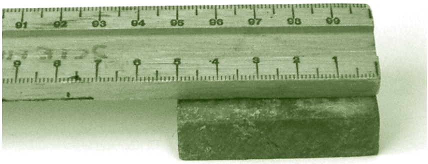
## Examples

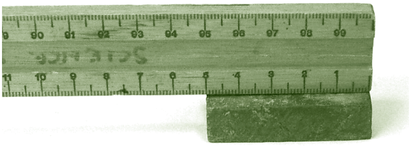
### Using a meter ruler

Parallax error can be present when using a metre ruler.



***Parallax error in reading a ruler***

The ruler is positioned so that its scale is not near the length being measured. The left-hand end of the metal block is aligned with the 5.0 cm mark of the ruler. However, it is difficult to see if the right-hand end is aligned with the ruler's zero mark.



***Reducing parallax error***

A better method of positioning the scale is next to the length being measured. This reduces parallax error considerably.

### Using an analogue current meter

The analogue current meter shown uses a mirror next to the measuring scale.

A person taking a reading places their eyes so that the reflection of the pointer is hidden by the pointer itself. When this happens, the person's eyes are directly over the pointer and a reading can then be taken.

The meter is 'zeroed' correctly (i.e. it has no zero error).

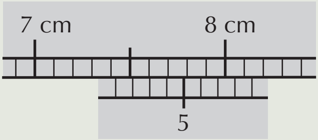
This particular meter measures alternating current (shown by the ~ symbol beneath the A), so it does not matter which way round the leads are connected to the meter.

The range of possible measurements for this meter is from 0.2 to 1.0 A. The scale is non-linear from zero to 0.2 A and is kept blank.

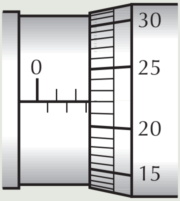
## *Activity 2B: Taking measurements*

**1.** Determine the readings indicated on the following scales:

**a.**



**b.**



## Example

The slope of the graph in the preceding example can be found from the coordinates of points A and B. Points A and B are chosen as far apart as possible to reduce uncertainty in the slope of a graph caused by uncertainties in reading the values of A and B from the graph.

Point A has coordinates (1.4 $cm^3$,12.0 g) and point B has coordinates (5.4 $cm^3$,46.0 g).

$$\Delta y = 46.0 - 12.0$$
$$= 34.0 \text{ g}$$

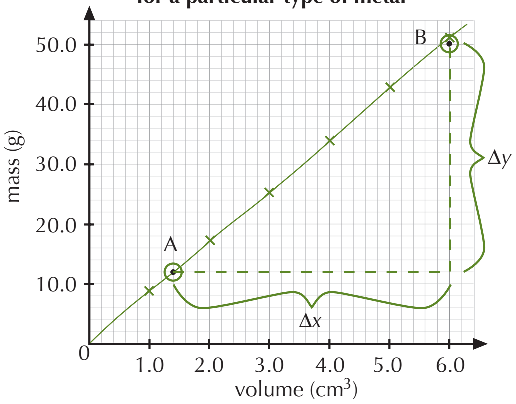
and $\Delta x = 5.4 - 1.4$

$$= 4.0 \text{ cm}^3$$

The slope is:

$$m = \frac{\Delta y}{\Delta x}$$
$$= \frac{34.0}{4.0}$$
$$= 8.5 \text{ g cm}^{-3} \text{ (to 2 sig figs)}$$

Mass against volume for a particular type of metal



The measurements between mass and volume can be expressed mathematically: mass = slope of graph × volume.

The slope of a graph often has units; in this case, the units g $cm^{-3}$ are those of density.

When the relationship between two variables is not linear, a *curved* graph results.

The slope of the graph in the preceding two examples is the density of the metal:

mass = density × volume

It is difficult to see the relationship between variables on a curved graph, especially if there is an amount of random error present.

Usually the variables are changed (by squaring or taking square roots, etc.) until a graph becomes linear. When a linear graph is obtained, the relationship is more clearly seen, since the changed variables are then proportional to one another.

The relationship between the frequency, *f*, of a wave and its period, *T*, is:

$$T = \frac{1}{f} \text{ or } f = \frac{1}{T}$$

The wave velocity, frequency and wavelength are related by the **wave equation**:

$$v = f\lambda$$

where $v$ is measured in m s$^{-1}$, $f$ in Hz and $\lambda$ in m.

