

# 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.

- 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**.

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

## 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**.

- 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).
- The force does 'work' to move the object and energy is transferred mechanically from one store to another (p.25).
- 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'.
- You can find out how much work has been done using:
- 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.

$$\text{work done} = \text{force} \times \text{distance} = 70 \times 1.2 = 84 \text{ J}$$

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

- 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,  $\text{efficiency} = \frac{\text{useful energy transferred by device}}{\text{total energy supplied to device}}$  (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

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

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

### EXAMPLE:

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

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

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

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

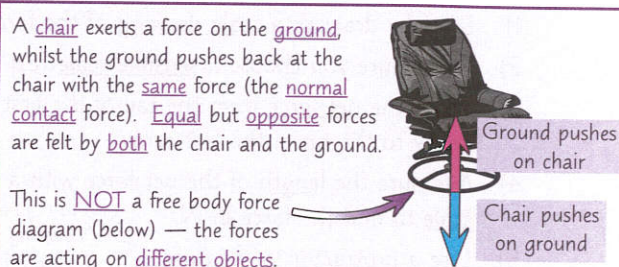
- Q1 A constant force of 20 N pushes an object 20 cm. Calculate the work done on the object. [2 marks]
- Q2 An appliance transfers 6000 J of energy in 30 seconds. Calculate its power. [2 marks]

# 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.

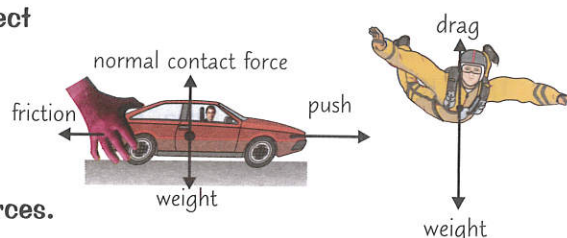
## Interactions Between Objects Cause Forces

- 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**).



## Free Body Force Diagrams Show All the Forces Acting on Objects

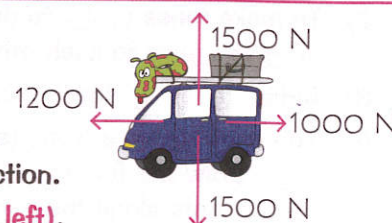
- 1) A **free body force diagram** shows an **isolated body** (an object or system on its own), and **all** the **forces** acting on it.
- 2) It should include **every** force acting **on the body**, but **none** of the forces it **exerts** on the rest of the world.
- 3) The **sizes** of the arrows show 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 ( $1500\text{ N} - 1500\text{ N} = 0\text{ N}$ ).
- 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.
- $1200\text{ N} - 1000\text{ N} = 200\text{ N}$ . 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]

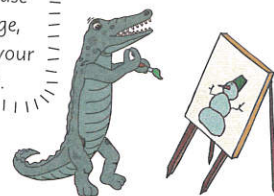
# Forces and Vector Diagrams

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.

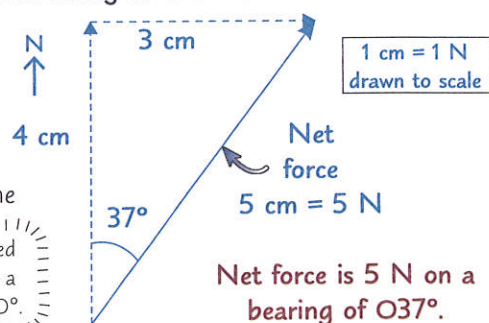


### EXAMPLE:

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.

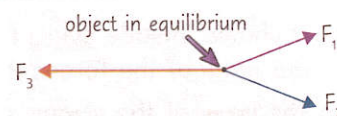
- 1) Start by drawing a **scale drawing** of the forces acting.
- 2) Make sure you choose a **sensible scale** (e.g. 1 cm = 1 N).
- 3) Draw the **net force** from the tail of the first arrow to the tip of the last arrow.
- 4) Measure the **length** of the net force with a **ruler** and use the **scale** 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.  $10^\circ = 010^\circ$ .



