牛　津

专业英语基础丛书

Advanced PHYSICS through diagrams

物理学专业英语基础

（图示教程）

Stephen Pople

上海外语教育出版社
外教社

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叶谋仁 注释

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through diagrams

Stephen Pople

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出 版 前 言

1999年出版的《大学英语教学大纲(修订本)》明确提出，“学生在完成基础阶段的学习任务，达到四级或六级后，都必须修读专业英语”。这是大纲修订组在对用人单位进行了广泛调查的基础上，结合英语学习的规律，对大学英语教学提出的新要求。因此，目前国内急需一套内容全面、语言地道的专业英语教材和读物。

《牛津专业英语基础丛书》原版由牛津大学提供，包括物理学、化学、生物学、人体生物学、商务、地理学、心理学、经济学等8种。该丛书原为英国A-level(相当于大学预科)考试的复习用书。书中以图表的形式，归纳整理了学科的主要知识。其中不仅包括常用的专业词汇和句型，还有连贯的短文，十分适合作为大学生专业英语的自学教材。

为了方便读者使用，本社约请了复旦大学、华东理工大学、华东师范大学、上海理工大学、上海财经大学等高校有关专业既有专业特长，又精通英语的教授对该丛书作了详细的注释，并给难读的单词加注了音标。

本丛书既能帮助大学生复习巩固专业知识，又能提高专业英语水平，还可以作为有关专业的人员提高专业阅读和翻译能力的教材或读物。

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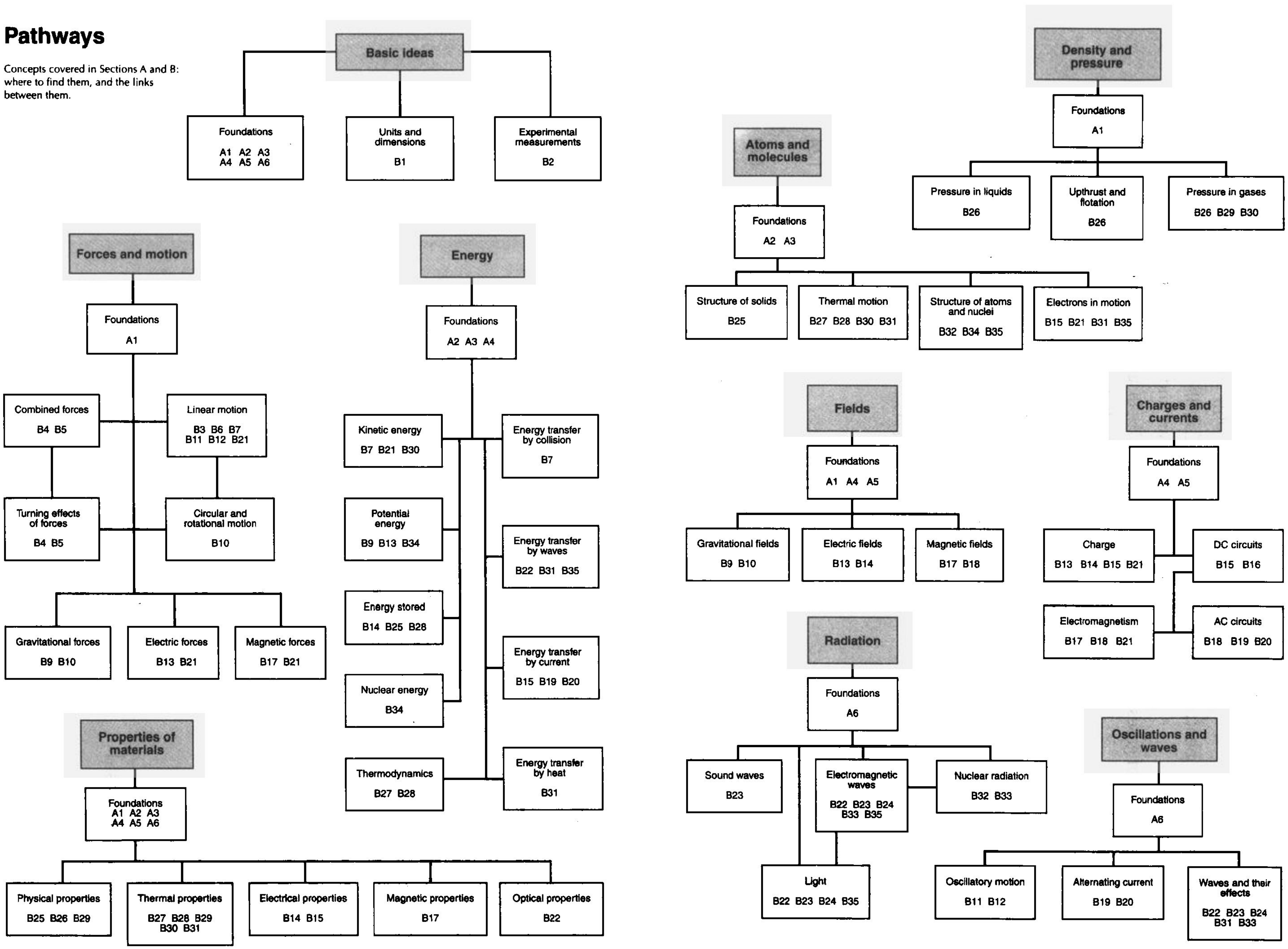
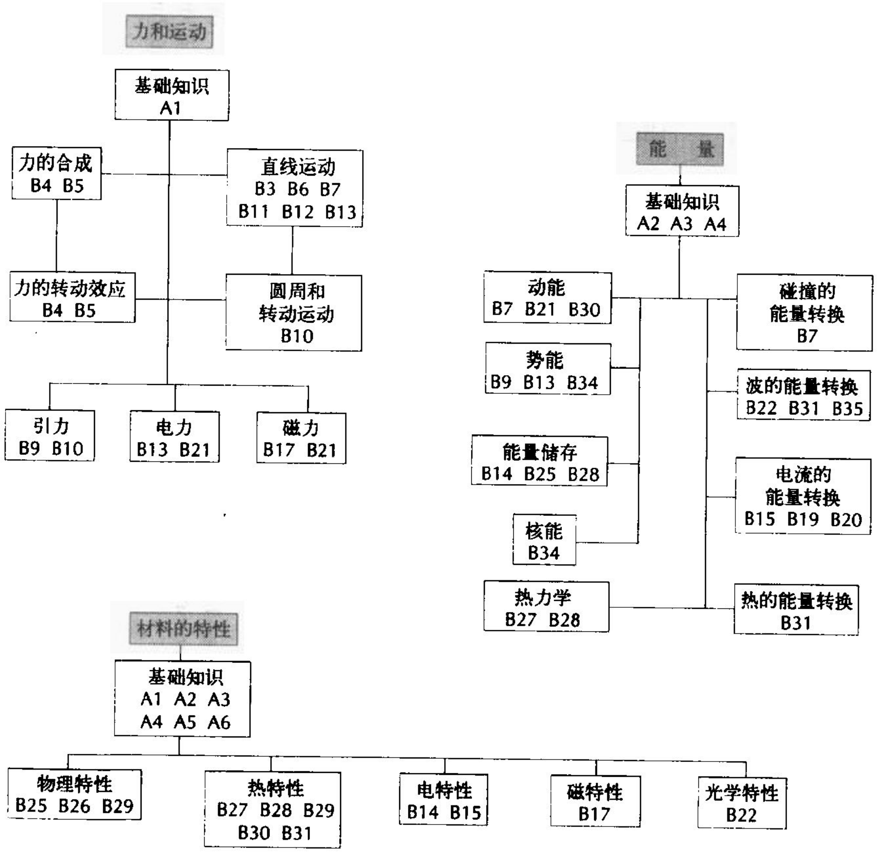
Pathways

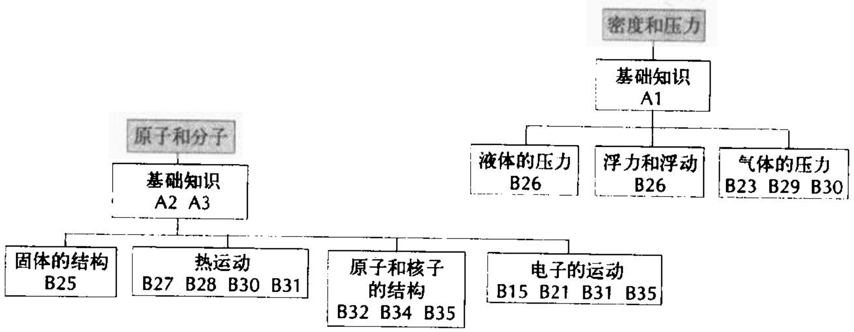
Concepts covered in Sections A and B: where to find them, and the links between them.

