National 5 Physics

Dynamics and Space

Notes

Name…………………………………………………………….

Key Area Notes, Examples and Questions

Other Notes

Key Area: Vectors and Scalars

Success Criteria

1.1 I can define average speed and instantaneous speed.

1.2 I can solve problems involving using $d = \bar{v}t$ and $d = vt$.

1.3 I can describe experiments to measure average and instantaneous speed.

1.4 I can state what is meant by a scalar and vector quantities.

1.5 I can understand the relationship between; distance and displacement, speed and velocity.

1.6 I can calculate the resultant of two vectors.

1.7 I can find the resultant of vectors by drawing a scale diagram.

1.1 I can define average speed and instantaneous speed.

Average speed is defined as

The total distance travelled by the object (m)

$$\bar{v} = \frac{d}{t}$$

Average Speed (ms^{-1})

Total time taken (s)

In the relationships sheet this is written as $d = \bar{v}t$

Instantaneous speed is defined as

The distance travelled by the object over a short time interval (m).

$$v = \frac{d}{t}$$

Instantaneous Speed (ms^{-1})

Time taken over a short time interval (s)

In the relationships sheet this is written as $d = vt$

1.2 I can solve problems involving using $\mathbf{d} = \bar{\boldsymbol{v}}\boldsymbol{t}$ and $\boldsymbol{d} = \boldsymbol{vt}$.

<u>Example 1 – Average Speed</u>
A pupil on sports day runs 400m in 67s. Find her average speed.

<u>Solution 1 – Average Speed</u>

$d = 400\mathrm{m}$
$\bar{v} =?$
$t = 67\mathrm{s}$

$$d = \bar{v}t$$

$$400 = \bar{v} \times 67$$

$$\bar{v} = \frac{400}{67}$$

$$\bar{v} = 6.0\mathrm{ms}^{-1}$$

Example 2 – Average Speed

On a car journey from Glasgow to Edinburgh a car travels 50km in 45minutes and then 20km in 30minutes. Find the average speed of the car.

Solution

Total Distance, $d = 50 + 20 = 70\text{km} = 70 \times 10^3\text{m}$

Total Time, $t = 45 + 30 = 75\text{minutes} = 75 \times 60 = 4500\text{s}$

$$d = \bar{v}t$$

$$70 \times 10^3 = \bar{v} \times 4500$$

$$\bar{v} = \frac{70 \times 10^3}{4500}$$

$$\bar{v} = 16\text{ms}^{-1}$$

Example – Instantaneous Speed

In the Beijing Olympics Usain bolt ran the 100m sprint with an average speed of 10.3ms^{-1}.
He ran the first 10m of this race in 1.85s.

a. Find his instantaneous speed at the start of the race.

b. Why are the instantaneous and average speeds different?

Solution – Instantaneous Speed

a.

$d = 10\text{m}$

$v = ?$

$\text{t} = 1.85\text{s}$

$$d = vt$$

$$10 = v \times 1.85$$

$$v = \frac{10}{1.85}$$

$$v = 5.4\text{ms}^{-1}$$

b. His speed increases during the race.

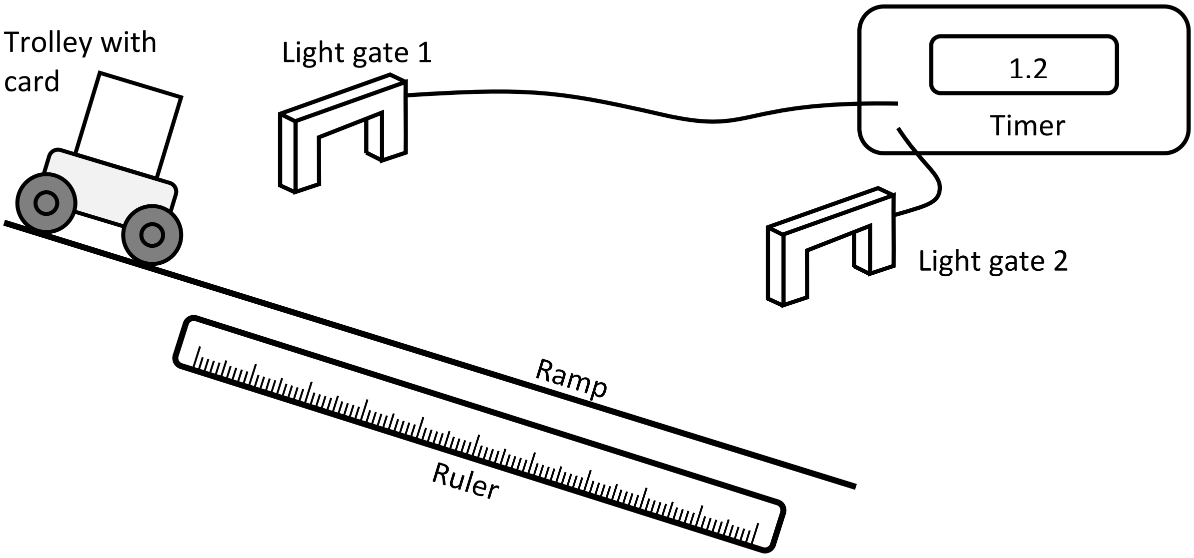
Dynamics and Space Problem Book Pages 5 and 6 Questions 19 to 28.

1.3 I can describe experiments to measure average and instantaneous speed.

Measuring Average Speed

The diagram below shows the set up to measure average speed.

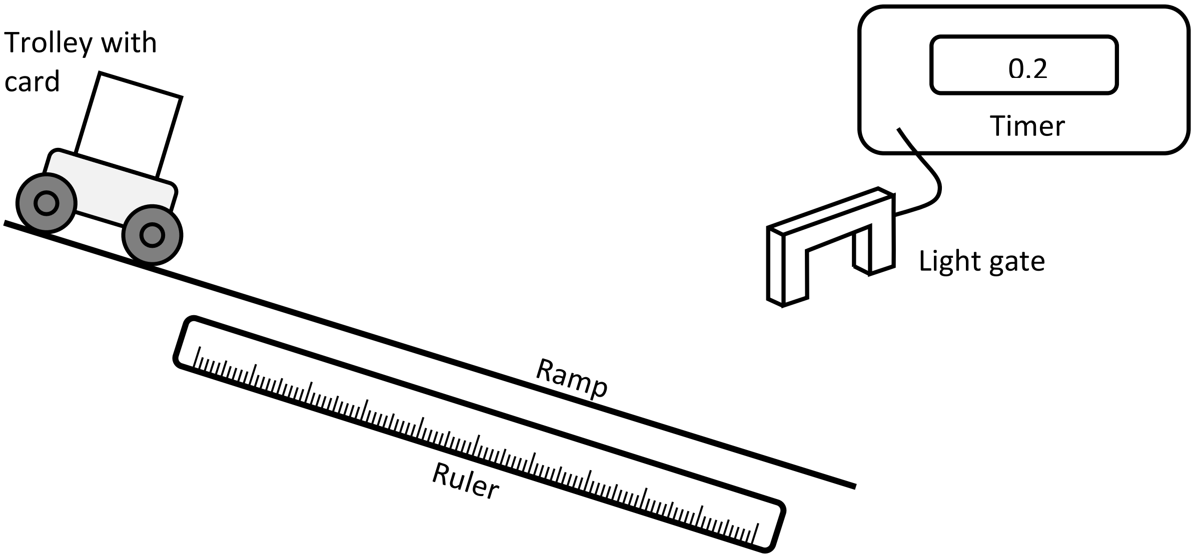
- Roll the trolley down the slope.
- As the card mounted on the trolley passes through light gate 1 the timer will start. As it rolls through light gate 2 the timer will stop.
- Read the time from the timer
- Measure the distance between light gate 1 and light gate 2.
- Use the relationship $\bar{v} = \frac{d}{t}$ to find the average speed.
- Repeat 5 times then find the mean of the average speeds.



Measuring Instantaneous Speed

The diagram below shows the set up to measure average speed.

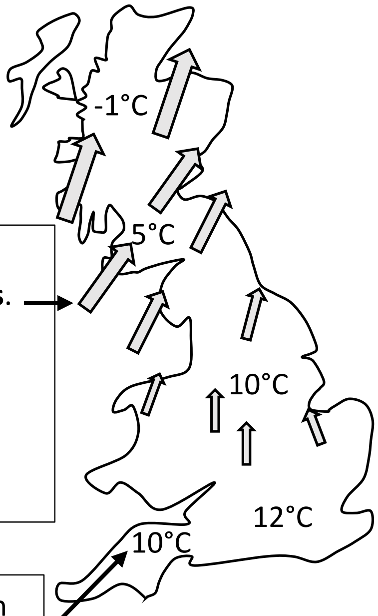
- Roll the trolley down the slope.
- As the card mounted on the trolley passes through the light gate the timer will start. As leaves the light gate the timer will stop.
- Read the time from the timer
- Measure the length of the card.
- Use the relationship $v = \frac{d}{t}$ to find the instantaneous speed.
- Repeat 5 times then find the mean of the instantaneous speeds.



1.4 I can state what is meant by a scalar and vector quantities.

A **scalar quantity** has a size (magnitude) only. A scalar quantity is represented as a positive or negative number only together with a unit.
e.g. 10°C, 10m, 5.26s

Examples of scalar quantities are; distance, speed, time, temperature, mass, volume, energy etc.



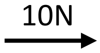
Wind speed arrows on weather maps are **vectors**. The size of the arrow indicates the speed of the wind and the direction of the arrow shows the direction of the wind.

Temperature readings on weather maps are **scalars**. The temperature can be positive or negative but there is no direction associated with it.

A **vector quantity** has a size (magnitude) and a direction.

A vector quantity can be represented as an arrow with the length of the arrow indicating the magnitude of the vector and the direction of the arrow the vector's direction.

A force of ten Newtons to the right could be represented as



A force of twenty Newtons downwards could be represented as

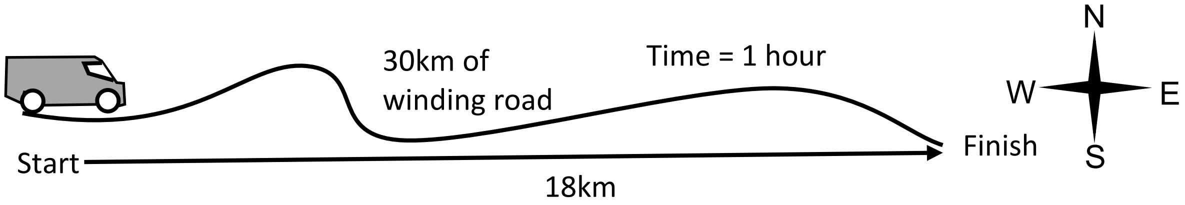
Examples of vector quantities are displacement, velocity, force, weight, acceleration etc.

Dynamics and Space Problem Book Page 1 Questions 1 and 2.

1.5 I can understand the relationship between; distance and displacement, speed and velocity.

Distance and Displacement

Distance is the length travelled by the object being considered. In the diagram below the van drives 30km along the winding road from the start to the finish. The vans distance travelled is 30km.



Displacement is the direct line length from the start to the finish together with the direction from the start of the finish. The van's displacement is 18km to the east.

Speed is defined in section 1.1 as

$v = \frac{d}{t}$ and $\bar{v} = \frac{d}{t}$

In the case of the van the average speed would be

$$\boldsymbol{\bar{v} = \frac{d}{t} = \frac{30}{1} = 30\mathbf{kmhr}^{-1}}$$

Velocity is defined as

The total displacement the object (m)

$$\bar{v} = \frac{s}{t}$$

Average velocity (ms^{-1})

Total time taken (s)

In the relationships sheet this is written as $s = \bar{v}t$

The displacement the object over a short time interval (m)

$$v = \frac{s}{t}$$

Instantaneous velocity (ms^{-1})

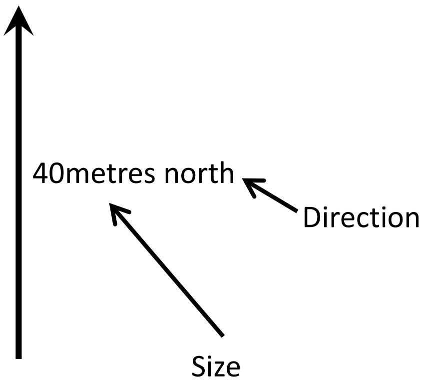
Time taken over a short time interval (s)

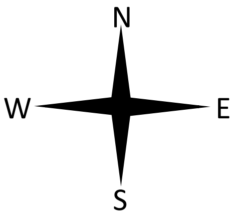
In the relationships sheet this is written as $s = vt$

In the case of the van the velocity would be $v = \frac{d}{t} = \frac{18}{1} = 18\mathrm{kmhr}^{-1}$ to the east

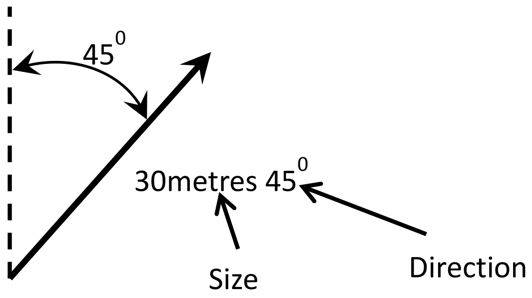
1.6 I can calculat the resultant of two vectors.

Drawing Vectors



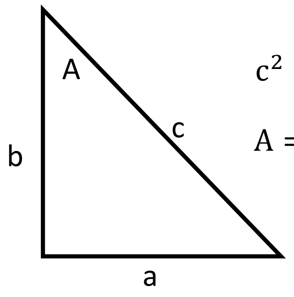


- Vectors have a size and a direction.
- Vectors are drawn as arrows.
- Vectors are drawn to scale.
- North is at the top of the page.



- Direction angles are frequently measured clockwise from north.

