Nelson Thornes
Distance Learning

A2 Physics

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First edition published in 2009. This edition published in 2010 by:
Nelson Thornes Distance Learning
Delta Place
27 Bath Road
CHELTENHAM
GL53 7TH
United Kingdom

10 11 12 13 14 15 16 / 10 9 8 7 6 5 4 3 2

Printed in Great Britain by Berforts Group

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Contents

PHYSICS A2

This course is based on the AQA exam board syllabus: subject code 2451.

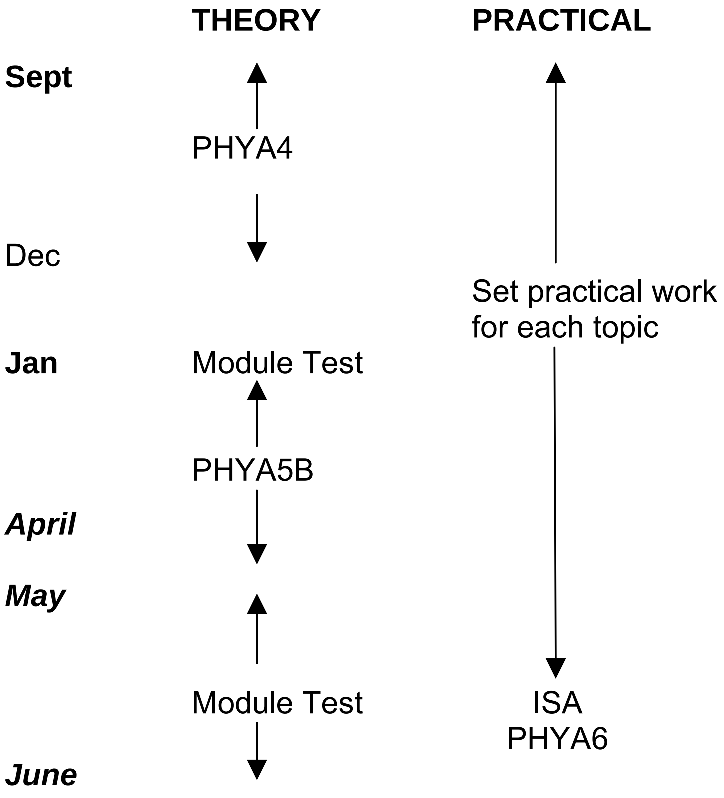
Again this year you will be studying two separate theory modules and you will be undergoing an assessment of your investigative and practical skills as the third module.

The first theory module you will be studying for your A2 course is PHYA4, entitled ‘Fields and Further Mechanics’. This module test is available in January.

Later in January, the second theory module, PHYA5B, will be started. This is divided into two sections; section A is entitled ‘Nuclear and Thermal Physics’ and section B is entitled ‘Medical Physics’ and this will be completed around Easter. After this you will begin preparation for the Theory Module Tests in May/June.

You will be preparing for the final module, PHYA6, the ‘Investigative and Practical Skills in A2 Physics’, continually during the whole course by completing the practicals in each section.

Time lines



PHYA4 Fields and Further Mechanics

This section is a **complete list** of all the topics covered in **PHYA4**.

The boxes are for you to use as a checklist to confirm you have completed **all the work**. When you have completed a topic, indicate this by writing in the box the **page number(s)** where you have found the relevant theory on that topic. In this way you will build your own index which will be useful when you come to revise for the Module Test.

PHYA4 is found in unit 3.4 of the specification.

Unit	Section	Topic	Skills	Page
3.4.1	Further Mechanics			
		Motion	Momentum	
			Circular motion	
		Oscillations	Simple harmonic motion	
			Simple harmonic systems	
			Forced vibrations and resonance	
3.4.2	Gravitation			
		Gravity	Newton’s law	
			Gravitational field strength	
			Gravitational potential	
		Orbits	Planets and satellites	
3.4.3	Electric fields			
		Calculations	Coulomb’s law	
			Electric field strength	
			Electric potential	
		Comparison	Electric vs gravitational fields	
3.4.4	Capacitance			
		Capacity	Definition	
			Energy stored by a capacitor	
			Capacitor discharge	

3.4.5	Magnetic Field			
		Calculations	Magnetic flux density	
			Moving charges	
			Magnetic flux and linkage	
			Electromagnetic induction	

Further Mechanics: Motion

AIMS: ***This section will help you to understand:***

Momentum	
Impulse	
Conservation of momentum	
Collisions	
Circular motion	
Centripetal acceleration	
Centripetal force	

Tick the boxes when you have achieved each aim.

READING: Use the course textbook 'Physics A' (The A2 book)

Start at Unit 4, Force and Momentum on page 2.

Read the introduction and check what you should already know, listed on page 3.

Read the following sections of Chapter 1, Force and momentum

1.1 Momentum and impulse on pages 4–7
1.2 Impact forces on pages 8–10
1.3 Conservation of momentum on pages 11–13
1.4 Elastic and inelastic collisions on pages 14–15
1.5 Explosions on pages 16–17

Newton’s Laws of Motion and their Origins

A force is required to both start and stop things moving, so the link between force and motion is very well established today. In an earlier civilisation, that of ancient Greece, it was thought that a force was also required to keep an object in motion. This idea has persisted for a very long time due to the simple observation that if you stop pushing something, sooner or later it stops. Of course the reason for this is the force of friction, which acts to oppose motion. Knowledge of friction enables us to understand that the force that seemed to be required to keep things moving was in fact the force required to overcome the friction. This is more obvious in modern times due to the advent of space travel. Once a space vehicle is up to speed, the engines shut down and the speed of the vehicle is not affected by friction, since there is none in the vacuum of space.

Galileo, who suggested that a **force** was required to change an objects **velocity**, first expressed these modern ideas during the Italian Renaissance. Some time later, Newton took up these ideas and formed his laws about motion and the forces causing it. In 1686 he published a very famous book called, ‘**Principia**’, in which the laws of mechanics were explained and three ‘laws of motion’ were central to this:

- **Law 1**

  Every body continues in its state of rest or uniform motion in a straight line, unless impressed forces act on it.
- **Law 2**

  The rate of change of momentum of a body is proportional to the applied force and takes place in the direction in which the force acts.
- **Law 3**

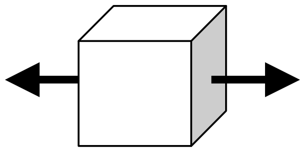
  To every action there is an equal and opposite reaction.

The next three sections explain each of these laws in more modern terms.

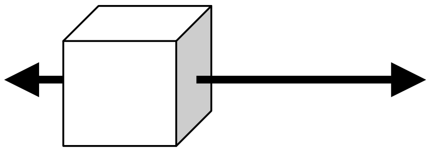
Newton's First Law

This law actually explains what a force is.

'A force accelerates a body and only if there is no net force on a body, then the body will continue its motion in a straight line at constant velocity' (if that is what it was doing before). If it was stationary before, it will remain stationary. The first law is really a special case of the second law, where the force acting on a body is zero.



Balanced forces, no acceleration



unbalanced forces, acceleration

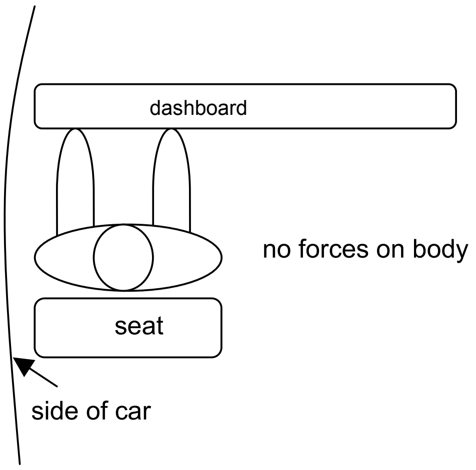
Inertia

Another way of thinking about Newton's first law is to explore the concept of **inertia**. Inertia is the reluctance of a body to start moving if stationary, or its reluctance to stop moving if it is already moving. The mass of a body is a measure of its inertia. A passenger in a powerful car knows all about inertia. As the car accelerates hard, the passenger is thrown backwards into the seat as the car surges forwards, and to some extent the passenger's body remains where it was until the force exerted by the seat back propels it. As the car reaches a steady speed, the passenger feels no forces since there is then no acceleration. The car then approaches a bend in the road, and although the car's speed may not change much, its velocity does as the car changes direction.

