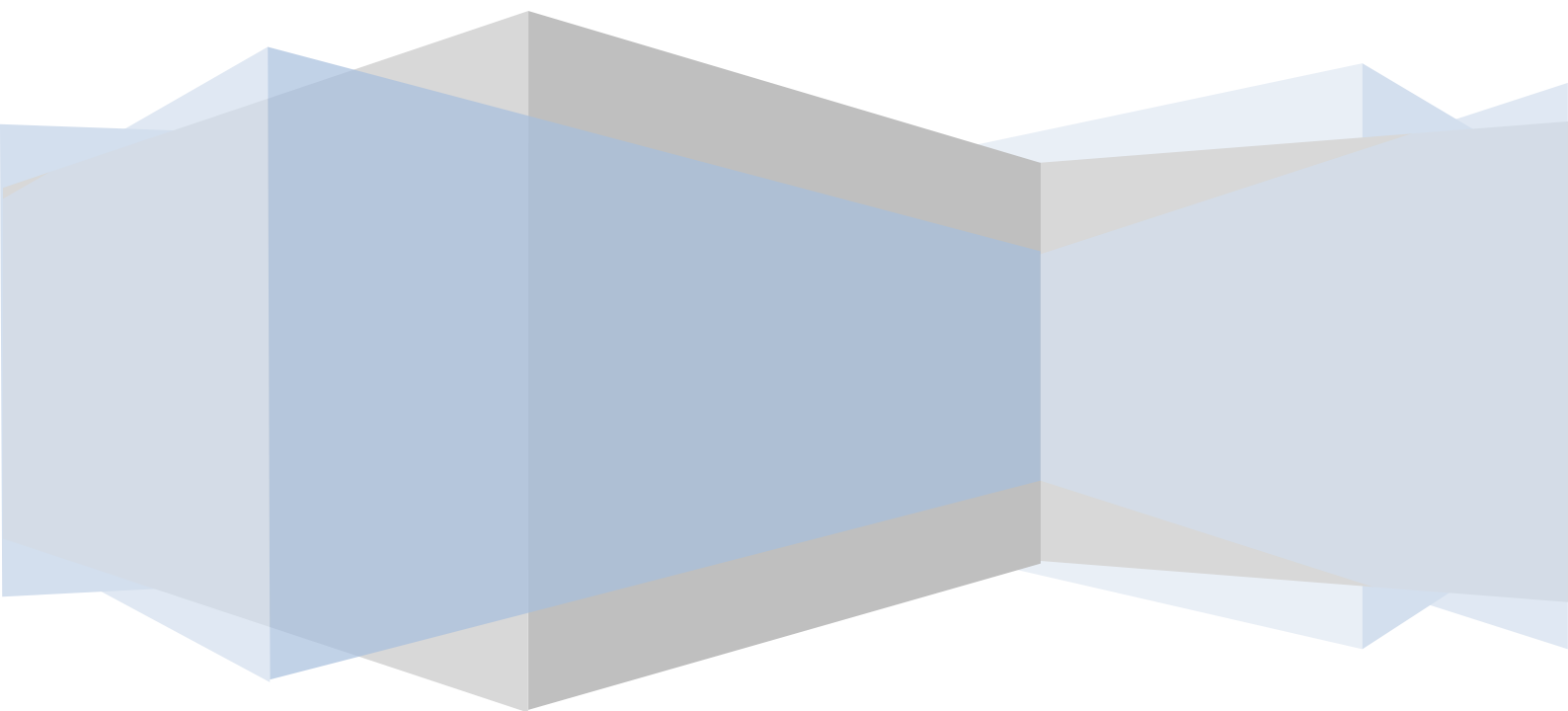


Version 1- updated 5 Feb 2011

**Year 12 Physics-Unit 3-Motion-v2**  
**Brief notes on motion**  
V1



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## MOTION YEAR 12

Homework for Unit 3 Physics Text Book: Jacaranda Physics 2- VCE Physics Unit 3 and 4 – [3<sup>rd</sup> edition]

Topic	Questions to do	Extra Worksheets
<b>Motion in one and two dimensions</b>		
<b>Chapter 1-Forces in action</b>		
Analysing Motion	3	
Newton's laws of motion	6-7-8-9-10	
Applying Newton's Second Law of Motion	11-12-13-14-15-16	
Impulse and Momentum	18-20-22-	
<b>Chapter 2-Collisions and other interactions</b>		
Momentum and impulse	2	
Conservation of momentum	4-5-6	
Work in energy transfers and transformations	8-	
Strain potential energy and springs	10-13-14-15-16	
Elastic and inelastic collisions	17-21-22-23-	
<b>Chapter 3-Projectile and circular motion</b>		
Projectile motion	1-4-8-10-11-12-14-15-16-18-19-	
Uniform circular motion	20-21-22-23-24-25-26-27-28-29-30-31-32	
Modelling the motion of satellites	33-34-35-36-37-38-	
Motion of the planets	41-42-	
Satellites of Earth	43-44-47-48-49-50-	

1-CORE	<b>Study Design 2009 – 2012</b> <b>Unit 3: Motion in one and two dimensions</b>
	<b>apply</b> Newton’s <b>three</b> laws of motion to situations <b>where</b> two or more <b>coplanar</b> forces acting along a straight line and in two dimensions;
	analyse the uniform circular motion of an object moving in a horizontal plane ( $F_{net} = \frac{mv^2}{r}$ ) <b>such as a vehicle moving around a circular road; a vehicle moving around a banked road; masses on the end of a string;</b>
	apply Newton’s laws of motion to circular motion in a vertical plane; consider forces at the highest and lowest positions only;
	<b>Investigate</b> and analyse the motion of projectiles near the Earth’s surface <b>including a qualitative description of the effect of air resistance;</b>
	apply law of energy and momentum conservation in isolated systems;
	analyse impulse (momentum transfer) <b>in an isolated system</b> , for collisions between objects moving in a straight line ( $F\Delta t = m\Delta v$ );
	<b>Apply</b> the concept of work done by a constant force – <b>work done = constant force × distance moved in the direction of the net force</b> – <b>work done = area under force-distance graph;</b>
	analyse <b>transformations</b> of energy between kinetic energy; <b>strain potential energy, gravitational potential energy; and energy dissipated to the environment considered as a combination of heat, sound and deformation of material</b> – <b>kinetic energy, i.e. <math>\frac{1}{2}mv^2</math>, elastic and inelastic collisions in terms of conservation of kinetic energy</b> – <b>strain potential energy, i.e. area under force-distance graph including ideal springs obeying Hooke’s Law, <math>F = -k\Delta x</math> )</b> – <b>gravitational potential energy, i.e. <math>mg\Delta h</math> or from area under force-distance graph and area under a field-distance graph multiplied by mass;</b>
	apply <b>gravitational field and gravitational force</b> concepts, $g = \frac{GM}{r^2}, F = \frac{GM_1M_2}{r^2}$
	<b>model</b> satellite motion ( <b>artificial, moon, planet</b> ) as uniform circular orbital motion ( $a = \frac{v^2}{r} = \frac{4\pi^2r}{T^2}$ )
	apply the concepts of weight ( $W=mg$ ), apparent weight (reaction force, $N$ ), weightlessness ( $W=0$ ) and apparent weightlessness ( $N=0$ );
	<b>Identify and apply</b> safe and responsible practices when working moving objects and equipment <b>in investigations of motion.</b>

## Quick Review of the past concepts

### Quick Definitions

Review of concepts																																																									
Metric units	<p>We use the metric units system in Physics and so it is a good idea to be able to convert between the different units .Below is a quick table</p> <table border="1"> <thead> <tr> <th>Prefix</th> <th>Symbol</th> <th>Multiplier</th> </tr> </thead> <tbody> <tr> <td>tera</td> <td>T</td> <td><math>1 \times 10^{12}</math></td> </tr> <tr> <td>Giga</td> <td>G</td> <td><math>1 \times 10^9</math></td> </tr> <tr> <td>mega</td> <td>M</td> <td><math>1 \times 10^6</math></td> </tr> <tr> <td>Kilo</td> <td>k</td> <td><math>1 \times 10^3</math></td> </tr> <tr> <td>cent</td> <td>c</td> <td><math>1 \times 10^{-2}</math></td> </tr> <tr> <td>milli</td> <td>m</td> <td><math>1 \times 10^{-3}</math></td> </tr> <tr> <td>micro</td> <td><math>\mu</math></td> <td><math>1 \times 10^{-6}</math></td> </tr> <tr> <td>nano</td> <td>n</td> <td><math>1 \times 10^{-9}</math></td> </tr> <tr> <td>pico</td> <td>p</td> <td><math>1 \times 10^{-12}</math></td> </tr> </tbody> </table> <p>Remember learn to use your calculator well and be very careful about using the correct buttons when entering numbers and especially exponentials numbers</p>	Prefix	Symbol	Multiplier	tera	T	$1 \times 10^{12}$	Giga	G	$1 \times 10^9$	mega	M	$1 \times 10^6$	Kilo	k	$1 \times 10^3$	cent	c	$1 \times 10^{-2}$	milli	m	$1 \times 10^{-3}$	micro	$\mu$	$1 \times 10^{-6}$	nano	n	$1 \times 10^{-9}$	pico	p	$1 \times 10^{-12}$																										
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Example on the metric system	<p>Example on using the above</p> <p>Convert 2000m into km</p> <p>Write 400nm in meters?</p>																																																								
Physics used the metric system- (S.I) These are mainly- kg,m, s	<p>The S.I units have the following prefixes that you should be aware of. In fact you should be able to change the various units into the standard units</p> <table border="1"> <thead> <tr> <th>Prefix</th> <th>Symbol</th> <th>Meaning</th> <th>Example of</th> </tr> </thead> <tbody> <tr> <td>Pico</td> <td><math>p</math></td> <td><math>10^{-12}</math></td> <td><math>20pF = 20 \times 10^{-12} F</math></td> </tr> <tr> <td>Nano</td> <td><math>n</math></td> <td><math>10^{-9}</math></td> <td><math>50ns = 50 \times 10^{-9} s</math></td> </tr> <tr> <td>Micro</td> <td><math>\mu</math></td> <td><math>10^{-6}</math></td> <td><math>25\mu A = 25 \times 10^{-6} A</math></td> </tr> <tr> <td>Milli</td> <td><math>m</math></td> <td><math>10^{-3}</math></td> <td><math>30ms = 30 \times 10^{-3} s</math></td> </tr> <tr> <td>Centi</td> <td><math>c</math></td> <td><math>10^{-2}</math></td> <td><math>40cm = 40 \times 10^{-2} m</math></td> </tr> <tr> <td>Kilo</td> <td><math>k</math></td> <td><math>10^3</math></td> <td><math>5km = 5 \times 10^3 m</math></td> </tr> <tr> <td>Mega</td> <td><math>M</math></td> <td><math>10^6</math></td> <td><math>40MW = 40 \times 10^9 W</math></td> </tr> <tr> <td>Giga</td> <td><math>G</math></td> <td><math>10^9</math></td> <td><math>40GW = 40 \times 10^9 W</math></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table> <p>Be very careful when using your calculator</p>	Prefix	Symbol	Meaning	Example of	Pico	$p$	$10^{-12}$	$20pF = 20 \times 10^{-12} F$	Nano	$n$	$10^{-9}$	$50ns = 50 \times 10^{-9} s$	Micro	$\mu$	$10^{-6}$	$25\mu A = 25 \times 10^{-6} A$	Milli	$m$	$10^{-3}$	$30ms = 30 \times 10^{-3} s$	Centi	$c$	$10^{-2}$	$40cm = 40 \times 10^{-2} m$	Kilo	$k$	$10^3$	$5km = 5 \times 10^3 m$	Mega	$M$	$10^6$	$40MW = 40 \times 10^9 W$	Giga	$G$	$10^9$	$40GW = 40 \times 10^9 W$																				
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Calculator	<p>You are only allowed to use a scientific calculator for your exams.</p> <p>A few things to keep in mind</p> <ul style="list-style-type: none"> <li>- Make sure the calculator is in DEG mode! A simple test is to put the following into your calculator – <math>(\sin 30^\circ = 0.5)</math>. If your calculator does not show the answer in the brackets, it is in the wrong mode</li> <li>- Be careful when entering numbers especially if you double hit a key</li> <li>- Watch out when dealing with exponents particularly</li> </ul>																			
Understanding standard notation and scientific notation	<p>When we write numbers like we normally do it is said to be in standard notation, for example 1234.6 is standard notation.</p> <p>We can convert it into scientific notation by counting how many times we would need to move the decimal back so that is between the first digit and the second digit. So in the example above we would write the above number as</p> <table border="1" data-bbox="395 633 1437 835"> <thead> <tr> <th>Standard form</th> <th>Move the decimal place</th> <th>Scientific notation</th> </tr> </thead> <tbody> <tr> <td>1234.6</td> <td>moved decimal 4 places to left so we have added a positive power</td> <td><math>1.2346 \times 10^4</math></td> </tr> <tr> <td>0.00123</td> <td>moved decimal to right by 3 places</td> <td><math>1.23 \times 10^{-3}</math></td> </tr> </tbody> </table> <p>So that is how we convert</p> <p>If we move the decimal to the right we show that by using a negative index power</p> <p>If we move the decimal to the left we show that by using a positive index power.</p> <p>Try these few examples to get you going</p> <p>Remember we do not need to convert it if number is not a really small or really big. Convert the following numbers into <b>scientific notation</b>.</p> <table border="1" data-bbox="483 1144 1353 1216"> <tbody> <tr> <td>1) 3689.32</td> <td>2) 6999.023</td> </tr> <tr> <td>3) 0.00002568</td> <td>4) 0.00245</td> </tr> </tbody> </table> <p>Convert the following numbers into standard notation</p> <table border="1" data-bbox="400 1384 1437 1469"> <tbody> <tr> <td>1) <math>4.3 \times 10^3</math></td> <td>2) <math>1.00007 \times 10^4</math></td> <td>3) <math>7.23 \times 10^9</math></td> </tr> <tr> <td>4) <math>4.2156 \times 10^{-11}</math></td> <td>5) <math>2.1173 \times 10^{-5}</math></td> <td>6) <math>5.333 \times 10^{-7}</math></td> </tr> </tbody> </table> <p>Be very careful in making sure you move the correct number of decimal places.</p>	Standard form	Move the decimal place	Scientific notation	1234.6	moved decimal 4 places to left so we have added a positive power	$1.2346 \times 10^4$	0.00123	moved decimal to right by 3 places	$1.23 \times 10^{-3}$	1) 3689.32	2) 6999.023	3) 0.00002568	4) 0.00245	1) $4.3 \times 10^3$	2) $1.00007 \times 10^4$	3) $7.23 \times 10^9$	4) $4.2156 \times 10^{-11}$	5) $2.1173 \times 10^{-5}$	6) $5.333 \times 10^{-7}$
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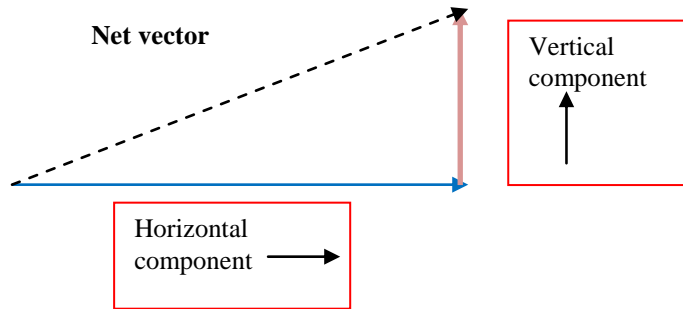
### Difference between scalars and vectors