Pythagoras' Theorem and trigonometry reminder

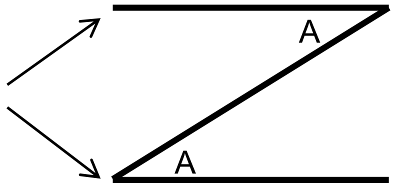


$$c^2 = a^2 + b^2$$

$$A = \tan^{-1}\left(\frac{a}{b}\right)$$

The “z” Angles

If these lines are parallel
Angles A are the same size.



Resultant Displacement

To find the resultant of two vectors place them “tip” to “tail”. Then find the length and direction from the starting point to the finish.

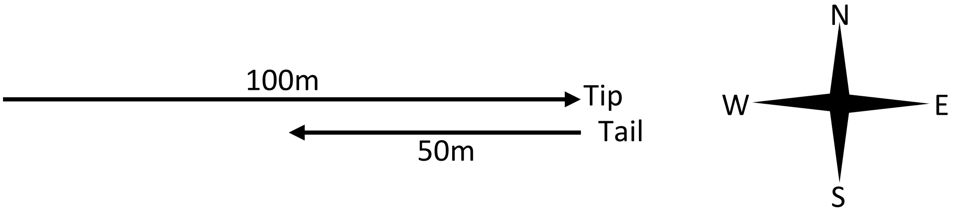
Example

A donkey taking rides on the beach walks 100m east then 50m west in 2.0 minutes. Find

a. distance travelled by the donkey
b. the displacement of the donkey
c. the average speed of the donkey
d. the average velocity of the donkey.

Solution

Sketch a diagram of the vectors.



a. The donkey has travelled a total distance $= 100 + 50 = 150\text{m}$

b. The donkey is now 50m east from its starting point.

c.

$d = 150\text{m}$
$\bar{v} = ?$
$t = 2 \text{ minutes} = 2 \times 60 = 120\text{s}$

$$d = \bar{v}t$$
$$150 = \bar{v} \times 120$$
$$\bar{v} = \frac{150}{120}$$
$$\bar{v} = 1.3\text{ms}^{-1}$$

d.

$s = 50\text{m}$
$\bar{v} = ?$
$t = 120\text{s}$

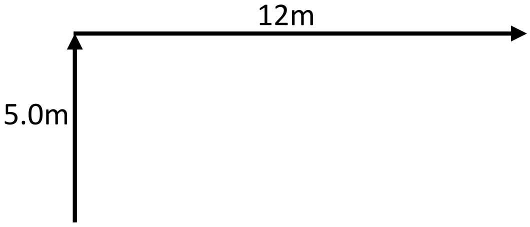
$$s = \bar{v}t$$
$$50 = \bar{v} \times 120$$
$$\bar{v} = \frac{50}{120}$$
$\bar{v} = 0.42\text{ms}^{-1}$ to the east.

Example

An object moves 5.0m north then 12m east. Find

a. The distance travelled.

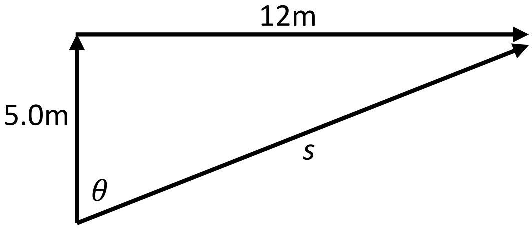
b. The displacement of the object.



Solution

a. Total distance $= 5.0 + 12 = 17\text{m}$

b. Use Pythagoras' theorem to find the length of the resultant vector, *s*.



$$s^2 = 5.0^2 + 12^2$$

$$s = \sqrt{25 + 144}$$

$$s = 13\text{m}$$

Use trigonometry to find the angle θ

$$\tan\theta = \frac{12}{5}$$

$$\theta = \tan^{-1}\left(\frac{12}{5}\right)$$

$$\theta = 67°$$

Displacement is 13m at 067°

Dynamics and Space Problem Book Page 1 to 3 Questions 3 to 10.

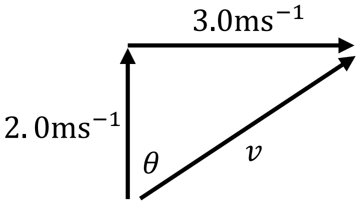
Resultant Velocity

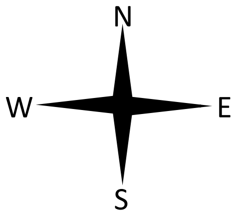
Two velocity vectors can be combined by placing them tip to tail in the same way as displacement vectors

Example

A boat is moving northwards across a river at 2.0ms^{-1}. The river is flowing east at 3.0ms^{-1}. Find the resultant velocity of the boat.

Solution





$$v^2 = 2.0^2 + 3.0^2$$

$$v = \sqrt{4.0 + 9.0}$$

$$v = 3.6\text{ms}^{-1}$$

Use trigonometry to find the angle θ

$$\tan\theta = \frac{3.0}{2.0}$$

$$\theta = \tan^{-1}\left(\frac{3.0}{2.0}\right)$$

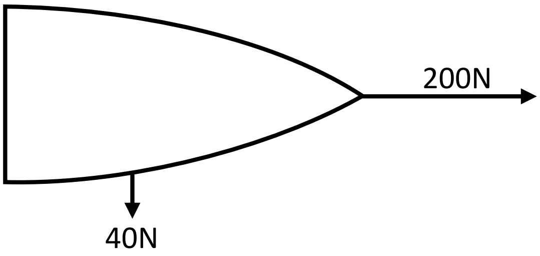
$$\theta = 56°$$

Velocity is 3.6ms^{-1} at 056°

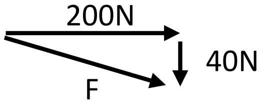
Dynamics and Space Problem Book Page 3 and 4 Questions 11 to 18.

Resultant Force
Two force vectors can be combined by placing them tip to tail in the same way as displacement and velocity vectors.

Example
A boat's engine produces an force of 200N. The current in the sea is producing a force of 20N at right angles to the engine force. Calculate the magnitude of resultant force on the boat.



Solution
Place the vectors tip to tail.



$$F^2 = 200^2 + 40^2$$

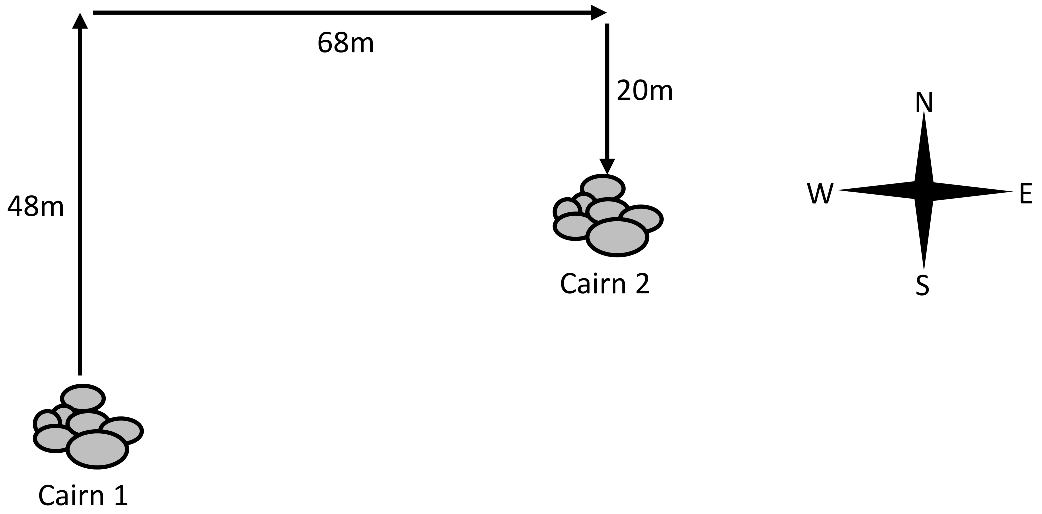
$$F = \sqrt{40{,}000 + 1600}$$

$$F = 204\text{N}$$

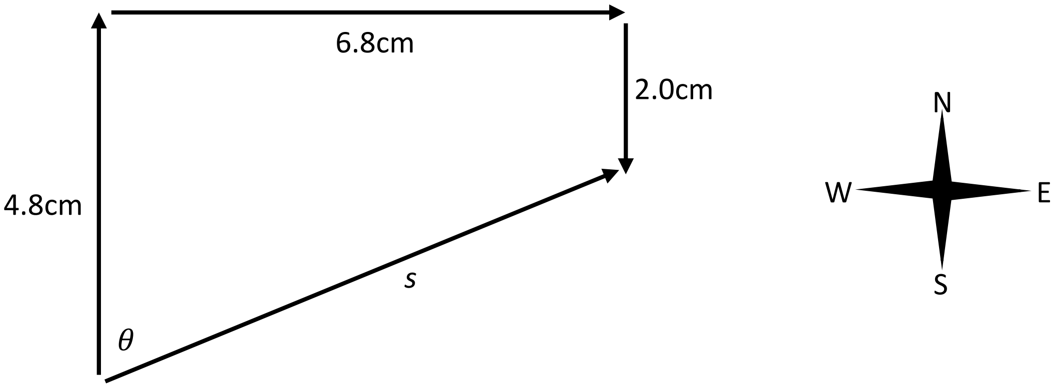
1.8 I can find the resultant of vectors by drawing a scale diagram.

Pythagoras' Theorem with trigonometry can be used to find the resultant of vectors. It is also possible to obtain a resultant vector from a scale diagram. This method is best used when you are asked to obtain the resultant of more than two vectors.

Example
A surveyor of ancient monuments is mapping the layout of cairns. He walks around the boundary of the field from cairn 1 to cairn 2. Find his displacement from cairn 1 to cairn 2.



Solution
Draw a scale diagram. In this case use 10m to 1cm (other scales could be chosen).



Measure the displacement s and the angle θ. Then use the scale to give the measurement in metres.
This gives the displacement a 74m at 055°

In the exam questions, you are allowed ±10% in the answer when using scale drawings.

Unless a question says otherwise, any vector problem can be completed using Pythagoras' theorem with trigonometry or by using a scale diagram. You choose which method you want to use.

Key Area: Velocity-time Graphs

Success Criteria

2.1 I can draw speed time and velocity time graphs from data.

2.2 I can describe the motion of an object by examining its velocity time graph.

2.3 I can find displacement from a velocity time graph.

2.1 I can draw speed time and velocity time graphs from data.

Example

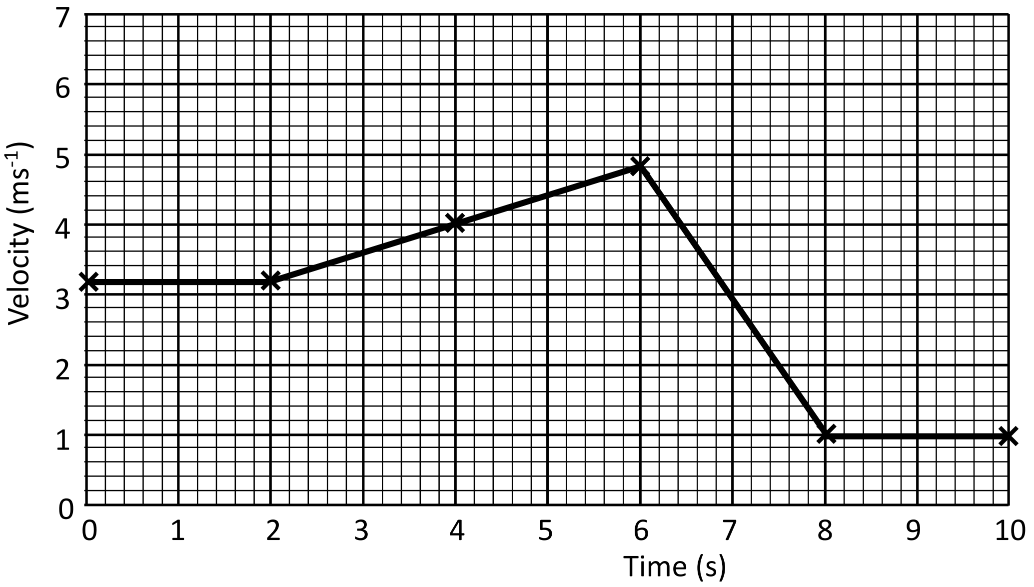
Draw a velocity time graph for the data in the table below

Time (s)	Velocity (ms^{-1})
0	3.2
2	3.2
4	4.0
6	4.8
8	1.0
10	1.0

Solution

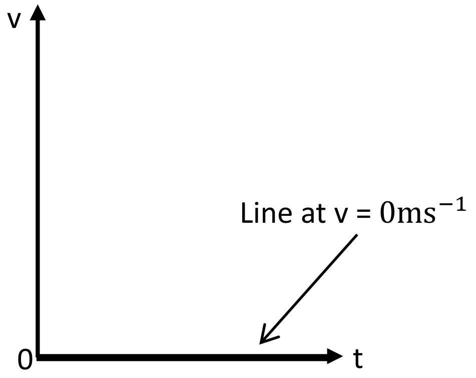
Draw

- Suitable scales
- Label the axes
- Plot the points
- Join the points with a suitable line

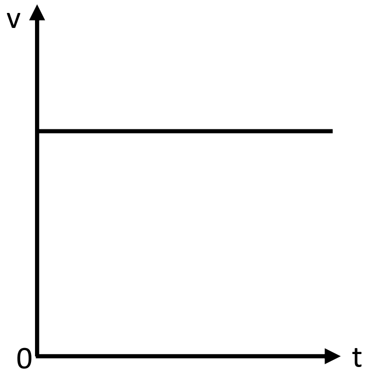


2.2 I can describe the motion of an object by examining its velocity time graph.

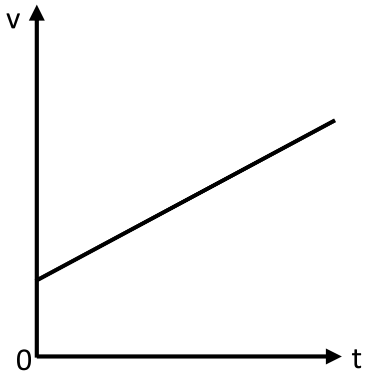
The slope of the line on a velocity time graph can be used to describe the motion of an object. This is done using the terms stationary, constant velocity, accelerating and decelerating. These are shown on the graphs below.



