Summer Homework 2024 - Physics

Starting Points

In Physics we have a program called starting points, where, before we start a unit, we ensure all students are at the expected GCSE level. At the beginning of your second lesson, you will be given a GCSE level **test** on the unit we are about to begin. This is to ensure that all students are at the expected level and alert your teacher if you need extra support.

Our first unit is **Statics.** This consists of **Forces, Vectors, Moments** and their applications. Our second unit is **Dynamics.** The test for this will be about 3 weeks into the term, so you should get started on revision for this too. To help evidence this, you are expected to do some work from **Isaac Physics.**

In order to do the Isaac Physics work you need to go to https://isaacphysics.org/ and create an account. You will then need to join the class. Go to my account/teacher connections and type this code in.

NAYZGK

If you are accessing this document electronically, follow this link, or copy and paste the URL.

https://isaacphysics.org/account?authToken=NAYZGK

This will allow you to join the group – "2024 Welcome to Solihull Sixth Form College" You will then be able to go to "My Boards" and see that you have been assigned 11 boards to complete. Please complete these to evidence your summer revision on these important key topics.

If you have any questions or problems please e-mail brendan.foster@solihullsfc.ac.uk, rick.homer@solihullsfc.ac.uk or erin.riordan-jarvis@solihullsfc.ac.uk

The boards you need to **complete** are listed below. Please feel free to use the table to track your progress.

	Board Name	**Completed?**	**Which questions do you need help with?**
4.	Vectors and Scalars		
8.	Speed, Distance and Time		
9.	Displacement and Distance		
10.	Motion Graphs: Displacement-Time		
11.	Acceleration		
12.	Motion graphs – velocity-time		
13.	Resultant Force and Acceleration		
16.	Moments, Turning and Balancing		
19.	Introducing Momentum and Impulse		
20.	Momentum Conservation		
21.	Motion with Constant Acceleration		

Contact and Non-Contact Forces

When you're talking about the forces acting on an object, it's not enough to just talk about the size of each force. You need to know their direction too — force is a vector, with a size and a direction.

Vectors Have Magnitude and Direction

1) Force is a vector quantity — vector quantities have a magnitude and a direction.
2) Lots of physical quantities are vector quantities:

   Vector quantities: force, velocity, displacement, acceleration, momentum, etc.

3) Some physical quantities only have magnitude and no direction. These are called scalar quantities:

   Scalar quantities: speed, distance, mass, temperature, time, etc.

4) Vectors are usually represented by an arrow — the length of the arrow shows the magnitude, and the direction of the arrow shows the direction of the quantity.

Velocity is a vector, but speed is a scalar quantity.
Both bikes are travelling at the same speed, v (the length of each arrow is the same).
They have different velocities because they are travelling in different directions.

Forces Can be Contact or Non-Contact

1) A force is a push or a pull on an object that is caused by it interacting with something.
2) All forces are either contact or non-contact forces.
3) When two objects have to be touching for a force to act, that force is called a contact force.

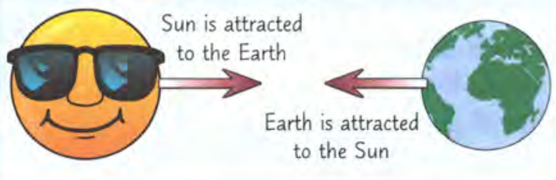
   E.g. friction, air resistance, tension in ropes, normal contact force, etc.

4) If the objects do not need to be touching for the force to act, the force is a non-contact force.

   E.g. magnetic force, gravitational force, electrostatic force, etc.

5) When two objects interact, there is a force produced on both objects.
   An interaction pair is a pair of forces that are equal and opposite and act on two interacting objects. (This is basically Newton's Third Law — see p.65.)

The Sun and the Earth are attracted to each other by the gravitational force. This is a non-contact force. An equal but opposite force of attraction is felt by both the Sun and the Earth.



A chair exerts a force on the ground, whilst the ground pushes back at the chair with the same force (the normal contact force). Equal but opposite forces are felt by both the chair and the ground.

My life's feeling pretty scalar — I've no idea where I'm headed...

This all seems pretty basic, but it's vital you understand it if you want to make it through the rest of this topic.

Q1 A tennis ball is dropped from a height. Name one contact force and one non-contact force that act on the ball as it falls. [2 marks]

Q2 Name two examples of: a) a scalar quantity b) a vector quantity [4 marks]

Weight, Mass and Gravity

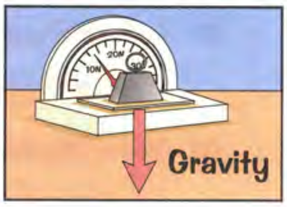
Now for something a bit more attractive — the force of gravity. Enjoy...

Gravitational Force is the Force of Attraction Between Masses

Gravity attracts all masses, but you only notice it when one of the masses is really really big, e.g. a planet. Anything near a planet or star is attracted to it very strongly.

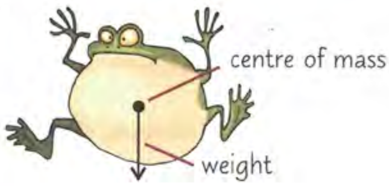
This has two important effects:

1) On the surface of a planet, it makes all things fall towards the ground.
2) It gives everything a weight.