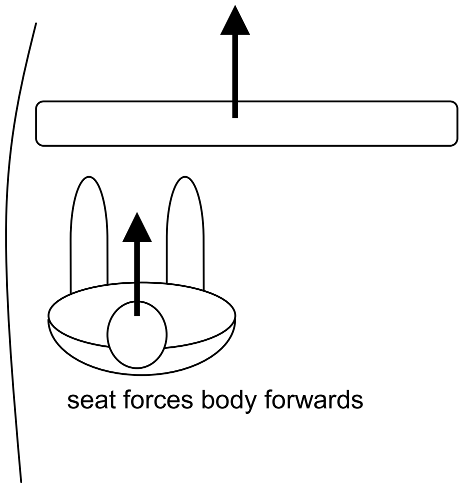
This time inertia tries to make our poor passenger carry on the original straight path, so the passenger then comes into forceful contact with either the door or the driver’s seat, which again exert a force to make the passenger move in the new direction of the car.

Finally, as the car brakes sharply, the inertia of the passenger requires that the passenger keeps on moving at the car’s original high speed and the poor passenger lurches forward making contact with the dashboard, if not restrained by seatbelt or airbag. Where a car crashes it is inertia that results in injuries to the passenger, reducible to some extent by the use of seatbelts and airbags.

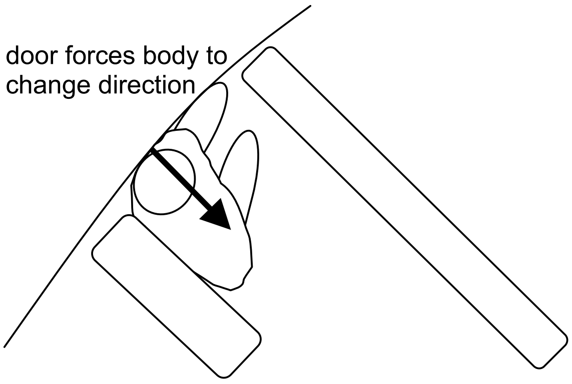
car stationary or at constant velocity



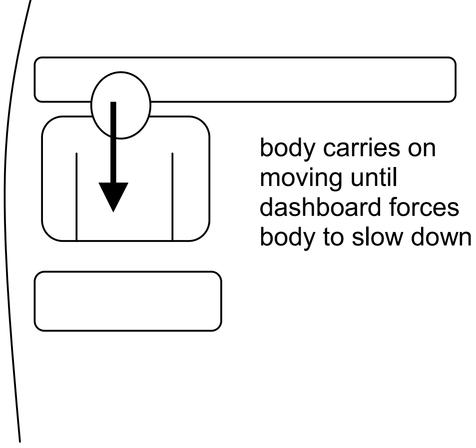
car accelerates



car travels around bend



car stops



Momentum

Before studying Newton's second law, it is necessary to consider the momentum of a moving body. Momentum, put simply, is the mass of a body multiplied by its velocity, since both are important when considering the force required to stop a moving object, or to get a stationary object moving.

Momentum = mass × velocity

Since mass has units of kilograms, and velocity is in metres per second, momentum is measured in kilogram metres per second, kg m s^{-1}.

Moving objects are a danger due to their momentum and the forces required to stop them. An intercity express train of 500 tonnes mass has a huge momentum, even at quite low speeds, and at high speed has a stopping distance of over 1 km. Even at 10 m s^{-1} (just over 20 mph) the momentum of a train is:

$$\mathbf{500\,000\ kg \times 10\ m\ s^{-1} = 5\,000\,000\ kg\ m\ s^{-1}}$$

Contrast this with a small meteorite moving through space at a typical speed of 50 km s^{-1}.
If the meteorite has a mass of just 1 kg its momentum is:

$$\mathbf{1\ kg \times 50\,000\ m\ s^{-1} = 50\,000\ kg\ m\ s^{-1}}$$

So a high velocity gives even a small mass a lot of momentum.

Newton's second law (on the next page) is about the rate of change of momentum and the amount of force required to cause the change.

Newton's Second Law

This states that '**the rate of change of momentum of a body is proportional to the applied force in the direction in which the force acts'.**

If a body travelling initially at velocity, **u**, has a force, **F**, acting on it for a certain amount of time, **t**, then it will accelerate to a new velocity, **v**.

Its original momentum was **mu**,

its new momentum is now **mv**,

so its change of momentum is **mv–mu**.

Since it took **t** seconds to do this, then the rate of change of momentum is:

$$\frac{mv - mu}{t}$$

Since in the SI system we measure the force, F, in Newtons, then:

$$F = \frac{mv - mu}{t}$$

In most situations, where the mass of the body stays constant, and since

$\frac{v - u}{t}$ is the change of velocity in the time t, known as its acceleration a,

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

Therefore **F = m a**

It can clearly be seen here that force, mass and acceleration, are linked, and no force means that there can be no acceleration, which leads back to Newton's first law. This equation also provides a definition of the Newton:

1 Newton force will accelerate a 1 kg mass by 1 m s $^{-2}$

Weight

This is simply the force generated due to mass being present in the gravitational field of the Earth. Earth's gravitational field gives an acceleration to a body in the field, since this is a special case of an acceleration, **g** is used as a symbol rather than the general case, when **a** would be used. Similarly, **W** is used for weight, which is a special case of the downward force, which would have been termed **F** generally.

The weight **W** of a mass **m** in Earth's gravity **g** is given by

$$W = m g$$

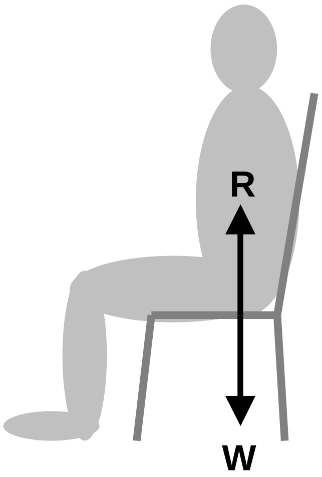
This is another version of Newton's second law, and a special case of F = ma.

Newton's Third Law

'To every action there is an equal and opposite reaction.'

When a person sits on a chair, the downward force of the person on the chair (weight) is balanced by an upward force generated by the chair on the person. The upward force is called a reaction force, and probably explains why people cannot sit for long on a hard chair, which causes pressure points and an uncomfortable feeling after a while.

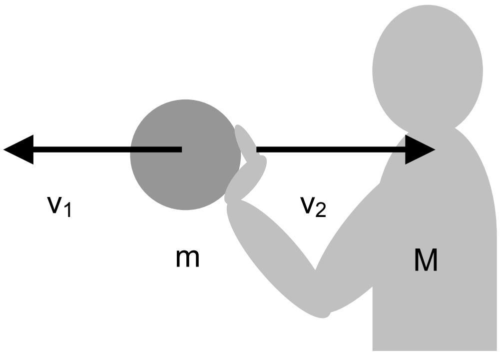
A cushion helps by spreading the force over a larger area, so although it becomes less noticeable, it is still there. If the chair is strong enough (as are most chairs) it can provide the reaction force. A weak chair would collapse and the person would then fall, due to the unbalanced force. The very fact that a person can sit still on a chair, supported by its reaction force, means that the weight and the reaction force are exactly balanced. Remember Newton's first law.



The Law of the Conservation of Momentum

‘When two or more bodies act on each other, their total momentum remains constant, providing no external forces are present.’

If a person throws a heavy ball forwards, they experience a backwards movement themselves. This is because before the ball was thrown, the person and the ball were stationary and so had no momentum. The only way to give the ball forward momentum is for the person to accept that they will receive the same amount of momentum in the opposite direction. Since the person will have a much greater mass then even a heavy medicine ball, the ball will have a greater velocity in one direction than the person will have in the opposite direction.

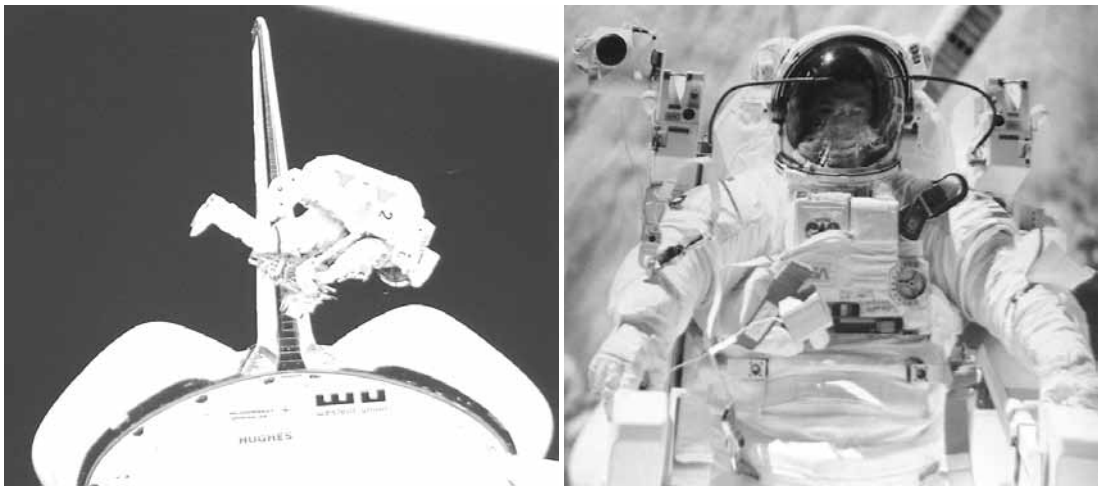


For momentum to be conserved;

$$m v_1 = M v_2$$

The arrows on the diagram, representing velocities, could also represent forces of action and reaction in this case, but would start from the point at which the ball touches the throwers hand.