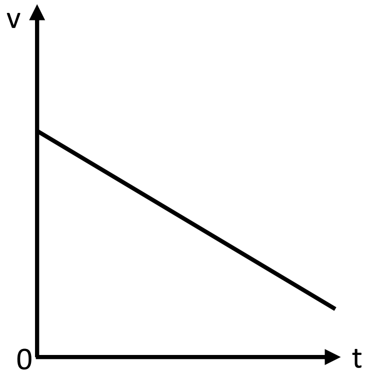
Stationary



Constant Velocity



Accelerating

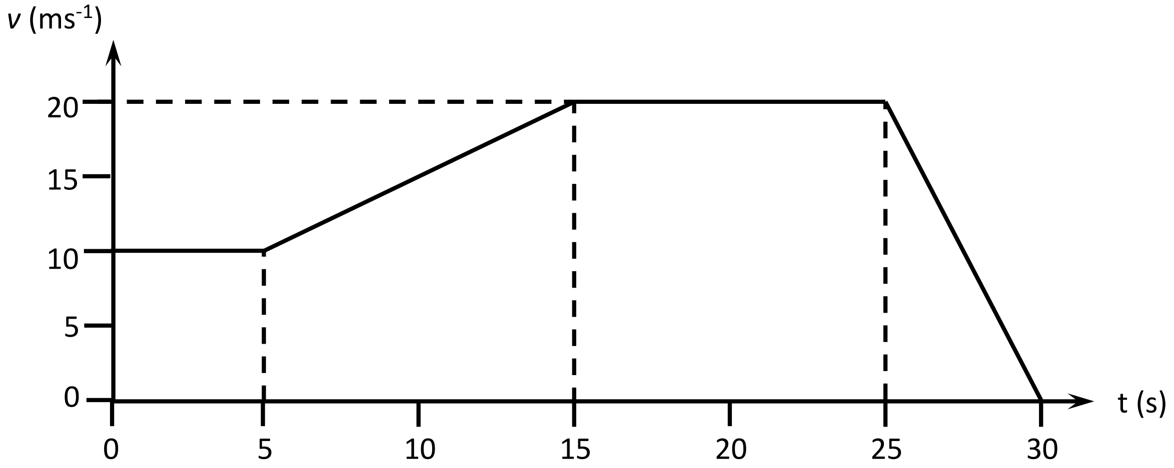


Accelerating
(You can also use
decelerating)

Example

Describe the motion of the object below between

a. 0s to 5s
b. 5s to 15s
c. 15s to 25s
d. 25s to 30s



Solution

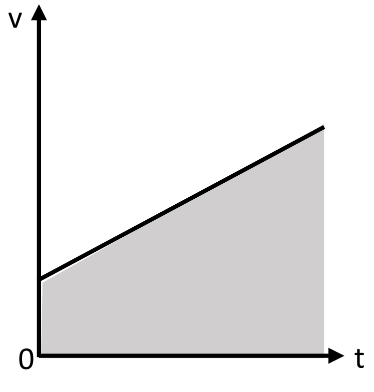
Compare the slope of the line on the graph to the lines on the graphs on the previous page.

a. Constant velocity
b. Accelerating
c. Constant velocity
d. Accelerating or decelerating.

Dynamics and Space Problem Book Page 7 Questions 31.

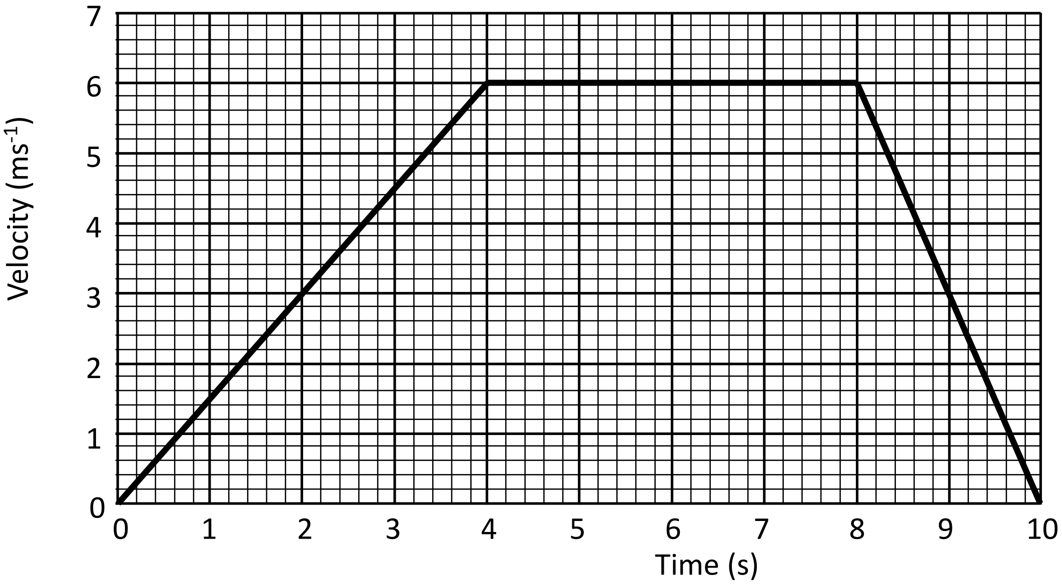
2.3 I can find displacement from a velocity time graph.

The displacement of a moving object can be found from its velocity time graph. The area between the line of its motion and the horizontal time axis gives its displacement. The area of the shaded part of the graph gives the displacement.



Example

The graph below shows the first 10 seconds of the motion of an object. Find the objects displacement after 10 seconds.



Solution

To find the area under the graph split the motion into rectangular and triangular sections, which will make the area easy to calculate.

Area of Section from 0s to 4s

This area is a triangle

$$\text{Area} = \frac{1}{2} \times 4 \times 6 = 12\text{m}$$

Area of Section from 4s to 8s

This area is a rectangle

$$\text{Area} = (8 - 4) \times 6 = 24\text{m}$$

Area of Section from 8s to 10s

This area is a triangle

$$\text{Area} = (10 - 8) \times 6 = 12\text{m}$$

$$\text{Displacement} = \text{Total area} = 12 + 24 + 12 = 48\text{m}$$

Unless other information is given, the direction of the displacement cannot be obtained from the graph so need not be stated.

Dynamics and Space Problem Book Page 7 to 9 Questions 32 to 35.

Key Area: Acceleration

Previous Knowledge

Success Criteria

3.1 I can describe an experiment to measure acceleration.

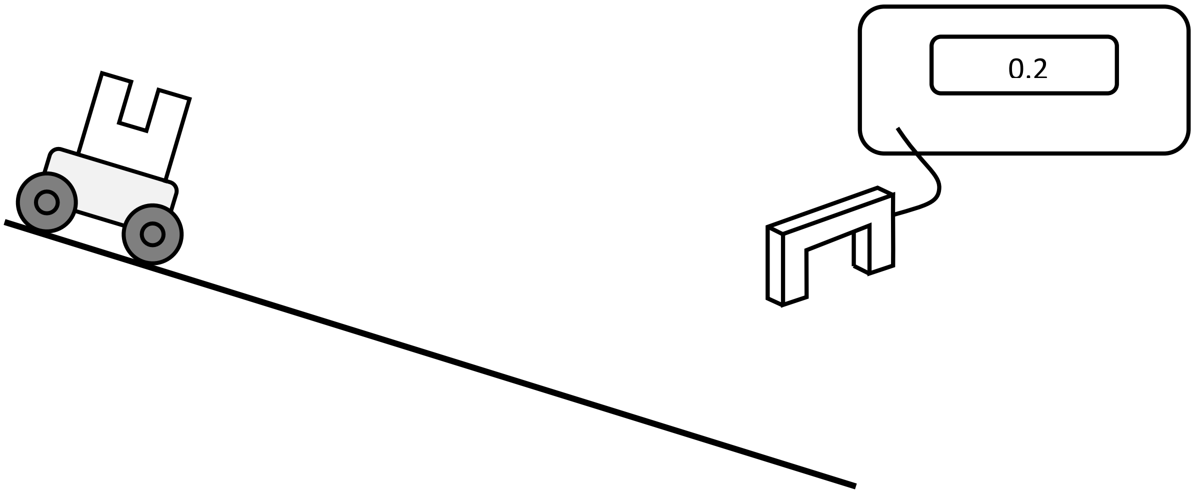
3.2 I can use the relationship $a = \frac{v - u}{t}$ to solve problems involving acceleration, initial velocity (or speed), final velocity (or speed) and time.

3.3 I can find acceleration from a velocity-time graph.

3.1 I can describe an experiment to measure acceleration.

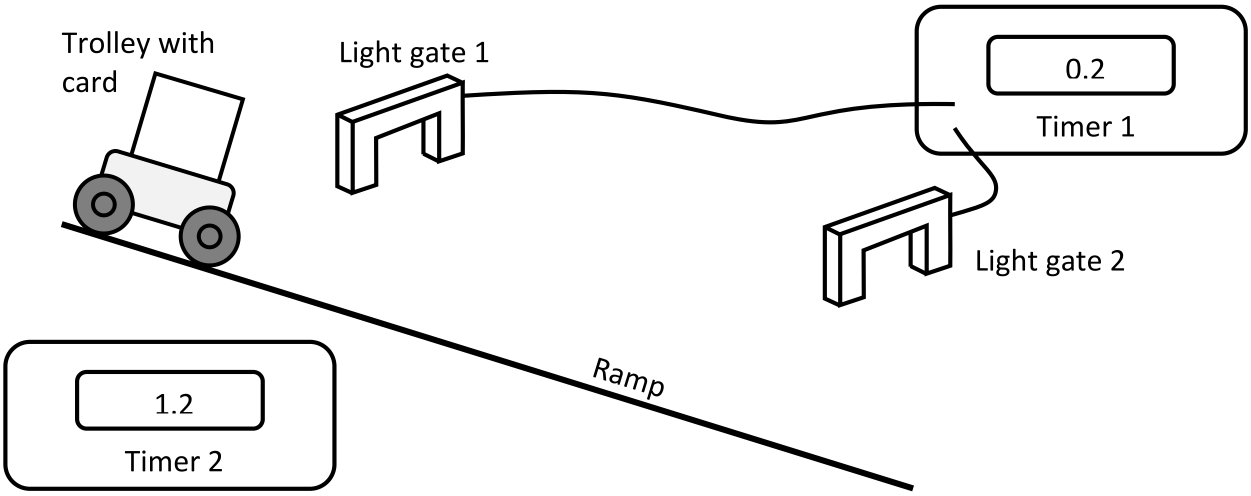
Acceleration with a single light gate

The equipment is set up as shown below. The double slit on the card allows the data logger to measure two speeds and a time and so can calculate the acceleration. Allow the trolley to run down the slope through the light gate. The data logger will measure acceleration. This must be done at least five times and a mean value of acceleration calculated.



Acceleration with two light gates

- Measure the length of the card
- Run the trolley down through the light gates
- Record both times from timer 1
- Use the length of the card and the times from timer to calculate the speeds
- Record the time from timer 2
- Use the relationship $a = \frac{v-u}{t_2}$ to find the acceleration.
- Repeat at least five times and calculate the mean value of acceleration



3.2 I can use the relationship $a = \frac{v - u}{t}$ to solve problems involving acceleration initial velocity (or speed), final velocity (or speed) and time.

The acceleration of an object is its change in velocity divided by time. It is given by the relationship below.

$$\underset{\text{Acceleration (ms}^{-2}\text{)}}{a} = \frac{\overset{\text{Final Velocity (ms}^{-1}\text{)}}{v} - \overset{\text{Initial Velocity (ms}^{-1}\text{)}}{u}}{\underset{\text{Time (s)}}{t}}$$

In this relationship, the initial and final velocities can also be replaced with initial and final speeds to give acceleration.

- Acceleration will be positive if the velocity (or speed) is increasing.
- Acceleration will be negative if the velocity (or speed) is decreasing.

Example

A car initially moving at 2.0ms^{-1} accelerates to 27ms^{-1} in 9.6s. Calculate the car's acceleration.

Solution

$a = ?$

$u = 2.0\text{ms}^{-1}$

$v = 27\text{ms}^{-1}$

$t = 9.6\text{s}$

$$a = \frac{v - u}{t}$$

$$a = \frac{27 - 2.0}{9.6}$$

$$a = 2.6\text{ms}^{-2}$$

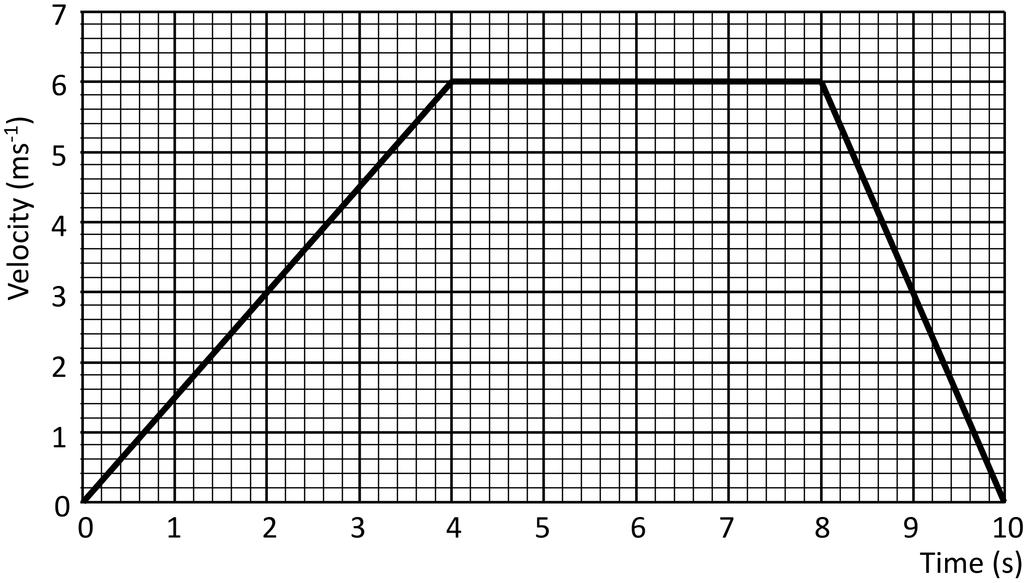
Dynamics and Space Problem Book Page 10 to 11 Questions 37 to 43.