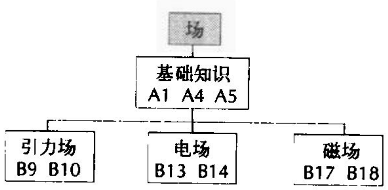


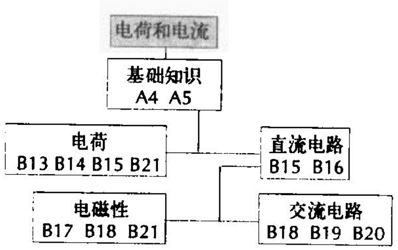
路径

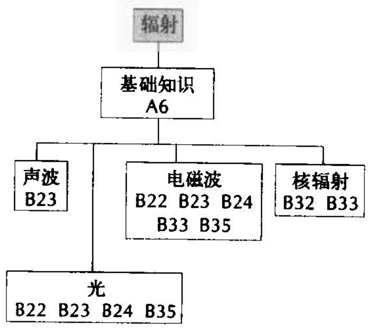
在 A 篇和 B 篇中具有的概念:
哪里可找到它们以及它们之间的联系。

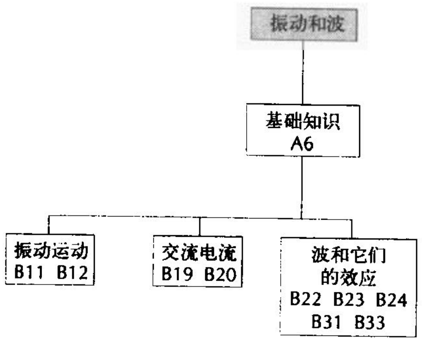












A1 Motion, mass, and forces

Units of measurement

Scientists make measurements using SI units such as the metre, kilogram, second, and newton. These and their abbreviations are covered in detail in B1. However, you may find it easier to appreciate the links between different units after you have studied the whole of section A.

For simplicity, units will be excluded from some stages of the calculations in this book, as in this example:

total length = 2 + 3 = 5 m

Strictly speaking, this should be written:

total length = 2 m + 3 m = 5 m

Displacement

Displacement is distance moved in a particular direction. The SI unit of displacement is the ***metre*** (m).

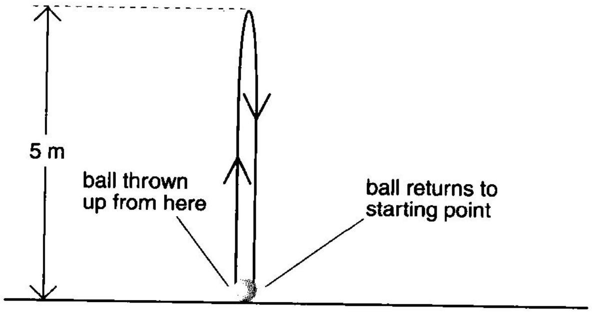
Quantities, such as displacement, which have both magnitude (size) and direction, are called ***vectors***.

$$A \xrightarrow{12\text{ m}} B$$

The arrow above represents the displacement of a particle which moves 12 m from A to B. However, with horizontal or vertical motion, it is often more convenient to use a '+' or '–' to show the vector direction. For example:

Movement of 12 m *to the right*: displacement = +12 m
Movement of 12 m *to the left*: displacement = –12 m

Displacement is not necessarily the same as distance travelled. For example, when the ball below has returned to its starting point, its vertical displacement is zero. However, the distance travelled is 10 m.



Speed and velocity

Average speed is calculated like this:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

The SI unit of speed is the metre/second, abbreviated as m s^{-1}. For example, if an object travels 12 m in 2 s, its average speed is 6 m s^{-1}.