Answer: Scalar quantities are completely defined by a number and a unit. For example the mass of someone is 50 kg, or the temperature of an object

Vector quantities require a direction on top, so they need a number, a unit and a direction. Example forces need a size and a direction. Vectors can be added together using the head to tail method to find the overall vector.

## Vector Components

A vector can normally be separated into various components. The two most common components are the horizontal component and the vertical component.



Notice how we have the dashed line; this is the resultant vector of the two components, the horizontal component and the vertical component

### Skill builder

Break the following vectors into their x and y components. You will need to use trigonometry. Do not forget to make sure your calculator is in degrees when using trigonometry			
Question	Vector size and direction	X component	Y component
1	12 Newton N 30° E		
2	25 Newton S 45° W		
3	128.94 N in the direction of N 45° E		
Find the magnitude and direction of the vector given the following axial components			
4	$V_x = 5.0 \text{ m}$	$V_y = 5.0 \text{ m}$	
5	$V_x = 15.0 \text{ m}$	$V_y = 15.0 \text{ m}$	
6	$V_x = -6.5 \text{ m}$	$V_y = -5.0 \text{ m}$	
Add the following vectors both mathematically and graphically			
7	9 cm W and 6 cm S		
8	2 Newton North and 10 Newton South		
9	5 m N and 7.5 m W		

Remember distance is a scalar and displacement is a vector. So with vectors we always must give the direction of the final vector.

## Understanding difference between speed and velocity

**Scalar-** Only needs size no direction (examples: speed, distance, time)

**Vector-** Needs direction + Size (examples: displacement, velocity, acceleration, force)

Working out the displacement: We need to find the distance between the final position and the initial position.

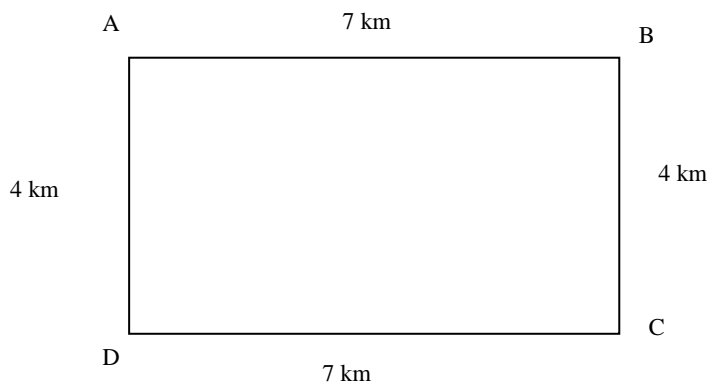
Speed	$Speed = \frac{\text{distance}}{\text{time}}$	
Velocity	$velocity = \frac{\text{displacement}}{\text{time}}$	
To find displacement	$\Delta x = x_{final} - x_{initial}$	Remember we need to use vectors and find the distance between the final position and the initial position

## Skill builder

### Question

Betty has just got her new scooter and decides to go for a ride around her area.. She starts from A and goes to B and then to C and then to D and finally returns to A, the starting point

Below are some of the times it took her on her scooter: AB- 20minutes, BC- 12 minutes, CD- 18 minutes and DA-10 minutes



Complete the following table

Calculation of Distances	Calculation of Displacement
AB-	AB-
AC-	AC-
AD-	AD-
AA-	AA-

Answer the following questions

**Question 1:** How long did it take Betty to complete her trip? (Starting from A and returning to A) in seconds?

**Question 2:** What is the total distance she travelled on her scooter in metres?

**Question 3:** What is her average speed for A to A?

**Question 4:** What is her velocity for A to A?

**Question 5:** What is her speed for AB?

**Question 6:** What is her velocity for AB?

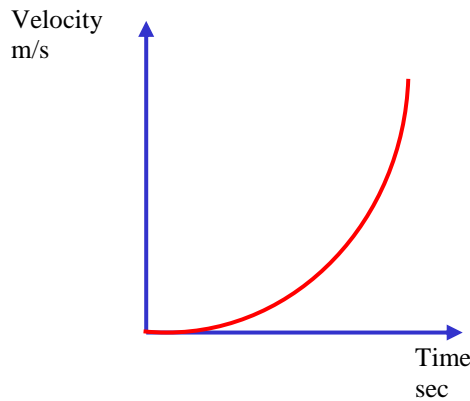
**Question 7:** What is her speed for AA?

**Question 8:** What is her velocity for AA?

Quick note; Instantaneous velocity is the velocity at a specific time whereas average velocity is the total displacement divided by total time.

## Graphs

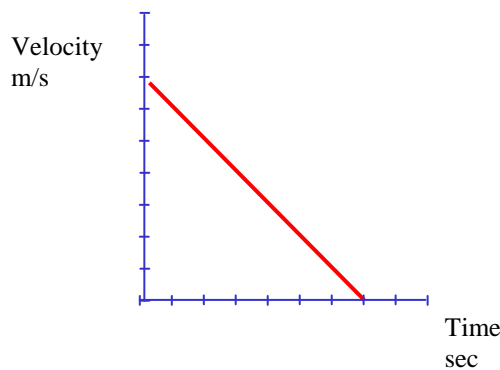
It is often useful to represent information in the form of graphs. There are many different types of graphs but in Physics we are mainly interested in looking at graphs that give you a quick summary of the relationship between two variables. For example



Here we see the general relationship between displacement and time. In simple terms as time passes the displacement increases.

Another type of graph is one which is much more precise.

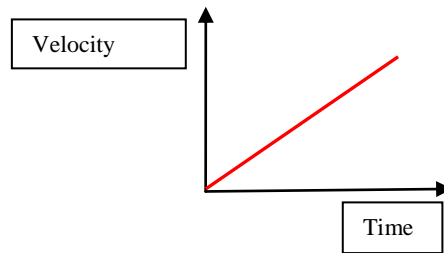
Here you might be asked to find the acceleration at  $t = 3$  seconds [ you will need to use the scale provided]



<p>Graphs</p>	<p>What is the relationship between displacement vs time and velocity vs time and acceleration vs time graphs</p> <div style="text-align: center;"> <p>A graph with 'Displacement' on the vertical axis and 'Time' on the horizontal axis. A red curve starts at the origin (0,0) and curves upwards with an increasing slope.</p> </div> <p>From the displacement vs time graph we can directly read the displacement at a certain time. We can find the velocity by finding the slope at that particular time by</p>
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using the gradient at that particular point

Velocity-Time graphs



These tend to be the most versatile graphs as you can get a lot of information from a velocity versus time graphs

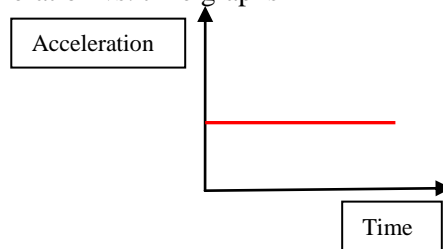
You can find the acceleration at a particular point by finding the gradient at that point

You can find the displacement travelled by finding the area under the graph

You can read the velocity directly from the graph itself

You can have positive or negative velocity because velocity is a vector.

Acceleration vs. time graphs



The acceleration graph can tell us the following

We can read the acceleration at a particular point by reading directly from the graph

The area under acceleration is equal to the change of velocity

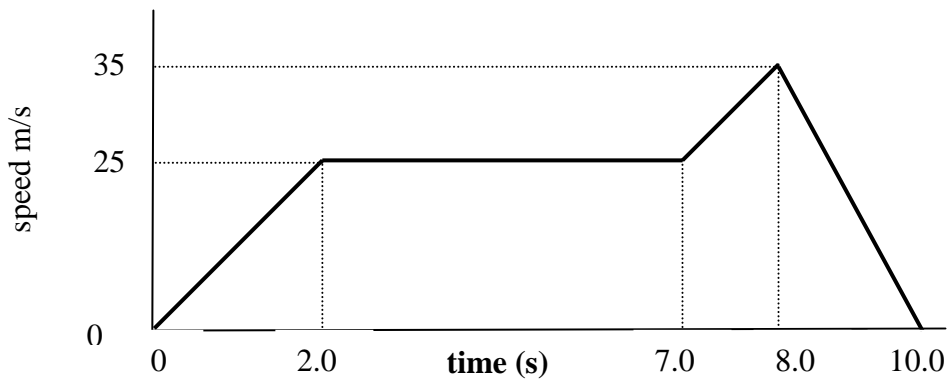
## Skill builder

1 Use the words in the box below to fill in the missing gaps in the paragraph:

Speed is the \_\_\_\_\_ a vehicle travels each second. The units for speed are \_\_\_\_\_. When a car increases its speed, we say that it is \_\_\_\_\_. A car that gets slower each second is said to be \_\_\_\_\_ or to have a \_\_\_\_\_ acceleration. The units of acceleration are \_\_\_\_\_.

negative    decelerating    distance    m/s    m/s<sup>2</sup>    accelerating

- 2 Rachel and Jasmine decided to take a ride on the rollercoaster at their local fairground. They plotted a graph to show how the speed varied during the trip. Here it is:



Use the graph to find out the following values. Show all your calculations.

- What is the fastest speed reached by the rollercoaster?
- For how many seconds was the rollercoaster travelling at 25 m/s?
- What was the acceleration during the first 2 seconds?
- What was the acceleration during the final 2 seconds?
- What was the acceleration of the rollercoaster between 7.0 and 8.0 seconds?