3.3 I can find acceleration from a velocity-time graph.

Finding acceleration from a velocity-time graph involves reading values of initial velocity, final velocity and time from the graphs.
The relationship $a = \frac{v-u}{t}$ can then be used to find the acceleration.

Example
Using the graph below find

a. The acceleration between 0s and 4s
b. The acceleration between 4s and 8s
c. The acceleration between 8s and 10s



a.
$a = ?$
$u = 0\text{ms}^{-1}$
$v = 6.0\text{ms}^{-1}$
$t = 4.0\text{s}$

$$a = \frac{v-u}{t}$$
$$a = \frac{6.0-0}{4.0}$$
$$a = 1.5\text{ms}^{-2}$$

b. Horizontal line means $a = 0\text{ms}^{-2}$

c.
$a = ?$
$u = 6.0\text{ms}^{-1}$
$v = 0\text{ms}^{-1}$
$t = 10 - 8 = 2.0\text{s}$

$$a = \frac{v-u}{t}$$
$$a = \frac{0-6.0}{2.0}$$
$$a = -3.0\text{ms}^{-2}$$

Dynamics and Space Problem Book Page 11 and 12 Questions 44 to 46.

Key Area: Newton's Laws

Success Criteria

4.1 I can understand the terms balanced forces and unbalanced forces.

4.2 I can find the unbalanced force resulting from forces acting in a straight line.

4.3 I can understand Newton's First Law and can use it to explain the constant velocity (or speed) for a moving object.

4.4 I can use Newton's Second Law to solve problems involving unbalanced force, mass and acceleration.

4.5 I can use the relationship $E_w = Fd$ to solve problems involving work done, force and distance.

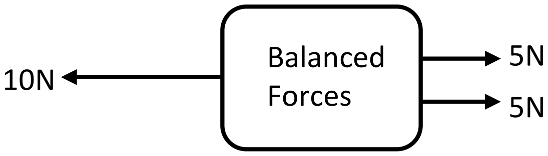
4.6 I understand what is meant by the terms weight, mass and gravitational field strength.

4.7 I can solve problems involving rocket launches , space travel and landings.

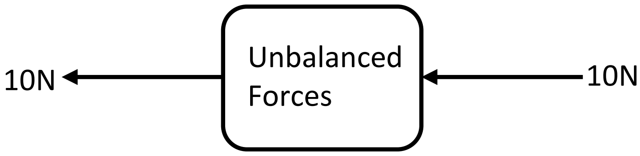
4.8 I can state Newton's Third Law and the effect of the reaction force on motion.

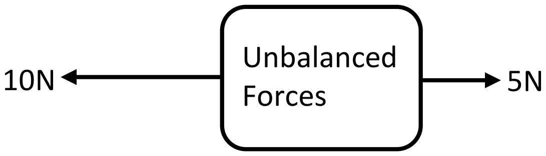
4.1 I can understand the terms balanced forces and unbalanced forces

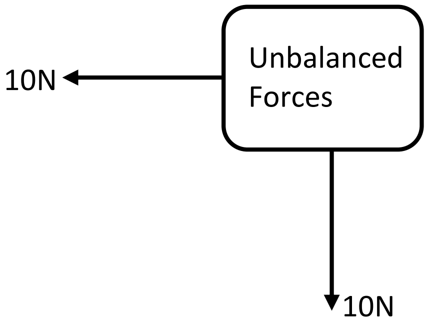
When forces applied to an object are of equal magnitude and act in opposite directions the forces are balanced.



When forces applied to an object are not of equal magnitude and in opposite directions the forces are unbalanced.





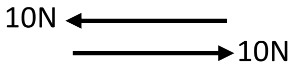


4.2 I can find the unbalanced force resulting from forces acting in a straight line.

An unbalanced force can be found by finding the resultant forces of all the forces acting on an object.

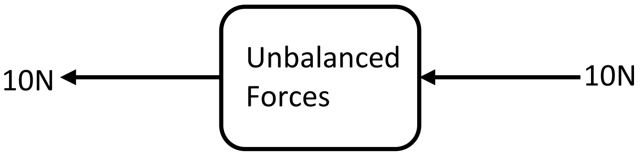
<u>Example 1</u>
Find the unbalanced force on the object shown.

<u>Solution 1</u>
The unbalaned force is obtained by combining the force vectors

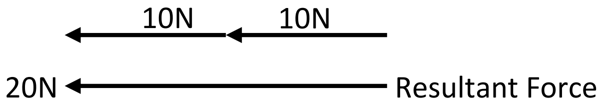


The unbalanced force is zero. When forces are balanced the unbalanced force is always zero.

<u>Example 2</u>
Find the unbalanced force on the object shown.

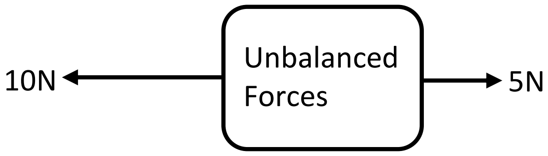


<u>Solution 2</u>
The unbalanced force is obtained by combining the force vectors.



Unbalanced Force, $F_u = 20\text{N}$ to the left

<u>Example 3</u>
Find the unbalanced force on the object shown.



<u>Solution 3</u>

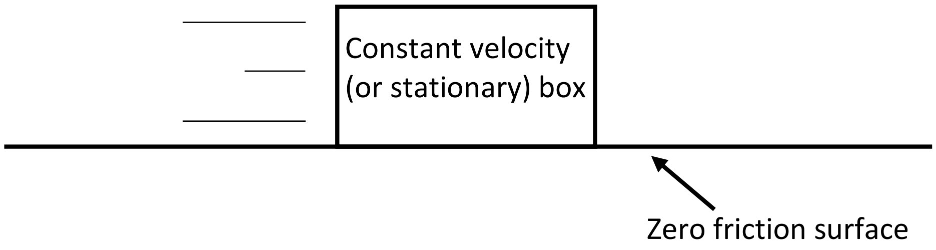
Unbalanced Force, $F_u = 5\text{N}$ to the left

4.3 I can understand Newton's First Law and can use it to explain the constant velocity (or speed) for a moving object.

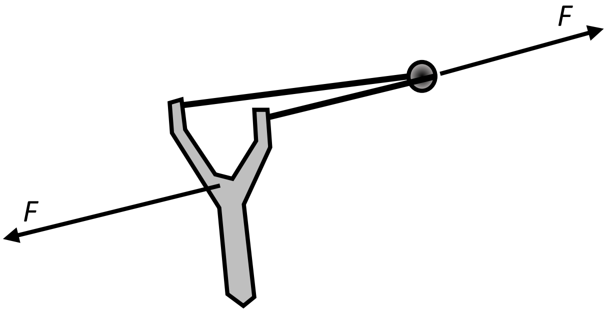
Newton's First Law states

> *An object in motion will move at a constant speed in a straight line unless acted upon by an unbalanced force.*

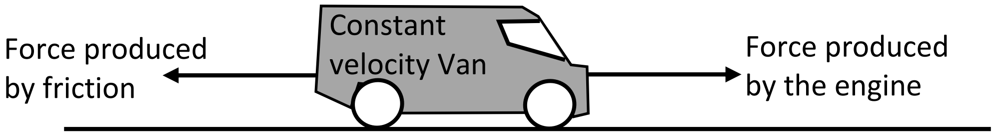
Constant Velocity (or stationary) No Forces
The consequence of Newton's First Law is that when all friction (and other forces) is absent the box below would keep moving at a constant speed (or remain stationary).
Real world boxes and other objects are subject to frictional forces which apply and unbalanced force. This force would cause the box to decelerate to a stop.



Stationary Balanced Forces
When the forces on and object are balanced the object can remain stationary. In a catapult about to be fired the forward and backward forces are balanced. The catapult remains in the same position.



Constant Velocity Balanced Forces
The van below is travelling at a constant velocity. The force produced by the engine is balanced by the frictional force. The unbalanced force is zero so the van travels at a constant velocity.



Dynamics and Space Problem Book Page 15 to 17 Questions 51 to 58.

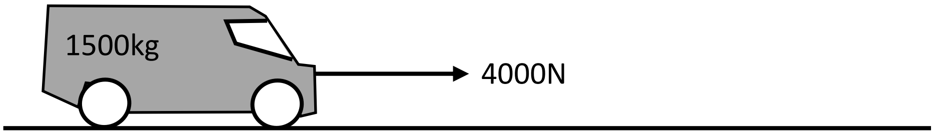
4.4 I can use Newton’s Second Law to solve problems involving unbalanced force, mass and acceleration.

Newton’s Second Law is a relationship between acceleration, mass and unbalanced force.

$$\underset{\text{Unbalanced Force (N)}}{F_{un}} = \underset{\text{Mass (kg)}}{m}\overset{\text{Acceleration (ms}^{-2}\text{)}}{a}$$

Example 1

The van below accelerates from stationary with only the engine force being applied. Calculate the van’s acceleration.



Solution 1

$F_{un} = 4000\text{N}$
$m = 1500\text{kg}$
$a = ?$

$$F_{un} = ma$$

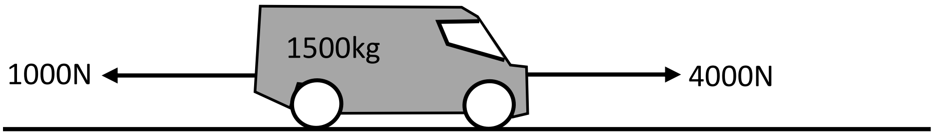
$$4000 = 1500 \times a$$

$$a = \frac{4000}{1500}$$

$$a = 2.7\text{ms}^{-2}$$

Example 2

Once the van starts moving air resistance increases as shown in the diagram. Find the acceleration of the van.



Solution 2

Find the unbalanced force
$F_{un} = 4000 - 1000 = 3000\text{N}$
$m = 1500\text{kg}$
$a = ?$

$$F_{un} = ma$$

$$3000 = 1500 \times a$$

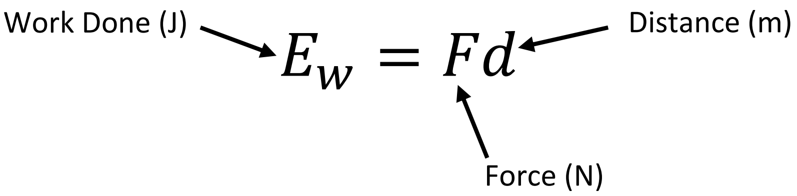
$$a = \frac{3000}{1500}$$

$$a = 2.0\text{ms}^{-2}$$

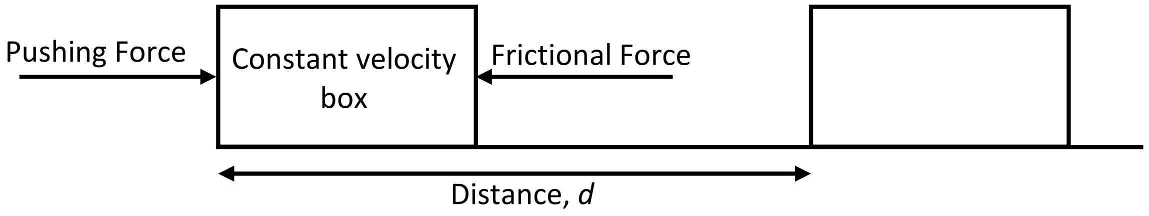
Dynamics and Space Problem Book Page 17 to 19 Questions 59 to 70.

4.5 I can use the relationship $E_w = Fd$ to solve problems involving work done, force and distance.

Work done is a type of energy. It is defined as the energy transferred when a force is moved through a distance.

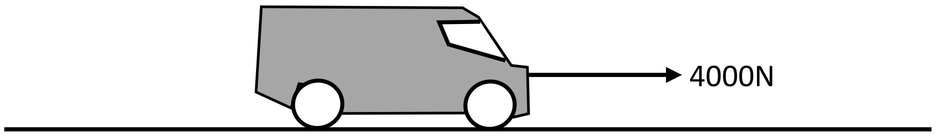


The pushing force moving the box through a distance *d* will transfer energy which will be transformed to heat by the frictional force. This energy is given by the relationship $E_w = Fd$.



Example

The van below is drives 20km at a consant speed. The engine produces a constant 4000N. Find the work done by the engine.