Average velocity is calculated like this:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

The SI unit of velocity is also the m s^{-1}. But unlike speed, velocity is a vector.

$$\xrightarrow{6\text{ m s}^{-1}}$$

The velocity vector above is for a particle moving to the right at 6 m s^{-1}. However, as with displacement, it is often more convenient to use a '+' or '–' for the vector direction.

Average velocity is not necessarily the same as average speed. For example, if a ball is thrown upwards and travels a total distance of 10 m before returning to its starting point 2 s later, its average speed is 5 m s^{-1}. But its average velocity is zero, because its displacement is zero.

Acceleration

Average acceleration is calculated like this:

$$\text{average acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

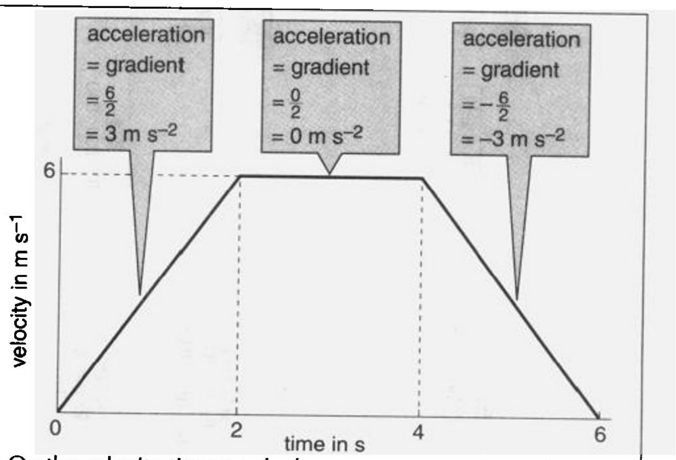
The SI unit of acceleration is the m s^{-2} (sometimes written m/s^2). For example, if an object gains 6 m s^{-1} of velocity in 2 s, its average acceleration is 3 m s^{-2}.

$$\xrightarrow{3\text{ m s}^{-2}}$$

Acceleration is a vector. The acceleration vector above is for a particle with an acceleration of 3 m s^{-2} to the right. However, as with velocity, it is often more convenient to use a '+' or '–' for the vector direction.

If velocity *increases* by 3 m s^{-1} every second, the acceleration is +3 m s^{-2}. If it *decreases* by 3 m s^{-1} every second, the acceleration is –3 m s^{-2}.

Mathematically, an acceleration of –3 m s^{-2} *to the right* is the same as an acceleration of +3 m s^{-2} *to the left*.



On the velocity-time graph above, you can work out the acceleration over each section by finding the *gradient* of the line. The gradient is calculated like this:

$$\text{gradient} = \frac{\text{gain along } y\text{-axis}}{\text{gain along } x\text{-axis}}$$

Force

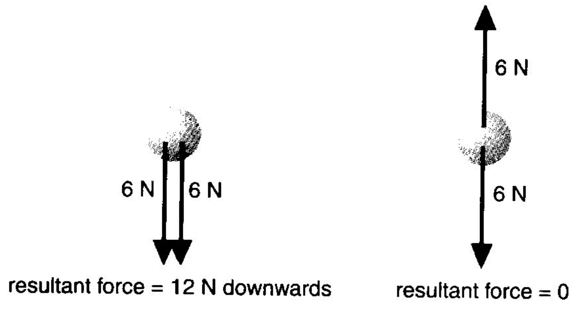
Force is a vector. The SI unit is the ***newton*** (N).

If two or more forces act on something, their combined effect is called the ***resultant force***. Two simple examples are shown below. In the right-hand example, the resultant force is zero because the forces are ***balanced***.

A resultant force acting on a mass causes an acceleration. The force, mass, and acceleration are linked like this:

resultant force = mass × acceleration $F = ma$

For example, a 1 N resultant force gives a 1 kg mass an acceleration of 1 m s^{-2}. (The newton is defined in this way.)