The law of conservation of momentum is used to provide control for space vehicles. A vehicle's velocity can be adjusted using jets of gas, which cause a reaction on the vehicle and change its velocity in the opposite direction. An astronaut's MMU (man manoeuvring unit) works on this principle.



An astronaut floating free, manoeuvres around the shuttle using the MMU

How not to get wet!

The law of the conservation of momentum also explains why it is wise to have someone hold a rowing boat to a jetty or tie it up before stepping out of the boat onto the jetty. A person standing still in a stationary rowing boat forms a system which has no momentum, so as fast as the person tries to walk off an unsecured boat, the boat will move away from the jetty by a similar amount due to the similarity in mass of the person and the boat. This means that the step forward made is only half what the person expected, and usually results in an unexpected soaking.

Momentum and Collisions

When two bodies collide, they can either bounce apart after the collision (called an **elastic collision**), or they can stick together after the collision (called an **inelastic collision**). Momentum is conserved in both cases, so:

Total momentum before collision = Total momentum after collision.

This also applies to situations other than collisions where two initially stationary bodies separate, such as in the previous examples of the person and the rowing boat, or the person throwing the medicine ball. This then results in a more general form of the law of conservation of momentum that applies to any such interaction:

Total momentum before interaction = Total momentum after interaction.

You should note that the area under a force-time graph would give the change in momentum for that situation.

Questions on force and momentum

You have now completed this topic on forces and momentum.
Make sure you have studied the textbook pages on this.

Now attempt the following questions:

Assignment 1

Summary questions page 7	1, 2
Summary questions page 10	1, 2
Summary questions page 13	1, 2
Summary questions page 15	1, 2
Summary questions page 17	1, 2

Circular Motion

Read the following sections of Chapter 2, Motion in a circle

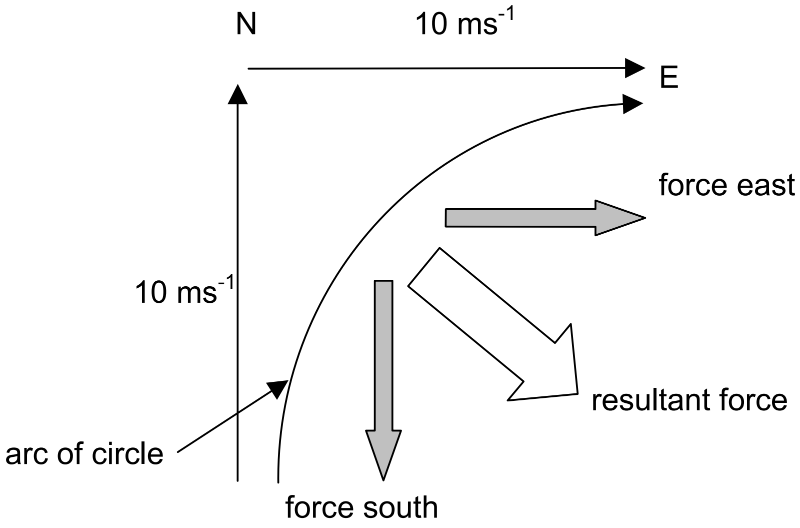
2.1 Uniform circular motion on pages 22–23
2.2 Centripetal acceleration on pages 24–25
2.3 On the road on pages 26–27
2.4 At the fairground on pages 28–29

Circular Motion

Lots of things move in circles, from computer disks in disk drives, to Pluto in the Solar System, and even our whole galaxy, the Milky Way. Circular motion is interestingly different from motion in a straight line that you studied earlier in AS Physics, but the same laws, i.e. Newton's laws of motion, apply.

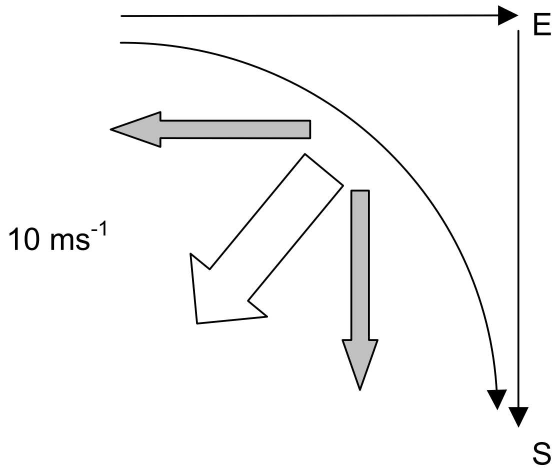
How is an object made to travel in a circle?

Remember velocity is a vector–its direction is as important as its speed. For an object initially travelling due north at 10 ms^{-1}, to be made to travel due east at 10 ms^{-1}, requires that a force acts on the object.



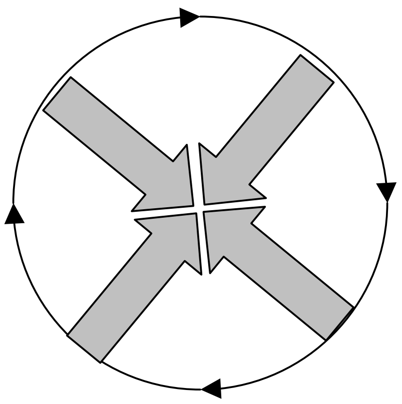
This force must oppose and cancel the northerly motion and create an easterly motion of 10 ms^{-1}, which must require forces to the south and east, as shown above. These forces combine to give a resultant force acting southeast, towards the centre of the inscribed circle whose arc is shown on the diagram above.

If the object is then made to change velocity again until it is travelling due south at 10 ms^{-1}, then a further force acts as shown.



A westerly force opposes and cancels the easterly motion and a southerly force creates further southerly motion of 10 ms^{-1}. These again combine this time to give a force to the southwest, again towards the centre of the circle.

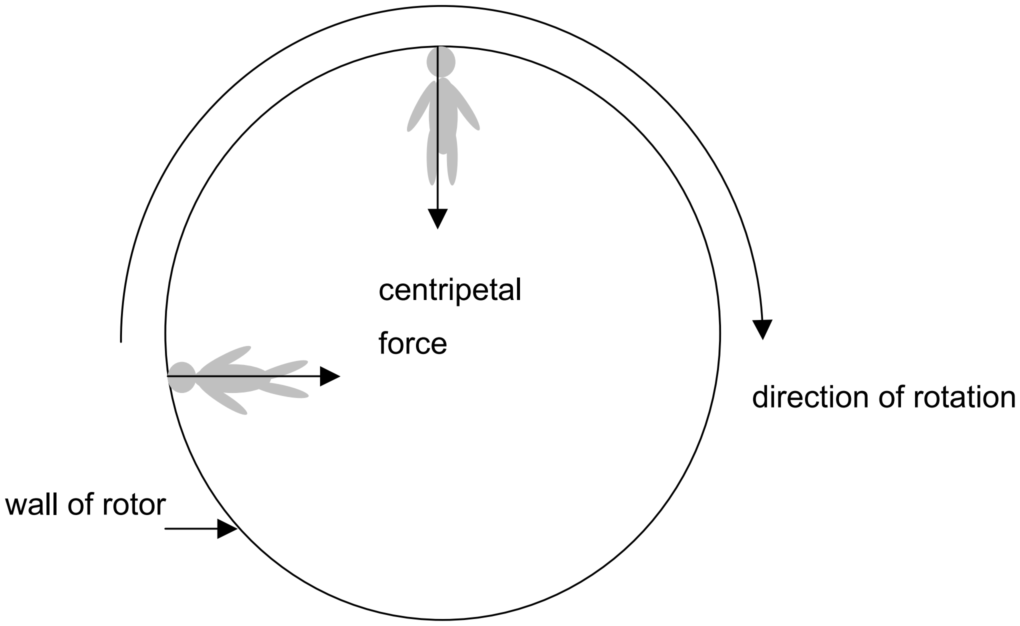
The object has now effectively made a motion of a half circle and the next half circle will require appropriate forces to act. The very important conclusion is that to make an object move continually in a circle, a continual force must be acting towards the centre of the circle. The whole picture is shown below:



To make an object move in a circle requires a force directed to the centre of the circle. This is known as **centripetal force**. An object moving in a circle is continually changing the direction of motion and so it is continually accelerating. The force to cause this motion has to be inwardly directed, and hence its name, centripetal force.

