= 2.65 \text{ W m}^{-2}$$

**Q14.**

$$d = 1 \div 300\,000$$

$$= 3.333 \times 10^{-6} \text{ m}$$

**Q15.**

$$d = 1 \div 600\,000$$

$$= 1.666 \times 10^{-6} \text{ m}$$

$$2^{\text{nd}} \text{ order} = 21^\circ$$

$$2\lambda = 1.666 \times 10^{-6} \sin 21$$

$$\lambda = 298 \text{ nm}$$

## SOLUTIONS

### Answers to heat questions

**Q1.**

See pages 94 and 95.

**Q2.**

$$100 + 273 = 373 \text{ K}$$

**Q3.**

$$83 - 273 = -190 \text{ }^\circ\text{C}$$

$$95 - 273 = -178 \text{ }^\circ\text{C}$$

$$125 - 273 = -148 \text{ }^\circ\text{C}$$

**Q4.**

$$10 + 273 = 283 \text{ K}$$

$$0 + 273 = 273 \text{ K}$$

$$165 + 273 = 438 \text{ K}$$

**Q5.**

Energy on  $5 \text{ m}^2$  in 1 hour

$$= 1500 \times 5 \times 60 \times 60$$

$$= 2.7 \times 10^7 \text{ J}$$

Energy on  $3 \text{ m}^2$  in 1 hour

$$= 1500 \times 3 \times 60 \times 60$$

$$= 1.62 \times 10^7 \text{ J}$$

Useful energy at 30%

$$= 0.3 \times 1.62 \times 10^7$$

$$= 4.86 \times 10^6 \text{ J}$$

**Q6.**

Use  $E = mc\Delta\theta$ .

For water:

$$E = (150 \times 10^{-3}) \times 4200 \times 20$$

$$= 12\,600 \text{ J}$$

For copper:

$$E = (90 \times 10^{-3}) \times 390 \times 20$$

$$= 702 \text{ J}$$

Total energy =  $12\,600 + 702$

$$= 13\,302 \text{ J}$$

**Q7.**

Use  $E = mc\Delta\theta$ .

$$11\,000 = 1.5 \times c \times (26 - 17)$$

$$11\,000 = 28.5c$$

$$c = 385.96 \text{ J kg}^{-1} \text{ K}^{-1}$$

**Q8.**

$$3 \times 10^6 = m \times 280 \times (300 - 10)$$

$$m = 36.95 \text{ kg}$$

**Q9.**

$$0.05 \times 4200 \times (100 - \theta)$$

$$= 0.1 \times 4200 \times (\theta - 22)$$

$$210(100 - \theta) = 420(\theta - 22)$$

$$21\,000 - 210\theta = 420\theta - 9240$$

$$630\theta = 30\,240$$

$$\theta = 48 \text{ }^\circ\text{C}$$

**Q10.**

$$E = 8.5 \times 4200 \times (83 - 25)$$

$$= 2\,070\,600 \text{ J}$$

$$2.5 \text{ kW} = 2500 \text{ J s}^{-1}$$

$$\text{Time taken} = 2070600 \div 2500$$

$$= 828.24 \text{ seconds}$$

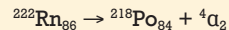
$$= 13.8 \text{ minutes}$$

### Answers to particle physics questions

**Q1.**

See pages 100 to 103.

**Q2.**



$$218 : 4 = 54.5 : 1$$

$$54.5 + 1 = 55.5$$

$$7.8 \times 10^{-13} / 55.5 = 1.405 \times 10^{-14}$$

$E_k$  of alpha particle

$$= (1.405 \times 10^{-14}) \times 54.5$$

$$= 7.659 \times 10^{-13} \text{ J}$$

**Q3.**

Use  $E = mc^2$ .

$$150 \times 10^6 = m \times (3 \times 10^8)^2$$

$$m = 1.67 \times 10^{-9} \text{ kg}$$

**Q4.**

Use  $eV = \frac{1}{2}mv^2 = E_k$ .