Weight and Mass are Not the Same

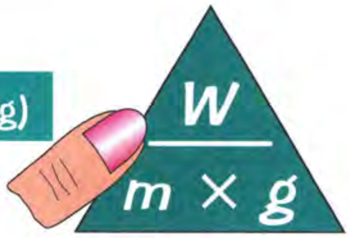
1) Mass is just the amount of 'stuff' in an object. For any given object this will have the same value anywhere in the universe.
2) Weight is the force acting on an object due to gravity (the pull of the gravitational force on the object). Close to Earth, this force is caused by the gravitational field around the Earth.
3) Gravitational field strength varies with location. It's stronger the closer you are to the mass causing the field, and stronger for larger masses.
4) The weight of an object depends on the strength of the gravitational field at the location of the object. This means that the weight of an object changes with its location.
5) For example, an object has the same mass whether it's on Earth or on the Moon — but its weight will be different. A 1 kg mass will weigh less on the Moon (about 1.6 N) than it does on Earth (about 9.8 N), simply because the gravitational field strength on the surface of the Moon is less.
6) Weight is a force measured in newtons. You can think of the force as acting from a single point on the object, called its centre of mass (a point at which you assume the whole mass is concentrated). For a uniform object (one that's the same density, p.38, throughout and is a regular shape), this will be at the centre of the object.
7) Weight is measured using a calibrated spring balance (or newtonmeter).
8) Mass is not a force. It's measured in kilograms with a mass balance (an old-fashioned pair of balancing scales).



Mass and Weight are Directly Proportional

1) You can calculate the weight of an object if you know its mass (m) and the strength of the gravitational field that it is in (g):

Weight (N) = Mass (kg) × Gravitational Field Strength (N/kg)



2) For Earth, $g \approx 9.8$ N/kg and for the Moon it's around 1.6 N/kg. Don't worry, you'll always be given a value of g to use in the exam.
3) Increasing the mass of an object increases its weight. If you double the mass, the weight doubles too, so you can say that weight and mass are directly proportional.
4) You can write this, using the direct proportionality symbol, as $W \propto m$.

I don't think you understand the gravity of this situation...

Remember that weight is a force due to gravity that acts from an object's centre of mass. It changes depending on the strength of the gravitational field the object is in (and is directly proportional to the mass of the object too).

Q1 Calculate the weight in newtons of a 5 kg mass:
a) on Earth ($g \approx 9.8$ N/kg) b) on the Moon ($g \approx 1.6$ N/kg) [4 marks]

Resultant Forces

I'm sure you're no stranger to doing work, but in physics it's all to do with overall forces and energy.

Free Body Diagrams Show All the Forces Acting on an Object

1) You need to be able to describe all the forces acting on an isolated object or a system (p.11) — i.e. every force acting on the object or system but none of the forces the object or system exerts on the rest of the world.
2) For example, a skydiver's weight acts on him pulling him towards the ground and drag (air resistance) also acts on him, in the opposite direction to his motion.
3) This can be shown using a free body diagram like the one on the right.
4) The sizes of the arrows show the relative magnitudes of the forces and the directions show the directions of the forces acting on the object.

A Resultant Force is the Overall Force on a Point or Object

1) In most real situations there are at least two forces acting on an object along any direction.
2) If you have a number of forces acting at a single point, you can replace them with a single force (so long as the single force has the same effect as all the original forces together).
3) This single force is called the resultant force. (There's a downward resultant force acting on the skydiver above.)
4) If the forces all act along the same line (they're all parallel), the overall effect is found by adding those going in the same direction and subtracting any going in the opposite direction.

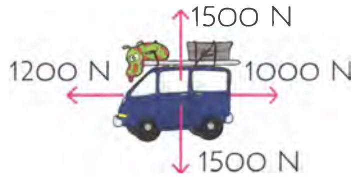
EXAMPLE: For the following free body diagram, calculate the resultant force acting on the van.

1) Consider the horizontal and vertical directions separately.
2) State the size and direction of the resultant force.

Vertical: 1500 – 1500 = 0 N

Horizontal: 1200 – 1000 N = 200 N

The resultant force is 200 N to the left.



Calculating Forces

Scale drawings are useful things — they can help you resolve forces or work out the resultant force.

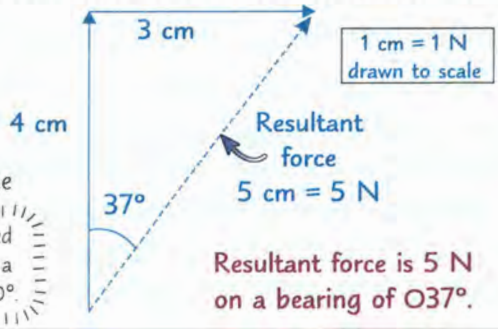
Use Scale Drawings to Find Resultant Forces

1) Draw all the forces acting on an object, to scale, 'tip-to-tail'.
2) Then draw a straight line from the start of the first force to the end of the last force — this is the resultant force.
3) Measure the length of the resultant force on the diagram to find the magnitude and the angle to find the direction of the force.

EXAMPLE: A man is on an electric bicycle that has a driving force of 4 N north. However, the wind produces a force of 3 N east. Find the magnitude and direction of the resultant force.

1) Start by drawing a scale drawing of the forces acting.
2) Make sure you choose a sensible scale (e.g. 1 cm = 1 N).
3) Draw the resultant from the tail of the first arrow to the tip of the last arrow.
4) Measure the length of the resultant with a ruler and use the scale to find the force in N.
5) Use a protractor to measure the direction as a bearing.

A bearing is an angle measured clockwise from north, given as a 3 digit number, e.g. 10° = 010°.

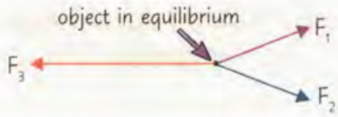


Resultant force is 5 N on a bearing of 037°.