You can find how far something has travelled by finding the area beneath the line. Using this knowledge, calculate how far the rollercoaster travels when it is moving at a constant speed.

### Equations of Motion- Constant Acceleration

The following equations of motion can only be used for constant acceleration

Common equations of motions	Explanation of symbols
$v = u + at$	v- final velocity u- initial velocity a-acceleration t-time
$v^2 = u^2 + 2as$	v- final velocity u- initial velocity s-displacement
$s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$	s-displacement u-initial velocity a-acceleration t-time
$s = \frac{1}{2}(u + v)t$	s-displacement u-initial velocity v-final velocity t-time

$v = \frac{\text{displacement}}{\text{time}}$	
$a = \frac{\Delta v}{\Delta t} = \frac{v_{\text{final}} - v_{\text{initial}}}{\Delta t}$	$\Delta v$ - means change in velocity ( be careful this is a vector)

**Hints when using these formulae**

1. Always draw a diagram
2. List the variables we have
3. Choose the initial direction as being positive and adjust all the other variables. For example if a ball is thrown up then choose up as been the positive direction, so the displacement upwards is positive while acceleration will be negative.
4. Units must be standard- time must be seconds, velocity is in metres/ second
5. To convert *km/hr* to *m/s* – Divide by 3.6 ( to convert *m/s* to *km/hr* multiply by 3.6)
6. The acceleration due to gravity, *g*, is 9.81 m/s/s. Use it unless the question asks you to use 10 m/s/s
7. I would recommend students to write velocity as *m/s* rather  $ms^{-1}$  ( **same applies to acceleration**)
8. Always re-read the question very carefully. It is normal to read a question at least a few times before attempting it.
9. Start writing your own sheet with hints at the start of the Unit rather than waiting till the end
10. To improve in your ability to do physics questions requires lots of practice, so do not give up!

**Skill builder**

**Question 1:** Complete the following table of conversions

Metres per second	Kilometres per Hour
23 m/s	?
34.6 m/s	?
?	230 km/hr
?	60 km/hr

**Question 2:**

- a) A brand new SS Commodore can reach a 100 km/hr from stand still in just over 6.5 seconds. Assume that the acceleration is constant, find its acceleration.
- b) Assuming this acceleration can be maintained how long would it take to cover 400 metres starting from rest?
- c) The driver, Gina, is extremely excited about having such a powerful car, and decides to push the pedal to the ground, as it were and reach a top speed of 239 km/ hr. How long would it take to get to that speed.

**Question 4:**

A ball is dropped from the top of a 120 metre building. Assuming the ball is released at rest, answer the following questions (assume  $g = 10 \text{ m/s/s}$ )

- a) How long would it take to reach the ground?
- b) What would be the final speed of the ball the moment before it hits the ground?

**Question 5:**

- a) Find the rate of acceleration if a car changes its velocity from 20 km/hr to 70 km/hr in 4 seconds?
- b) Find the rate of acceleration if a person changes its velocity from 2 m/s to 6 m/s in 10 seconds?

Quick Note: The equations can only be used for constant acceleration

**Forces****Main Concepts:**

- A force is a pull or a push
- Forces are measured in Newton (N)
- Forces are vectors meaning that you will need to assign a direction as well as a size to the force

**Different types of Forces**

- Contact forces- in which two interacting objects are physically touching each other for example frictional forces, tension forces ,
- Field forces- two interacting objects are not in contact. Examples are gravitational forces, magnetic forces

**What can forces do?**

- Start motion
- Change motion
- Change direction
- Sometime it will appear that there is no effect since force applied is smaller than the force required to overcome friction.

**Weight Force**

- Weight is the result of the gravitational force acting on a mass
- Weight and mass are not the same thing, even though many people confuse them. Weight is a vector and it is given by the formula  $W = m \times g$  whereas mass is amount of matter in an object.
- Of course there is a relationship between weight and mass and that is the formula above
- Weight Force = Mass  $\times$  acceleration of gravity

**Reaction Force**

- All objects will experience a weight force acting on them. But when an object is placed on the ground then they will stay stationary. Why? A force equal to the weight force but acting in the opposite direction comes into existence. This force is called the reaction force or more commonly known as the NORMAL force.
- The reaction forces or the normal forces only exists when an object touch another object.
- It is of interest to note that the WEIGHT force and the NORMAL force are not action reaction pair since when a object is free falling there is no reaction force but there is still a weight force

## Newton's Laws

**First Law-** “An object remains in a state of rest or uniform motion unless acted on by an external force”.

- Explanation: So a stationary object will not move unless it is pushed or pulled by an external force. Not so obvious is the fact that an already moving object will continue to stay at the same speed unless it is acted by an external force. Now the reason objects actually stop is due to frictional or resistance forces which exist in our world.
- So a force is not needed to keep an object in motion, but it requires a net force to change the velocity of an object
- 

**Second Law-** “The acceleration of an object depends on the mass of the object and the force applied to it”.

Explanation: We should really be saying the Net Force on an object will produce acceleration  $F_{net} = m \times a$

Remember the following:

- Net force is the vector sum of all the forces acting on an object
- The acceleration and the net force is always in the same direction

**Third Law:** “Every action has an equal and opposite reaction”.

- Explanation: Remember the action and reaction forces acts on two different bodies. So if we push the door, action is on the door but the reaction forces are on our hand.
- Do not forget about how vector forces add or subtract
- Action- reaction forces always occur in pairs, single isolated forces never occur, they occur at the same time but act in opposite directions to each other

### Quick Review of Concepts

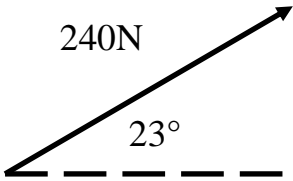
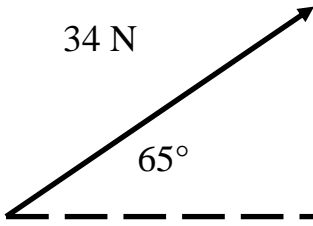
**Question 1:** Find the acceleration of

- a) A car going from 20 km/hr to 60 km/hr in 20 seconds
- b) A student that goes from 2 m/s to 12 m/s in 25 seconds
- c) A missile going from 200 km/hr to 1200 km/hr in 100 seconds

**Question 2:** Complete the below table using Newton's second law

	Force	Mass	Acceleration
a)	?	7.3 kg	30 m/s/s
c)	100N	23 kg	?
e)	350 N	?	5.45 m/s/s

**Question 3:** Find the resultant forces by finding the component forces horizontally and vertically


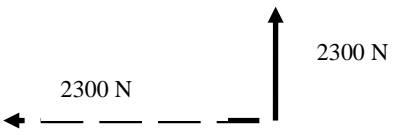
Diagram	Horizontal component	Vertical component
 <p>240N 23°</p>		
 <p>34 N 65°</p>		

**Question 4-** A mass of 20 kg is accelerated by a force of 200 N. What is the acceleration?

**Question 5:** What is the weight force that a person of mass of 82 kg exerts on the ground?

**Question 6:** A stone of mass 1.3 kg is free falling from the top of a building. What is the downward force acting on the stone while in the air?

**Question 7:** What is the net force acting on the following body? Also find the net acceleration (assuming mass = 20kg)

a)	 <p>1400 N                      2300 N</p>
b)	 <p>2300 N                      2300 N</p>

## Further Comments on Newton's Laws

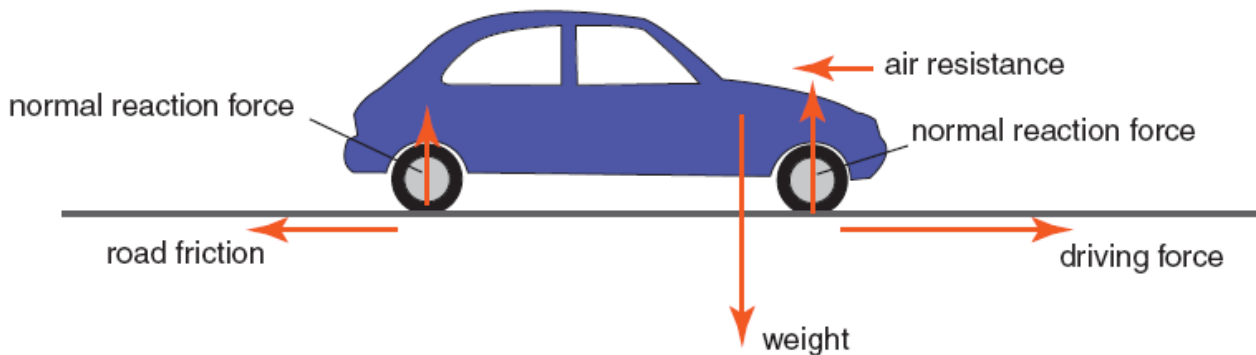
### Newton's 1<sup>st</sup> law

Newton's First Law of Motion is often referred to as the Law of Inertia. The **inertia** of an object is its tendency to resist changes to its motion. Inertia is not a force; it is a property of all objects and depends only on its mass.

A large adult on a playground swing is more difficult to get moving than a small child on the same swing. It is also more difficult to stop or change the direction of motion of a large adult than a small child.

### Cruising along

The forces acting on a car being driven along a straight horizontal road are:



- **Weight.** A medium-sized sedan containing a driver and passenger has a weight of about  $1.5 \times 10^4$  N. The weight acts through the **centre of mass** of the car. This is normally closer to the front of the car than the back due to the placement of the engine
- The **normal reaction force**. This force pushes up on all four wheels. Its magnitude is normally greater at the front wheels than the rear wheels. On a horizontal road, the sum of these normal reaction forces has the same magnitude as the weight.
- The **driving force**. This is provided by the road and is applied to the driving wheels. As the tyre pushes back on the road, the road pushes forward on the tyre, propelling the car forward. The forward push of the road on the tyre is a type of friction commonly referred to as **traction**, or **grip**.
- **Road friction** is the force required to drive the, non-driving wheels of front-wheel-drive cars roll as they or are pulled along the road by the moving car. It is also referred to as **rolling resistance**.
- **Air resistance.** The drag, or air resistance acting on the car, increases as the car moves faster.  

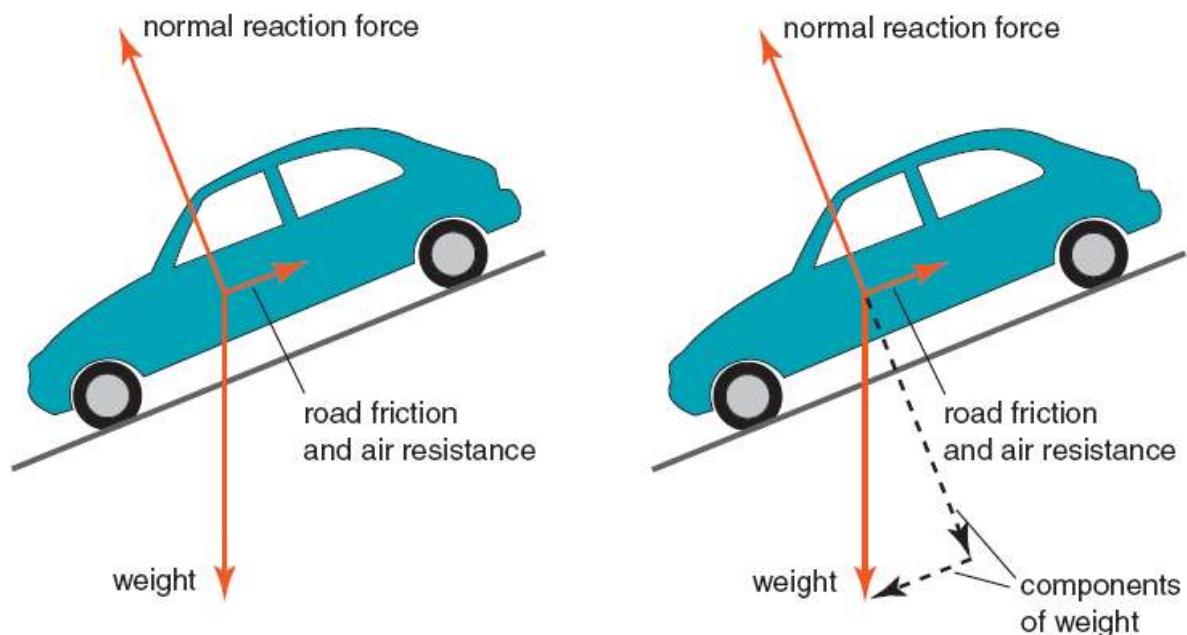
$$\text{resistance} \propto (\text{velocity})^3$$
As a fluid friction force, air resistance can be reduced by streamlining the vehicle.