Proton mass =

$$1.6726 \times 10^{-27} \text{ kg}$$

$$eV = (1.6 \times 10^{-19})(800 \times 10^3)$$

$$= 1.28 \times 10^{-13} \text{ J}$$

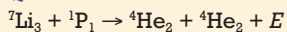
$$E_k = \frac{1}{2} \times (1.6726 \times 10^{-27})v^2$$

$$= (8.363 \times 10^{-28})v^2$$

$$(8.363 \times 10^{-28})v^2 = 1.28 \times 10^{-13}$$

$$v^2 = 1.53 \times 10^{14}$$

$$v = 1.24 \times 10^7 \text{ m s}^{-1}$$

**Q5.****Q6.**

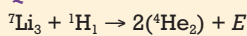
$$\begin{aligned} &1.165007 \times 10^{-26} \\ &+ 1.6726 \times 10^{-27} \\ &= 1.332267 \times 10^{-26} \text{ kg} \end{aligned}$$

$$\begin{aligned} &6.646322 \times 10^{-27} \times 2 \\ &= 1.3292644 \times 10^{-26} \text{ kg} \end{aligned}$$

$$\Delta m = 3.0026 \times 10^{-29} \text{ kg}$$

Use  $E = mc^2$ .

$$\begin{aligned} E &= 3.0026 \times 10^{-29} \times (3 \times 10^8)^2 \\ &= 2.70234 \times 10^{-12} \text{ J} \end{aligned}$$

**Q7.****Q8.**

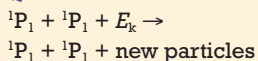
It has no charge.

**Q9.**

In a nuclear reaction, mass-energy, electric charge and momentum are conserved. In the case of  $\beta$  decay this did not seem to be the case, so a particle called the neutrino was proposed to account for the missing energy and momentum.

**Q10.**

It has small mass and interacts weakly with matter.

**Q11.**

$$e^+ + e^- \rightarrow 2hf$$

**Q12.**

$$9.1 \times 10^{-31} \times 2 = 1.82 \times 10^{-30} \text{ kg}$$

From  $E = mc^2$ 

$$\begin{aligned} E &= 1.82 \times 10^{-30} \times (3 \times 10^8)^2 \\ &= 1.638 \times 10^{-13} \text{ J} \end{aligned}$$

Also,  $E = hf$ 

$$1.638 \times 10^{-13} = 6.626 \times 10^{-34} \times f$$

$$\text{Min. } f = 2.472 \times 10^{20} \text{ Hz}$$

**Q13.**

$$\begin{aligned} &1.6726 \times 10^{-27} \times 2 \\ &= 3.3452 \times 10^{-27} \text{ kg} \end{aligned}$$

From  $E = mc^2$ 

$$E = 3.3452 \times 10^{-27} \times (3 \times 10^8)^2$$

$$= 3.0107 \times 10^{-10} \text{ J}$$

Also,  $E = hf$ 

$$3.01 \times 10^{-10} = 6.6261 \times 10^{-34} \times f$$

$$f = 4.5434 \times 10^{23} \text{ Hz}$$

**Q14.**

Neutron = udd

Proton = uud

**Q15.**

Electrons are elementary particles not made from any simpler structure.

**Q16.**

$$\begin{aligned} &1.5 \times 10^9 \times 1.6 \times 10^{-19} \\ &= 2.4 \times 10^{-10} \text{ J} \\ &2.4 \times 10^{-10} \times 2 \\ &= 4.8 \times 10^{-10} \text{ J} \end{aligned}$$

Pion mass is 273 relative to electron mass.

Pion mass

$$= 9.1 \times 10^{-31} \times 273$$

$$= 2.484 \times 10^{-28} \text{ kg}$$

Three pions, so

$$2.484 \times 10^{-28} \times 3$$

$$= 7.4529 \times 10^{-28} \text{ kg}$$

From  $E = mc^2$  the  $E$  needed to make 3 pions is

$$\begin{aligned} E &= 7.4529 \times 10^{-28} \times (3 \times 10^8)^2 \\ &= 6.70761 \times 10^{-11} \text{ J} \end{aligned}$$

The spare  $E$  is  $E_k$ .

$$E_k = 4.8 \times 10^{-10} - 6.70761 \times 10^{-11}$$

$$= 4.1292 \times 10^{-10} \text{ J}$$

**Q17.**

Baryon: three quarks or antiquarks

Meson: one quark and one antiquark

**Q18.**

Lepton: elementary particle

Examples: electron, positron

## Answers to applied electricity questions

**Q1 to Q12.**

See pages 108 to 111.