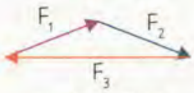
An Object is in Equilibrium if the Forces on it are Balanced

1) If all of the forces acting on an object combine to give a resultant force of zero, the object is in equilibrium.
2) On a scale diagram, this means that the tip of the last force you draw should end where the tail of the first force you drew begins. E.g. for three forces, the scale diagram will form a triangle.
3) You might be given forces acting on an object and told to find a missing force, given that the object is in equilibrium. To do this, draw out the forces you do know (to scale and tip-to-tail), join the end of the last force to the start of the first force. This line is the missing force so you can measure its size and direction.

Make sure you draw the last force in the right direction. It's in the opposite direction to how you'd draw a resultant force.



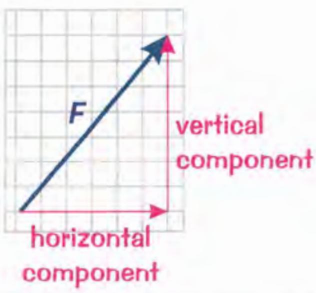
Tip-to-tail the forces join up...



...so the resultant force is zero.

You Can Split a Force into Components

1) Not all forces act horizontally or vertically — some act at awkward angles.
2) To make these easier to deal with, they can be split into two components at right angles to each other (usually horizontal and vertical).
3) Acting together, these components have the same effect as the single force.
4) You can resolve a force (split it into components) by drawing it on a scale grid. Draw the force to scale, and then add the horizontal and vertical components along the grid lines. Then you can just measure them.



Don't blow things out of proportion — it's only scale drawings...

Keep those pencils sharp and those scale drawings accurate — or you'll end up with the wrong answer.

Q1 A toy boat crosses a stream. The motor provides a 12 N driving force to the north. The river's current causes a force of 5 N west to act on the boat. Find the magnitude of the resultant force. [2 marks]

Moments

Once you can calculate moments, you can work out if a seesaw is balanced. Useful thing, physics.

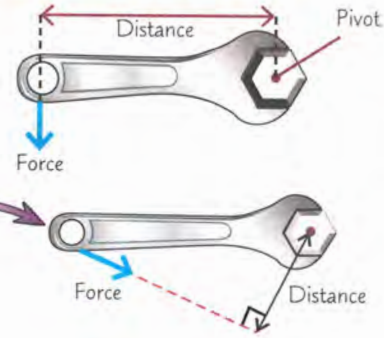
A Moment is the Turning Effect of a Force

A force, or several forces, can cause an object to rotate. The turning effect of a force is called its moment. The size of the moment of the force is given by:

$$M = Fd$$

Moment of a force (Nm) — M; Force (N) — F; Distance (m) — the perpendicular distance from the pivot to the line of action of the force — d

1) The force on the spanner causes a turning effect or moment on the nut (which acts as pivot). A larger force or a longer distance (spanner) would mean a larger moment.
2) To get the maximum moment (or turning effect) you need to push at right angles (perpendicular) to the spanner. Pushing at any other angle means a smaller distance, and so a smaller moment.



If the total anticlockwise moment equals the total clockwise moment about a pivot, the object is balanced and won't turn. You can use the equation above to find a missing force or distance in these situations.

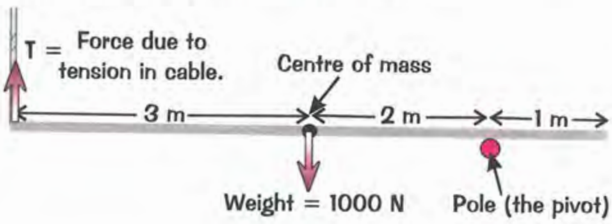
EXAMPLE: A 6 m long steel girder weighing 1000 N rests horizontally on a pole 1 m from one end. What is the tension in a supporting cable attached vertically to the other end?

1) For the girder to balance, the total anticlockwise moment should equal the total clockwise moment.

   $1000 \times 2 = 5 \times T$

2) Stick in the numbers you know and rearrange for T.

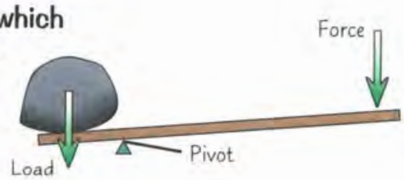
   $T = 2000 \div 5 = 400$ N

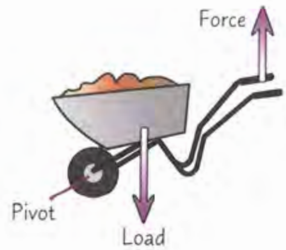


Levers Make it Easier for us to Do Work

Levers increase the distance from the pivot at which the force is applied. Since $M = Fd$ this means less force is needed to get the same moment.

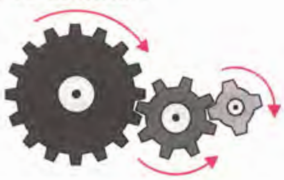
This means levers make it easier to do work, e.g. lift a load or turn a nut.





Gears Transmit Rotational Effects

1) Gears are circular discs with 'teeth' around their edges.
2) Their teeth interlock so that turning one causes another to turn, in the opposite direction.
3) They are used to transmit the rotational effect of a force from one place to another.
4) Different sized gears can be used to change the moment of the force. A force transmitted to a larger gear will cause a bigger moment, as the distance to the pivot is greater.
5) The larger gear will turn slower than the smaller gear.



Don't get in a spin — gear up for some more physics...

Moments can be used in lots of different situations, so get your head around them sooner rather than later.

Q1 Your brother weighs 300 N and sits 2 m from the pivot of a seesaw. If you weigh 600 N, what distance from the pivot, on the other side of the seesaw, should you sit to balance it? [3 marks]

Distance, Displacement, Speed and Velocity

Time for a quick recap on distance and speed. You should race through this page. On your marks...