In the diagram above the net force acting on the car is **zero**. It is therefore moving along the road at **constant speed**.

If the driving force were to increase, the car would speed up until the sum of the air resistance and road friction grew large enough to balance it. Then, once again, the car would be moving at a constant although higher, speed.

If the driver stopped pushing down on the accelerator, the motor would stop turning the driving wheels and the driving force would become zero. The net force would be to the left. As the car slowed down, the air resistance and road friction would gradually decrease until the car came to a stop.

### Rolling downhill



A car left parked on a hill will begin to roll down the hill with increasing speed if it is left out of gear and the handbrake is off. The diagram above shows the forces acting on the car and are modelled as acting through a single point (C of M).

The direction of net force acting on the car is down the hill. It is clear that the pull of gravity (the weight of the car), is the major contributor to the downhill motion of the car.

It is often useful to divide vectors into parts called **components**.

The diagram shows how the weight can be resolved into two components, one **parallel** to the slope and one **perpendicular** to the slope. Note that -

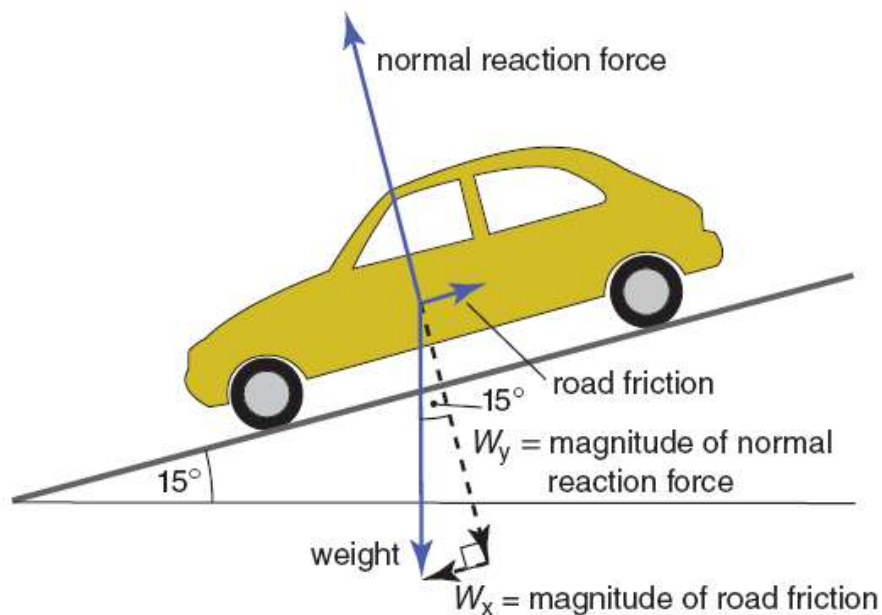
1. The normal reaction force is balanced by the component of weight that is perpendicular to the surface. Because the car does not move off the road surface the sum of these two forces must be zero.
2. The magnitude of the net force is simply the difference between the magnitude of the component of weight that is parallel to the surface and the sum of the road friction and air resistance.

### Worked example

A car of mass 1600 kg left parked on a steep but rough road begins to roll down the hill. After a short while it reaches a constant speed. The road is inclined at  $15^\circ$  to the horizontal. Its speed is sufficiently slow that the air resistance is insignificant and can be ignored.

1. Determine the size of the normal reaction force.
2. Determine the magnitude of the net force on the car as it just begins to roll.
3. Determine the magnitude of the road friction on the car while it is rolling at constant speed.

Solution:



1. perpendicular to the road

$$F_N = W_y$$

$$\cos 15^\circ = \frac{W_y}{W}$$

$$W = 1600 \times 10 = 1.6 \times 10^4 \text{ N}$$

$$F_N = 1.6 \times 10^4 \times \cos 15^\circ$$

$$F_N = 1.5 \times 10^4 \text{ N}$$

2. just at the point of rolling the only unbalanced force is  $W_x$

$$\sin 15^\circ = \frac{W_x}{W}$$

$$W_x = W \times \sin 15^\circ$$

$$W_x = 1.6 \times 10^4 \times \sin 15^\circ$$

$$W_x = 4.1 \times 10^3 \text{ N}$$

3. because the car is rolling at constant speed, the net force acting on it is zero.

$$F_{\text{friction}} = W_x = \underline{4.1 \times 10^3 \text{ N}}$$

## Newton's 2<sup>nd</sup> law

Casual observations indicate that the acceleration of a given object increases as the net force on the object increases. It is also clear that lighter objects change their velocity at a greater rate than heavier objects when the same force is applied.

It can be shown experimentally that the acceleration,  $a$ , of an object is:

- proportional to the net force,  $F_{\text{net}}$
- inversely proportional to the mass,  $m$ .

$$a \propto F_{\text{net}} \quad \text{and} \quad a \propto 1/m$$

$$\text{thus,} \quad a \propto F/m \quad \text{or} \quad a = kF$$

where  $k$  = a constant of proportionality.

The SI unit of force, the newton (N), is defined such that a net force of 1 N causes a mass of 1 kg to accelerate at  $1 \text{ m s}^{-2}$ . The value of the constant,  $k$ , is 1 and it has no units. Thus:

$$F_{\text{net}} = ma$$

This equation is known as Newton's Second Law of Motion.

It allows you to –

- determine the net force acting on an object.
- determine the mass of an object.
- predict the effect of a net force on the motion of an object of known mass.

### Example #1

What is the magnitude of the average force applied by a tennis racquet to a 58 g tennis ball during service if the average acceleration of the racquet is  $1.2 \times 10^4 \text{ m s}^{-2}$ ?

Example #2

A toy car is pulled across a smooth, polished, horizontal table with a spring balance. The reading on the spring balance is 2.0 N and the acceleration of the toy car is measured to be  $2.5 \text{ m s}^{-2}$ . What is the mass of the toy car?

Example #3

A 65 kg physics teacher, starting from rest, glides gracefully down a slide in the local playground. The net force on her during the slide is a constant 350 N. How fast will she be travelling at the bottom of the 8.0 m slide?

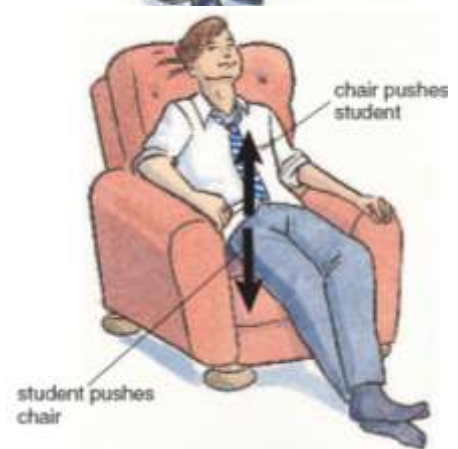
**Newton's 3rd law**

Forces **always** act in pairs.

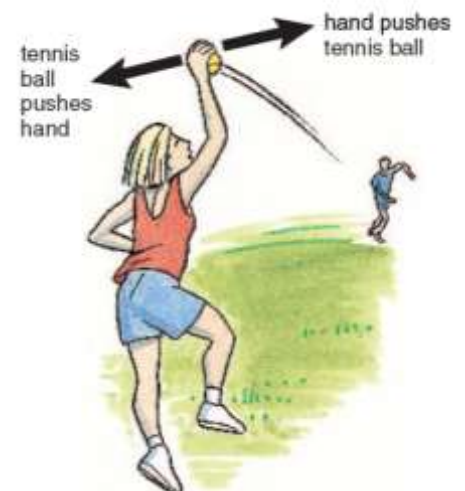
When you lift a heavy school bag you can feel it pulling down on you.



When you slump into a comfortable chair at the end of a long day at school, you can feel it pushing up on you.



When you catch a fast-moving ball, you can feel it push on your hand as you apply the force to stop it.



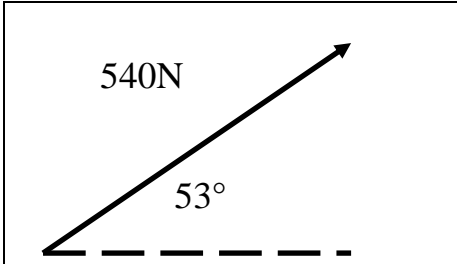
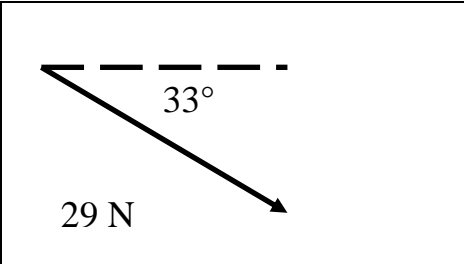
Sir Isaac Newton recognised that forces always acted in pairs in his Third Law of Motion, which is most commonly stated as:

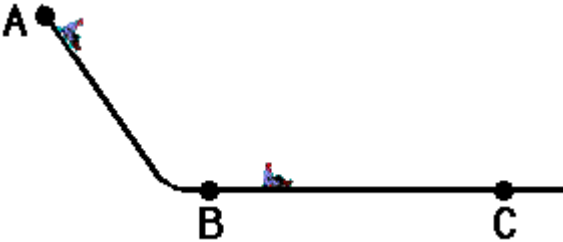
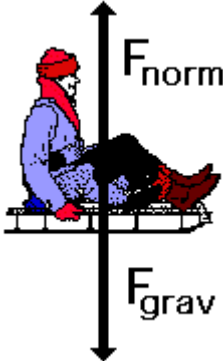
*For every action there is an equal and opposite reaction.*

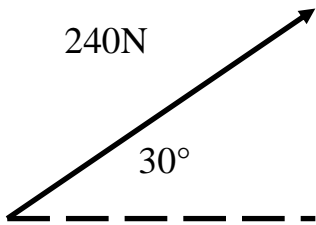
A more precise statement of Newton's third law is:

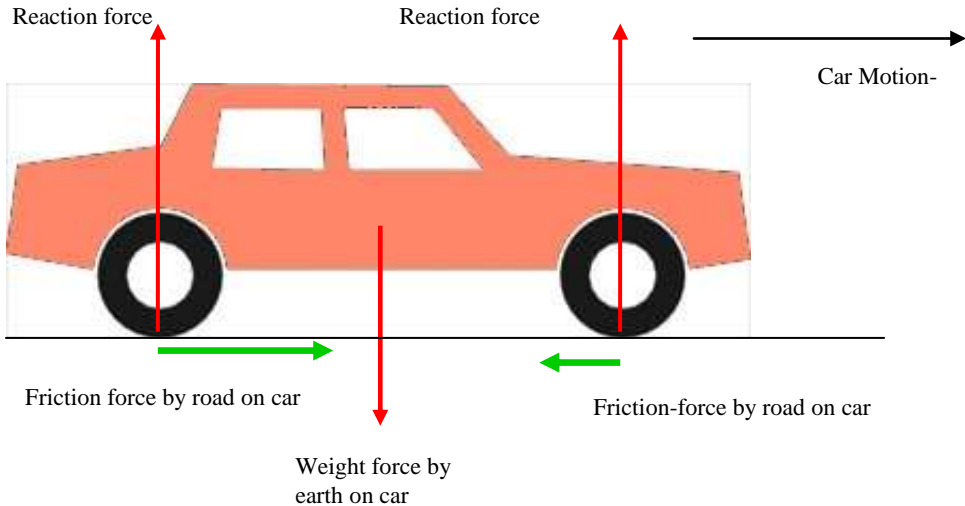
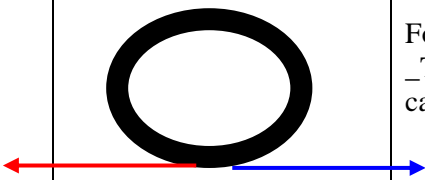
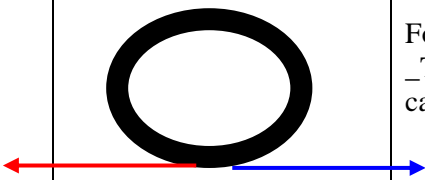
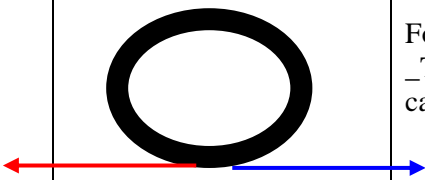
*Whenever an object applies a force (an action) to a second object, the second object applies an equal and opposite force (a reaction) to the first object.*

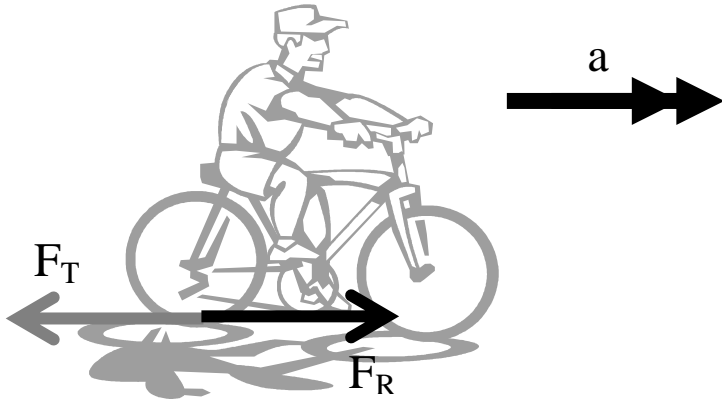
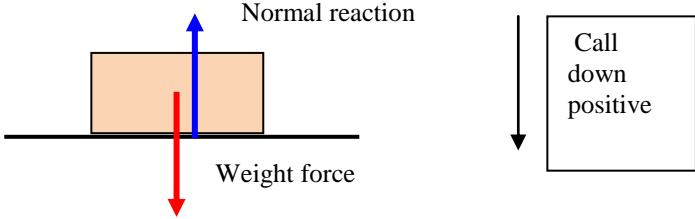
It is very important to remember that the forces that make up action–reaction pairs act on different objects, so even though they are equal and opposite, they do not cancel each out.