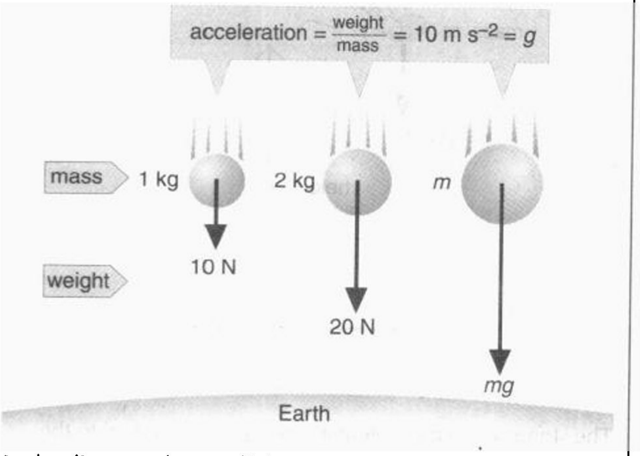
The more mass something has, the more force is needed to produce any given acceleration.

When balanced forces act on something, its acceleration is zero. This means that it is *either* stationary *or* moving at a steady velocity (steady speed in a straight line).

Weight and *g*

On Earth, everything feels the downward force of gravity. This gravitational force is called ***weight***. As for other forces, its SI unit is the newton (N).

Near the Earth's surface, the gravitational force on each kg is about 10 N: the ***gravitational field strength*** is 10 N kg^{-1}. This is represented by the symbol g.



In the diagram above, all the masses are falling freely (gravity is the only force acting). From $F = ma$, it follows that all the masses have the same downward acceleration, g. This is the ***acceleration of free fall***.

You can think of g:

either as a gravitational field strength of 10 N kg^{-1}

or as an acceleraton of free fall of 10 m s^{-2}

In more accurate calculations, the value of g is normally taken to be 9.81, rather than 10.

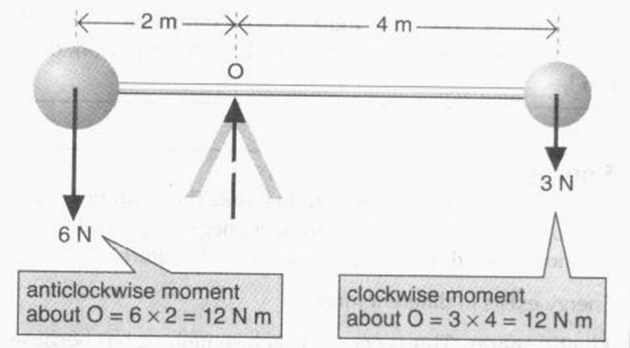
Moments and balance

The turning effect of a force is called a ***moment***:

moment of force about a point = force × perpendicular distance* from point

* measured from the line of action of the force.

The dumb-bell below balances at point O because the two moments about O are equal but opposite.



The dumb-bell is made up of smaller parts, each with its own weight. Together, these are equivalent to a single force, the total weight, acting through O. O is the ***centre of gravity*** of the dumb-bell.

Density

The density of an object is calculated like this:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

The SI unit of density is the kilogram/cubic metre (kg m^{-3}).

For example, 2000 kg of water occupies a volume of 2 m^3. So the density of water is 1000 kg m^{-3}.

Density values, in kg m^{-3}

alcohol	800	iron	7 900
aluminium	2 700	lead	11 300

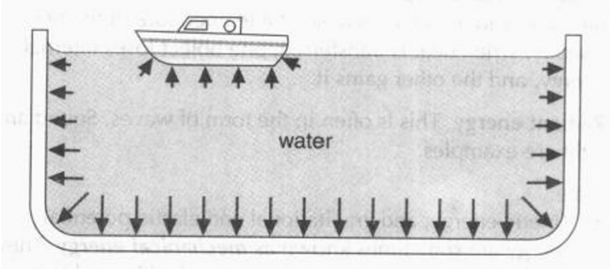
Pressure

Pressure is calculated like this:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

The SI unit of pressure is the newton/square metre, also called the ***pascal*** (**Pa**). For example, if a force of 12 N acts over an area of 3 m^2, the pressure is 4 Pa.

Liquids and gases are called ***fluids***.



In a fluid:

- Pressure acts in all directions. The force produced is always at right-angles to the surface under pressure.
- Pressure increases with depth.

A2 Work, energy, and power

Work

Work is done whenever a force makes something move.
It is calculated like this:

work done = force × distance moved in direction of force

The SI unit of work is the ***joule*** (J). For example, if a force of 2 N moves something a distance of 3 m, then the work done is 6 J.