Distance is Scalar, Displacement is a Vector

1) Distance is just how far an object has moved. It's a scalar quantity (p.51) so it doesn't involve direction.
2) Displacement is a vector quantity. It measures the distance and direction in a straight line from an object's starting point to its finishing point — e.g. the plane flew 5 metres north. The direction could be relative to a point, e.g. towards the school, or a bearing (a three-digit angle from north, e.g. 035°).
3) If you walk 5 m north, then 5 m south, your displacement is 0 m but the distance travelled is 10 m.

Speed and Velocity are Both How Fast You're Going

1) Speed and velocity both measure how fast you're going, but speed is a scalar and velocity is a vector:

   Speed is just how fast you're going (e.g. 30 mph or 20 m/s) with no regard to the direction.
   Velocity is speed in a given direction, e.g. 30 mph north or 20 m/s, 060°.

2) This means you can have objects travelling at a constant speed with a changing velocity. This happens when the object is changing direction whilst staying at the same speed. An object moving in a circle at a constant speed has a constantly changing velocity, as the direction is always changing (e.g. a car going around a roundabout).
3) If you want to measure the speed of an object that's moving with a constant speed, you should time how long it takes the object to travel a certain distance, e.g. using a ruler and a stopwatch. You can then calculate the object's speed from your measurements using this formula:

   $s = vt$ distance travelled (m) = speed (m/s) × time (s)

4) Objects rarely travel at a constant speed. E.g. when you walk, run or travel in a car, your speed is always changing. For these cases, the formula above gives the average (mean) speed during that time.

You Need to Know Some Typical Everyday Speeds

1) Whilst every person, train, car etc. is different, there is usually a typical speed that each object travels at. Remember these typical speeds for everyday objects:

A person walking — 1.5 m/s	A car — 25 m/s
A person running — 3 m/s	A train — 55 m/s
A person cycling — 6 m/s	A plane — 250 m/s

2) Lots of different things can affect the speed something travels at. For example, the speed at which a person can walk, run or cycle depends on their fitness, their age, the distance travelled and the terrain (what kind of land they're moving over, e.g. roads, fields) as well as many other factors.
3) It's not only the speed of objects that varies. The speed of sound (330 m/s in air) changes depending on what the sound waves are travelling through, and the speed of wind is affected by many factors.
4) Wind speed can be affected by things like temperature, atmospheric pressure and if there are any large buildings or structures nearby (e.g. forests reduce the speed of the air travelling through them).

Ah, speed equals distance over time — that old chestnut...

Remember those typical speeds of objects — you might need to use them to make estimates.

Q1 A sprinter runs 200 m in 25 s. Calculate his speed. [3 marks]

Q2 Marie walks her dog after school. She takes a route of 1500 m that starts at and returns to her house.
State: a) the distance she travels b) her displacement [2 marks]

Acceleration

Uniform acceleration sounds fancy, but it's just speeding up (or slowing down) at a constant rate.

Acceleration is How Quickly You're Speeding Up

1) Acceleration is definitely not the same as velocity or speed.
2) Acceleration is the change in velocity in a certain amount of time.
3) You can find the average acceleration of an object using:

$$a = \frac{\Delta v}{t}$$

Acceleration (m/s²) — a; Change in velocity (m/s) — Δv; Time (s) — t

4) Deceleration is just negative acceleration (if something slows down, the change in velocity is negative).

EXAMPLE:

A cat accelerates at 2.5 m/s² from 2.0 m/s to 6.0 m/s. Find the time it takes to do this.

$t = \Delta v \div a$

$= (6.0 - 2.0) \div 2.5 = 1.6$ s

You Need to be Able to Estimate Accelerations

You might have to estimate the acceleration (or deceleration) of an object. To do this, you need the typical speeds from the previous page:

EXAMPLE:

A car is travelling along a road, when it collides with a tree and comes to a stop. Estimate the deceleration of the car.

1) First, give a sensible speed for the car to be travelling at.
2) Next, estimate how long it would take the car to stop.
3) Put these numbers into the acceleration equation.
4) The question asked for the deceleration, so you can lose the minus sign (which shows the car is slowing down):

The typical speed of a car is ~25 m/s.

The car comes to a stop in ~1 s.

$a = \Delta v \div t$

$= (-25) \div 1$

$= -25$ m/s²

So the deceleration is ~25 m/s²

The ~ symbol just means it's an approximate value (or answer).

Uniform Acceleration Means a Constant Acceleration

1) Constant acceleration is sometimes called uniform acceleration.
2) Acceleration due to gravity (g) is uniform for objects in free fall. It's roughly equal to 9.8 m/s² near the Earth's surface and has the same value as gravitational field strength (p.52).
3) You can use this equation for uniform acceleration:

$$v^2 - u^2 = 2as$$

Final velocity (m/s) — v; Initial velocity (m/s) — u; Acceleration (m/s²) — a; Distance (m) — s

Initial velocity is just the starting velocity of the object.

EXAMPLE:

A van travelling at 23 m/s starts decelerating uniformly at 2.0 m/s² as it heads towards a built-up area 112 m away. What will its speed be when it reaches the built-up area?

1) First, rearrange the equation so v^2 is on one side.
2) Now put the numbers in — remember a is negative because it's a deceleration.
3) Finally, square root the whole thing.

$v^2 = u^2 + 2as$

$v^2 = 23^2 + (2 \times -2.0 \times 112)$

$= 81$

$v = \sqrt{81} = 9$ m/s

Uniform problems — get a clip-on tie or use the equation above...

You might not be told what equation to use in the exam, so make sure you can spot when to use the equation for uniform acceleration. Make a list of the information you're given to help you see what to do.