<p>What is a force</p>	<ul style="list-style-type: none"> <li>▪ A force is a pull or a push</li> <li>▪ Forces are measured in Newton (N)</li> <li>▪ Forces are vectors meaning that you will need to assign a direction as well as a size to the force</li> </ul>												
<p>Newton’s first law</p>	<p><b>First Law-“An object remains in a state of rest or uniform motion unless acted on by an external force”.</b></p> <ul style="list-style-type: none"> <li>▪ Explanation: So a stationary object will not move unless it is pushed or pulled by an external force. Not so obvious is the fact that an already moving object will continue to stay at the same speed unless it is acted by an external force. Now the reason objects actually stop is due to frictional or resistance forces which exist in our world.</li> </ul>												
	<p>Forces can be resolved into their various components- namely horizontal or vertical components</p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="border: 1px solid black; padding: 10px; width: 45%;">  <p style="text-align: center;">540N 53°</p> <p>Find the horizontal and the vertical components of the force in the above</p> </div> <div style="border: 1px solid black; padding: 10px; width: 45%;">  <p style="text-align: center;">33° 29 N</p> <p>Find the horizontal and the vertical components of the force in the above</p> </div> </div> <p>Using trigonometry resolve the above into the various components</p>												
<p>Newton’s second law</p>	<p><b>Second Law-“The acceleration of an object depends on the mass of the object and the force applied to it”.</b></p> <p>Explanation: We should really be saying the Net Force on an object will produce acceleration <math>F_{net} = m \times a</math></p>												
	<p>Quick examples on using Newton’s second law</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>Force</th> <th>Mass</th> <th>Acceleration</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">?</td> <td style="text-align: center;">20kg</td> <td style="text-align: center;">3m/s/s</td> </tr> <tr> <td style="text-align: center;">2000N</td> <td style="text-align: center;">?</td> <td style="text-align: center;">25m/s/s</td> </tr> <tr> <td style="text-align: center;">100N</td> <td style="text-align: center;">15kg</td> <td style="text-align: center;">?</td> </tr> </tbody> </table> <p>Remember to convert into the appropriate units</p>	Force	Mass	Acceleration	?	20kg	3m/s/s	2000N	?	25m/s/s	100N	15kg	?
Force	Mass	Acceleration											
?	20kg	3m/s/s											
2000N	?	25m/s/s											
100N	15kg	?											

<p>Newton's third law</p>	<p><b>Third Law: "Every action has an equal and opposite reaction".</b></p> <ul style="list-style-type: none"> <li>▪ Explanation: Remember the action and reaction forces acts on two different bodies. So if we push the door, action is on the door but the reaction forces are on our hand.</li> <li>▪ Do not forget about how vector forces add or subtract</li> </ul> <p>Weight Force = Mass × acceleration of gravity</p>
<p>Do we need a force to keep things moving?</p>	<p>This is a popular misconception which we do not the time to go into it except to state the many people believe that a force is needed for motion to continue on and on</p> <p>Let use a example to see how things can be explained.</p> <p>Imagine your are sledding down a snow hill and then slide along a level ground from B to C</p> <p>So let us imagine that there is no friction between B and C. What would happen?</p> <p>Well from A to B you would be picking up speed since you would be acceleration but once you have passed point B what would happen with your speed?</p> <p>The answer is that you would continue with the speed you had at point B provided there was no friction opposing your motion.</p> <p>Would you be picking up speed? No , so there would be no more acceleration which in turn means there would be no force acting in the direction B to C. So here we have a situation where there is no more force and yet you would continue to move in a constant speed for as long as there is no opposing force or friction!</p> <div style="display: flex; justify-content: space-around; align-items: center;">   </div> <p>What are the forces acting on the sled between point B and C</p> <p>The forces acting upon the sled from point B to point C would be the normal force (the</p>

	<p>snow pushes up on the sled) and the gravity force (see diagram above). These forces are balanced and since the sled is already in motion at point B it will continue in motion with the same speed and direction. So, an object can be moving to the right even if the only forces acting upon the object are vertical forces. Forces do not cause motion; forces cause accelerations.</p> <p>Newton's first law of motion declares that a force is <u>not</u> needed to keep an object in motion.</p>
Why do things slow down then?	<p>Slide a book along a school desk and what would you notice happening? It would slow down and eventually stop. Why? The book comes to a stop not because of a the absence of a force but because of the existence of a force and in this case it is the force of friction which is acting in the opposite direction which ultimately slows down the book. If there was no friction then the book would continue on and one until the falls of f the desk. So we see the point namely that the presence of a force is what causes the book to slow down and stop.</p>
Newton's Law- 1 <sup>st</sup> Law	<p><b>First Law-“An object remains in a state of rest or uniform motion unless acted on by an external force”.</b></p> <ul style="list-style-type: none"> <li>Explanation: So a stationary object will not move unless it is pushed or pulled by an an external force. Not so obvious is the fact that an already moving object will continue to stay at the same speed unless it is acted by an external force. Now the reason objects actually stop is due to frictional or resistance forces which exist in our world.</li> </ul>
Newton's Law-2 Law	<p><b>Second Law-“The acceleration of an object depends on the mass of the object and the force applied to it”.</b></p> <p>Explanation: We should really be saying the Net Force on an object will produce acceleration <math>F_{net} = m \times a</math></p>
Newton's Law-3 <sup>rd</sup> Law	<p><b>Third Law: “Every action has an equal and opposite reaction”.</b></p> <ul style="list-style-type: none"> <li>Explanation: Remember the action and reaction forces acts on two different bodies. So if we push the door, action is on the door but the reaction forces are on our hand.</li> <li>Do not forget about how vector forces add or subtract</li> </ul>
Components of a force	<p>A force can be split into two components- the horizontal component and the vertical component To do this we need to use simple trigonometry</p>  <p>So look at the example at the top</p> <p>Horizontal component is given by the following: <math>240 \cos 30</math> Vertical component is given by the following: <math>240 \sin 30</math></p>

<p>Mass and Weight</p>	<p>Mass is how much mass a object has, its mass will remain the same no matter where it is in the Universe                  Weight is the amount of force acting on a mass and it is a vector. Since the force of gravity changes in different locations , therefore weight changes                  To find the weight we use the formula- <math>Weight = Mass \times acceleration</math></p>			
<p>Friction</p>	<p>Friction is a force that acts on an object when it moves. The force of friction acts in the opposite direction of movement.                  If an object is on an inclined and it is not moving then we can say that the friction force is holding the object stationary.                  The cause of friction is the roughness of the surface as it slides along another surface</p> <p>When we look at surfaces under the microscope we will see that they are not smooth like ice is just contain jugged edges and hills and it is this abnormality that causes friction to occur.                  Normally friction is considered a force that slows down objects but in other circumstances such as walking friction is a necessary force that helps movement happen.</p>			
<p>Examples dealing with friction forces</p>	<p>Let look at a car and why it move- this is a rear driven car</p>  <p>Notice                  The front tyres are turned by the road, whereas the rear wheels are turned by the engine                  Back tyre diagram</p> <table border="1" data-bbox="416 1559 1442 1865"> <tr> <td data-bbox="416 1559 759 1865"> <p>Force by Tyre on Road from the engine</p> </td> <td data-bbox="759 1559 1098 1865">  </td> <td data-bbox="1098 1559 1442 1865"> <p>Force by Road on Tyre _The driving force on the car</p> </td> </tr> </table> <p>The rear wheels are turned by the engine, so the tyre pushes back on the road. So by Newton's third law the road pushes forward on the tyre</p> <p>On the front wheel the friction of the road makes the tyre rotate and reduces the effect of the driving force. Even though the horizontal forces on the car are both frictional</p>	<p>Force by Tyre on Road from the engine</p>		<p>Force by Road on Tyre _The driving force on the car</p>
<p>Force by Tyre on Road from the engine</p>		<p>Force by Road on Tyre _The driving force on the car</p>		

	<p>they do not cancel out. The forward friction on the back wheels is far greater than that of the front wheels and the car goes forward</p>
<p>More explanation on friction on how it causes movement</p>	<p><b>What is the direction of the force of friction on the front wheel of a bike?</b>          Answer- The frictional force is backward on the front wheel. Why?          Remember that the force of friction is always in the direction opposite to the applied force. So the front wheel is rolling freely on the surface in the forward direction. So force of friction opposes this motion. So for the front wheel the force of friction is in the backward direction</p> <p><b>Now for the rear wheel the force of friction is forward</b>          Why?          When you are paddling a bike you are exerting a force in the backward direction on the rear wheel. As as the force of friction is always in the opposite direction to the applied force therefore for the rear wheel the force of friction is in the forward direction.</p>  <p>What about cars tyres then?          Imagine a car on a horizontal surface. The car is stationary and you want it to move. If the surface has no friction , say it was on ice, then the tyres would simply spin and the car would not move.          But friction from the ground acts to prevent the tyres slipping. The tyres try to slip backward, friction prevents that by pushing forward. That forward push accelerates the car forward.</p>
<p>Normal reaction</p>	<p>The normal reaction is the force a surface acts on an object when an object is pulled down by the its weight. The force acts at right angles to the surface and that is the reason why we call it the “normal” reaction force.</p>  <p>(here the normal reaction force is equal to the weight force but that is not always the case!)</p>

Look at the diagram above

The blue arrow is the normal reaction force and it is the force by the floor on the box  
The red arrow is the weight which is the force by the earth on the box

**Be very careful-** these two forces are not always equal to each other as they act on the same object and therefore we cannot use them as an example of Newton's third law

What is the cause of the normal reaction force?

The cause of the normal reaction is the weight force pulling the box into the surface. As a result this squashes as it were the atomic layers of the surface. These atomic layers push back providing an upward force.

We could imagine ourselves sitting on a soft couch, our weight pulls us down until the cushion is compressed to such an extent that the size of the upwards force balances our weight force.