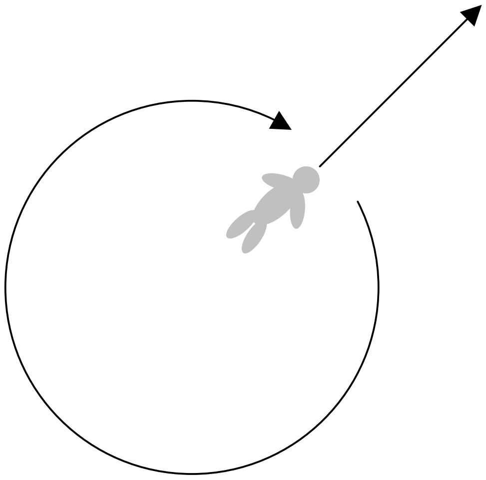
Go on a fairground ride and you will be sure the force is acting to push you outwards, only because the seat, or wall or support, is pushing you inwards to make you move in a circle. The 'Rotor' or 'Wall of Death' spins you around and it is the walls of the ride that provide the inward push.

The Rotor



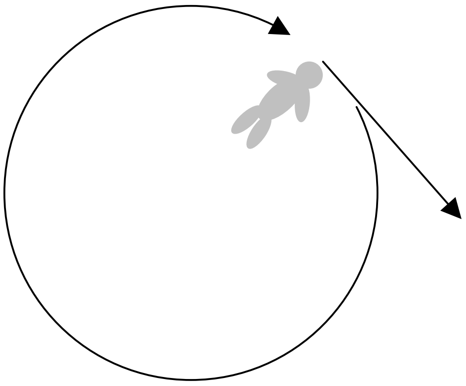
If the walls collapsed, everybody thinks you will be thrown outwards, instead of remembering Newton's First Law that you would simply continue your motion in a straight line if there were nothing to make you move in a circle.
See the diagram on the next page.

Wrong idea



Radial motion **never** happens.

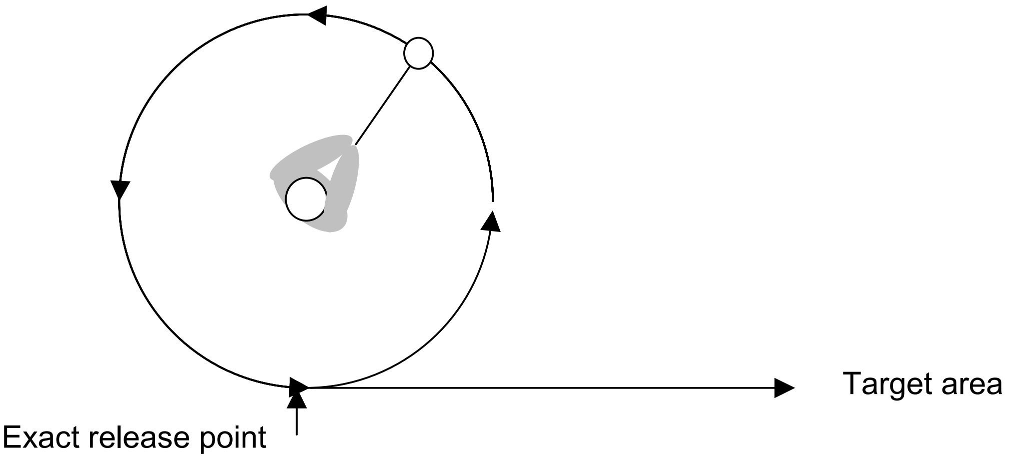
Correct idea



Tangential motion would result.

The hammer thrower

Where in this circular motion would the hammer thrower release his grip? This plan diagram shows it may not be where you expected.



This is just what makes circular motion so interesting.

What provides the centripetal force?

For the computer disk, the disk itself provides the force. If a 56-speed CD ROM drive really went 56 times faster than standard, the forces would shatter the plastic.
For Pluto, the sun's gravity provides the force.

Calculating acceleration and force in circular motion

The faster an object travels around a circular path, the larger the change in velocity as the object rotates, and the greater is the centripetal acceleration required to keep it moving in a circle. The smaller the radius of the circular path means that the velocity is changing more rapidly and so the greater the acceleration.

It can be shown that the acceleration **a,** of an object travelling at velocity **v** around a circular path of radius **r** is:

$$a = \frac{v^2}{r}$$

The size of the centripetal force **F** required to keep an object of mass **m** moving in a circle is given using Newton's second law where:

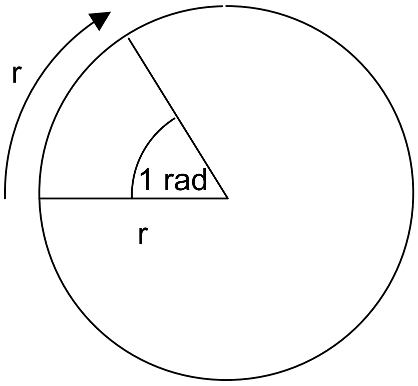
$$F = m a$$

Combining these two equations by substituting $\frac{v^2}{r}$ for **a** gives the centripetal force

$$F = \frac{mv^2}{r}$$

Angular displacement and the radian

As an alternative to giving the velocity of a body as it travels in a circle, (which is not a true velocity since the direction continuously changes), its angular speed may be given instead. To do this requires that some angular measure be used. Since a complete circle consists of 360°, this may seem at first to be useful, but there is a more useful system called the **radian**.



1 radian is the angle where the arc length around the circumference of the circle is exactly the same as the radius.

Since the circumference of a circle is $2\pi r$, then there are 2π radians in 360°. This makes 1 radian approximately 57°.

It is then possible to give angular speeds in radians per second, where angular speed ω,

$$\omega = \frac{\textbf{number of radians turned through}}{\textbf{time taken}}$$

It can be shown that the velocity **v** of an object travelling at **ω** rad s^{-1} around a circle radius **r** is:

$$v = r\omega$$

Which makes the acceleration **a** of an object travelling at **ω** rad s^{-1}, substituting **r ω** from the above relationship for **v** in $a = \frac{v^2}{r}$ gives:

$$a = \frac{(r\omega)^2}{r}$$

which simplifies to:

$$a = r\omega^2$$

Using **F = ma**, the centripetal force **F** now becomes:

$$F = m r \omega^2$$

There are now two ways of calculating acceleration and force due to circular motion, using linear velocity **v (ms^{-1})** or angular speed **ω (rads^{-1})**. These are summarised in the following table:

Quantity	**Using linear velocity v (ms^{-1})**	**Using angular velocity ω (rad s^{-1})**
acceleration	$a = \frac{v^2}{r}$	$a = r\omega^2$
centripetal force	$F = \frac{m v^2}{r}$	$F = m r \omega^2$

Questions on motion in a circle

You have now completed this topic on motion in a circle.

Make sure you have studied the textbook pages on this.

Now attempt the following questions:

Assignment 2

Summary questions page 23	1, 4
Summary questions page 25	1, 4
Summary questions page 27	1, 2
Summary questions page 29	1, 4

Momentum Practical Work

For these practicals you need to use dynamics trolleys, a suitable track and simple timing apparatus often called a “ticker timer”, so called because it prints exactly 50 dots per second on to a strip of tape (“ticker tape”). There are more modern ways of collecting results using a data logger or computer and “light gates”, but this takes away the simple approach and persuades some that in order to collect results you need complex apparatus; you do not. Since the time interval between dots on the tape is one fiftieth of a second, (0.02s) you get a permanent printout of where the dynamics trolley was every fiftieth of a second. Your school should have a low-voltage 6–8 V ac power supply to power the ticker-timer.

Newton’s second law and the law of conservation of momentum can be investigated using one or two trolleys on the track. Each experiment is broken down into two parts;

- the first where a trial experiment can be done and observation made ‘by eye’, using a digital timer.
- the second part of each experiment involves attaching a strip of paper tape, called ‘ticker-tape’, to a trolley, which it then draws through the ticker-timer, which prints 50 dots per second onto the tape, which provides for accurate analysis of the motion of the trolley.

Before any practical is undertaken, you must carry out these tasks:

1. Read thoroughly any instruction notes for the dynamics kit found in your school if available. This should give you an idea of how the apparatus is assembled, and the basis for all the investigations that follow.

2. Compensate your track for friction. This must be checked prior to each different investigation. If the track were perfectly horizontal (check using a spirit level), the trolley would not travel along the track with uniform motion– it would slow down due to the friction in the wheel axles and track. Set the track perfectly horizontal and give the trolley a **very** small push. You will see it slow down and maybe even stop before it reaches the buffer on the pulley bracket, due to the friction in the system.

   Now raise the ticker-timer end slightly (probably less than 1 cm) so that a small component of the weight of the trolley acts down the slope, providing a small forward force to balance out the friction. You will know you have got it right when the trolley continues along the whole track at a constant speed, having again been given a small push. Mark or note the track position that does this.