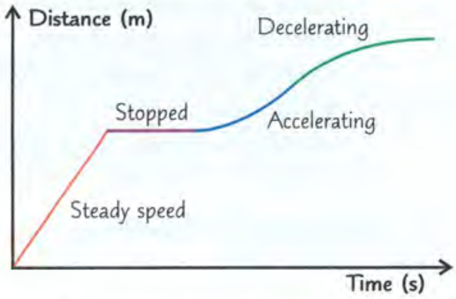
Q1 A ball is dropped from a height, h, above the ground. The speed of the ball just before it hits the ground is 7 m/s. Calculate the height the ball is dropped from. (acceleration due to gravity ≈ 9.8 m/s²) [3 marks]

Distance-Time and Velocity-Time Graphs

You need to be able to draw and interpret distance and velocity-time graphs.

You Can Show Journeys on Distance-Time Graphs

If an object moves in a straight line, its distance travelled can be plotted on a distance-time graph.

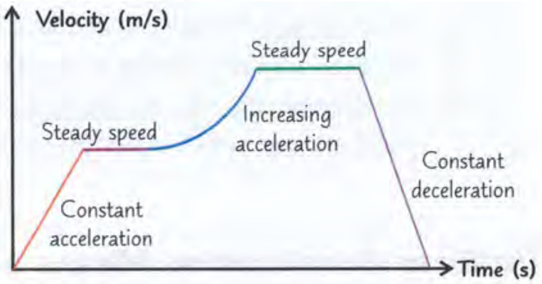


1) Gradient = speed. (The steeper the graph, the faster it's going.) This is because: speed = distance ÷ time = (change in vertical axis) ÷ (change in horizontal axis).
2) Flat sections are where it's stationary — it's stopped.
3) Straight uphill sections mean it is travelling at a steady speed.
4) Curves represent acceleration or deceleration (p.61)
5) A steepening curve means it's speeding up (increasing gradient).
6) A levelling off curve means it's slowing down.
7) If the object is changing speed (accelerating) you can find its speed at a point by finding the gradient of the tangent to the curve at that point, p.7.

You Can Also Show them on a Velocity-Time Graph

How an object's velocity changes as it travels can be plotted on a velocity-time graph.

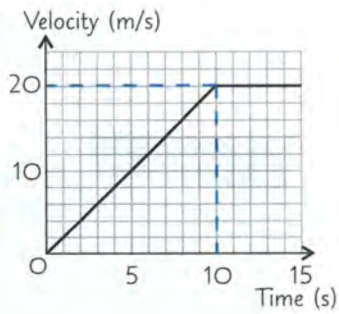
1) Gradient = acceleration, since acceleration is change in velocity ÷ time.
2) Flat sections represent travelling at a steady speed.
3) The steeper the graph, the greater the acceleration or deceleration.
4) Uphill sections (/) are acceleration.
5) Downhill sections (\) are deceleration.
6) A curve means changing acceleration.
   If the graph is curved, you can use a tangent to the curve at a point to find the acceleration at that point.



7) The area under any section of the graph (or all of it) is equal to the distance travelled in that time interval.
8) If the section under the graph is irregular, it's easier to find the area by counting the squares under the line and multiplying the number by the value of one square.

EXAMPLE:

The velocity-time graph of a car's journey is plotted.
a) Calculate the acceleration of the car over the first 10 s.
b) How far does the car travel in the first 15 s of the journey?



a) This is just the gradient of the line: $a = \Delta v \div t = 20 \div 10 = 2\ m/s^2$

b) Split the area into a triangle and a rectangle, then add together their areas. Area = (½ × 10 × 20) + (5 × 20) = 200 m

Or find the value of one square, count the total number of squares under the line, and then multiply these two values together.
1 square = 2 m/s × 1 s = 2 m
Area = 100 squares = 100 × 2 = 200 m

Understanding motion graphs — it can be a real uphill struggle...

Make sure you know the difference between distance-time and velocity-time graphs, and how to interpret them.

Q1 Sketch the distance-time graph for an object that accelerates before travelling at a steady speed. [2 marks]

Q2 A stationary car starts accelerating increasingly for 10 s until it reaches a speed of 20 m/s. It travels at this speed for 20 s until the driver sees a hazard and brakes. He decelerates uniformly, coming to a stop 4 s after braking. Draw the velocity-time graph for this journey. [3 marks]

Terminal Velocity

Ever wondered why it's so hard to run into a hurricane whilst wearing a sandwich board? Read on to find out...

Friction is Always There to Slow Things Down

1) If an object has no force propelling it along it will always slow down and stop because of friction (unless you're in space where there's nothing to rub against).
2) Friction always acts in the opposite direction to movement.
3) To travel at a steady speed, the driving force needs to balance the frictional forces (see next page).
4) You get friction between two surfaces in contact, or when an object passes through a fluid (drag).

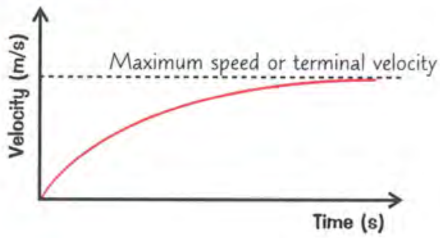
Drag Increases as Speed Increases

1) Drag is the resistance you get in a fluid (a gas or a liquid). Air resistance is a type of drag.
2) The most important factor by far in reducing drag is keeping the shape of the object streamlined. This is where the object is designed to allow fluid to flow easily across it, reducing drag. Parachutes work in the opposite way — they want as much drag as they can get.
3) Frictional forces from fluids always increase with speed. A car has much more friction to work against when travelling at 70 mph compared to 30 mph. So at 70 mph the engine has to work much harder just to maintain a steady speed.