Now lets us say that the mass of the box is 4 kg what is the normal reaction force here then?

$$\Sigma F = ma$$

$$W - N = ma$$

Now we know that the

$$W = mg$$

$$W = 4 \times 10$$

$$W = 40N$$

And since the box is not accelerating  $a = 0$  so we have the following equation

$$W - N = ma$$

$$W - N = 0$$

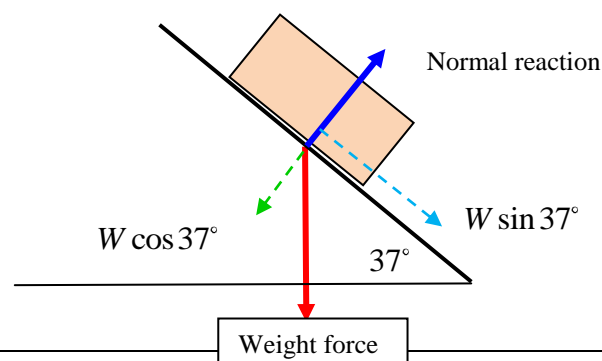
$$W = N$$

$$W = 40N$$

So here we see that the Normal reaction force is equal to the weight force but now lets see where that is not the case

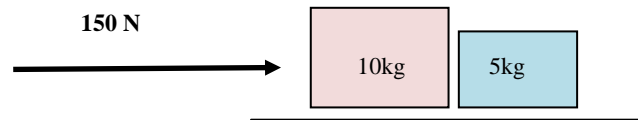
Let us look at an example where the normal reaction force is not equal to the weight force

Same box but this time it is on an inclined plane like the one below



	<p>So with a little bit of mathematics we can show that the weight force (<math>W</math>) is equal to</p> $F_{normal} = W \cos 37$ $F_{normal} = 4 \times 10 \times \cos 37$ $F_{normal} = 32N$ <p>Notice how the normal reaction force is not the same as the previous box example!</p>
Unusual problems	<p>Newton's Third law type of problems</p> <p>Newton's third law of motion was discovered and formulated, during the investigation of the fact that in all experiments it appeared that "when ever a body exerts a force on a second body, the second body always exerts a force on the first one"</p> <p>Let us visualize and understand this phenomena with an experiment.</p> <p>Suppose, we throw a stone on a surface of good strength; and the surface is made of glass, one finds it broken (the surface). From here one concludes that a force was exerted by stone on the surface and consequently it was broken.</p> <p>Now, the question is, did that surface also exert a force on the stone. Just to know about it let us change our throwing object from stone to an egg of almost equal mass. Now, one throws this egg on the same surface of good strength with the same throwing force which he used for the stone. What happens? Obviously with your daily experience you know that the egg will be broken (And the damage to the surface will not be visible due to egg's spoiling the observation).</p> <p>This is only possible if there was a force acting on the egg at the time it hit the surface. In fact we can now conclude that there is a mutual force acting on the contact point of the surface and the object thrown. The breaking of either one (or may be both) depends on their ability to absorb forces without getting damaged (that is their strength) so in precise words:</p> <ul style="list-style-type: none"> <li>▪ To every action there is always opposite and equal reaction, it is equivalent to say that mutual actions of two bodies upon each other are always equal and directed to contrary parts.</li> <li>▪ The most important fact to notice here is that these oppositely directed equal action and reaction can never balance or cancel each other because they always act, on two different point (broadly on two different objects) For balancing any two forces the first requirement is that they should act on one and the same object. (or point, if object can be treated as a point mass, which is a common practice).</li> </ul> <p>Find the forces acting on the interface if a force of 150 N acts as shown in the diagram</p>

below



Solution

Since the two bodies are together we can assume safely that they will both accelerate at the same rate. So we can treat them as one mass ( $m = 10 + 5 = 15 \text{ kg}$ )

Now using the formula  $F_{net} = ma$  we can find the net acceleration of both bodies

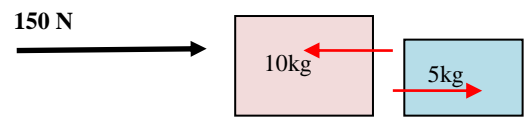
$$F_{net} = ma$$

$$150 = 15a$$

$$a = \frac{150}{15} = 10$$

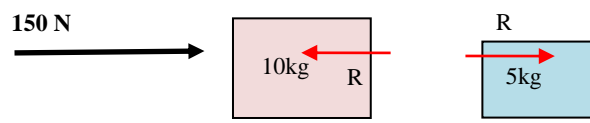
So the acceleration of both these two bodies will be  $10 \text{ m/s}^2$

Now we want to find the contact forces in other words the reaction forces. To help us do this let us break up both bodies and show the forces acting on each body separately



Now the reaction forces ( shown in red) act on different bodies

So let us set up the equation of the net force on the body with mass  $10 \text{ kg}$



Choose positive direction to the right

So the net force equation that is acting on mass  $10 \text{ kg}$

$$150 - R = 10a$$

Remember that the mass accelerates with  $10 \text{ m/s}^2$

So this equation becomes  $150 - R = 100$

The net force equation that is acting on mass  $5 \text{ kg}$  is given by

	$R = 5a$  Remember that this mass accelerates with 10ms/s/  $R = 5 \times 10 = 50$  Now we have found the reaction force, 50 N  This should not surprise us as the action and reaction forces are equal as from Newton's law.  Question dealing with pulleys system overhanging of a side- To be added
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## Momentum Main Concepts

- Momentum is the product of mass multiplied by velocity and it is a vector
- Momentum is conserved provided the system is closed, in other words there is no outside external forces
- The faster an object moves the higher is the momentum.
- The units of momentum is kg/m/s
- Elastic collisions , total energy is the same before and after
- Inelastic collisions, the total energy are not the same afterwards.

### Main Formulas for momentum

$$p = m \times v$$

Total Momentum Before = Total Momentum After

$$F = \frac{\Delta p}{\Delta t}$$

$$I = F \times \Delta t$$

Example on how to use Momentum

#### Example 1:

A car of mass 1200 kg is moving North at a velocity of 2 m/s, what is its momentum?

**Answer:** We must always choose a direction for which we will define as positive, in this case we will choose North as being the positive direction

So  $p = m \times v$

$$\rightarrow p = 1200 \times 2$$

$$\rightarrow p = 2400 \text{ kgm/s North}$$

You must always give a direction when working out the momentum, since it is a vector!

#### Example 2:

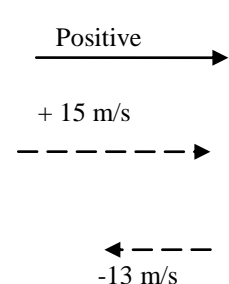
A 20 g squash ball hits a wall horizontally at a speed of 15 m/s and bounces back in the opposite direction at a speed of 13 m/s. It is in contact with the wall for a time of 0.002 seconds. Answer the following questions

- a) What is the change in momentum of the squash ball

Draw a diagram is always important.

Step 1: Pick a direction to be positive and adjust all other variables

Step 2: Use the correct equation and proceed to solve problem.



$$\Delta p = p_{final} - p_{initial}$$

$$\Delta p = \left(\frac{20}{1000} \times -13\right) - \left(\frac{20}{1000} \times 15\right)$$

$$\Delta p = (-0.26) - (0.3)$$

$$\Delta p = -0.56$$

b) What is the impulse on the squash ball?

Impulse is the same as change in momentum, so it is the answer from above

$$I = \Delta p = -0.56$$

c) What is the size of the force exerted by the wall on the squash ball?

Using the formula  $F = \frac{\Delta p}{\Delta t}$  we get the Force that is exerted by the wall on the ball, which is also the force the ball exerts on the wall

$$F = \frac{\Delta p}{\Delta t} = \frac{-0.56}{0.002} = -129.93 \text{ N}$$

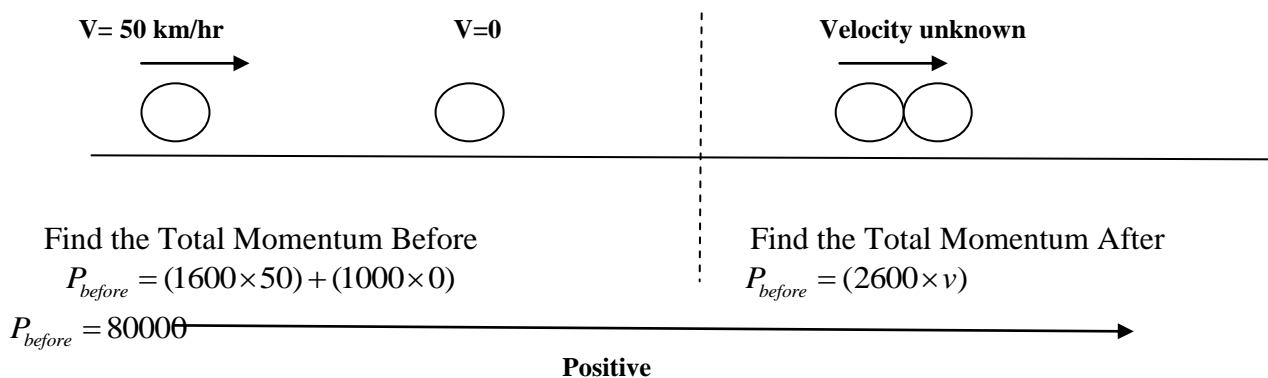
Do you notice how we get a negative force; this is showing us that the force has the opposite direction to the direction we choose as positive.

### Example 3

An absentminded motorist (his car has a mass of 1600 kg) is travelling at a speed of 50 km/hr and slams into a stopped car at the lights (mass of stationary car 1000 kg). After the collision both cars become attached and travel at an unknown speed. What is the unknown speed?

Solution:

Once again a diagram is extremely important



Since Total Momentum Before = Total Momentum After

$$2600v = 80000$$

$$v = \frac{80000}{2600}$$

$$v = 30.77 \text{ km/hr}$$

Normally we should convert km/hr into m/s but it is ok to have km/hr provided we keep it consistent.

## More comments on Momentum

- The idea of momentum is useful when analysing collisions. For example when a car hits a tree both the momentum and velocity before equals to zero. The momentum has been transferred to the Earth, since it has a huge mass its change in velocity is hardly noticed. If the time of the crash can be lengthened then the force which is produced can be reduced thereby reducing impact on the passengers.
- Modern vehicles use this concept to reduce the force by the usage of airbags and crumple zones.
- Remember that Impulse is equal to change on momentum so if the impulse is a fixed quantity then the individual values of  $F$  and  $T$  can vary as long as they multiply to the fixed momentum. As a result time is extended thereby making the force smaller.

## ELASTIC AND INELASTIC COLLISIONS

- Elastic collisions both momentum and kinetic energy conserved- do not occur often
- Inelastic collisions only momentum is conserved but kinetic energy is not. Most popular type of collision. . The difference in kinetic energy is normally converted to other forms of energy such as sound, heat and light etc

## Skill Builder

**Question 1:** Find the momentum of an elephant of mass 12000 kg walking at a speed of 3 m/s.

**Question 2:** Find the momentum of an flea of mass 0.05grams and has a speed of 200 km/hr.

**Question 3:**

A tennis ball is thrown at a wall (due East) with a speed of 13 m/s and it rebounds with a speed of 11 m/s. Answer the following:

- a) What is the initial momentum of the tennis balls assuming the initial direction can be taken as being positive?
- b) What is the final momentum of the tennis ball
- c) What is the change in momentum?
- d) What is the change in velocity of the tennis ball
- e) What is the force the tennis ball experienced assuming it remains in contact with the wall for 0.02 seconds?

**Question 4:**

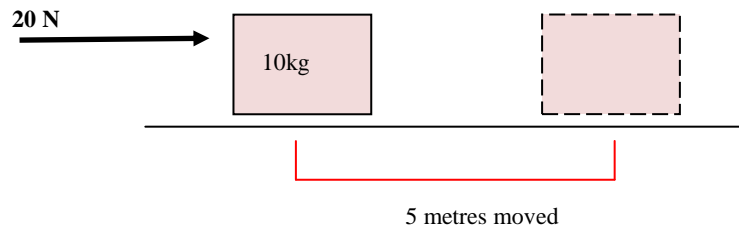
A car with a total mass of 1500 kg (including passengers) travelling at 95 km/hr hits a large tree and stops in 0.075 seconds.

- a) What impulse is applied to the car by the tree?
- b) What is the change in momentum?
- c) What is the force is exerted by the tree on the car?
- d) What is the size of the deceleration of the 70 kg driver of the car if he is wearing a properly fitted seatbelt?

**Question 9:**

- a) Find the final velocity of the car on the right hand side.





Question: What is the work that has been done by the force of 20 N on the box?

Answer

Since the force is parallel to the direction of motion we can then use the formula-

$$W = F \times d$$

Thereby we get the following

$$W = F \times d$$

$$W = 20 \times 5 = 100J$$

So the answer is 100 Joules of energy ( Work has the same units as energy)

Here are some interesting facts about work

Force	Type of work done
If force helps motion	We call it positive work
If force opposes motion	We call it negative work
If the force is parallel to the motion	We can find the amount of work done
If the force is perpendicular to motion	There is no work

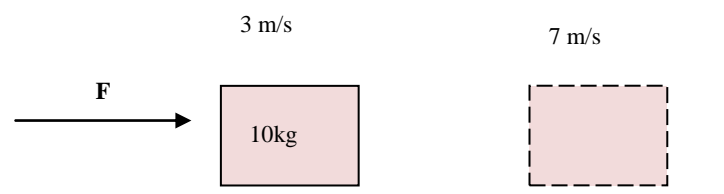
Remember work is a scalar and not a vector

Here is another formula that we can use involving work

$$W = F \times \Delta s = \Delta E_k = \Delta E_p$$

Let examine the same problem as before but this time let us imagine that the box is already moving and suddenly because of a force it increase it speed. What is the work done now on the box?