Solution

$E_w = ?$

$F = 4000\text{N}$

$d = 20\text{km} = 20 \times 10^3\text{m}$

$$E_w = Fd$$

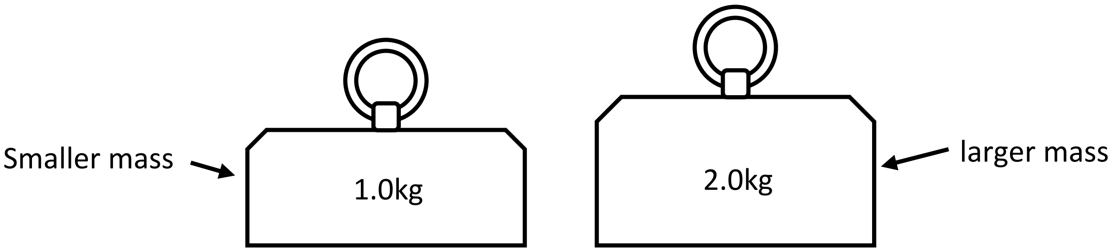
$$E_w = 4000 \times 20 \times 10^3$$

$$E_w = 8.0 \times 10^7\text{J}$$

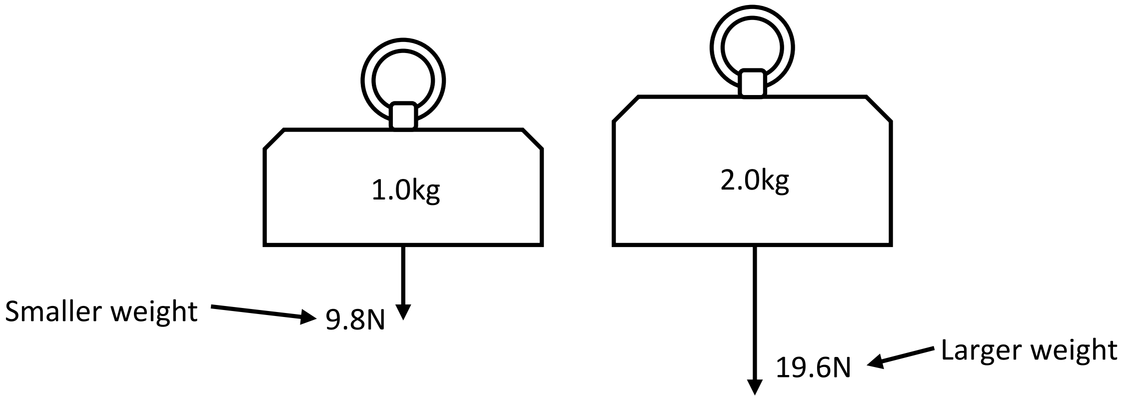
Dynamics and Space Problem Book Page 19 to 20 Questions 71 to 75.

4.6 I understand what is meant by the terms mass, weight and gravitational field strength.

Mass
Mass is a measure of the quantity of material in an object.
Mass is measured in kilograms (kg).
Mass is a scalar quantity.

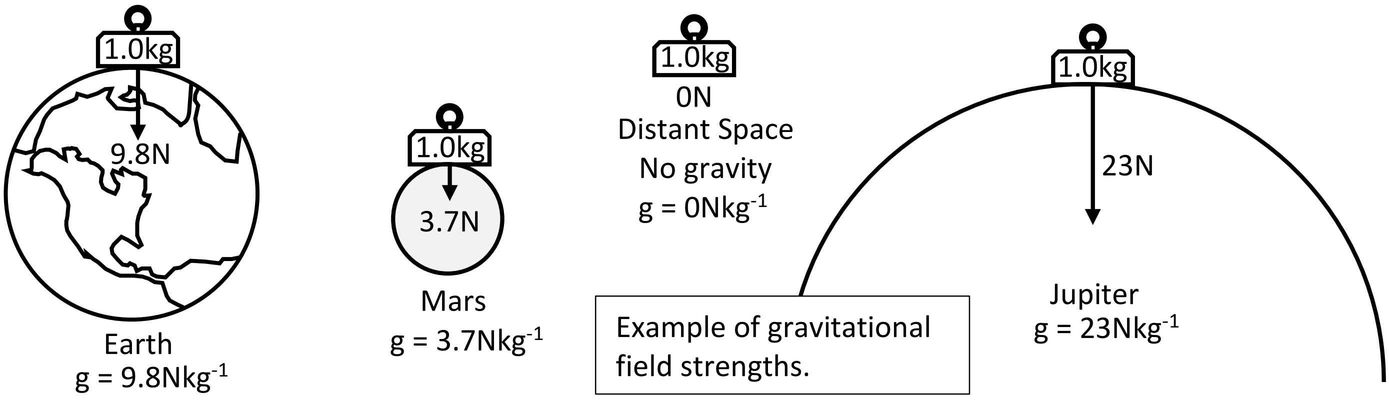


Weight
Weight is the gravitational force on a mass.
Weight is measured in Newtons (N).
Weight is a vector quantity.



Gravitational Field Strength

Gravitational field strength is the gravitational force per kilogram.
Gravitational field strength is measured in Newtons per kilogram (Nkg^{-1})
Gravitational field strength changes with the mass of the planet. The larger the planet's mass the greater the gravitational field strength.
Gravitational field strength changes with distance from the centre of a planet. The greater the distance the smaller the gravitational field strength.



Example of gravitational field strengths.

4.6 I can use the relationship $w = mg$ to solve problems involving weight, mass and gravitational field strength.

The relationship between weight, mass and gravitational field strength is given below.

$$\underset{\text{Weight (N)}}{w} = \underset{\text{Mass (kg)}}{m}\,\underset{\text{Gravitational Field Strength (Nkg}^{-1}\text{)}}{g}$$

To solve problems with this relationship you will need to look up values of gravitational field strength in the data sheet at the end of these notes.

<u>Example</u>

During the Apollo Moon landings the lander had a mass of 16,400kg. Calculate its weight

a. On Earth

b. On the Moon.

<u>Solution</u>

a.

$w = ?$

$m = 16{,}400\text{kg}$

$g = 9.8\text{Nkg}^{-1}$

$$w = mg$$

$$w = 16{,}400 \times 9.8$$

$$w = 160{,}000\text{N}$$

b.

$w = ?$

$m = 16{,}400\text{kg}$

$g = 1.6\text{Nkg}^{-1}$

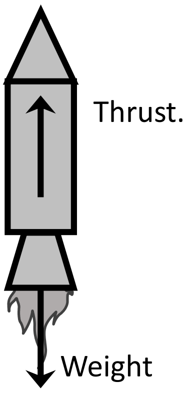
$$w = mg$$

$$w = 16{,}400 \times 1.6$$

$$w = 26{,}000\text{N}$$

Dynamics and Space Problem Book Page 20 to 22 Questions 76 to 85.

4.7 I can solve problems involving rocket launch, space travel and landings.



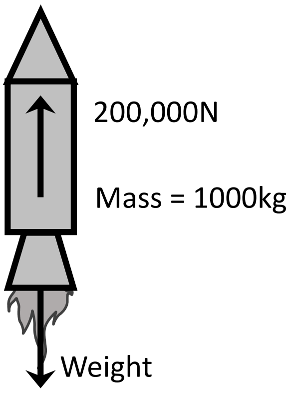
Rockets
When solving problems with rockets you need to find the resultant unbalanced force of two forces.

- Thrust which is the upward force produced by the engine.
- Weight produced by the mass of the rocket plus fuel in the gravitational field.

This unbalanced force can then be used in Newton's Second Law.

Example 1 Rocket Launch
A rocket is launched from the surface of the Earth. It has a of mass 1000kg and produces a thrust of 200,000N.

a. Calculate the initial acceleration of the rocket.
b. As the rocket rises state why its acceleration increases



Solution 1 Rocket Launch
Calculate the weight of the rocket

$w = ?$
$m = 1{,}000\text{kg}$
$g = 9.8\text{Nkg}^{-1}$

$$w = mg$$
$$w = 1{,}000 \times 9.8$$
$$w = 98{,}000\text{N}$$

Calculate the unbalanced force
$F_u = 200{,}000 - 98{,}000 = 102{,}000\text{N}$ upwards

Use Newtons Second Law to find the acceleration
$$F_u = ma$$
$$102{,}000 = 1000 \times a$$
$$a = \frac{102{,}000}{1000}$$
$a = 100\text{ms}^{-2}$ (Two significant figures in the answer as g is to two significant figures)

b. The acceleration increases for the following reasons
  - The mass of the rocket reduces as fuel is burnt.
  - The gravitational field strength reduces as its height increases.

Example 2 Space Flight

The Mars Explorer spacecraft is approaching Mars at 5.06 kilometres per second. It must decelerate at 0.38ms^{-2} for 35 minutes to slow its speed sufficiently to enter orbit around Mars. The mass of the spacecraft is 264kg. Find the thrust that needs to be produced by the engine. Assume that the spacecraft is far enough away from Mars that the gravitational field strength is negligible and that the variation in mass due to the fuel used is negligible.

Solution 2 Space Flight

$F_u = ?$

$m = 264\text{kg}$

$a = 0.38\text{ms}^{-2}$

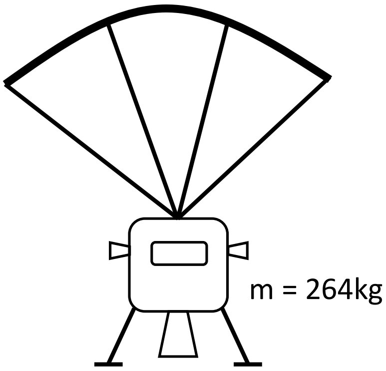
$$F_u = ma$$

$$F_u = 264 \times 0.38$$

$$F_u = 100\text{N}$$

Example 3 Landings

The Mars Explorer spacecraft in example 2 descends by parachute to the surface of Mars. It must approach the surface at a constant speed of 1.2ms^{-1}. Find the upward force produced by the parachute.



Example 3 Landings

The lander is approaching the surface at a constant speed so the forces must be balanced. The upward force from the parachute must balance the weight of the spacecraft.

$w = ?$

$m = 264\text{kg}$

$g = 3.7\text{Nkg}^{-1}$

$$w = mg$$

$$w = 264 \times 3.7$$

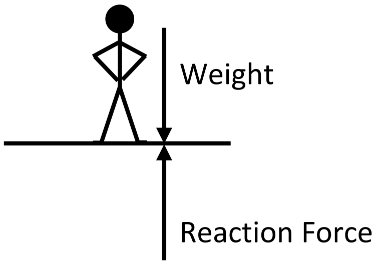
$$w = 980\text{N}$$

Dynamics and Space Problem Book Page 24 Question 87.

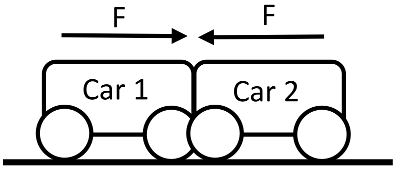
4.8 I can state Newton's Third Law and the effect of the reaction force on motion.

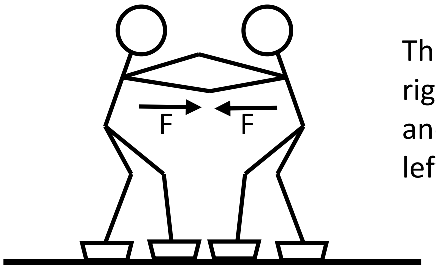
Newton's Third Law states
When one object exerts a force on another object the second object produces a force on the first object of the same magnitude but opposite direction.

The weight of someone standing on the ground deforms the ground enough to produce an equal and opposite reaction force.



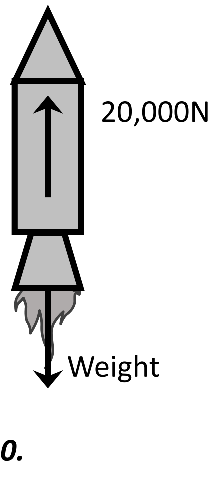
During a collision car 1 exerts a force on car 2. Car 2 exerts and equal and opposite force on car 1.





The skater on the left pushes the skater on the right. The skater on the right produces an equal and opposite reaction force on the skater on the left. Both skaters move in opposite directions.

The rocket produces a force on the exhaust gases and the exhaust gases produce and equal and opposite reaction force on the rocket. The rocket moves upward and the exhaust gases downwards.

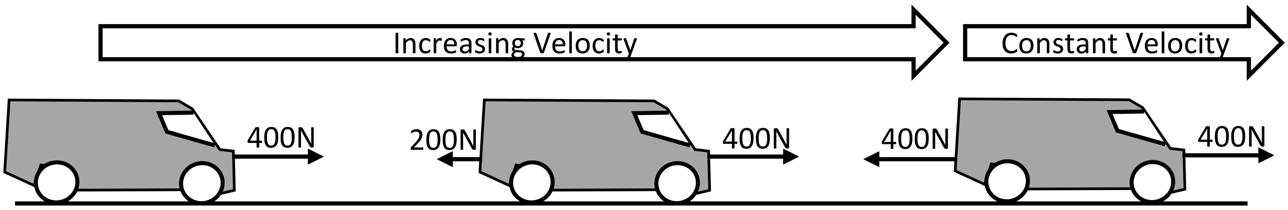


Dynamics and Space Problem Book Page 24 and 25 Question 88 to 90.

4.9 I can explain free-fall and terminal velocity.

Terminal Velocity

When an unbalanced force is acting on an object it will accelerate. When moving through the air, as its speed increases the friction also increases. This will reduce the size of the unbalanced force and reduce the acceleration. The object will continue to accelerate until the forces are balanced. It will then travel at constant velocity. This is called terminal velocity.