3. For the more accurate experiments using the ticker-tape it will be necessary to re-compensate the track due to the friction of the ticker-tape. Attach a 1 or 2m length of ticker-tape to the trolley (attach it to the top of the trolley using adhesive tape), feed the ticker-tape through the slots on the ticker-timer, and repeat the compensation process. The track will have to be supported at a slightly steeper angle due to the extra friction of the tape.

Apparatus for all these practicals:

retort stands and bosses
dynamics trolleys
ticker timer
track
low voltage ac power supply
digital timer

Practical 1. Newton's Second Law of Motion

Aim:

To demonstrate that acceleration is proportional to force.

Method:

Use a fine thread to pull the trolley along the track. Attach the thread to the trolley, and then the thread should pass over a pulley fastened to the end of the track, and have on its end suitable masses whose weight will provide varying amounts of force. The first trial can use one small mass. A second mass can be added to double the force for the second trial, and then three and so on.

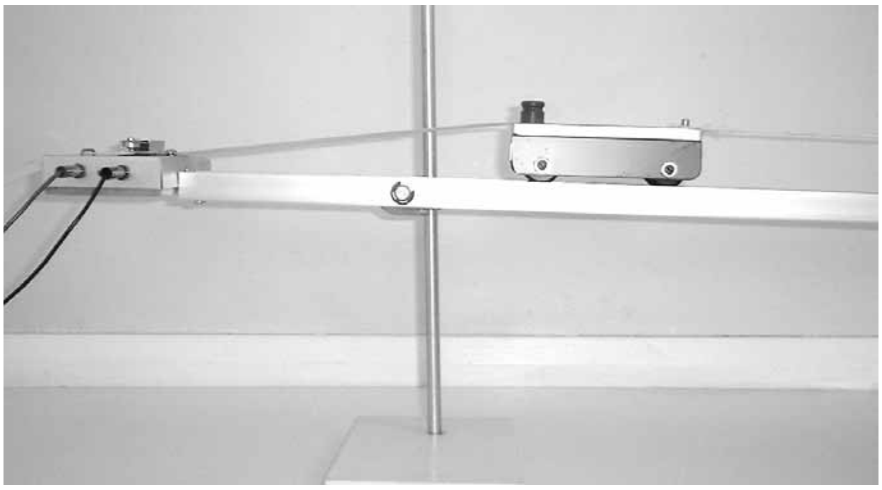


Photo of ticker-timer end of track with trolley, tape and cord attached

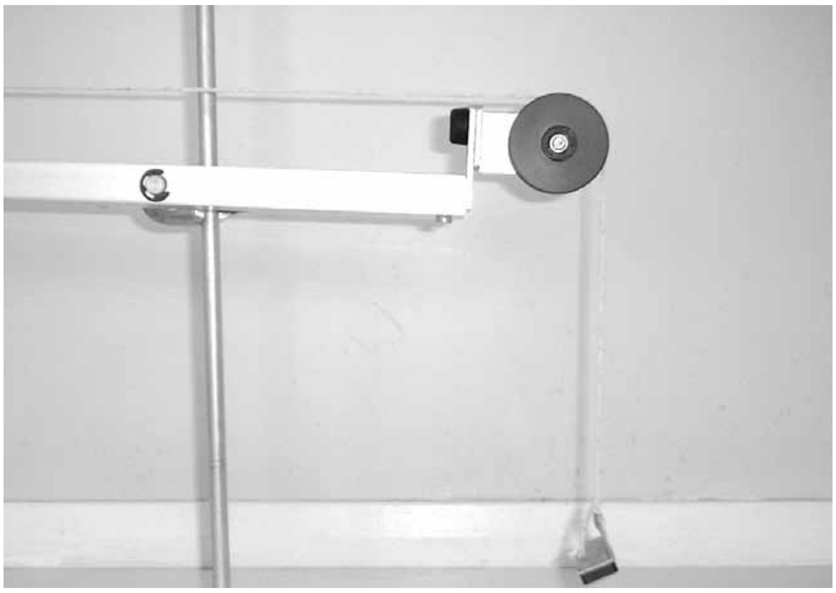


Photo of pulley end of track with cord and mass visible

Compensate for friction and observe the motion of the trolley with three different forces on it. There should be a noticeable increase in acceleration with increase in force. To investigate this more accurately, attach a length of ticker-tape to the trolley, and holding the trolley back with the tape where it passes through the ticker-timer, switch on the power and let go. You should have then produced a strip of the tape with dots, which have an increasing space between them as the trolley accelerates.

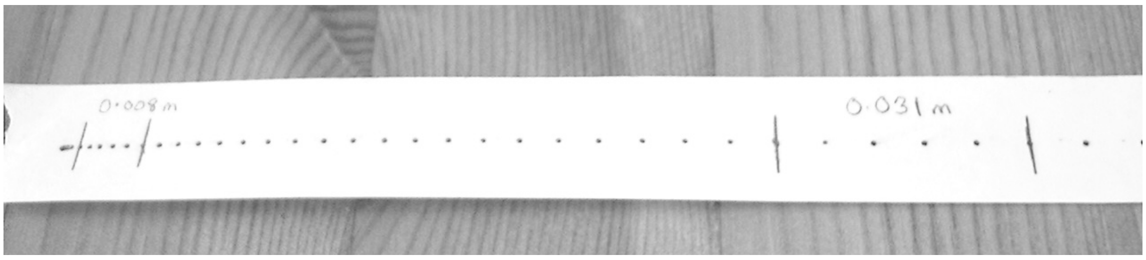
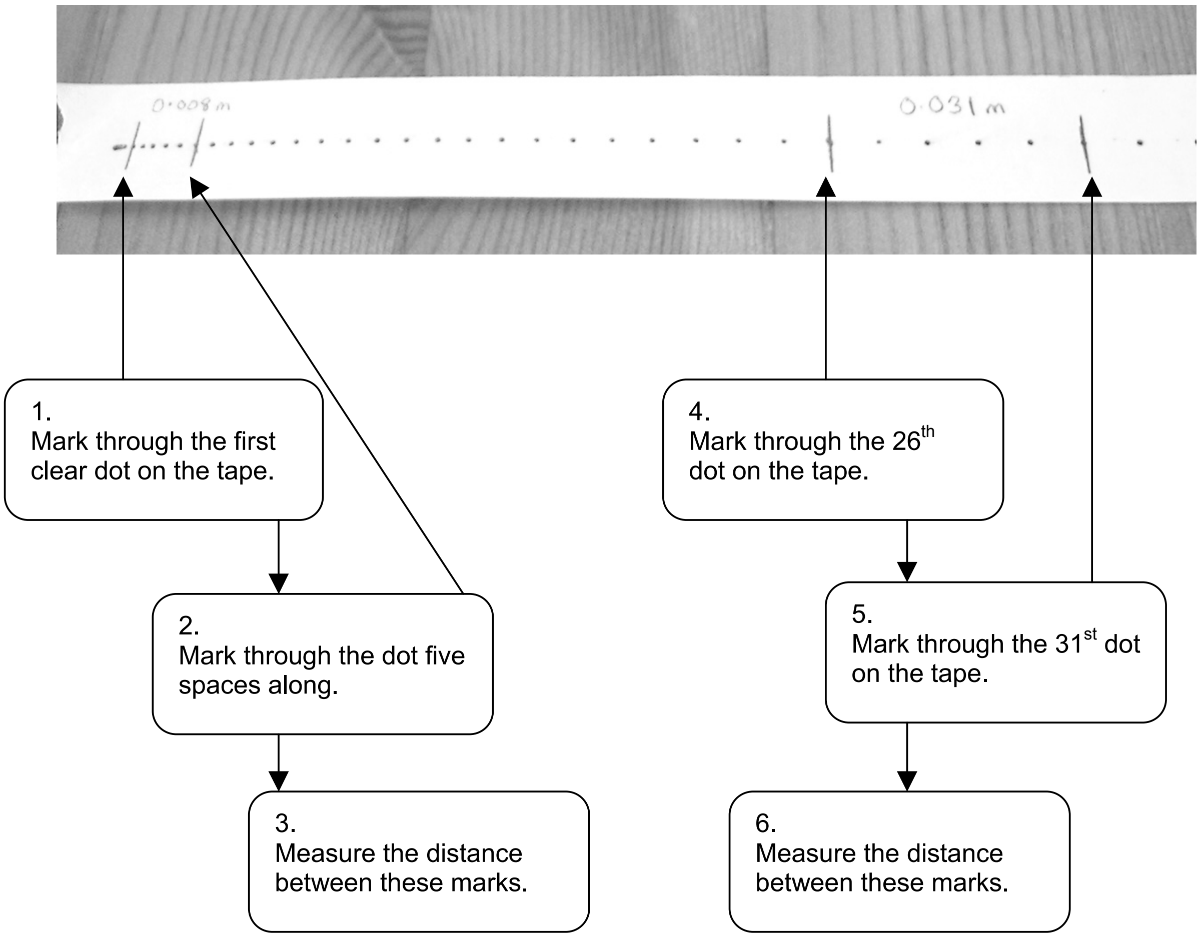


Photo of ticker-tape from this practical

Analysing the ticker-tape:



1.
Mark through the first clear dot on the tape.

2.
Mark through the dot five spaces along.

3.
Measure the distance between these marks.

4.
Mark through the 26th dot on the tape.

5.
Mark through the 31st dot on the tape.

6.
Measure the distance between these marks.

Since the timer makes 50 dots s^{-1}, the space between each dot is 1/50s or 0.02s. Five spaces occupy 0.1 s.