Energy

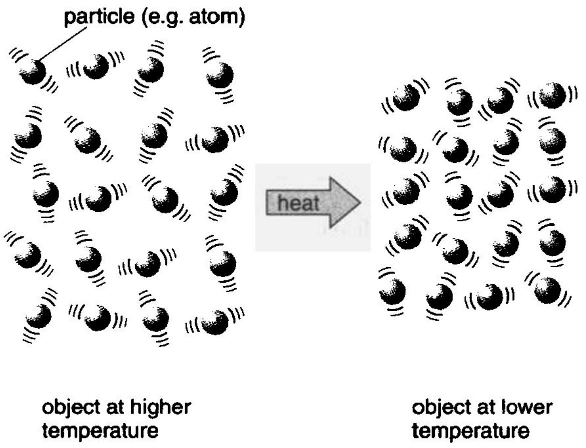
Things have energy if they can do work. The SI unit of energy is also the joule (J). You can think of energy as a 'bank balance' of work which can be done in the future.

Energy exists in different forms:

Kinetic energy This is energy which something has because it is moving.

Potential energy This is energy which something has because of its position, shape, or state. A stone about to fall from a cliff has ***gravitational*** potential energy. A stretched spring has ***elastic*** potential energy. Foods and fuels have ***chemical*** potential energy. Charge from a battery has ***electrical*** potential energy. Particles from the nucleus (centre) of an atom have ***nuclear*** potential energy.

Internal energy Matter is made up of tiny particles (e.g. atoms or molecules) which are in random motion. They have kinetic energy because of their motion, and potential energy because of the forces of attraction trying to pull them together. An object's internal energy is the total kinetic and potential energy of its particles.



Heat (thermal energy) This is the energy transferred from one object to another because of a temperature difference. Usually, when heat is transferred, one object loses internal energy, and the other gains it.

Radiant energy This is often in the form of waves. Sound and light are examples.

Note:

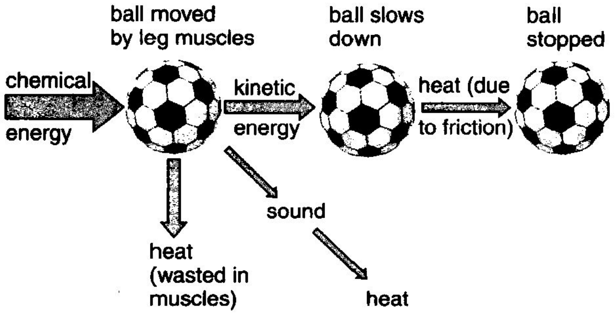
- Kinetic energy, and gravitational and elastic potential energy are sometimes known as ***mechanical energy***. They are the forms of energy most associated with machines and motion.
- Gravitational potential energy is sometimes just called potential energy (or PE), even though there are other forms of potential energy as described above.

Energy changes

According to the ***law of conservation of energy***:

> Energy cannot be made or destroyed, but it can be changed from one form to another.

The diagram below shows the sequence of energy changes which occur when a ball is kicked along the ground. At every stage, energy is lost as heat. Even the sound waves heat the air as they die away. As in other energy chains, all the energy eventually becomes internal energy.



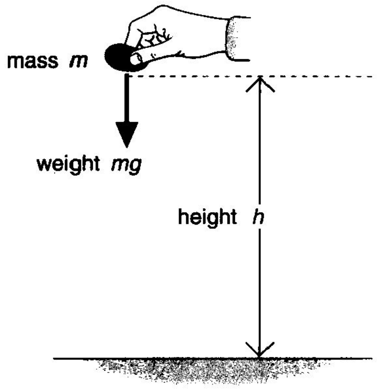
Whenever there is an energy change, work is done – although this may not always be obvious. For example, when a car's brakes are applied, the car slows down and the brakes heat up, so kinetic energy is being changed into internal energy. Work is done because tiny forces are making the particles of the brake materials move faster.

An energy change is sometimes called an energy transformation. Whenever it takes place:

work done = energy transformed

So, for each 1 J of energy transformed, 1 J of work is done.

Calculating potential energy (PE)



The stone above has potential energy. This is equal to the work done in lifting it to a height h above the ground.

The stone, mass m, has a weight of mg.
So the force needed to overcome gravity and lift it is mg.