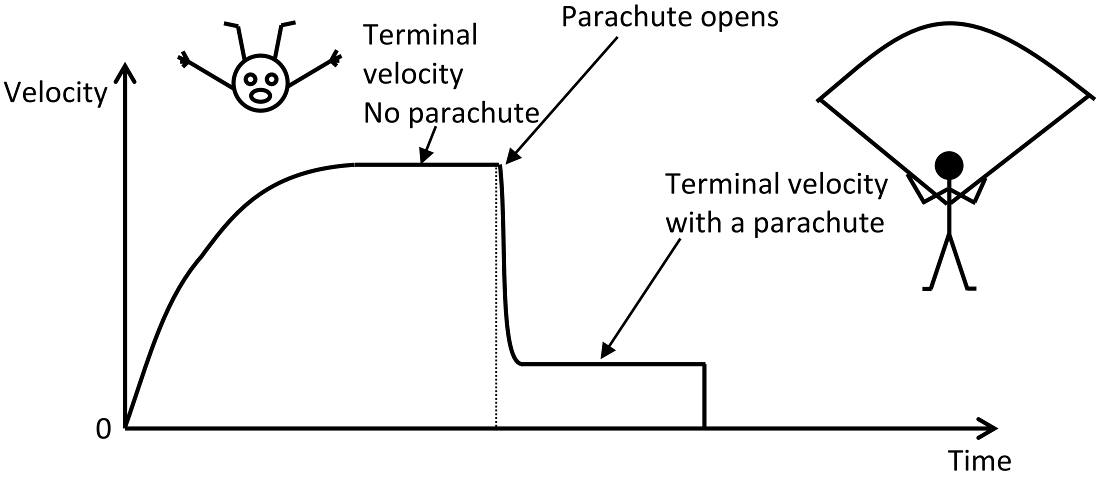
Van accelerating from stationary
Engine force = 400N
Friction force = 0N

Moving, accelerating van
Engine force = 400N
Friction force = 200N

Faster van, terminal velocity
Engine force = 400N
Friction force = 400N

Free-fall

When stepping out of an aeroplane, initially the only force acting of the parachutist is the weight. As they fall their velocity and the frictional force acting on them increase until they balance the weight. The parachutist then descends at terminal velocity.
Once the parachute is opened the frictional force is increased. The parachutist decelerates until the frictional force balances the weight again. The parachutist then descends at a lower terminal velocity.



Dynamics and Space Problem Book Page 26 and 27 Question 93.

Key Area: Projectile Motion

Success Criteria

5.1 I can explain projectile motion.

5.2 I can use the relationships $a = \frac{v-u}{t}$ and $v = \frac{s}{t}$ to solve problems involving projectiles launched horizontally.

5.3 I can use velocity time graphs to solve problems involving projectiles launched horizontally.

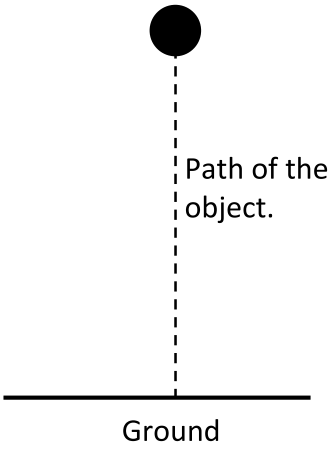
5.4 I can explain satellite orbits in terms of projectile motion, horizontal velocity and weight.

5.1 I can explain projectile motion

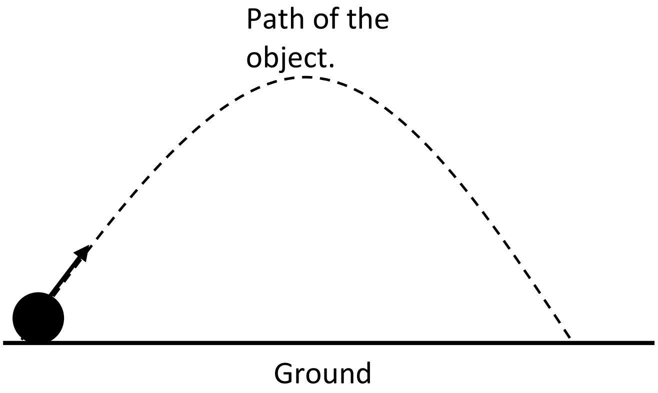
A projectile is an object which is moving solely under the influence of gravity. There are no other forces acting on the object other than the gravitational force.

The paths followed by projectiles will be either a straight vertical path or a parabolic path.

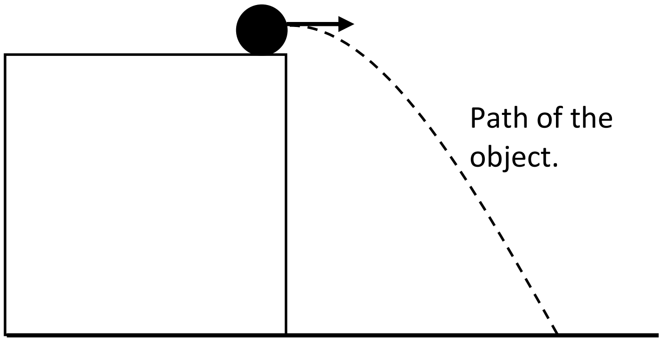
An object dropped vertically



An object Launched at an angle.



An object Launched horizontally.



The parabolic path of an object can be understood by splitting the path into two parts called components; a horizontal component and a vertical component.

Horizontal Component

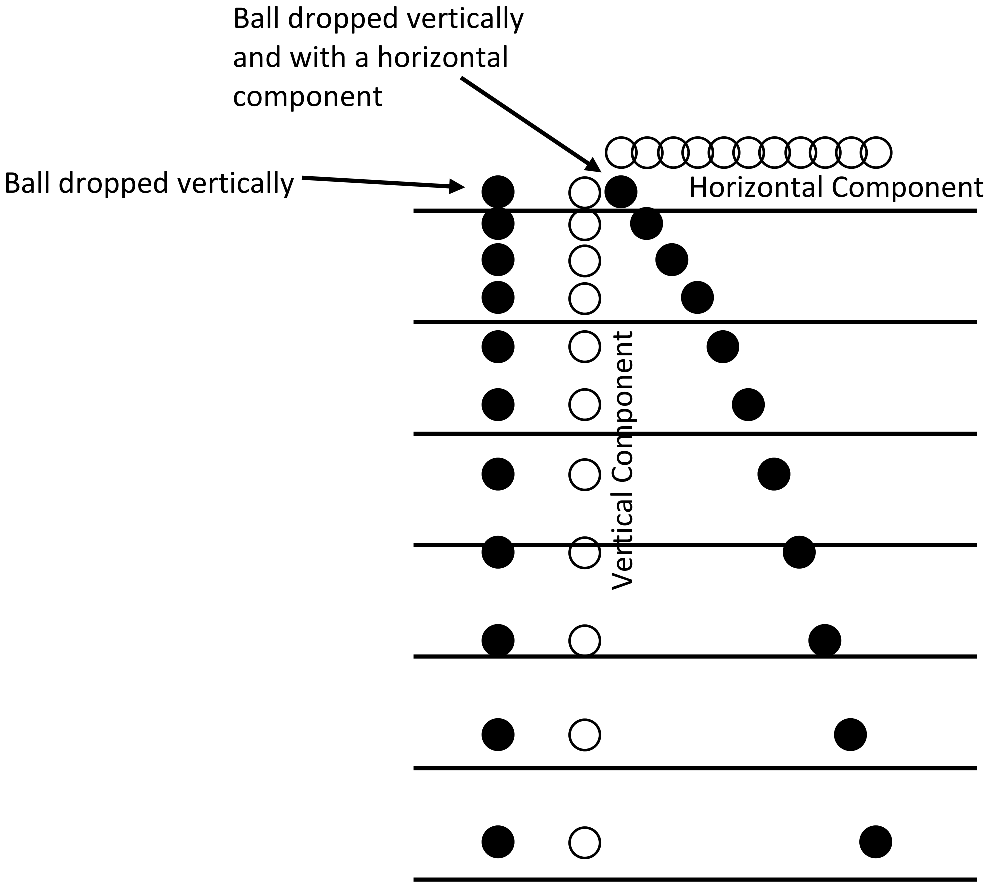
As there is no horizontal force the object will move horizontally at a constant velocity. The relationship $v = \frac{s}{t}$ can be used for solving problems.

Vertical Component

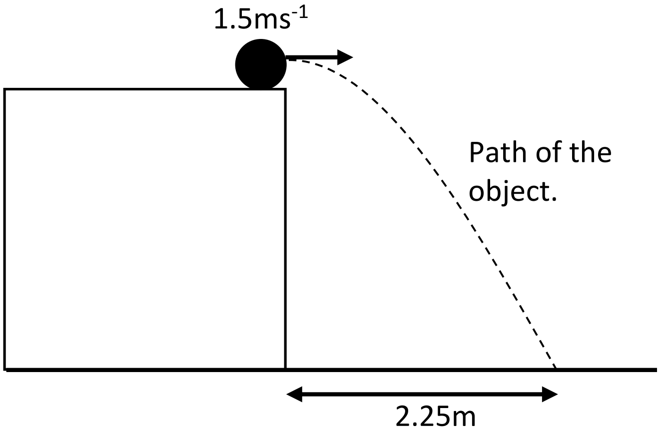
The force of gravity (weight) of the object will cause it to accelerate vertically downwards. The relationship $a = \frac{v-u}{t}$ can be used when solving problems.

In the diagram below, the left ball initially has zero vertical and zero horizontal components. It accelerates downwards. The right ball has a zero vertical component but is given a horizontal component to its motion.

The horizontal and vertical components act independently. This can be seen in the diagram. The vertical motion for both balls is identical. The horizontal motion given to the ball on the right does not affect its vertical motion.



5.2 I can use the relationships $a = \frac{v-u}{t}$ and $v = \frac{s}{t}$ to solve problems involving projectiles launched horizontally.



Example

A ball roll from a table at a velocity of 1.5ms^{-1}.

a. State the initial horizontal velocity of the ball.

b. State the initial vertical velocity of the ball.

c. If the ball hits the ground 2.25m from the launch find the time taken for the ball to fall.

d. Find the vertical velocity of the ball as it strikes the ground.

Solution

a. 1.5ms^{-1}

b. 0ms^{-1}

c. Take horizontal motion

$v = 1.5\text{ms}^{-1}$
$s = 2.25\text{m}$
$t = ?$

$$v = \frac{s}{t}$$
$$1.5 = \frac{2.25}{t}$$
$$t = \frac{2.25}{1.5}$$
$$t = 1.5\text{s}$$

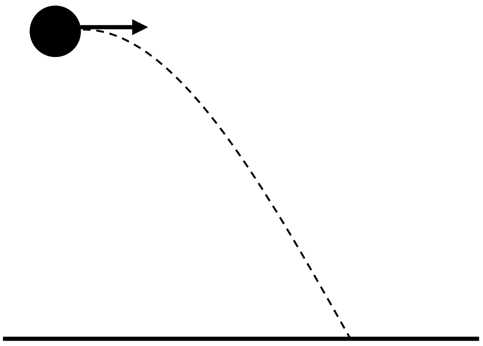
d. Take vertical motion

$a = 9.8\text{ms}^{-2}$
$u = 0\text{ms}^{-1}$
$v = ?$
$t = 1.5\text{s}$

$$a = \frac{v-u}{t}$$
$$9.8 = \frac{v-0}{1.5}$$
$$v = 1.5 \times 9.8$$
$$v = 15\text{ms}^{-1}$$

Problem book page 27 and 28 questions 94 to 96

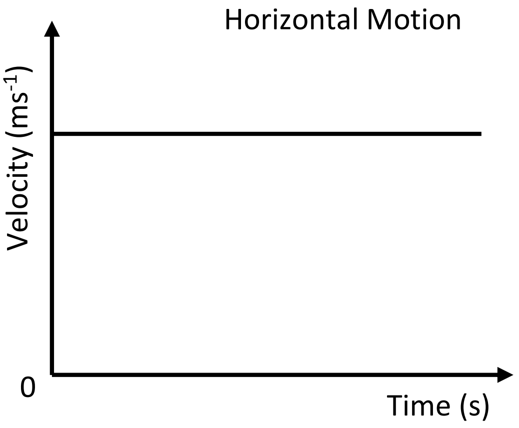
5.3 I can use velocity time graphs to solve problems involving projectile launched horizontally.

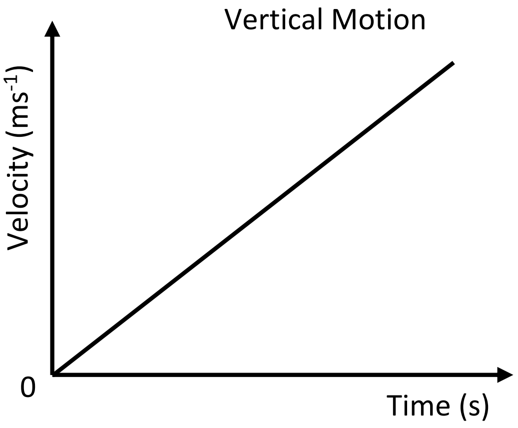


For a projectile launched horizontally

- The horizontal motion will be constant velocity.
- Vertical motion will be constant acceleration.

Graphs of horizontal motion and vertical motion are shown below.



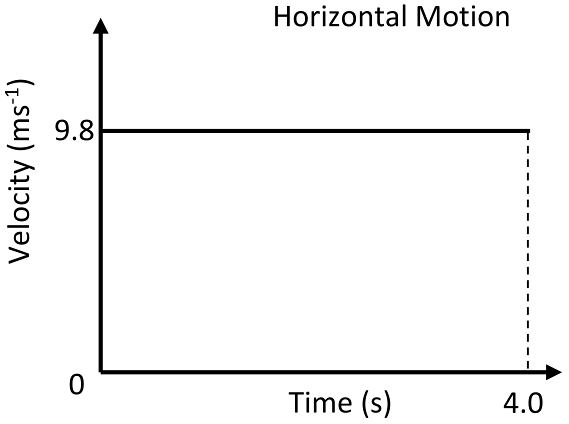


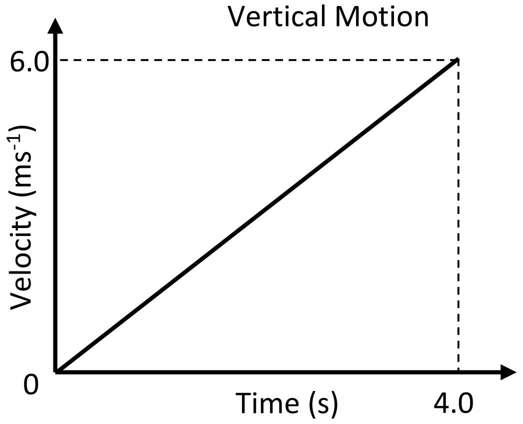
Information read from these velocity time graphs can be used to solve projectile motion problems. The table below show what can be found from each graph.