Measure the length of the first clear 5-space interval, let this length be A. This is the distance the trolley travelled in 0.1 s early after release. Multiply A by 10 to give its velocity at this time. Count another 20 spaces along the tape and measure the next 5-space length after this, let this length be B. This is 25 spaces along from the start of the first 5-space length, and so exactly 0.5 s later. Multiply B by 10 to give its velocity, 0.5 s later than A.

Use the fact that:

$$\textbf{acceleration} = \frac{\textbf{change of speed}}{\textbf{time taken}}$$

to find the acceleration of your trolley.

In this case it is:

$$\textbf{acceleration} = \frac{10 \times B - 10 \times A}{0.5}$$

$$= 20 \times (B - A)$$

Results

Forces	A (m)	B (m)	Acceleration (m s^{-2})
1			
2			
3			

Comment on your results. How does the acceleration vary as the force is increased?

Practical 2. Newton’s Second Law of Motion

Aim:

To demonstrate that acceleration is inversely proportional to mass.

Method:

Use the same procedure as in Practical 1, but this time keep the force constant. Use the same mass to provide a constant acceleration force. The variable this time will be the mass of the trolley, which can be doubled and tripled by stacking trolleys or mass blocks and pegs to hold them together.

The first reading and calculation from Practical 1 can be used here since it has the single trolley mass and the (now) constant force. Observe the motion of the trolley as its mass is increased from 1 to 3 times its original mass. Investigate more accurately using ticker-tape, analysing the ticker-tape in exactly the same way as in Practical 1.

Results

Masses	A (m)	B (m)	Acceleration (m s^{-2})
1			
2			
3			

Comment on your results. How does the acceleration vary as the mass is increased?

Practical 3. Conservation of Momentum

Aim:

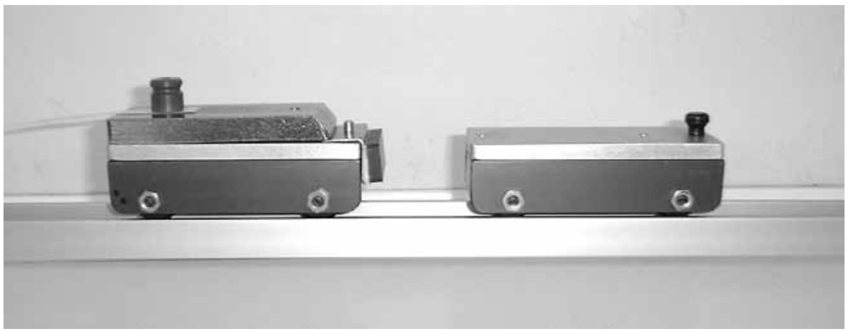
To investigate inelastic collisions.

Method:

An inelastic collision is where two trolleys collide and stick together. This can be achieved using magnets, a cork and a pin, or even blu-tak, it depends which type of dynamics trolleys you have in school. Place one trolley two-thirds the way along the track (do not forget to compensate for friction), and give the other trolley a push from the left hand side. You should observe the speed of the single trolley before the collision, and the speed of the combined trolleys after the collision.

Comment on your observations:

Investigate the motion of the trolleys more accurately by attaching a ticker-tape to the initially moving trolley. Analyse the tape by choosing a 5-space length of tape that represents the motion of the single trolley, and another 5-space length that represents the combined trolley motion. Since it takes 0.1 s for the 5-space interval, the lengths should be multiplied by 10 to give the speeds in m s^{-1}.



a 1 kg trolley about to collide inelastically with a 0.5 kg trolley

Repeat the experiment with different masses.

In each case calculate the momentum of the trolley before the collision (the stationary trolley has no momentum), and the momentum of the combined trolleys after the collision. The mass of each trolley and mass block is either approximately 1kg or 500g depending on which type of trolley you have.

Results

Mass of trolley (kg)		Speed of trolley (m s $^{-1}$)		Momentum (kg m s $^{-1}$)	
moving	**stationary**	**initial**	**final**	**before collision**	**after collision**

Comment on your observations:

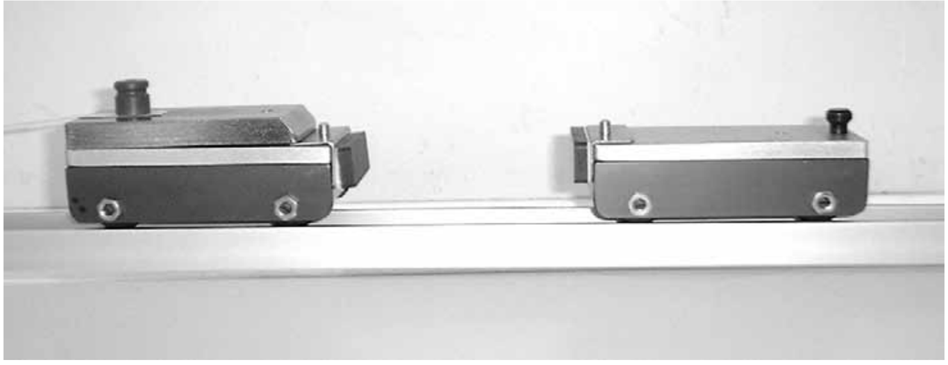
Practical 4. Conservation of Momentum

Aim:

To investigate an elastic collision.

Method:

Investigate the collision between a heavy trolley (trolley 1) (add a mass block or extra trolley on top) travelling into a stationary light trolley (trolley 2). Each trolley should be fitted with a magnet or spring so that the trolleys repel one another. Carry out a trial experiment with no ticker-tape.

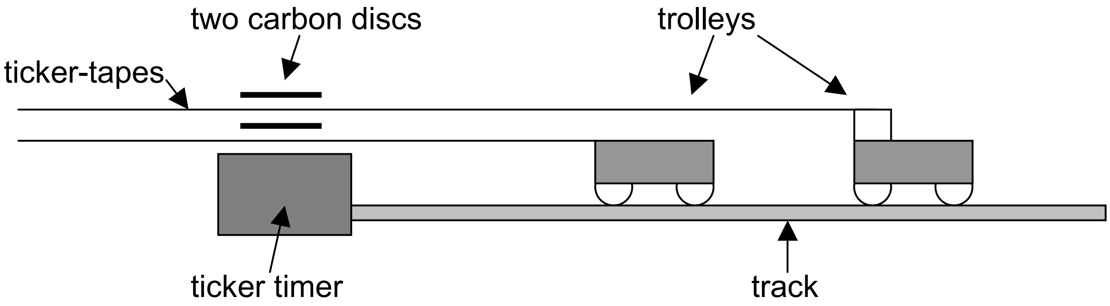


an elastic collision about to happen

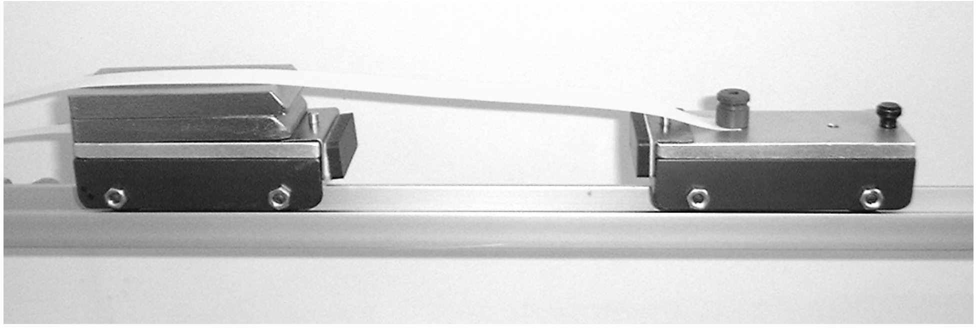
Comment on your observations:

Investigate the elastic collision more accurately using ticker-tape. One ticker-tape is attached to the initially moving trolley (trolley 1) to measure its speed before and after the collision. A second tape is required to measure the speed of the initially stationary trolley (trolley 2) as it moves off after the collision.