### Example

A fisherman standing on some rocks counts 4 waves in 30 seconds. The frequency of the waves is $\frac{4}{30}$ = 0.13 Hz.

The time taken for one wave to pass him is $\frac{30}{4}$ = 7.5 s.

### Example

1. Water waves are produced in a tank at a frequency of 20 Hz and with a wavelength of 2 cm. The speed of the wavefront is:

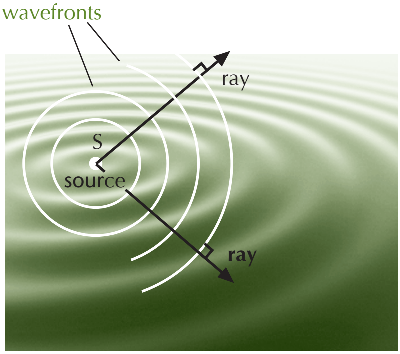
$$\begin{aligned} v &= f\lambda \\ &= 20 \times 2 && \text{[substituting]} \\ &= 40 \text{ cm s}^{-1} \end{aligned}$$

2. Sound travels at 330 m s$^{-1}$ in air. A note with frequency 110 Hz will have a wavelength of:

$$\begin{aligned} v &= f\lambda \\ \lambda &= \frac{330}{110} && \text{[substituting and rearranging]} \\ &= 3.0 \text{ m} \end{aligned}$$

## Wavefronts

Consider waves generated at a **point source**, S, as shown in the diagram alongside. This could be done by dipping a finger regularly in and out of the water of a calm pond or water tank. The waves travel outwards and form concentric circles called **wavefronts**. Wavefronts are at right angles to the direction in which the waves are travelling. A line in the direction of a wave's motion is called a **ray**.



As time goes on, each wave travels further out while new wavefronts are generated and move out from the point source. At points far away from S, the wavefronts become nearly straight.

Since wavefronts become nearly straight away from a light source, the light from the Sun reaches the Earth in plane flat wavefronts.

## CHAPTER 8

# Motion

NCEA Level 2 Physics material covered in this chapter helps to meet the requirements for Achievement Standard 91171 (Physics 2.4) ‘Demonstrate understanding of mechanics’. The chapter covers the following topics.

- Distance, displacement, velocity and acceleration.
- Constant acceleration in a straight line.
- Kinematic equations.

## Introduction

The **motion** of an object (e.g. car, satellite, tennis ball) can be described using various quantities such as distance, speed and acceleration.

Motion also involves the *direction* in which an object moves. When direction is important, the quantities of distance and speed are replaced by the quantities of displacement and velocity.

## Distance and displacement

The symbol used for both **distance** and **displacement** is *d*. Distance and displacement both involve a change in position.

Distance is a **scalar** quantity, because it only involves the *size* and not the direction of movement.

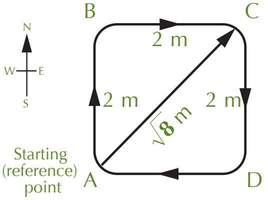
Displacement is a **vector** quantity, because it involves both *size* of movement *and direction* from a reference or starting point.

The distance an object travels and its displacement are often different.

### Example

A model train travels around a track. The table shows the distance moved by the train, and its displacement at various stages of the journey around the track.

| | Distance travelled | Displacement from start |
|---|---|---|
| At B | 2 m | 2 m north |
| At C | 4 m | $\sqrt{8}$ m northeast |
| At D | 6 m | 2 m east |
| Back at start, A | 8 m | 0 m |



# Force, motion and equilibrium

CHAPTER
10

NCEA Level 2 Physics material covered in this chapter helps to meet the requirements for Achievement Standard 91171 (Physics 2.4) 'Demonstrate understanding of mechanics'. The chapter covers the following topics.

- Force components.
- Vector addition of forces.
- Unbalanced force and acceleration.
- Equilibrium (balanced forces and torques).

## Introduction

**Forces** are a fundamental concept in all areas of physics.

- **Force** is a vector, and so it has size (magnitude) *and* direction.
- A **resultant** (or **net**) force is produced when two or more forces are added or subtracted (vectorially).
- When a resultant force acts on an object, the object will accelerate in the direction of the resultant force. The relationship between the resultant force, $F_{res}$, the object's mass, $m$, and its acceleration, $a$, is:

$$F_{res} = ma$$

This relationship is the second of Newton's Laws of Motion.