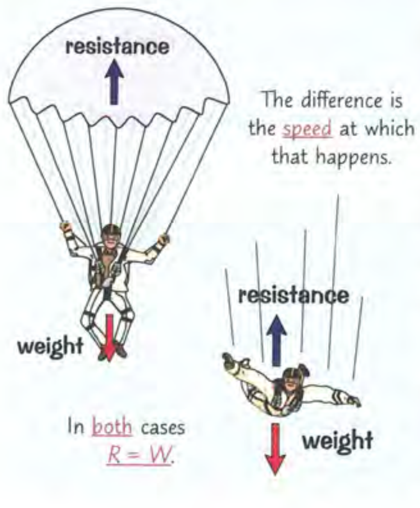
Air flows easily over a streamlined car.

Objects Falling Through Fluids Reach a Terminal Velocity

When a falling object first sets off, the force of gravity is much more than the frictional force slowing it down, so it accelerates. As the speed increases the friction builds up. This gradually reduces the acceleration until eventually the frictional force is equal to the accelerating force (so the resultant force is zero). It will have reached its maximum speed or terminal velocity and will fall at a steady speed.



Terminal Velocity Depends on Shape and Area



The accelerating force acting on all falling objects is gravity and it would make them all fall at the same rate if it wasn't for air resistance. This means that on the Moon, where there's no air, hamsters and feathers dropped simultaneously will hit the ground together. However, on Earth, air resistance causes things to fall at different speeds, and the terminal velocity of any object is determined by its drag in comparison to its weight. The frictional force depends on its shape and area.

The most important example is the human skydiver. Without his parachute open he has quite a small area and a force of "$W = mg$" pulling him down. He reaches a terminal velocity of about 120 mph. But with the parachute open, there's much more air resistance (at any given speed) and still only the same force "$W = mg$" pulling him down. This means his terminal velocity comes down to about 15 mph, which is a safe speed to hit the ground at.

Learning about air resistance — it can be a real drag...

Learn what terminal velocity is and why it happens, it's a term that crops up a fair bit in physics.

Q1 Explain why a ball falling from the top of a tall building reaches terminal velocity. [4 marks]

Newton's First and Second Laws

In the 1660s, a chap called Isaac Newton worked out his dead useful Laws of Motion. Here are the first two.

A Force is Needed to Change Motion

This may seem simple, but it's important. Newton's First Law says that a resultant force (p.53) is needed to make something start moving, speed up or slow down:

> If the resultant force on a stationary object is zero, the object will remain stationary. If the resultant force on a moving object is zero, it'll just carry on moving at the same velocity (same speed and direction).

So, when a train or car or bus or anything else is moving at a constant velocity, the resistive and driving forces on it must all be balanced. The velocity will only change if there's a non-zero resultant force acting on the object.

1) A non-zero resultant force will always produce acceleration (or deceleration) in the direction of the force.
2) This "acceleration" can take five different forms: starting, stopping, speeding up, slowing down and changing direction.
3) On a free body diagram, the arrows will be unequal.

Acceleration is Proportional to the Resultant Force

1) The larger the resultant force acting on an object, the more the object accelerates — the force and the acceleration are directly proportional. You can write this as $F \propto a$.
2) Acceleration is also inversely proportional to the mass of the object — so an object with a larger mass will accelerate less than one with a smaller mass (for a fixed resultant force).
3) There's an incredibly useful formula that describes Newton's Second Law:

$$F = ma$$

Resultant force (N) — F; Acceleration (m/s^2) — a; Mass (kg) — m

EXAMPLE: A van of mass of 2080 kg has an engine that provides a driving force of 5200 N. At 70 mph the drag force acting on the van is 5148 N. Find its acceleration at 70 mph.

1) Work out the resultant force on the van. (Drawing a free body diagram may help.)
   Resultant force = 5200 – 5148 = 52 N
2) Rearrange $F = ma$ and stick in the values you know.
   $a = F \div m$
   $= 52 \div 2080 = 0.025$ m/s^2

You can use Newton's Second Law to get an idea of the forces involved in everyday transport. Large forces are needed to produce large accelerations:

EXAMPLE: Estimate the resultant force on a car as it accelerates from rest to a typical speed.

1) Estimate the acceleration of the car, using typical speeds from page 60. (The ~ means approximately.)
   A typical speed of a car is ~25 m/s.
   It takes ~10 s to reach this.
   So $a = \Delta v \div t = 25 \div 10 = 2.5$ m/s^2
2) Estimate the mass of the car.
   Mass of a car is ~1000 kg.
3) Put these numbers into Newton's 2nd Law.
   So using $F = ma = 1000 \times 2.5 = 2500$ N
   So the resultant force is ~2500 N.

Accelerate your learning — force yourself to revise...

Short and sweet, just how I like my equations. Unfortunately you can't get away with just learning those symbols — make sure you've got your head around both of those laws, before moving on to Newton's third and final law.

Q1 Find the force needed for an 80 kg man on a 10 kg bike to accelerate at 0.25 m/s^2. [2 marks]

Inertia and Newton's Third Law

Inertia and Newton's Third Law can seem simple on the surface, but they can quickly get confusing. Make sure you really understand what's going on with it — especially if an object is in equilibrium.

Inertia is the Tendency for Motion to Remain Unchanged

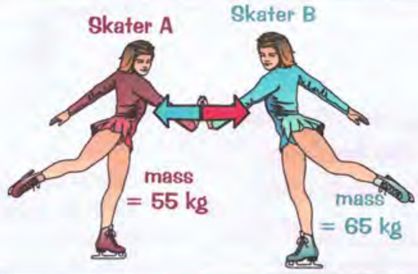
1) Until acted upon by a resultant force, objects at rest stay at rest and objects moving at a steady speed will stay moving at that speed (Newton's First Law). This tendency to continue in the same state of motion is called inertia.
2) An object's inertial mass measures how difficult it is to change the velocity of an object.
3) Inertial mass can be found using Newton's Second Law of $F = ma$ (previous page). Rearranging this gives $m = F \div a$, so inertial mass is just the ratio of force over acceleration.