Horizontal Motion Graph	Vertical Motion Graph
Horizontal speed (constant)	Vertical speed
Horizontal range from the area under the graph	Vertical height from the area under the graph
	Acceleration from the gradient of the graph

Example

The velocity time graphs of a horizontally launched projectile are shown below.





Find

a. The initial horizontal velocity of the projectile
b. The vertical velocity as it hits the ground
c. The horizontal distance travelled.
d. The height from which the projectile was launched.

Solution

a. From the left graph 9.8ms^{-1}.
b. From the right graph 6.0ms^{-1}.
c. Horizontal distance is given by area under the horizontal velocity time graph.

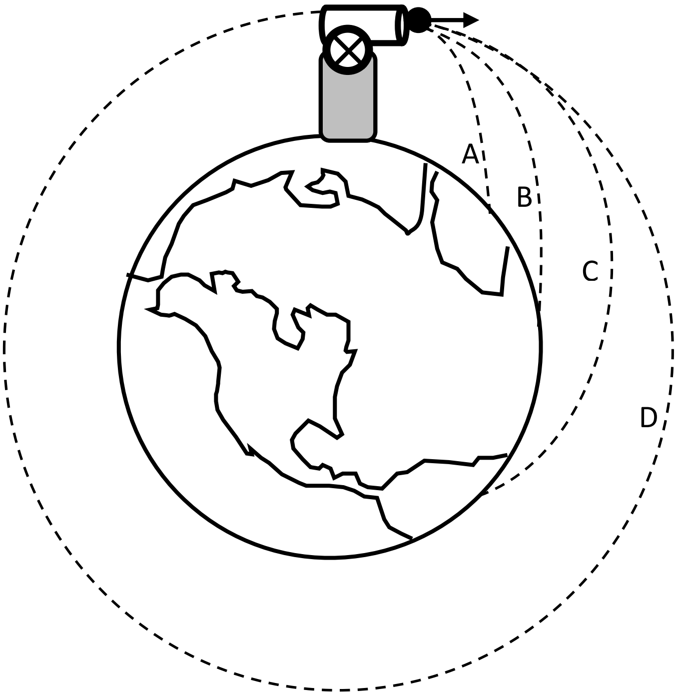
$$\text{Distance} = 9.8 \times 4.0 = 39\text{m}$$

d. The vertical distance is given by the area under the vertical speed time graph.

$$\text{Height} = \frac{1}{2} \times 4.0 \times 6.0 = 12\text{m}$$

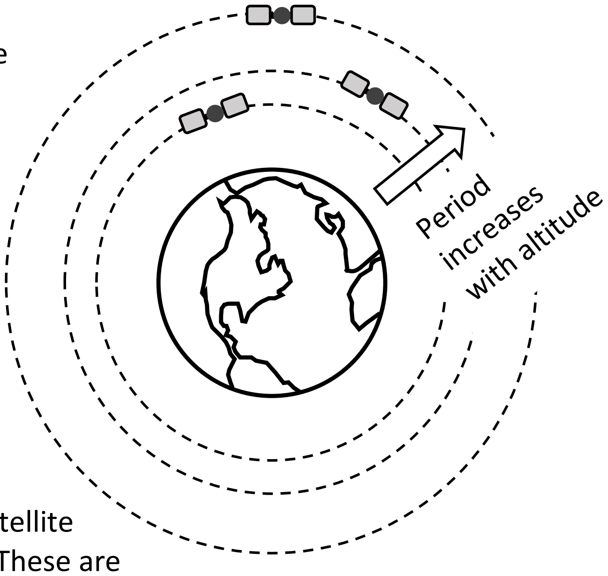
Problem book page 28 questions 97, page 35 question 112 and 113

5.4 I can explain satellite orbits in terms of projectile motion, horizontal velocity and weight.



Newton's Thought Experiment
Newton imagined a cannon placed on a high mountain. This fired a cannonball at different horizontal velocities. The cannon ball would move in a straight line at constant speed if there was no weight acting on the ball. The weight causes the ball to change direction and follow a curved path. As the horizontal velocity of the cannonball is increased the range increases from A to C. As the Earth is curved the range is larger than it would be on a flat surface. The Earth curves away from the falling projectile. If launched at a high enough horizontal velocity, D, the rate at which the cannonball falls is the same as the curvature of the Earth. The cannonball never strikes the surface and continues to circle the Earth as a satellite.

5.5 I know the relationship between the altitude of a satellite and its period.



When a satellite orbits the Earth the time it takes to make one orbit is called the period. The period of satellites depends on their altitude. The greater the altitude the longer the period.

Satellite	Altitude	Period
International Space Station	400km	93 minutes
GPS satellites	20200km	12hours
Sky TV Astra Satellite	36000km	24hours

When a satellite is placed in an orbit at an altitude of 36,000km above the equator its period will be 24hours. This matches the period of rotation of the Earth so the satellite will remain at the same point above the Earth's surface. These are called geostationary satellites. They are usually used as commutation satellites as satellite dishes on the ground can be kept pointing to the same spot in the sky.

Problem book page 29 questions 98 and 99.
page 34 question 111

Key Area: Space Exploration

Previous Knowledge

Success Criteria

6.1 I can use the following terms correctly: planet, dwarf planet, moon, Sun, asteroid, solar system, star, exoplanet, galaxy, universe.

6.2 I can describe some of the benefits of using satellites.

6.3 I can describe some of the risks of space exploration.

6.4 I understand the term “latent heat” and can solve problems using the relationship $E = ml$.

6.5 I am aware of the challenges of space travel.

6.1 I can use the following terms correctly: planet, dwarf planet, moon, Sun, asteroid, solar system, star, exoplanet, galaxy, universe.

Astronomical Term	Definition
planet	A large natural satellite of a star
dwarf Planet	A small natural satellite of a star big enough to be spherical
moon	Any natural object orbiting a planet
Sun	The Star in our solar system
asteroid	A rocky object, smaller than a dwarf planet.
Solar System	This consists of the Sun, the planets and their moons, asteroids and comets.
star	A large ball of gas where nuclear reactions produce heat and light.
exoplanet	A planet orbiting any star other than the Sun
galaxy	A large group of stars held together by gravity.
Universe	All the galaxies and all space. Everything!

6.2 I can describe some of the benefits of using satellites

There are many benefits of space exploration. The table below show some examples of the benefits of satellites.

Satellite System	Benefits
Communication Satellites	Provides long distance telephone calls, television, data transfer
GPS satellites	Navigation, vehicle tracking, speed data for sporting activities
Weather satellites	Can predict the weather and give storm warnings.
Agricultural tracking	Monitoring the growth of crops over a large area.
Space telescopes	Telescopes in space to explore the solar system and deep space.

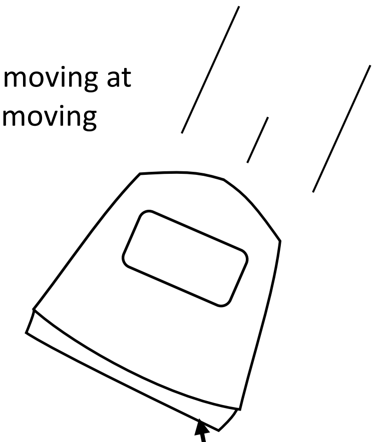
6.3 I can describe some of the risks of space exploration

There are many risks assassinated with space exploration. Examples of these are;

- The vacuum of space. There is no atmosphere beyond the surface of the earth. Other planet possess and atmosphere but this cannot used for breathing.
- Low temperatures. The temperature of space far from the Sun is 2.7K is very low.
- Risk of explosion during launch.
- Radiation exposure increased during space flight.
- Re-entering the Earth's atmosphere from space causes dangerous heating of the spacecraft.

Problem book
page 30 and 31 question 101.
page 34 question 110
page 36 question 114

6.4 I understand the term "latent heat" and can solve problems using the relationship $E = ml$.



When spacecraft are re-entering the Earth's atmosphere they are usually moving at high speed. These spacecraft are slowed by the friction of the spacecraft moving through the atmosphere. This causes the spacecraft to heat up to high temperatures.

The heat shield on a spacecraft can do two things

- It insulates the spacecraft from the high temperatures.
- It absorbs some of the energy produced by friction by evaporating material from the heat shield.

The energy absorbed and the mass of heat shield evaporated are related by the relationship $E = ml$.

Energy (J) →

$$E = ml$$

Mass (kg)

Latent heat of vaporisation
or
Latent heat of fusion
(Jkg^{-1})

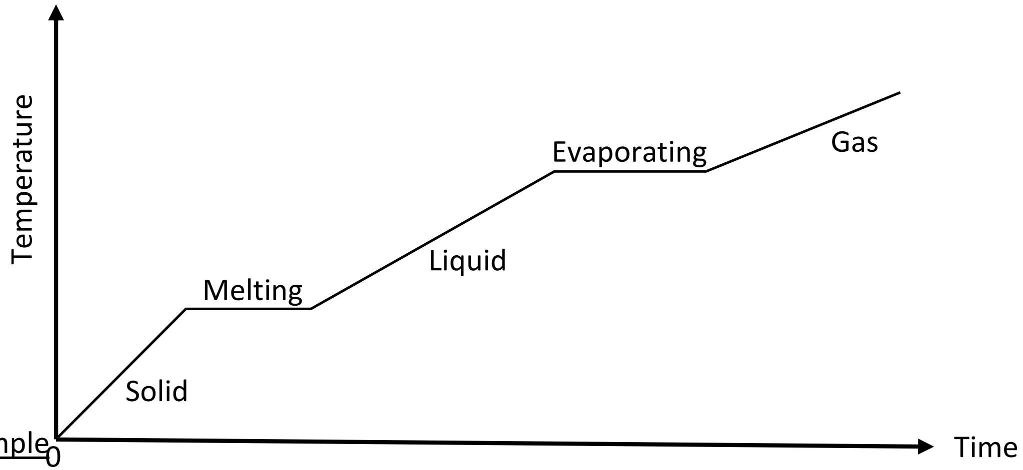
The latent heat term is specific to each type of material and is given in the data sheet.

Latent Heat of Fusion and Latent Heat of Vaporisation

The graph below shows a solid which is heated until it turns into a liquid and then into a gas. In the regions marked solid, liquid and gas the material is rising in temperature. In these regions, the relationship E$= mc\Delta T$ can be used to relate temperature and energy.

In the regions marked melting and evaporating the temperature is constant and the relationship $E = ml$ must be used.

The latent heat of fusion is used when the material is melting or freezing. The latent heat of vaporisation is used when the material is evaporation or condensing. For 1kg of a substance the quantity of heat required to change state between solid and liquid is different from the heat required to change between liquid and a gas.



Example

Medical supplies are kept cool using a 1.2kg block of ice which absorbs energy as it melts. Calculate the energy absorbed as all the ice melts.

Solution

$m = 1.2\text{kg}$

$l = 3.34 \times 10^5 \text{Jkg}^{-1}$

$$E = ml$$
$$E = 1.2 \times 3.34 \times 10^5$$
$$E = 400{,}000\text{J}$$

Problem book pages 32 and 33 to questions 102 to 109.

6.5 I am aware of the challenges of space travel.

There are several challenges to travelling in space.

Travelling large distances

Other than low orbit satellite travelling in space involves huge distances. e.g. the closest astronomical object is the Moon which is 384,400 km from Earth, the distance to Mars is 225 million km. All other distances are much larger.

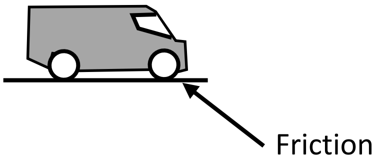
Travelling such distances can be done using either

- Chemical rockets where a large initial acceleration is given to the spacecraft which then travels a near constant speed to its destination.
- Gravity assistance from other planets where the energy of a moving planet is used to accelerate a spacecraft.
- Ion engine which provides a small force (approximately 1N) over a period of weeks or months to accelerate a spacecraft to high speed.

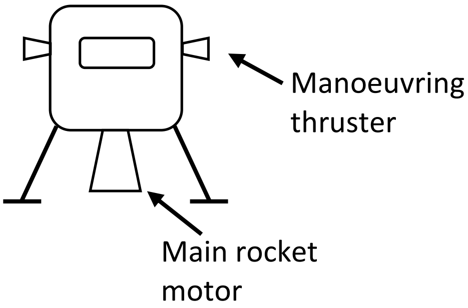
Frequently more than one of these methods are used. Currently only chemical rockets can be used to launch a spacecraft from the surface of the Earth.

Manoeuvring a space craft in a zero-friction environment

On Earth moving an object from one place to another usually involves friction e.g. to move a vehicle, friction between the tyres and the road is required.



In the vacuum of space there is no friction. Manoeuvring is usually achieved by using small thruster rockets.



Powering Spacecraft and Maintaining sufficient energy to operate life support system

There are three main methods of obtaining energy to power spacecraft.

Radioactive isotopes

These produce heat as the radioactive material decays. This is then converted to an electrical current using thermocouples. This method is used for robotic probes going to the outer solar system where there is insufficient sunlight to use solar cells.

Fuel Cells

These combine hydrogen and oxygen to directly produce an electrical current. These are limited to short duration trips as only a limited quantity fuel can be carried.