It is possible to pass both tapes through the same timer using a ‘sandwich’ of two carbon rings, one above each tape as shown below. This is a case where the use of light gates and a computer would be an easier technique to carry out.



close-up of the heavy trolley about to be launched



the heavy trolley travelling towards the stationary trolley

Measure five space lengths of tape to find the speed of the moving trolley before the collision, and both trolleys after the collision, or use your light gate data. Complete the table below:

Results

Speed (m s $^{-1}$)			Momentum (kg m s $^{-1}$)		
Trolley 1		Trolley 2	Trolley 1		Trolley 2
Before collision	After collision	After collision	Before collision	After collision	After collision

Comment on how accurately the momentum before the collision matches the momentum after the collision. Express the accuracy of your results in percentage terms:

Practical 5. Conservation of Momentum

Aim:

To demonstrate that momentum is conserved when two masses ‘explode’ apart.

Method:

Your trolleys will probably have a mechanism to release a loaded spring which will push two trolleys that are initially in contact, apart. Since the trolleys have equal mass, they should move apart with equal velocity. The track should be placed exactly level for this experiment, since the trolleys move in opposite directions. Use the spirit level to check this before you carry out a trial experiment, and observe the motion of the trolleys. (The challenge here is to attach a piece of ticker-tape to each trolley to analyse its motion, this is another case where light gates could be used.)

two trolleys having just ‘exploded’ apart (only the easy ticker-tape is shown)

The trolley furthest from the ticker-timer should have a piece of tape attached to it that runs straight to the ticker-timer (shown above). Run a tape from the other trolley **away** from the timer, to the pulley end of the track. Use a pulley to return the tape to the ticker-timer (it does work!). Use the same sandwich of two carbon discs on the ticker timer as for practical 4.

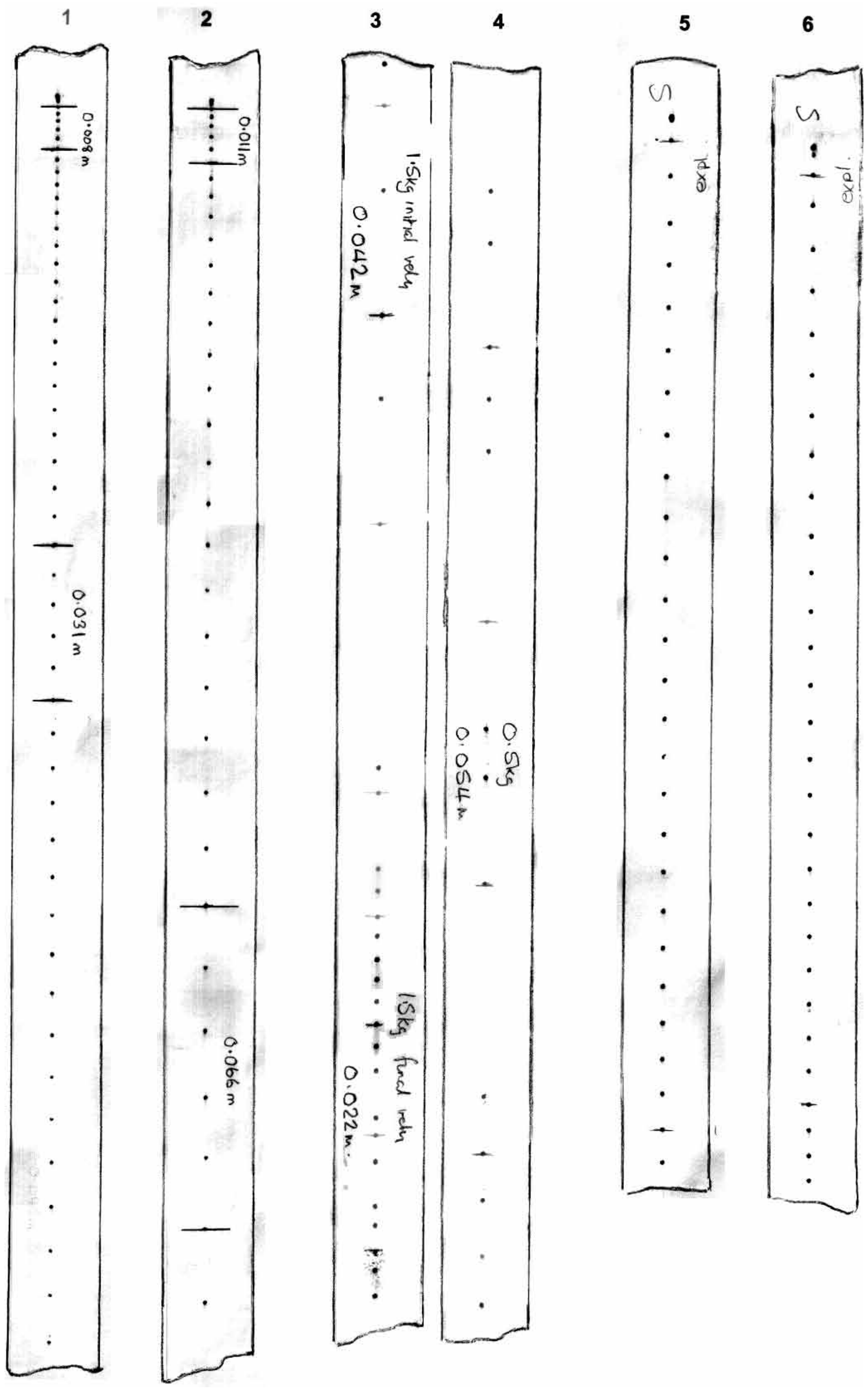
Analyse the two ticker-tapes produced when the trolleys move apart or your logged data. How closely do they match?

On the next page are actual tapes from some of the practicals, made when the practicals were designed and tested.

Tapes 1 and 2 are from Practical 1, where accelerating forces of F and 2F were used.

Tape 3 is from the initially moving trolley in Practical 4, and tape 4 is from the initially stationary trolley.

Tapes 5 and 6 were from Practical 5, showing the almost identical motions of the two trolleys after the ‘explosion’.


1
2
3
4
5
6
0.008 m
0.031 m
0.011 m
0.066 m
1.5kg initial vely
0.042m
1.5kg final vely
0.022m
0.5kg
0.054m
S
expl.
S
expl.

Circular Motion Practical Work

The first two practicals, which are slightly different versions of the same basic idea, enable a check to be carried out between the measured and calculated centripetal force required to keep an object moving in a circle.

SAFETY NOTE:

In the practicals, a mass is whirled around the experimenter's head on a length of string. This must only be carried out **away** from other **people** and **windows**. It is suggested that a location in the middle of a playground or grassed area with, at the **very least, 10m clear distance all around the experimenter is used**. The experimenter will have to observe the reading on a moving forcemeter in one practical, and maintain a balance between a suspended mass and a revolving mass in the other, whilst time revolutions of the apparatus. This will need practice!

Whatever your experimental arrangements, remember that the safety of yourself and others is paramount. You are likely to collect an audience as you continue, so choose a time and a place when this is unlikely to occur.

If you start to attract onlookers then STOP what you are doing.

Practical 1

Aim:

To compare the calculated centripetal force with the measured force for a mass moving in a circle.

Apparatus: brass ball with attachment eye
string
500g mass
timer
plastic tube (ballpoint pen casing)

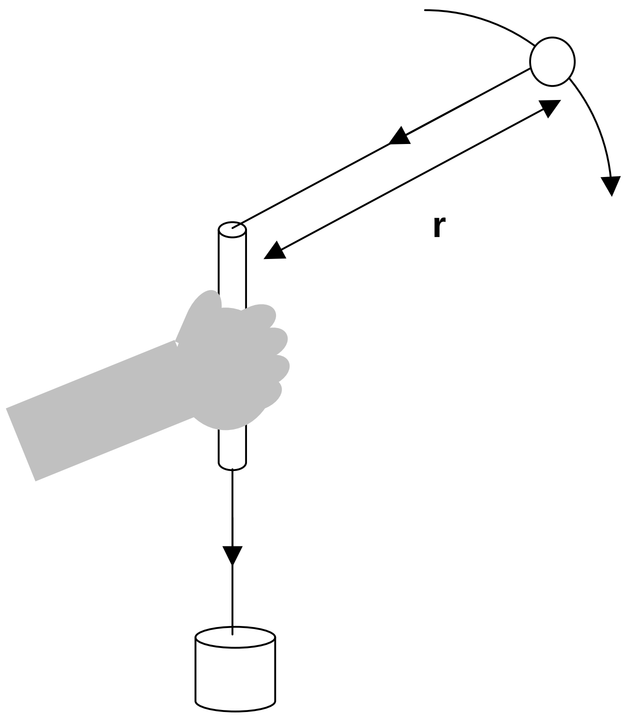
Method:

Thread 1.5m of string through an empty ballpoint pen case and fasten the brass ball on to one end and the 500g mass onto the other. Hold the pen case so that the string is free to move through it, and swing the brass ball around on about 1m of the string, holding the 500g mass until a steady motion has been obtained. Let go of the 500g mass, which should be supported by the tension in the string due to the upper section providing the centripetal force required to keep the brass ball in circular motion.