Newton's Third Law: Equal and Opposite Forces Act on Interacting Objects

Newton's Third Law says:

> When two objects interact, the forces they exert on each other are equal and opposite.

1) If you push something, say a shopping trolley, the trolley will push back against you, just as hard.
2) And as soon as you stop pushing, so does the trolley. Kinda clever really.
3) So far so good. The slightly tricky thing to get your head round is this — if the forces are always equal, how does anything ever go anywhere? The important thing to remember is that the two forces are acting on different objects.



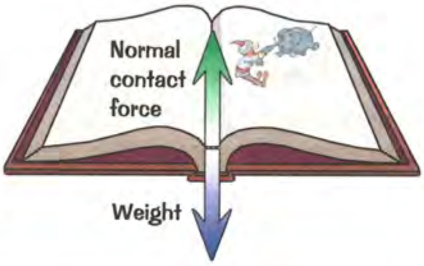
When skater A pushes on skater B, she feels an equal and opposite force from skater B's hand (the 'normal contact' force). Both skaters feel the same sized force, in opposite directions, and so accelerate away from each other.

Skater A will be accelerated more than skater B, though, because she has a smaller mass — remember $a = F \div m$.

An example of Newton's Third Law in an equilibrium situation is a man pushing against a wall. As the man pushes the wall, there is a normal contact force acting back on him. These two forces are the same size. As the man applies a force and pushes the wall, the wall 'pushes back' on him with an equal force.

It can be easy to get confused with Newton's Third Law when an object is in equilibrium. A book resting on the ground is in equilibrium. The weight of the book is equal to the normal contact force.

But this is NOT Newton's Third Law because the two forces are different types, and both acting on the book.



Newton's fourth law — revision must be done with tea...

Newton's 3rd law really trips people up, so make sure you understand exactly what the forces are acting on and how that results in movement (or lack of it). Then have a crack at this question to practise what you know.

Q1 Explain why you don't move when you lean on a wall, even though you are exerting a force. [3 marks]

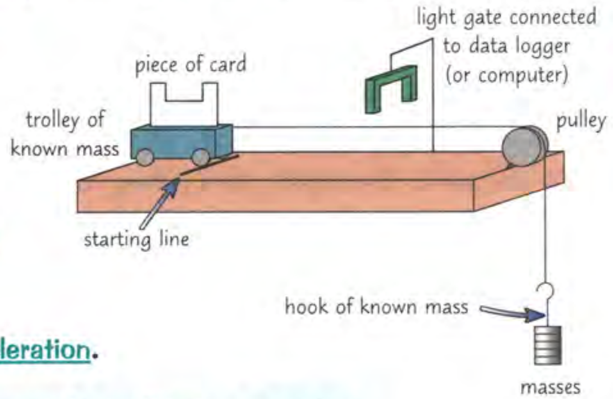
PRACTICAL Investigating Motion

Sure, you can learn the different laws of motion, but doing an experiment for yourself can really help you to understand what's going on. Read on for some snazzy ways to test how mass and force affect motion.

You can Investigate how Mass and Force Affect Acceleration

It's time for an experiment that tests Newton's 2nd law, $F = ma$ (p.64).

1) Set up the apparatus shown below. Set up the trolley so it holds a piece of card with a gap in the middle that will interrupt the signal on the light gate twice. If you measure the length of each bit of card that will pass through the light gate and input this into the software, the light gate can measure the velocity for each bit of card. It can use this to work out the acceleration of the trolley.
2) Connect the trolley to a piece of string that goes over a pulley and is connected on the other side to a hook (that you know the mass of and can add more masses to).
3) The weight of the hook and any masses attached to it will provide the accelerating force, equal to the mass of the hook (m) × acceleration due to gravity (g).
4) The weight of the hook and masses accelerates both the trolley and the masses, so you are investigating the acceleration of the system (the trolley and the masses together).
5) Mark a starting line on the table the trolley is on, so that the trolley always travels the same distance to the light gate.
6) Place the trolley on the starting line, holding the hook so the string is taut (not loose and touching the table), and release it.
7) Record the acceleration measured by the light gate as the trolley passes through it. This is the acceleration of the whole system.
8) Repeat this twice more to get an average acceleration.



1) To investigate the effect of mass, add masses to the trolley one at a time to increase the mass of the system. Don't add masses to the hook, or you'll change the force. Record the average acceleration for each mass.
2) To investigate the effect of force, you need to keep the total mass of the system the same, but change the mass on the hook. To do this, start with all the masses loaded onto the trolley, and transfer the masses to the hook one at a time, to increase the accelerating force (the weight of the hanging masses). The mass of the system stays the same as you're only transferring the masses from one part of the system (the trolley) to another (the hook). Record the average acceleration for each force.

The friction between the trolley and the bench might affect your acceleration measurements. You could use an air track to reduce this friction (a track which hovers a trolley on jets of air).

Newton's Second Law Can Explain the Results

1) Newton's Second Law can be written as $F = ma$. Here, F = weight of the hanging masses, m = mass of the whole system and a = acceleration of the system.
2) By adding masses to the trolley, the mass of the whole system increases, but the force applied to the system stays the same. This should lead to a decrease in the acceleration of the trolley, as $a = F \div m$.
3) By transferring masses to the hook, you are increasing the accelerating force without changing the mass of the whole system. So increasing the force should lead to an increase in the acceleration of the trolley.

My acceleration increases with nearby cake...

Know the ins and outs of that experiment — you could be asked about any part of it or to describe the whole thing.

Q1 Explain how a light gate can be used to measure the acceleration of a trolley. [3 marks]

Momentum

A large rugby player running very fast has much more momentum than a skinny one out for a Sunday afternoon stroll. It's something that all moving objects have, so you better get your head around it.