As the stone is lifted through a height h:

work done = force × distance moved = $mg \times h$

So **potential energy = mgh**

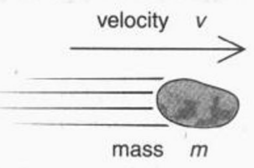
For example, if a 2 kg stone is 5 m above the ground, and g is 10 N kg^{-1}, then the stone's PE = 2 × 10 × 5 = 100 J.

Calculating kinetic energy (KE)

The stone on the right has kinetic energy. This is equal to the work done in increasing the velocity from zero to v.
B7 shows you how to calculate this. The result is:

$$\text{kinetic energy} = \tfrac{1}{2}mv^2$$

For example, if a 2 kg stone has a speed of 10 m s^{-1}, its KE = $\tfrac{1}{2} \times 2 \times 10^2 = 100$ J



PE to KE

The diagram on the right shows how PE is changed into KE when something falls. The stone in this example starts with 100 J of PE. Air resistance is assumed to be zero, so no energy is lost to the air as the stone falls.

By the time the stone is about to hit the ground (with velocity v), all of its potential energy has been changed into kinetic energy. So:

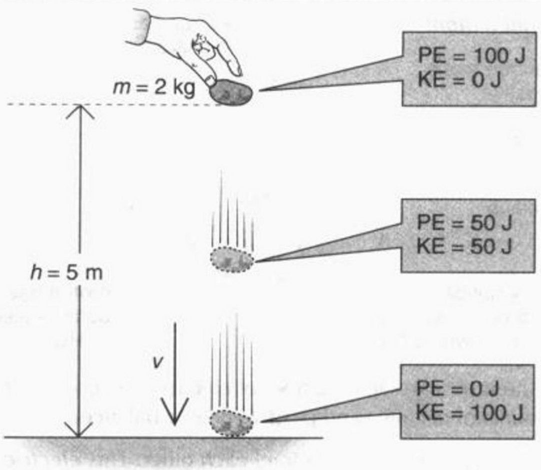
$$\tfrac{1}{2}mv^2 = mgh$$

Dividing both sides by m and rearranging:

$$v = \sqrt{2gh}$$

In this example, $v = \sqrt{2 \times 10 \times 5} = 10$ m s^{-1}.

Note that v does not depend on m. A heavy stone hits the ground at exactly the same speed as a light one.

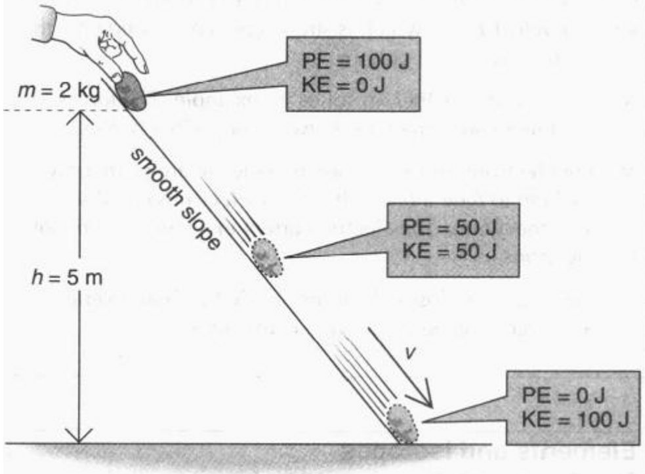


Vectors, scalars, and energy

Vectors have magnitude and direction. When adding vectors, you must allow for their direction. In A1, for example, there are diagrams showing two 6 N forces being added. In one, the resultant is 12 N. In the other, it is zero.

Scalars are quantities which have magnitude but no direction. Examples include mass, volume, energy, and work. Scalar addition is simple. If 6 kg of mass is added to 6 kg of mass, the result is always 12 kg. Similarly, if an object has 6 J of PE and 6 J of KE, the total energy is 12 J.

As energy is a scalar, PE and KE can be added without allowing for direction. The stone on the right has the same total PE + KE throughout its motion. As it starts with the same PE as the stone in the previous diagram, it has the same KE (and speed) when it is about to hit the ground.