- Gravitational attraction between an object and Earth causes the object to have a weight force. The relationship between the weight force, $F_w$, the mass of the object, $m$, and the acceleration due to gravity, $g$, is:

$$F_w = mg$$

$g$ is usually rounded to a value of 10 m $s^{-2}$ to make calculations easier.

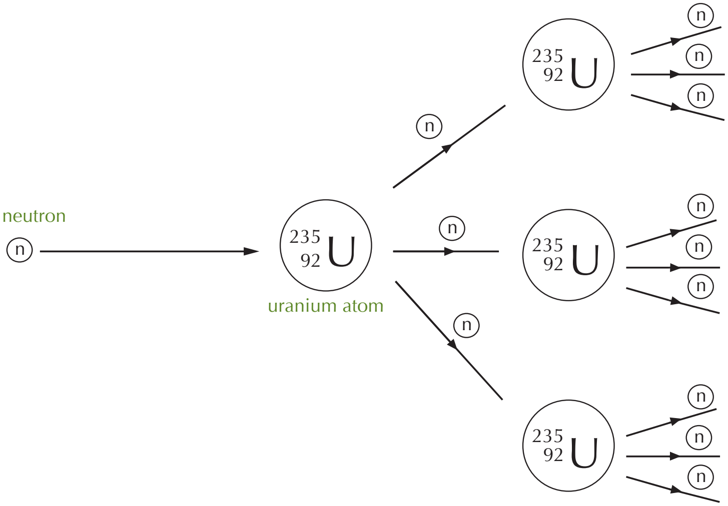
## Newton's laws of motion

Isaac Newton discovered several relationships between forces and their effects on different objects.

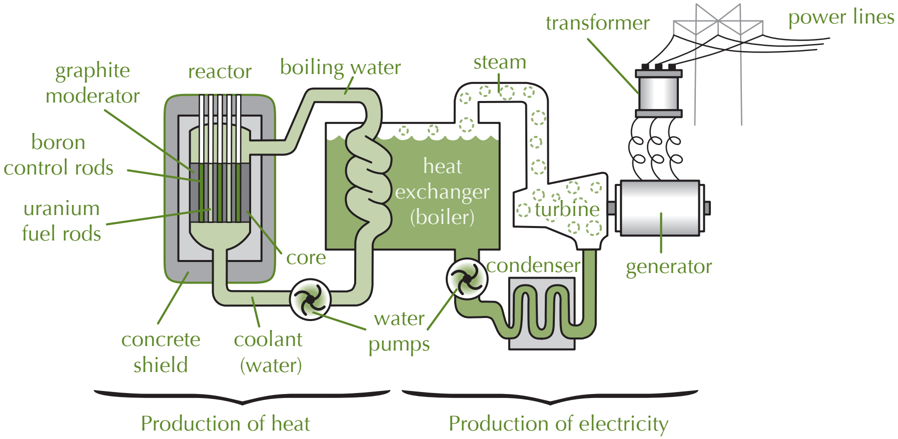
### Newton's first law of motion

If the resultant force on an object is zero, the acceleration of the object will be zero. An object with an acceleration of zero will either have a speed of zero (i.e. it will be stationary) or it will have a constant velocity (constant speed in a straight line).

***Sir Isaac Newton (1643–1727): English physicist and mathematician***



*A nuclear chain reaction*



*Parts of a typical reactor*

The *fuel rods* are made of uranium-238 enriched with about 3% uranium-235. The fission of uranium-235 produces energy and releases neutrons that continue the chain reaction.

The *moderator* slows down the neutrons to the correct speed for fission to occur. If the neutrons move too fast they bounce off atoms instead of causing fission. The moderator is usually graphite or water.

The nuclear reaction is controlled by *control rods* made of cadmium or boron. These can be lowered into the core between the fuel rods to absorb neutrons to slow or stop the chain reaction.

