Energy Transfers and Systems

Re-read pages 24 and 25. You'll need to remember everything on those pages for this section. It could come up in the exam.

When a System Changes, Energy is Transferred

1) A system is just a fancy word for a single object (e.g. the air in a piston) or a group of objects (e.g. two colliding vehicles) that you're interested in. You can define your system to be anything you like.
2) When a system changes, energy is transferred (p.25). It can be transferred into or away from the system, between different objects in the system or between different types of energy stores.
3) Whenever a system changes, some energy is dissipated and stored in less useful ways (p.26).
4) The efficiency of a transfer is the proportion of the total energy supplied that ends up in useful energy stores (p. 26).
5) You can use diagrams to show how efficient a transfer is, and which stores the energy is transferred to (see p.25 and 27).
6) How you define your system changes how you describe the energy transfers that take place (see below). A closed system is one that's defined so that the net change in energy is zero (p.25).

Energy can be Transferred by Heating...

1) A pan of water is heated on a gas camping stove.
2) When the system is the pan of water, energy is transferred into the system by heating to the thermal energy stores of the pan and the water, which increases their temperature.
3) When the system is the camping stove and the pan, energy is transferred from the chemical energy store of the gas to the thermal energy stores of the pan and the water, increasing their temperature.

...by Forces Doing Work...

1) A box is lifted up off of the floor. The box is the system.
2) As the box is lifted, work is done (see next page) against gravity.
3) This causes energy to be transferred to the box's kinetic and gravitational potential energy stores.

If the box was dropped, the gravitational force would do work to transfer energy from the box's GPE store to its kinetic energy store.

...or by Electrical Equipment

1) Electrical devices work by transferring energy between different energy stores.
2) For example, electric irons transfer energy electrically from the mains power supply to the thermal energy store of their metal plates.

You can show energy transfers using diagrams — see p.25.

1) An electric toothbrush is a system. It transfers energy electrically from the chemical energy store of its battery to the kinetic energy store of its bristles.
2) Some of this energy is transferred out of the system to the surroundings by sound and by heating.

1) A hair dryer is a system. It transfers energy into the system electrically from the mains supply to the kinetic energy store of the fan inside of it.
2) It also transfers energy electrically to the thermal energy store of the heating element and some energy is transferred away by sound.

All this work, I can feel my energy stores being drained...

Make sure you understand exactly what a system contains before you describe any energy transfers.

Q1 Describe the energy transfers that occur when the wind causes a windmill to spin. [2 marks]

Work Done and Power

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

If A Force Moves An Object, Work is Done

When a force moves an object through a distance, WORK IS DONE on the object and ENERGY IS TRANSFERRED.

1) To make something move, some sort of force needs to act on it. The thing applying the force needs a source of energy (like fuel or food).
2) The force does 'work' to move the object and energy is transferred mechanically from one store to another (p.25).
3) Whether energy is transferred 'usefully' (e.g. lifting a load) or is 'wasted' (p.26) you can still say that 'work is done'. Just like Batman and Bruce Wayne, 'work done' and 'energy transferred' are indeed 'one and the same'.

4) You can find out how much work has been done using:
5) One joule of work is done when a force of one newton causes an object to move a distance of one metre. You can also write this as 1 J = 1 Nm (newton metre).

$$E = F \times d$$

Work done (J)
Force (N)
Distance moved in the direction of the force (m)

EXAMPLE: Find the energy transferred when a tyre weighing 70 N is lifted 1.2 m into the air.

work done = force × distance = 70 × 1.2 = 84 J

Here, work is being done against gravity. Energy is being transferred to the tyre's gravitational potential energy store.

6) A force doing work often causes a rise in temperature as energy is dissipated to the thermal energy stores of the moving object and its surroundings. This means that the process is wasteful and the efficiency of the process is reduced. Remember, efficiency = $\dfrac{\text{useful energy transferred by device}}{\text{total energy supplied to device}}$ (p.26).

When you push something along a rough surface (like a carpet) you are doing work against frictional forces. Energy is being transferred to the kinetic energy store of the object because it starts moving, but some is also being transferred to thermal energy stores due to the friction. This causes the overall temperature of the object to increase. (Like rubbing your hands together to warm them up.)

Power is How Much Work is Done per Second

1) Power is the RATE OF ENERGY TRANSFER. The unit of power is the watt (W). 1 W = 1 J/s. Another way of describing power is how much work is being done every second.
2) This is the very easy formula for power:

$$\text{power (W)} = \frac{\text{work done (J)}}{\text{time taken (s)}} \quad \text{or} \quad P = \frac{E}{t}$$

3) The larger the power of an object, the more work it does per second. E.g. if an electric heater has a power of 600 W this means it transfers 600 J of energy every second. A 1200 W heater would transfer twice as much energy per second and so would heat a room quicker than the 600 W heater.

EXAMPLE: A motor does 4.8 kJ of work in 2 minutes. Find its power output.