If you spin the brass ball too slowly, the 500g mass will drop down, so speed up the rate of rotation. If the brass ball orbits too quickly, the weight of the 500g mass will be insufficient to balance the extra centripetal force and will cause the 500g mass to rise. The friction between the string and the pen case will create a range of rotational speeds between these two extremes; try to spin the ball at a rate midway between the two extremes.

A diagram of the apparatus in motion is shown on the next page.

Diagram of apparatus



Measure as best you can the orbital radius **r** and the time for one complete orbit by timing several (say, 10) orbits, and dividing to find an accurate value for the time for one orbit.

Results and calculations

The centripetal force in this practical must be the weight of the 500g mass.

Since $\mathbf{F = m\,g}$

$\mathbf{F = 0.5 \times 9.8}$

$\mathbf{= 4.9N}$

Radius of orbit **r** = m

Distance around one orbit **d = 2 π r**

d = m

Orbit time:

Number of orbits	Total time (s)	Time for 1 orbit (s)

Calculate the orbital velocity **v** by dividing the distance around the orbit by the time taken:

$$\mathbf{v = \frac{d}{t}} \qquad \mathbf{v =} \quad \text{ms}^{-1}$$

Calculate the value of centripetal force **F**, since:

$$\mathbf{F = \frac{mv^2}{r}}$$

m is the mass of the brass ball, (a typical one is 0.07kg).

F = N

How does the calculated value for the centripetal force F compare with the 4.9N force produced by the 500g mass?

Practical 2

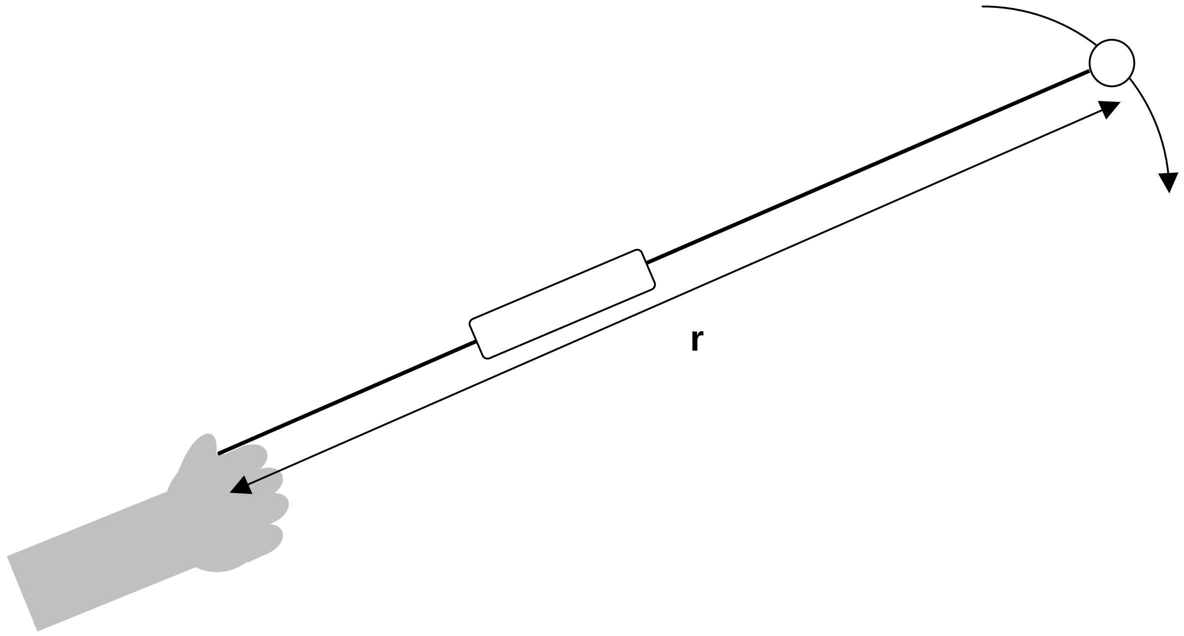
Aim:

To compare the calculated centripetal force with the measured force for a mass moving in a circle.

Apparatus: brass ball with attachment eye
string
0–10 N forcemeter
timer

Method:

Attach the brass ball to the hook on the forcemeter with 1m of string. The top of the forcemeter should have 0.5m of string attached to it. Swing the forcemeter and brass ball around in a circle and try to achieve a steady rate of one orbit per second. Observe the reading on the forcemeter as it circles! This will be the centripetal force. Measure the orbital radius (this can be done whilst stationary). Derive an accurate orbit time as you did in Practical 1.



Results and calculations

The centripetal force in this practical is the reading on the forcemeter **F**.

Observed force **F =** N

Radius of orbit **r =** m

Distance around one orbit $d = 2\pi r$

d = m

Orbit time:

Number of orbits	Total time (s)	Time for orbit (s)

Calculate the orbital velocity **v** by dividing the distance around the orbit by the time taken:

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

v = ms^{-1}

Calculate the value of centripetal force **F**, since:

$$\mathbf{F = \frac{m\,v^2}{r}}$$

m, the mass of the brass ball, (a typical one is 0.07kg).

Calculated value for **F =** ☐ N

How does the calculated value for F compare with the reading on the forcemeter?

☐

Practical 3

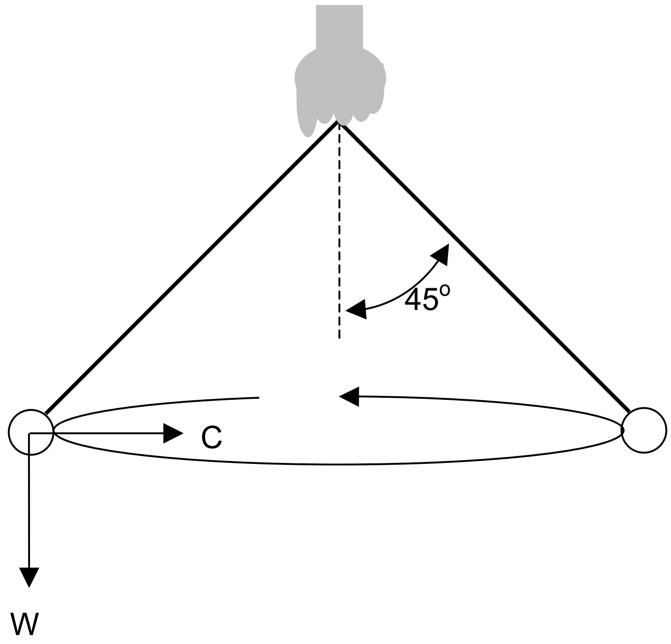
Aim:

To investigate the relationship between an orbiting mass and centripetal force.

Apparatus: brass ball with attachment eye
string
timer
metre rule

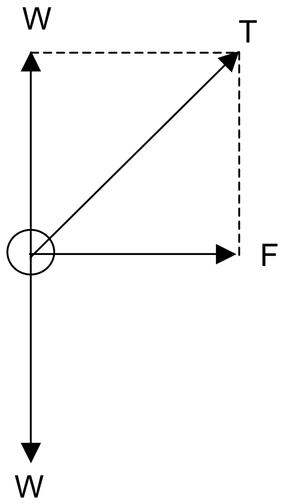
Method:

Attach the brass ball to 1m of string. Hold the other end of the string and cause the ball to move in a circle while the string maintains an angle of 45° to the vertical.



Due to the 45° angle of the string, the centripetal force C and the weight of the ball W are equal. Since the 70g ball has a weight of 0.7N, the centripetal force is also 0.7N.

The vector diagram below shows that **W = F** due to the 45° angle. The actual tension in the string **T** is unimportant.



Lay the metre rule on the floor as an aid to measuring the diameter of the orbit of the ball, and accurately determine the orbit time as previously.

Results and calculations

The centripetal force in this practical is the weight of the ball, (0.7 N is the common value for the brass ball).

Radius of orbit **r** = ☐ m

Distance around one orbit $d = 2 \pi r$

$d =$ m

Orbit time:

Number of orbits	Total time (s)	Time for orbit (s)

Calculate the orbital velocity **v** by dividing the distance around the orbit by the time taken:

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

$v =$ ms^{-1}

Calculate the value of centripetal force **F**, since:

$$F = \frac{m v^2}{r}$$

m, the mass of the brass ball, is 0.07kg (70g).

$F =$ N

How does this compare with the weight of the ball?