## 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**.



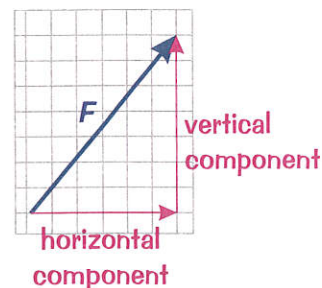
Tip-to-tail the forces join up...



...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 **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.

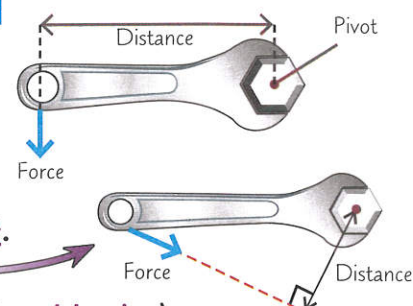
## A Moment is the Turning Effect of a Force

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:

$$\text{moment of a force (Nm)} = \text{force (N)} \times \text{distance (m)}$$

- 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.

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



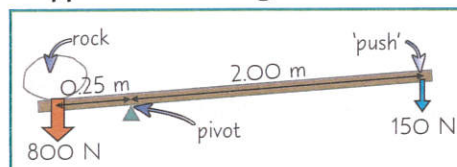
The **principle of moments** states that for an object in **equilibrium** (one that's **not turning**):

$$\text{the sum of the clockwise moments} = \text{the sum of the anticlockwise moments}$$

## 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**:

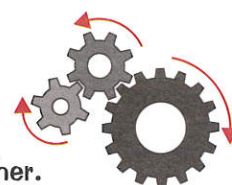
$$\text{Moment from the rock's weight} = F \times d = 800 \times 0.25 = \underline{200 \text{ Nm anticlockwise}}$$

$$\text{Moment from the push} = F \times d = 150 \times 2.00 = \underline{300 \text{ Nm clockwise}}$$

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  $16 : 8 = \underline{2 : 1}$ .

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]

## Revision Questions for Section 4

Well, that's that for [Section 4](#) — have a go at these questions, then reward yourself with a nice cup of tea.

- Try these questions and [tick off each one](#) when you [get it right](#).
- When you've done [all the questions](#) for a topic and are [completely happy](#) with it, tick off the topic.

### Energy, Work Done and Power (p.65-66)

- 1) What is a system?
- 2) Give three ways that the energy of a system can be changed.
- 3) Give the formula for calculating the work done by a force.
- 4) Describe how to convert between joules (J) and newton-metres (Nm).
- 5) True or false? A mechanical process becomes wasteful when it causes an increase in temperature.
- 6) Define power. State the equation relating power, work done and time.
- 7) What unit is power measured in?

### Forces (p.67-68)

- 8) True or false? Friction is a non-contact force.
- 9) What force causes the repulsion of two like electrical charges? What causes this force?
- 10) What is an interaction pair?
- 11) What is a free body force diagram?
- 12) What is meant by the resultant force acting on an object?
- 13) A parachuter has a weight of 900 N. At one point during his fall, the air resistance acting on him is 500 N. In what direction is his resultant force at this point?
- 14) What is the resultant force on an object in equilibrium?
- 15) Describe how you would use a scale diagram to work out the resultant force on an object.
- 16) True or false? The arrows on a scale diagram for the forces on an object in equilibrium join up to create a closed shape.
- 17) Describe how you would resolve a force into horizontal and vertical components using a scale drawing.

### Moments (p.69)

- 18) True or false? A moment is a turning effect of a force.
- 19) State the equation for calculating the size of a moment.
- 20) What is the principle of moments?
- 21) Explain how levers make it easier to do work.
- 22) True or false? For a given force, a larger gear will turn slower than a smaller gear.
- 23) If a gear is spinning clockwise, what direction will a second gear directly connected to it spin?
- 24) How can you improve the efficiency of a machine that uses gears?