1) Convert the values to the correct units first (see p.9). 4.8 kJ = 4800 J and 2 mins = 120 s
2) Substitute the values into the power equation. $P = E \div t = 4800 \div 120 = 40$ W

Watt's power? Power's watts...

Make sure you're happy using the equations on this page before you move on.

Q1 A constant force of 20 N pushes an object 20 cm. Calculate the work done on the object. [2 marks]

Q2 An appliance transfers 6000 J of energy in 30 seconds. Calculate its power. [2 marks]

Forces

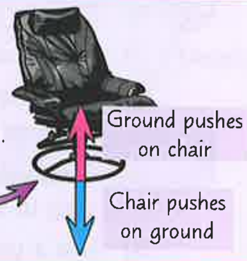
Force is a vector — it has both a size and a direction (unlike scalar quantities which only have a size — p.12). This means you can use arrows to represent the forces acting on an object or a system.

Interactions Between Objects Cause Forces

1) A force is a push or a pull on an object that is caused by it interacting with something.
2) Sometimes, objects need to be touching for a force to act. E.g. the normal contact force that acts between all touching objects, or friction between a car's tyre and the road. These are contact forces.
3) Other forces can act between objects that aren't touching (non-contact forces). They're usually caused by interacting fields. E.g. the gravitational attraction between objects (like the Earth and the Sun) is caused by their gravitational fields interacting.
4) Interacting magnetic fields (p.85) cause attraction or repulsion between magnetic objects, and the electrostatic force causing attraction and repulsion between electrical charges (p.82) is due to interactions between their electric fields (p.84).
5) Whenever two objects interact, both objects feel an equal but opposite force (Newton's 3rd Law). This pair of forces is called an interaction pair. You can represent an interaction pair with a pair of vectors (arrows).

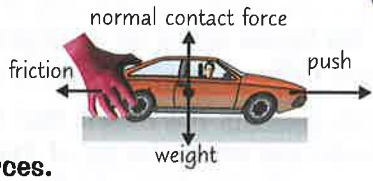
A chair exerts a force on the ground, whilst the ground pushes back at the chair with the same force (the normal contact force). Equal but opposite forces are felt by both the chair and the ground.

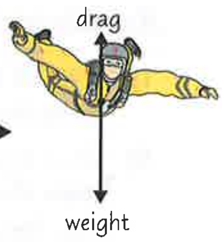
This is NOT a free body force diagram (below) — the forces are acting on different objects.



Free Body Force Diagrams Show All the Forces Acting on Objects

1) A free body force diagram shows an isolated body (an object or system on its own), and all the forces acting on it.
2) It should include every force acting on the body, but none of the forces it exerts on the rest of the world.
3) The sizes of the arrows show the relative magnitudes of the forces and the directions show the directions of the forces.

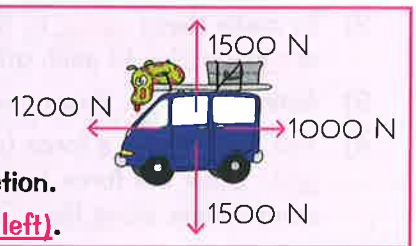




A Resultant Force is the Overall Force on a Point or Object

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 (or sometimes the net force on an object).
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.
5) Objects in equilibrium have a resultant force of zero — see the next page. Objects in equilibrium are either stationary, or moving at a steady speed (this is Newton's 1st Law — p.16).

- The normal contact force felt by the van is equal to its weight. These forces act in opposite directions, so there is no resultant force in the vertical direction (1500 N – 1500 N = 0 N).
- The frictional force acting on the van is smaller than the driving force pushing it forward, so there is a resultant force in the horizontal direction.
- 1200 N – 1000 N = 200 N. So the resultant force is 200 N (to the left).



Consolidate all your forces into one easy-to-manage force...

Free body force diagrams make most force questions easier, so if you can, always sketch one. Then get to work.

Q1 A car has a driving force of 2000 N and a weight of 1600 N. There is a total resistive force of 1200 N acting against the driving force. Draw the free body force diagram for the car. [2 marks]

Forces and Vector Diagrams

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

Use Scale Drawings to Find Resultant Forces

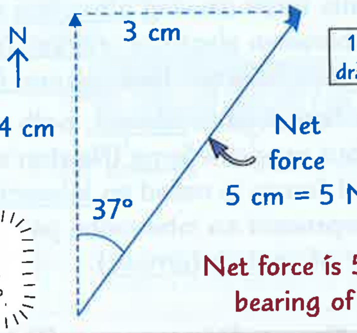
1) Draw all the forces acting on an object, to scale, 'tip-to-tail'.
2) Then draw a straight line from the start of the first force to the end of the last force — this is the resultant (or net) force.
3) Measure the length of the resultant force on the diagram to find the magnitude of the force and the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

Make sure the scale you use is sensible. You want large, clear diagrams that make your calculations easier to do.

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 net force acting on the man.