Solar Cells

These are used for the majority of spacecraft in the inner solar system and in Earth orbit. They give a long-term supply of electrical current. A disadvantage for spacecraft in orbit is that solar cells do not provide power when shaded by the Earth. This requires the spacecraft to be equipped with rechargeable batteries.

Key Area: Cosmology

Success Criteria

7.1 I understand the term light year and can convert between light years and metres.

7.2 I can describe some features of the observable universe, its origin and its age.

7.3 I know that different parts of the electromagnetic spectrum can be used to gather information about astronomical objects.

7.4 I can identify continuous and line spectra.

7.5 I can use line spectra to identify elements within stars.

7.1 I understand the term light year and can convert between light years and metres.

Definition: A light year is the **distance** travelled by light in a vacuum in one year.

A light year is used to give distances in space to objects that are outside our solar system e.g. the closest star Proxima Centauri is 4.24 light years from Earth.

The relationship between Light Years and Metres

Number of seconds in a year $\underbrace{365}_{\text{Number of days in a year}} \times \underbrace{24}_{\text{Number of hours in a day}} \times \underbrace{60}_{\text{Number of minutes in an hour.}} \times \underbrace{60}_{\text{Number of seconds in a minute}} = 31{,}536{,}000\mathrm{s}$

From the data sheet at the end of these notes the speed of light is $3.0 \times 10^8 \mathrm{ms}^{-1}$.
Using $d = vt$

$$d = 3.0 \times 10^8 \times 31{,}536{,}000$$

$$d = 9.5 \times 10^{15}\mathrm{m}$$

To convert light years into metres, multiply by 9.5×10^{15}
To convert metres into light years, divide by 9.5×10^{15}

Problem book
Page 37 questions 115 to 119
page 41 question 129.

7.2 I can describe some features of the observable universe, its origin and its age.

In the beginning the universe started in a hot dense state much smaller than an atom. From this state the universe expanded and cooled. This expansion is called “the Big Bang”. After around 370,000 years the universe had cooled sufficiently for atoms of hydrogen and helium to form. These atoms gathered together under the influence of gravity to form stars and groups of stars called galaxies.

Currently the observable universe consists of billions of galaxies each containing hundreds of billions of stars. There are also clouds of dust and gas which are either remains of old stars of some of the gas left from the start of the universe.

The size of the observable universe is 93 billion light years. There are parts of the universe which are beyond what it is possible to observe. The true extent is currently unknown.

Our solar system was formed 4.6 billion years ago. This is in the Milky Way galaxy which contains 100 to 400 billion stars.

The best current estimate of the age of the universe is 13.82 billion years $(1.382 \times 10^{10} \text{ years})$.

7.3 I know that different parts of the electromagnetic spectrum can be used to gather information about astronomical objects.

All the bands in the electromagnetic spectrum can be used to gather information about astronomical objects

Radio Waves	Microwaves	Infra-red	Visible	Ultraviolet	X-rays	Gamma

The earth atmosphere blocks most of the infra-red, ultraviolet, x-rays and gamma rays. Telescopes which use these wavelengths must be placed above the atmosphere, usually in orbit.

Radio Telescopes
These are large satellite dish telescopes frequently used in groups in order to form images of radio sources in galaxies.

Microwave Telescopes
These are usually used to look at the cosmic microwave background radiation which is radiation left from the formation of the universe.

Infra-red Telescopes
These telescopes are frequently used to observe the sun. These telescope can also be used to see though the dust cloud around the centre of our galaxy. They are either placed in orbit around the Earth or around the Sun.

Visible Telescopes
These are used to observe planets, stars, galaxies and other astronomical objects. They can be on the Earth or in orbit. The best know example is the Hubble Space Telescope.

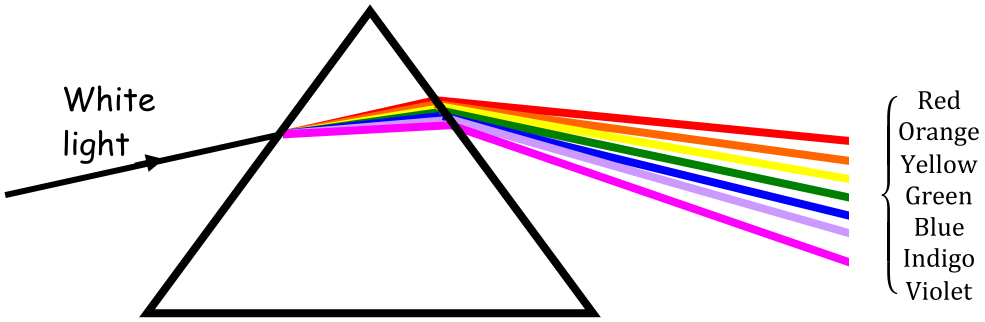
Ultraviolet Telescopes
There have been few ultraviolet telescopes as they must be above the Earth's atmosphere. These have been used to observe comets.

X-ray and gamma
These telescopes are placed in orbit and a used to look for high energy x-rays and gamma rays coming from distant quasars (very active distant galaxies).

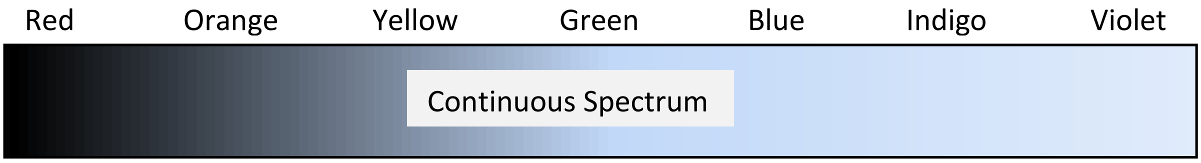
Problem book page 38 question 123

7.4 I can identify continuous and line spectra.

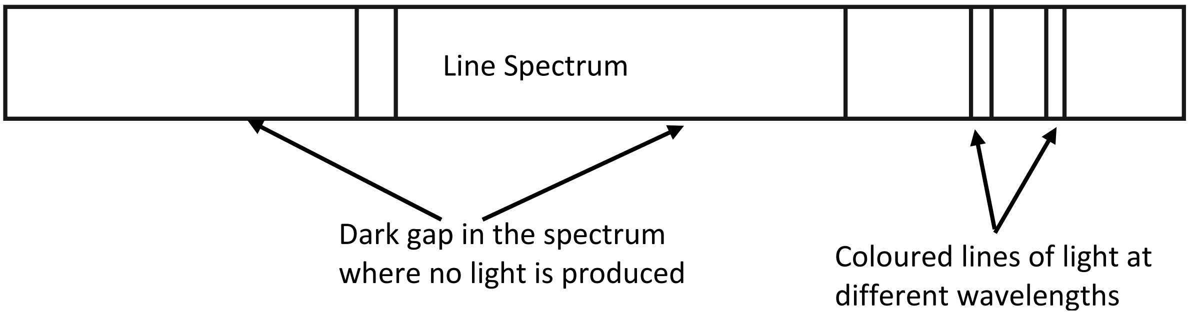
Light from distant stars and galaxies can be split into its spectrum of colours using a prism.



The spectrum produced is a continuous spectrum which consists of all the colours from red to violet without any gaps.



Another type of spectrum which can be produced is the line spectrum which consists of lines of different colours with dark gaps in between.

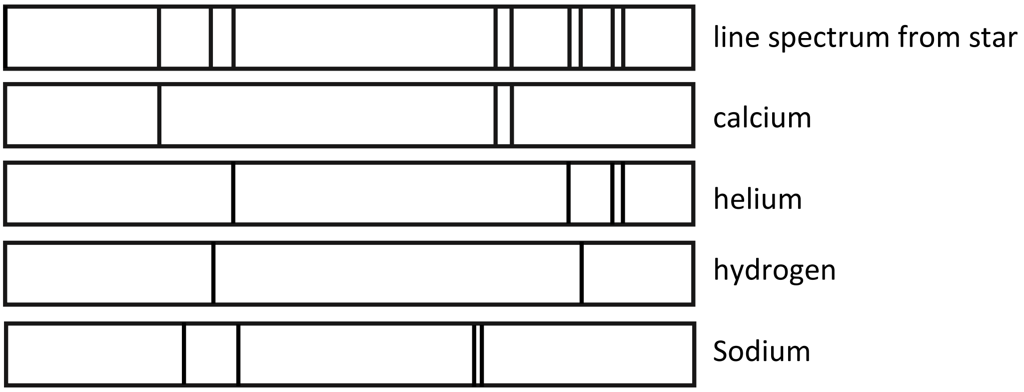


7.5 I can use line spectra to identify elements within stars.

Each element produces its own line spectrum which contains a different pattern of lines from the other elements. By comparing the spectrum produced by a star's light it is possible to work out which elements it contains.

Example

The line spectrum from the star is shown, along with the line spectra of the elements calcium, helium, hydrogen and sodium. Which elements are present in the star



Solution

Matching each of the lines in each of the elements to the lines in the spectrum. It can be seen that all the lines in calcium, helium and hydrogen occur in the line spectrum from the star. None of the sodium lines occur. The star must contain calcium, helium and hydrogen but no sodium.

Problem book Pages 39 and 40 questions 126 to 128

Quantities, Units and Multiplication Factors

Quantity	**Quantity Symbol**	**Unit**	**Unit Abbreviation**
Acceleration	a	Metre per second squared	ms^{-2}
Average Speed	$\bar{v}$	Metre per second	ms^{-1}
Displacement	s	Metre, degree	m,°
Energy	E	Joule	J
Force	F	Newton	N
Gravitational field strength	g	Newton per kilogram	Nkg^{-1}
Height	h	metre	m
Instantaneous Speed	v	metre per second	ms^{-1}
mass	m	kilogram	kg
Time	t	Second	s
Velocity	v	metre per second, degree	$\mathrm{ms}^{-1}, °$
Weight	w	Newton	N

Prefix Name	Prefix Symbol	Multiplication Factor
Pico	p	$\times 10^{-12}$
Nano	n	$\times 10^{-9}$
Micro	µ	$\times 10^{-6}$
Milli	m	$\times 10^{-3}$
Kilo	k	$\times 10^{3}$
Mega	M	$\times 10^{6}$
Giga	G	$\times 10^{9}$
Tera	T	$\times 10^{12}$

You **WILL NOT** be given the tables on this page in any tests or the final exam.

Relationships Sheet

You will be given this sheet in tests and the final exam.

$$E_p = mgh$$

$$E_k = \frac{1}{2}mv^2$$

$$Q = It$$

$$V = IR$$

$$R_T = R_1 + R_2 + \ldots$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

$$V_2 = \left(\frac{R_2}{R_1 + R_2}\right)V_s$$

$$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$

$$P = \frac{E}{t}$$

$$P = IV$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$E_h = cm\Delta T$$

$$p = \frac{F}{A}$$

$$\frac{pV}{T} = \text{constant}$$

$$p_1V_1 = p_2V_2$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

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

$$d = vt$$

$$v = f\lambda$$

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

$$A = \frac{N}{t}$$

$$D = \frac{E}{m}$$

$$H = Dw_R$$

$$\dot{H} = \frac{H}{t}$$

$$s = vt$$

$$d = \overline{v}t$$

$$s = \overline{v}t$$

$$a = \frac{v-u}{t}$$

$$W = mg$$

$$F = ma$$

$$E_w = Fd$$

$$E_h = ml$$

DATA SHEET

You will be given this sheet in tests and in the final exam.

Speed of light in materials

Material	*Speed* in m s^{-1}
Air	$3{\cdot}0 \times 10^8$
Carbon dioxide	$3{\cdot}0 \times 10^8$
Diamond	$1{\cdot}2 \times 10^8$
Glass	$2{\cdot}0 \times 10^8$
Glycerol	$2{\cdot}1 \times 10^8$
Water	$2{\cdot}3 \times 10^8$

Gravitational field strengths

	Gravitational field strength on the surface in N kg^{-1}
Earth	9·8
Jupiter	23
Mars	3·7
Mercury	3·7
Moon	1·6
Neptune	11
Saturn	9·0
Sun	270
Uranus	8·7
Venus	8·9

Specific latent heat of fusion of materials

Material	*Specific latent heat of fusion* in J kg^{-1}
Alcohol	$0{\cdot}99 \times 10^5$
Aluminium	$3{\cdot}95 \times 10^5$
Carbon Dioxide	$1{\cdot}80 \times 10^5$
Copper	$2{\cdot}05 \times 10^5$
Iron	$2{\cdot}67 \times 10^5$
Lead	$0{\cdot}25 \times 10^5$
Water	$3{\cdot}34 \times 10^5$

Specific latent heat of vaporisation of materials

Material	*Specific latent heat of vaporisation* in J kg^{-1}
Alcohol	$11{\cdot}2 \times 10^5$
Carbon Dioxide	$3{\cdot}77 \times 10^5$
Glycerol	$8{\cdot}30 \times 10^5$
Turpentine	$2{\cdot}90 \times 10^5$
Water	$22{\cdot}6 \times 10^5$

Speed of sound in materials

Material	*Speed* in m s^{-1}
Aluminium	5200
Air	340
Bone	4100
Carbon dioxide	270
Glycerol	1900
Muscle	1600
Steel	5200
Tissue	1500
Water	1500

Specific heat capacity of materials

Material	*Specific heat capacity* in J kg^{-1} °C^{-1}
Alcohol	2350
Aluminium	902
Copper	386
Glass	500
Ice	2100
Iron	480
Lead	128
Oil	2130
Water	4180

Melting and boiling points of materials

Material	*Melting point* in °C	*Boiling point* in °C
Alcohol	−98	65
Aluminium	660	2470
Copper	1077	2567
Glycerol	18	290
Lead	328	1737
Iron	1537	2737

Radiation weighting factors

Type of radiation	*Radiation weighting factor*
alpha	20
beta	1
fast neutrons	10
gamma	1
slow neutrons	3
X-rays	1