# APPENDIX A

# Formula reference

| | |
|---|---|
| $E \propto \frac{1}{d^2}$ | **64** |
| $\theta_1 = \theta_2$ | **65** |
| $f = \frac{r}{2}$ | **68** |
| $\frac{1}{f} = \frac{1}{D_i} + \frac{1}{D_o}$ | **71** |
| $m = \frac{H_i}{H_o} = \frac{D_i}{D_o}$ | **71** |
| $S_i S_o = f^2$ | **73** |
| $m = \frac{H_i}{H_o} = \frac{f}{S_o} = \frac{S_i}{f}$ | **73** |
| ${}_1n_2 = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$ | **79** |
| $n_1 \sin\theta_1 = n_2 \sin\theta_2$ | **80** |
| $T = \frac{1}{f}$ or $f = \frac{1}{T}$ | **49, 144** |
| $v = f\lambda$ | **49** |
| $\Delta$ = final amount – initial amount | **10** |
| $v = \frac{\Delta d}{\Delta t}$ | **92** |
| $a = \frac{\Delta d}{\Delta t}$ | **93** |
| $v_f = v_i + at$ | **95, 96** |
| $d = \left(\frac{v_i + v_f}{2}\right) t$ | **95, 96** |
| $d = v_i t + \frac{1}{2}at^2$ | **95, 97** |
| $v_f^2 = v_i^2 + 2ad$ | **95** |
| $d = v_f t - \frac{1}{2}at^2$ | **95** |
| $\underset{\sim}{v}_{\text{A rel B}} = \underset{\sim}{v}_{\text{A}} - \underset{\sim}{v}_{\text{B}}$ | **110** |
| $F_{res} = ma$ | **113, 114** |
| $F_w = mg$ | **113** |
| $\tau = Fd_{\perp}$ | **118** |
| $\Sigma F = 0$ and $\Sigma\tau = 0$ | **119** |
| $p = mv$ | **125** |
| $\Delta\underset{\sim}{p} = \underset{\sim}{p}_f - \underset{\sim}{p}_i$ | **126** |
| $F\Delta t = \Delta p$ | **128** |
| $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ | **132** |
| $v = \frac{2\pi r}{T}$ | **144** |
| $a = \frac{v^2}{r}$ | **145** |
| $F = \frac{mv^2}{r}$ | **145** |
| $a = \frac{4\pi^2 r}{T^2}$ | **146** |
| $F = \frac{m4\pi^2 r}{T^2}$ | **147** |
| $W = Fd$ | **151** |

**d.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| count in 10 seconds | 50 | 50 | 50 | 45 | 40 | 40 | 40 |

**e.** The paper has thickened. Because more beta particles have been absorbed.

**f.** **i.** 30 s approximately. **ii.** 90 m approximately.

**16.** Gamma rays from source A, alpha particles and gamma rays from source B, beta particles from source C.

## Activity 16A: Nuclear energy (page 181)

**1. a.** Total mass of uranium-235 = 1 500 × 14 × 0.03 = 630 kg

**b.** Total amount of heat energy produced = $630 \times 10^{14}$ J = $6.3 \times 10^{16}$ J

**c.** $P = \frac{E}{t}, t = \frac{E}{P} = \frac{6.3 \times 10^{16}}{2\,000 \times 10^{6}} = 3.2 \times 10^{7}$ s = 1 year

**2.** $E = mc^2 = 0.2 \times 10^{-3} \times (3 \times 10^{8})^2 = 2 \times 10^{13}$ J

**3. a.** ${}^{239}_{94}\text{Pu} + {}^{1}_{0}\text{n} \rightarrow {}^{93}_{38}\text{Sr} + {}^{142}_{56}\text{Ba} + 5\,{}^{1}_{0}\text{n}$

**b.** Mass difference is $0.3091 \times 10^{-27}$ kg

$E = mc^2 = 0.3091 \times 10^{-27} \times (3 \times 10^{8})^2 = 2.78 \times 10^{-11}$ J

**4.** The deuterium atoms would not be moving fast enough for them to have enough energy to start the fusion reaction.

## Activity 17A: Electric fields (page 192)

**1. a.** field **b.** charge **c.** direction **d.** positive **e.** direction
**f.** field **g.** vectors **h.** scalars **i.** field **j.** temperature
**k.** charge **l.** volts **m.** metre **n.** newton

**2.** Electric field strength has both magnitude and direction.

**3.** V $\text{m}^{-1}$ is equivalent to J $\text{m}^{-1}$ $\text{C}^{-1}$ since 1 V = 1 J $\text{C}^{-1}$ and 1 J = 1 N m, therefore:
J $\text{m}^{-1}$ $\text{C}^{-1}$ = N m $\text{m}^{-1}$ $\text{C}^{-1}$ = N $\text{C}^{-1}$