Momentum = Mass × Velocity

Momentum is mainly about how much 'oomph' an object has. It's a property that all moving objects have.

1) The greater the mass of an object, or the greater its velocity, the more momentum the object has.
2) Momentum is a vector quantity — it has size and direction.
3) You can work out the momentum of an object using:

$$p = mv \qquad \text{momentum (kg m/s)} = \text{mass (kg)} \times \text{velocity (m/s)}$$

EXAMPLE:

A 50 kg cheetah is running at 60 m/s. Calculate its momentum.

$p = mv = 50 \times 60$
$= 3000$ kg m/s

EXAMPLE:

A boy has a mass of 30 kg and a momentum of 75 kg m/s. Calculate his velocity.

$v = p \div m = 75 \div 30 = 2.5$ m/s

Momentum Before = Momentum After

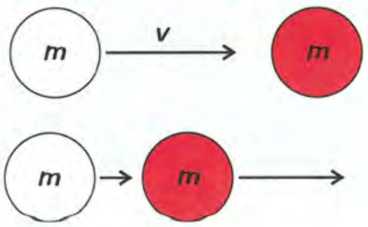
In a closed system, the total momentum before an event (e.g. a collision) is the same as after the event. This is called conservation of momentum.

A closed system is just a fancy way of saying that no external forces act.

In snooker, balls of the same size and mass collide with each other. Each collision is an event where the momentum of each ball changes, but the overall momentum stays the same (momentum is conserved).

Before:

After:



The red ball is stationary, so it has zero momentum. The white ball is moving with a velocity v, so has a momentum of $p = mv$.

The white ball hits the red ball, causing it to move. The red ball now has momentum. The white ball continues moving, but at a much smaller velocity (and so a much smaller momentum).

The combined momentum of the red and white ball is equal to the original momentum of the white ball, mv.

A moving car hits into the back of a parked car. The crash causes the two cars to lock together, and they continue moving in the direction that the original moving car was travelling, but at a lower velocity.

Before: The momentum was equal to mass of moving car × its velocity.
After: The mass of the moving object has increased, but its momentum is equal to the momentum before the collision. So an increase in mass causes a decrease in velocity.

If the momentum before an event is zero, then the momentum after will also be zero.
E.g. in an explosion, the momentum before is zero. After the explosion, the pieces fly off in different directions, so that the total momentum cancels out to zero.

Learn this stuff — it'll only take a moment... um...

Conservation of momentum is incredibly handy — there's more on using it over on the next page.

Q1 Calculate the momentum of a 60 kg woman running at 3 m/s. [2 marks]

Q2 Describe how momentum is conserved by a gun recoiling (moving backwards) as it shoots a bullet. [4 marks]

Changes in Momentum

A force causes the momentum of an object to change. A bigger force makes it change faster.

You Can Use Conservation of Momentum to Calculate Velocities or Masses

You've already seen that momentum is conserved in a closed system.
You can use this to help you calculate things like the velocity or mass of objects in an event.

EXAMPLE: Misha fires a paintball gun. A 3.0 g paintball is fired at a velocity of 90 m/s. Calculate the velocity at which the paintball gun recoils if it has a mass of 1.5 kg. Momentum is conserved.

The word recoil means to move backwards.

1) Calculate the momentum of the pellet. $p = 0.003 \times 90 = 0.27$ kg m/s
2) The momentum before the gun is fired is zero. This is equal to the total momentum after the collision. Momentum before = momentum after
   $0 = 0.27 + (1.5 \times v)$
3) The momentum of the gun is $1.5 \times v$.
4) Rearrange the equation to find the velocity of the gun. The minus sign shows the gun is travelling in the opposite direction to the bullet. $v = -(0.27 \div 1.5)$
   $= -0.18$ m/s

Forces Cause a Change in Momentum

1) You know that when a non-zero resultant force acts on a moving object (or an object that can move), it causes its velocity to change (p.64). This means that there is a change in momentum.
2) You also know that $F = ma$ and that a = change in velocity ÷ change in time.
3) So $F = m \times \frac{v-u}{t}$, which can also be written as:

$$F = \frac{m\Delta v}{\Delta t}$$

Force (N); $m\Delta v$ = Change in momentum (kg m/s); Δt = Change in time (s)

Equations tell you how variables are related. You should be able to use them to work out how changing one will affect the other.

4) The force causing the change is equal to the rate of change of momentum.
5) A larger force means a faster change of momentum.
6) Likewise, if someone's momentum changes very quickly (like in a car crash), the forces on the body will be very large, and more likely to cause injury.
7) This is why cars are designed to slow people down over a longer time when they have a crash — the longer it takes for a change in momentum, the smaller the rate of change of momentum, and so the smaller the force. Smaller forces mean the injuries are likely to be less severe.

Cars have many safety features, such as:
- Crumple zones crumple on impact, increasing the time taken for the car to stop.
- Seat belts stretch slightly, increasing the time taken for the wearer to stop.
- Air bags inflate before you hit the dashboard of a car. The compressing air inside it slows you down more gradually than if you had just hit the hard dashboard.

Bike helmets contain a crushable layer of foam which helps to lengthen the time taken for your head to stop in a crash. This reduces the impact on your brain.

Crash mats and cushioned playground flooring increase the time taken for you to stop if you fall on them. This is because they are made from soft, compressible (squishable) materials.

Don't crumple under the force of revision — take your time...

Make sure you understand how the formula above explains how safety features works.

Q1 A 10 kg object is travelling at 6 m/s. It hits a stationary 20 kg object and the two objects join together and keep moving in the same direction. Calculate the velocity of the combined object, assuming that momentum is conserved. [3 marks]