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 net force from the tail of the first arrow to the tip of the last arrow.
4) Measure the length of the net force 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°.

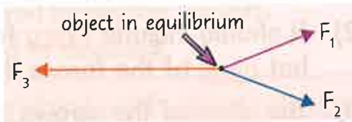


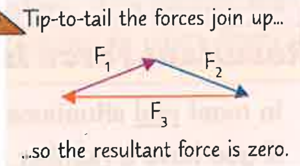
1 cm = 1 N
drawn to scale

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

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

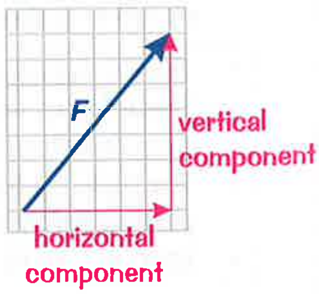
1) If all of the forces acting on an object combine to give a resultant force of zero, the object is in equilibrium.
2) On a scale diagram, this means that the tip of the last force you draw should end where the tail of the first force you drew begins. E.g. for three forces, the scale diagram will form 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.
4) To do this, draw out the forces you do know (to scale and tip-to-tail), then join the END of the LAST force to the START of the FIRST force. Make sure you draw this last force in the right direction — it's in the opposite direction to how you'd draw a resultant force.
5) This line is the missing force so you can measure its size and direction.





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 gridlines. 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 remote-controlled boat crosses a stream. The motor provides a 12 N driving force to the west. The river's current causes a force of 5 N north to act on the boat. Find the size of the net force. [2 marks]

Moments

Moments are all about rotations. Read this page thoroughly and don't let yourself get turned around.

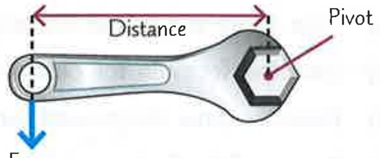
A Moment is the Turning Effect of a Force

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:

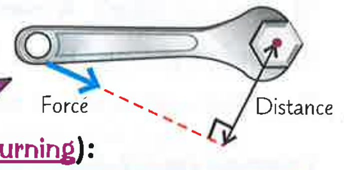
moment of a force (Nm) = force (N) × distance (m)

This is actually 'distance normal to the direction of the force'.

1) The force on the spanner causes a turning effect or moment on the nut (which acts as a pivot). A larger force or a longer distance (i.e. a longer 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. This is what the 'normal to the direction of the force' bit means.

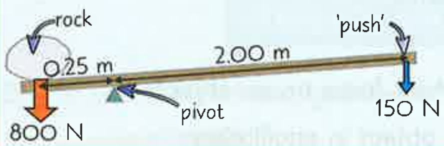


The principle of moments states that for an object in equilibrium (one that's not turning):

the sum of the clockwise moments = the sum of the anticlockwise moments

Levers Make it Easier for us to Do Work

Levers transfer the turning effect of a force — push one end of a lever down and the rotation around the pivot causes the other end to rise. Levers make it easier to do work as they increase the distance from the pivot at which a force is applied — the longer the lever, the smaller the force needed to give the same moment.



Calculate the moments from each force:

Moment from the rock's weight = $F \times d$ = 800 × 0.25 = 200 Nm anticlockwise

Moment from the push = $F \times d$ = 150 × 2.00 = 300 Nm clockwise

So there's a net CLOCKWISE moment of 100 Nm, meaning the rock will rise.

Gears Fit Together to Transmit Turning Effects

1) Gears are circular cogs with 'teeth' around their edge. Their teeth interlock so that turning one causes another to turn, in the opposite direction.
2) They are used to transmit the rotational effect of a force from one place to another.
3) A force applied to a small gear creates a small moment. This gear applies the same force to the next gear. If this next gear is larger, this force is applied further from its pivot, so the moment is larger.
4) Interlocked gears will rotate at different speeds — the larger the gear, the slower it spins.

You can work out how the speeds and moments will change between gears by looking at the gear ratios.

For example, look at the three gears above. The largest gear has 16 teeth and the medium gear has 8 teeth. The ratio of teeth between the largest gear and the medium gear is 16 : 8 = 2 : 1. This means that for every 1 turn the largest gear does, the medium gear will do 2 turns.

The force applied to each gear is the same, and the radius of a gear is equal to the distance of the applied force from the pivot. As moment = force × distance, this means that the ratio of moments of two gears is equal to the ratio of the gears' radii, and therefore equal to the ratio of teeth. For the gears above, the moment of the largest gear to the medium gear is also 2 : 1 — so the moment gets doubled.

Lubrication (p.27) reduces friction and unwanted energy transfers. Gears are often lubricated to improve the efficiency of machines.

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

It's easy to get confused by gear questions. Adding arrows to each gear to show which way it's rotating can help.

Q1 A 10 N force is applied normal to a door, 85 cm from its hinges. Calculate the moment created. [2 marks]