**4. a.** Part C. **b.** Part A. **c.** Part E.

**5. a.** 5 000 **b.** 0.018 **c.** $4 \times 10^{-14}$

**6. a.** $5 \times 10^{5}$ **b.** 2.0 **c.** $5 \times 10^{-4}$

**7. a.** $2.4 \times 10^{4}$ V $\text{m}^{-1}$ **b.** $3.8 \times 10^{-3}$ N **c.** Towards the positive plate.

**8. a.** 4 000 V $\text{m}^{-1}$ **b.** $6.4 \times 10^{-16}$ N **c.** To the left.

**9. a.** 10 000 V $\text{m}^{-1}$ **b.** $1.6 \times 10^{-17}$ J

**10. a.** Downwards. **b.** 500 V $\text{m}^{-1}$
**c.** $8 \times 10^{-17}$ N **d.** Parabolic.

**11. a.** $5.1 \times 10^{4}$ V $\text{m}^{-1}$ **b.** Field strength is the same, since the field is uniform.
**c.** $2.5 \times 10^{-15}$ J

## Activity 18A: Introductory electricity (page 202)

**1. a.** Ampere. **b.** Volt. **c.** Watt or joule per second.

**2. a.** $\frac{J}{C}$ is equivalent to a volt. $\frac{s}{C}$ is equivalent to an $\text{A}^{-1}$. V $\text{A}^{-1}$ = Ω

**b.** $\frac{J}{C}$ is equivalent to a volt. V $\text{A}^{-1}$ = Ω

**3.** P and R or R and S.

**3.**

| | $R_1$ (Ω) | $R_2$ (Ω) | $R_{\text{total}}$ (Ω) | $V$ (V) | $I_1$ (A) | $I_2$ (A) | $I_3$ (A) | $P_1$ (W) | $P_2$ (W) |
|---|---|---|---|---|---|---|---|---|---|
| **a.** | 4 | 6 | *2.4* | *2.4* | 0.6 | 0.4 | *1.0* | *1.44* | *0.96* |
| **b.** | 5 | 15 | *3.75* | *3.75* | *0.75* | *0.25* | 1 | *2.81* | *0.94* |
| **c.** | *3* | 1 | 0.75 | *0.9* | 0.3 | *0.9* | *1.2* | *0.27* | *0.81* |
| **d.** | *2.5* | *2.5* | *1.25* | 0.5 | 0.2 | 0.2 | *0.4* | *0.1* | *0.1* |

**4.** **a.** 0.5 J **b.** 2.5 C **c.** 8 Ω

**d.** Voltmeters are placed in parallel and have a high resistance so they draw no current.

**5.** **a.** 10 Ω **b.** 6 Ω **c.** 2 A **d.** 6 V **e.** 720 J

**6.** **a.** 1.2 Ω **b.** 6 Ω **c.** 4.8 Ω

**d.** **i.** 30 V **ii.** 36 V

**7.** **a.** $3.6 \times 10^3$ Ω

**b.** By adding a resistor in parallel, the overall resistance of the circuit is reduced. This will increase the total current in the circuit, leading to an increase in the voltage across resistor X and therefore a decrease in the voltage across resistor Y.

**8.** **a.** $2.2 \times 10^4$ Ω

**b.** Parallel branch has total resistance of $12 \times 10^3$ Ω. This is then added in series to the $10 \times 10^3$ Ω resistor for a combined resistance of $22 \times 10^3$ Ω.

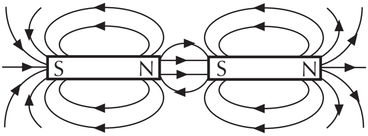
**c.** Across R and the 20 kΩ resistor. **d.** Through the battery and the 10 kΩ resistor.

**e.** $7.3 \times 10^{-4}$ W **f.** $1.6 \times 10^{-3}$ W

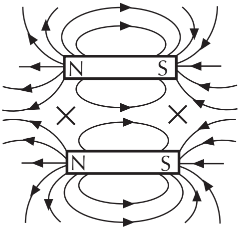
**g.** **i.** 140 J **ii.** Converted to heat.

## Activity 19A: Magnets (page 226)

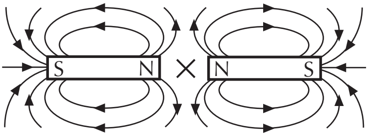
**1.** **a.**



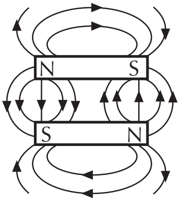
**b.**



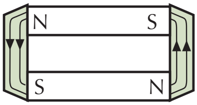
**c.**



**d.**



**2.**



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