Example involving  
change in kinetic  
energy



We do not know the force or the distance travelled by the box but we do know the respective speeds

$$W = F \times \Delta s = \Delta E_k = \Delta E_p$$

In particular we can work out the change in kinetic energy-  $\Delta E_k$

$$\Delta E_k = E_{kinetic-final} - E_{kinetic-initial}$$

Now remember that the formula for kinetic energy is the following-  $E_k = \frac{1}{2} \times m \times v^2$

So we can find the change in kinetic energy which in turn will give us the work done on the box

$$\Delta E_k = E_{kinetic-final} - E_{kinetic-initial}$$

$$\Delta E_k = \frac{1}{2} \times 10 \times 7^2 - \frac{1}{2} \times 10 \times 3^2 = 200J$$

$$W = F \times \Delta s = \Delta E_k = 200$$

If we are told for example that the box moved 2 metres then we can use the above formula and find the missing force which would simply be 100 N

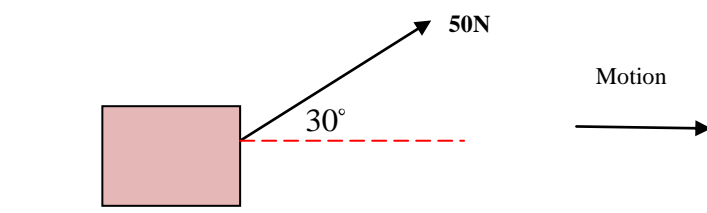
$$W = F \times \Delta s = \Delta E_k = 200$$

$$200 = F \times 2$$

$$F = \frac{200}{2} = 100N$$

Let us examine a special case where the box actually moves horizontally yet the force pulling at an angle

Consider the case below- the box moves 20 metres in the horizontal direction as shown by the arrow

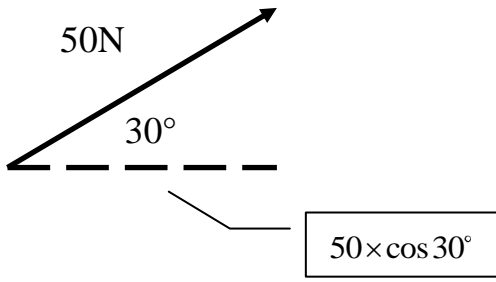


What if the force is at an angle?

Be very careful when using your calculators- make sure the calculator is in degrees mode!

All we need is to find the component of the force that is in the direction of the motion

We need to use a little bit of trigonometry here



So the component of the force that is acting in the horizontal direction-  $50 \times \cos 30^\circ$

Now just use the formula

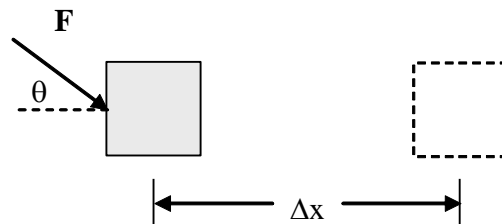
$$W = F \times d = 50 \cos 30^\circ \times 20 = 866.03 \text{ Joules}$$

Work is defined as the product of a force in the direction of a displacement times the displacement. If the force is parallel to the displacement then

$$W = F\Delta x \quad [\text{N}\cdot\text{m} = \text{joule (J)}]$$

If the force makes an angle with the displacement then

$$W = F\Delta x \cos\theta,$$

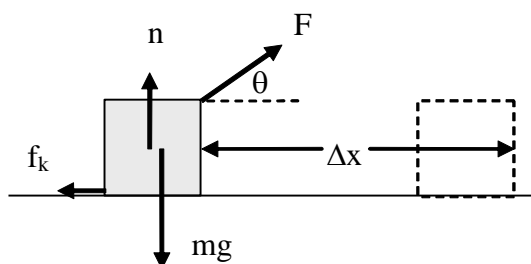


where  $\theta$  is the angle between the force and the displacement.

If  $\mathbf{F}$  is perpendicular to the displacement ( $\theta = 90^\circ$ ), then  $W = 0$ . If  $\mathbf{F}$  has a component opposite to the displacement ( $\theta > 90^\circ$ ), then the  $W$  is negative. Friction always does negative work on a moving object since the frictional force is opposite to the displacement.

**Example:**

A 20-kg mass is pulled along a level surface a distance of 4 m by a 150-N force directed  $30^\circ$  above the horizontal direction. The frictional force acting on the object is 50 N. Find the work done by each individual force acting on the mass and find the total work.



Applied force:  $W_F = F\Delta x \cos\theta = (150 \text{ N})(4 \text{ m})\cos(30^\circ) = \underline{519.6 \text{ J}}$

Normal force:  $W_n = n\Delta x \cos(90^\circ) = \underline{0}$

Gravity:  $W_g = mg\Delta x \cos(90^\circ) = \underline{0}$

Friction:  $W_f = f_k\Delta x \cos(180^\circ) = -f_k\Delta x = -(50 \text{ N})(4 \text{ m}) = \underline{-200 \text{ J}}$

Total work:  $W = W_F + W_n + W_g + W_n = 519.6 \text{ J} - 200 \text{ J} = \underline{319.6 \text{ J}}$

## Work-Energy Theorem

The net work done on an object is the change in the kinetic energy:

$$W_{\text{net}} = \Delta \text{KE}$$

**Kinetic energy** is defined as  $\text{KE} = \frac{1}{2} mv^2$ . Thus,

$$W_{\text{net}} = \frac{1}{2} mv_f^2 - \frac{1}{2} mv_i^2.$$

The work-energy theorem follows from Newton's 2<sup>nd</sup> law of motion:

$$W_{\text{net}} = F\Delta x = ma\Delta x$$

If the acceleration is constant, then  $v^2 = v_0^2 + 2a\Delta x$ , or  $a\Delta x = \frac{1}{2} (v^2 - v_0^2)$ . So

$$W_{\text{net}} = m \frac{1}{2} (v^2 - v_0^2) = \frac{1}{2} mv^2 - \frac{1}{2} mv_0^2 = \Delta \text{KE}$$

**Example:** In the above example, assume that the block starts with an initial speed of 5 m/s. What is its speed after it has moved 4 m?

$$\frac{1}{2} mv_f^2 = W_{\text{net}} + \frac{1}{2} mv_i^2 = 319.6 \text{ J} + \frac{1}{2} (20 \text{ kg})(5 \text{ m/s})^2 = 319.6 \text{ J} + 250 \text{ J} = 569.6 \text{ J}$$

$$\frac{1}{2} (20 \text{ kg})v_f^2 = 569.6 \text{ J}, \quad \underline{v_f = 7.5 \text{ m/s}}$$

## Potential Energy

The potential energy of a mechanical system is related to its position. That is, the position of an object in a system may allow it to do work.

### Gravitational potential energy

An object under that influence of a gravitational force will have potential energy relative to some fixed position. If an object falls a distance  $h$ , then the work done by gravity is

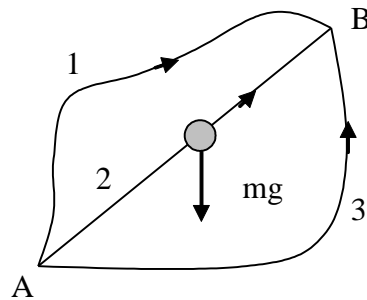
$$W_g = Fh = mgh$$

This work done by gravity on a falling object is the amount by which the gravitational potential energy is reduced. The work that you would do in lifting the object against the force of gravity would be the increase in potential energy. The potential energy is always defined relative to some fixed position. So if this fixed position is  $y = 0$ , then

$$PE = mgy$$

### Conservative and Non conservative Forces

A potential energy can only be associated with a force if it is *conservative*. A conservative force is one for which the work done by the force on an object as it goes from point A to point B doesn't depend on the path taken. The work done by gravity, for example, doesn't depend on the path since any horizontal motion is perpendicular to the force and doesn't contribute to the work.



force if  
from  
The  
on path  
force

In the illustration to the right, the work done by gravity as the object moves from A to B is the same for paths 1, 2 and 3. Another way to describe a conservative force is to say that the net work done by the force if the object goes in a closed path (e.g., from A to B and back to A) is zero.

A *non conservative* force is one for which the work depends on the path. Friction is a non conservative force. For example, if you slide a block on a surface along a closed path the work is not zero.

### Conservation of Mechanical Energy

The total energy of a system is the sum of the kinetic and the potential.

$$E = KE + PE$$

In the absence of friction, the total energy of a system does not change with time. This is the principle of *conservation of energy*.

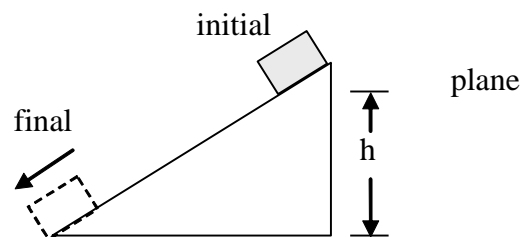
#### Example:

A block slides from rest down a frictionless inclined plane of height  $h$ . What is its speed at the base of the incline?

$$E_{\text{initial}} = E_{\text{final}}$$

$$KE_i + PE_i = KE_f + PE_f$$

$$\frac{1}{2} mv_i^2 + mgy_i = \frac{1}{2} mv_f^2 + mgy_f$$



Choose the base of the incline as  $y = 0$ . (The choice doesn't really matter as long as we are consistent.) Then  $y_i = h$  and  $y_f = 0$  and

$$0 + mgh = \frac{1}{2} mv_f^2$$

$$\text{and } v_f = \sqrt{2gh}$$

This speed is the same as would be obtained if the mass were dropped straight down from a height  $h$ . All that matters is the change in height. (Of course the time to slide down would be longer than the time to fall.)

### Example:

A projectile is fired into the air with speed  $v_0$ . What is its speed when it reaches a height  $h$ ? Using conservation of energy,

$$E_f = E_i$$

$$\frac{1}{2} mv_f^2 + mgy_f = \frac{1}{2} mv_i^2 + mgy_i$$

Cancelling out  $m$ , we can rewrite this as

$$v^2 = v_0^2 - 2g(y_f - y_i) = v_0^2 - 2gh$$

$$\text{or, } v = \sqrt{v_0^2 - 2gh}$$

## Potential Energy Stored in a Spring

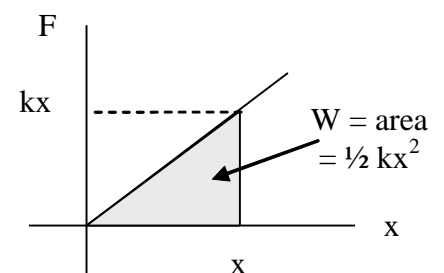
Many springs obey Hooke's law,

$$F = -kx$$

where  $F$  is the restoring force of the spring,  $x$  is the stretch (or compression) of the spring from its equilibrium position, and  $k$  is the force constant of the spring (a measure of the spring stiffness). The minus sign signifies that the restoring force is opposite to the displacement.

The spring force is a conservative force and a potential energy can be associated with the stretch or compression of the spring.

The graph to the right shows the force required to stretch a spring (opposite to the restoring force) as a function of the stretch. The potential energy stored in the stretched spring is the work required to stretch it. For a constant force  $W = Fx$ . If the force is not constant, then we use the average force. For the spring,



$$F_{\text{ave}} = \frac{1}{2} (F_i + F_f) = \frac{1}{2} (k(0) + kx) = \frac{1}{2} kx, \text{ and } W = F_{\text{ave}}x = \frac{1}{2} kx^2$$

(Note: Using the average force is the same as taking the work to be the area under the  $F$  versus  $x$  curve.)

Thus,  $PE = \frac{1}{2} kx^2$

**Example:**

A spring gun has a force constant  $k = 200 \text{ N/m}$ . It is used to fire a 10-g projectile horizontally. If the spring is compressed 7 cm in the cocked position, what is the speed of the projectile when it leaves the barrel of the gun?

We solve this using conservation of energy. We don't need to consider gravitational potential energy since the height of the projectile is the same in the cocked position and when it exits the barrel.

$$E_f = E_i$$

$$\frac{1}{2} mv_f^2 + \frac{1}{2} kx_f^2 = \frac{1}{2} mv_i^2 + \frac{1}{2} kx_i^2$$

$$\frac{1}{2} mv^2 + \frac{1}{2} k(0)^2 = \frac{1}{2} m(0)^2 + \frac{1}{2} kx^2$$

$$v = x \sqrt{\frac{k}{m}} = 0.07 \text{ m} \sqrt{\frac{200 \text{ N/m}}{0.01 \text{ kg}}} = 9.9 \text{ m/s}$$

**Example:**

This same spring gun is fired straight up into the air. How high does it go?

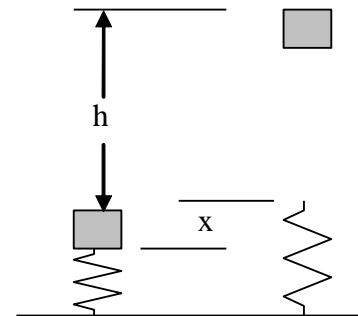
$$E_f = E_i$$

$$\frac{1}{2} mv_f^2 + mgy_f + \frac{1}{2} kx_f^2$$

$$= \frac{1}{2} mv_i^2 + mgy_i + \frac{1}{2} kx_i^2$$

$$0 + mgh + 0 = 0 + 0 + \frac{1}{2} kx^2$$

$$h = \frac{\frac{1}{2} kx^2}{mg} = \frac{\frac{1}{2} (200)(0.07)^2}{(0.01)(9.8)} = 5.0 \text{ m}$$



## Frictional Forces and Energy

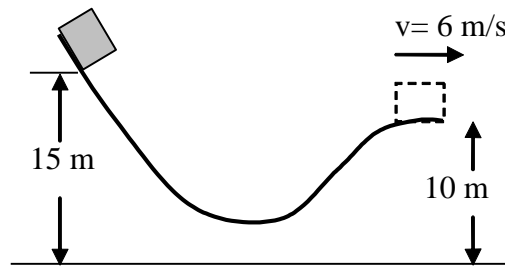
If friction or some other non conservative force is present, then energy is not conserved. In this case,

$$W_f = \Delta E = E_f - E_i$$

Since  $W_f$  is negative, this means that friction will reduce the total mechanical energy. (Some of the mechanical energy is converted into internal thermal energy.)

**Example:**

A 2-kg block is released from rest on a slide 15 m above the ground. It leaves the end of the slide 10 m above the ground with a speed of 6 m/s. How much work was done by friction on the block?



$$\begin{aligned}
 W_f &= (KE_f + PE_f) - (KE_i + PE_i) = \left(\frac{1}{2}mv_f^2 + mgy_f\right) - \left(\frac{1}{2}mv_i^2 + mgy_i\right) \\
 &= \left[\frac{1}{2}(2)(6)^2 + (2)(9.8)(10)\right] - \left[\frac{1}{2}(2)(0)^2 + (2)(9.8)(15)\right] \\
 &= 36 + 196 - 294 = \underline{-62 \text{ J}}
 \end{aligned}$$

### Power

Power is the rate at which work is done.

$$P = \frac{W}{\Delta t} \quad \text{Units are J/s = watt (W)}$$

Since  $W = F\Delta x$ , then  $P = \frac{F\Delta x}{\Delta t} = F\bar{v}$

### Example:

What is the average power required to lift a 60-kg person a height of 2 m in 5 seconds?

$$P = \frac{W}{\Delta t} = \frac{F\Delta y}{\Delta t} = \frac{mg\Delta y}{\Delta t} = \frac{(60)(9.8)(2)}{5} = 235.2 \text{ W}$$

## Total Energy= Kinetic + Potential energy

### Concepts

- Energy is a scalar quantity not a vector
- Energy is defined as the ability to do work
- Moving Energy = Called Kinetic energy ( energy of a moving ball etc )
- Stored Energy = Potential Energy (such as energy stored in springs etc)

- Total Energy remains the same for a closed system, in other words energy cannot be destroyed but it can change into its various different forms ( kinetic, potential, gravitational, thermal, light energy etc)
- $E_{\text{Total at one point x}} = E_{\text{Total at one point y}}$
- $E_{\text{Total}} = E_K + E_P$  - ( applies at a specific point of the closed system)
- Energy is measure in Joules

We will focus on Kinetic energy and Potential energy at this moment

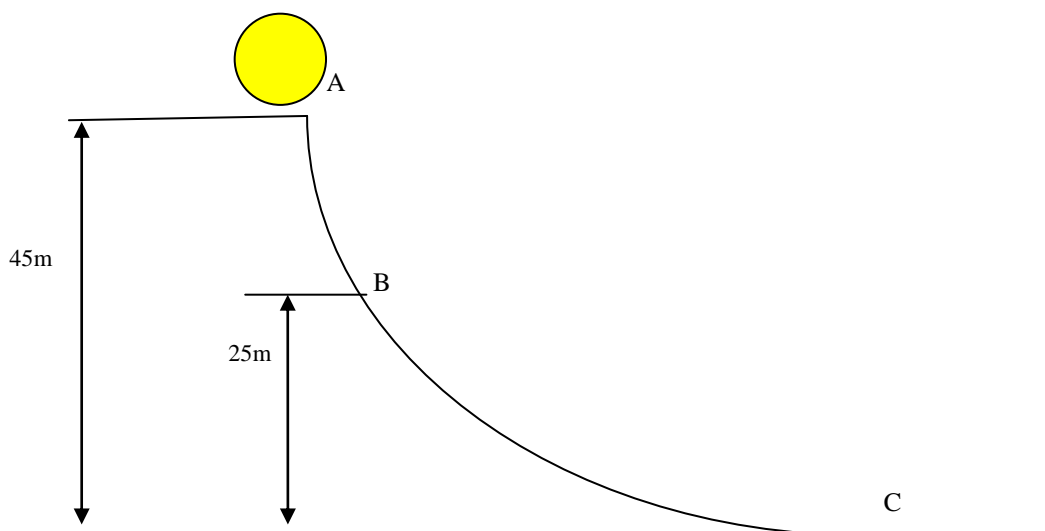
### Equations

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

$$E_p = mgh$$

Let's examine a particular case and see how these equations work

Imagine a ball of mass 4 kg resting on the edge of ramp as shown below. It starts from rest. Let us see how we can use the concepts of energy. Assume  $g = 10 \text{ m/s/s}$



**Question 1:** What is the kinetic energy at Point A?

**Question 2:** What is the potential energy at point A? (Take the lowest point C to have Zero potential energy)

**Question 3:** What is the total energy at point A? (Hint: Add Kinetic energy + Potential energy together)

**Question 4:** What is the total energy at point B?

**Question 5:** What is the total energy at point C?

**Question 6:** What is the total energy anywhere in this system?

Just as it passes point B answer the following specific questions

**Question 7:** What is the potential energy at point B?

**Question 8:** Using the equation  $E_{\text{Total at one point x}} = E_{\text{Total at one point y}}$  what is the total energy at point B?

**Question 9:** What is the kinetic energy at point B then?

**Question 10:** What is the velocity of the ball at point B?

Looking at point C now

**Question 7:** What is the potential energy at point C?

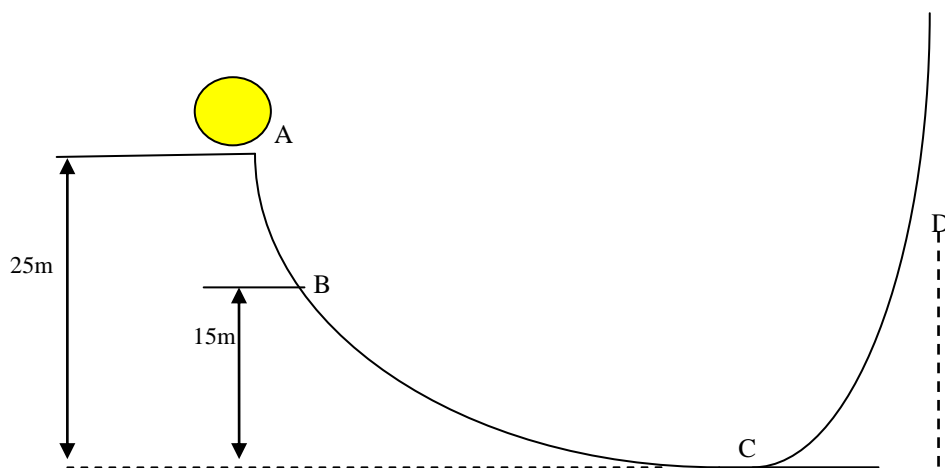
**Question 8:** Using the equation  $E_{\text{Total at one point x}} = E_{\text{Total at one point y}}$  what is the total energy at point C?

**Question 9:** What is the kinetic energy at point C then?

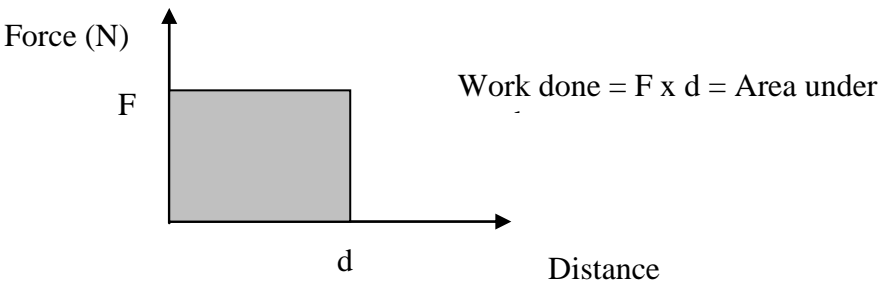
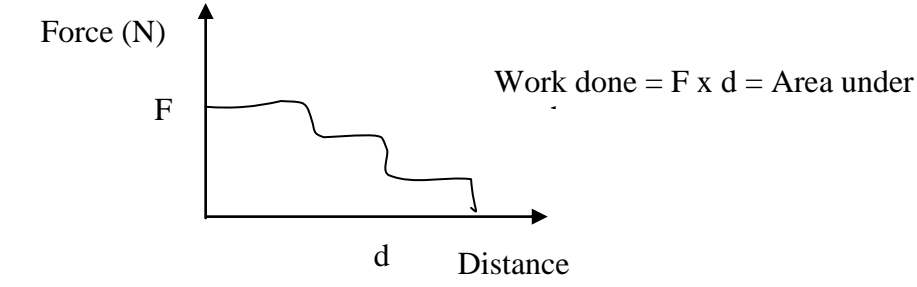
**Question 10:** What is the velocity of the ball at point C?

**Question 11:** What is the potential energy of the ball at point C?

**Question 12:** Assuming that there is not loss of energy due to heat, friction etc, how high will the ball rise? (D)



Power	<p>The rate at which work is done is called the power and it is measured in Watts ( W ) A simple formula to work out the power is as follows</p> $P = \frac{W}{t}$ <p>Here t = is measured in seconds and W – measured in Joules</p> <p>1 W = 1 J/s</p> <p>( 1 horsepower ( hp ) =746 W)</p> <p>Example</p> <p>How much power is generated by a simple motor that does 5500 joules of work in 35 seconds?</p> <p>Answer</p> $P = \frac{W}{t} = \frac{5500}{35} = 157.14$ <p>Question-2</p> <p>How long will it take a 36 W motor to pull a box across the floor 25 m with a force of 16 N?</p>
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	<p>Answer</p> <p>Sometimes we need to work out something firstly before we can put it into the formula          For example here we need to find the work done first and then use the formula for power</p> $W = F \times d = 16 \times 25 = 400J$ <p>Now we can use the power formula</p> $P = \frac{W}{t}$ $36 = \frac{400}{t}$ $t = \frac{400}{36} = 11.11\text{sec}$
<p>What is another expression for Power</p>	$P = \frac{W}{t} = Fv$ , where v is the velocity of the object
<p>How to find the work done on a body from a graph</p>	<p>We can find the work done on a body by finding the area enclosed by the graph-shaded area under the graph</p>  <p>Here in the graph above we have a constant force and so we can use our expression such as</p>
	<p>If the graph is not that simple we can still find the work done by estimating the area under the graph</p> 
<p>What happens if the box is raised vertically</p>	<p>If the box is raised vertically then we can work the change in potential energy and that would give us the change in energy and the work done against gravity to raise the box upwards.</p>