Power

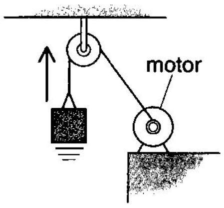
Power is calculated like this:

$$\text{power} = \frac{\text{energy transferred}}{\text{time taken}} \quad \text{or} \quad \text{power} = \frac{\text{work done}}{\text{time taken}}$$

The SI unit of power is the **watt** (W). A power of 1 W means that energy is being transformed at the rate of 1 joule/second (J s^{-1}), so work is being done at the rate of 1 J s^{-1}.

Below, you can see how to calculate the power output of an electric motor which raises a mass of 2 kg through a height of 12 m in 3 s:

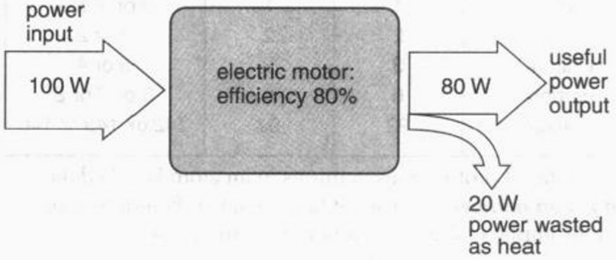
$$\begin{aligned} \text{PE gained} &= mgh \\ &= 2 \times 10 \times 12 = 240\ \text{J} \\ \text{power} &= \frac{\text{energy transferred}}{\text{time taken}} \\ &= \frac{240}{3} = 80\ \text{W} \end{aligned}$$



Efficiency

Energy changers such as motors waste some of the energy supplied to them. Their ***efficiency*** is calculated like this:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} = \frac{\text{useful power output}}{\text{power input}}$$



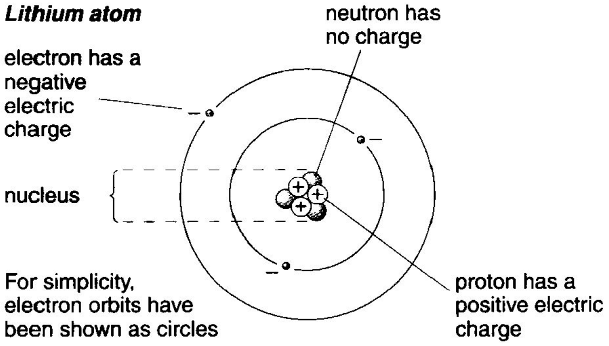
For example, if an electric motor's power input is 100 W, and its useful power output (mechanical) is 80 W, then its efficiency is 0.8. This can be expressed as 80%.

A3 Atoms and molecules in motion

Atoms

All matter is made from ***atoms***. It would take more than a million million atoms to cover this full stop.

An atom has a tiny central ***nucleus*** made of ***protons*** and ***neutrons*** (apart from the simplest atom, hydrogen, whose nucleus is a single proton). Orbiting the nucleus are much lighter particles called ***electrons***.



An atom has the same number of electrons as protons, so the amounts of negative and positive charge balance.

Unlike charges (– and +) attract each other. This ***electric force*** holds electrons in orbit around the nucleus.

Like charges (– and –, also + and +) repel each other. However, the particles in the nucleus are held together by a ***strong nuclear force***, which is strong enough to overcome the repulsion between the protons.

Atoms can stick together, in solids for example. The forces that bind them are attractions between opposite charges.

Moving electrons In metals, some of the electrons are only loosely held to their atoms. These ***free electrons*** can drift between the atoms. The electric current in a wire is a flow of free electrons.

If an atom gains or loses electrons, it is left with an overall – or + charge. Charged atoms are called ***ions***.

Elements and isotopes

Everything is made from about 100 substances called ***elements***. Each element has a different number of protons (and therefore electrons) in its atoms.

Elements exist in different versions, called ***isotopes***, each with a different number of neutrons in its atoms. Examples are shown below (italic numbers are for rarer isotopes).

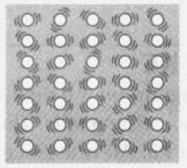
Element	Electrons	Protons	Neutrons
hydrogen	1	1	0 or *1* or *2*
helium	2	2	*1* or 2
lithium	3	3	*3* or 4
carbon	6	6	6 or *7* or *8*
uranium	92	92	*142* or *143* or 146

The total of protons plus neutrons in an atom is called the ***nucleon number***. It is used when naming different isotopes, for example: carbon-12, carbon-13, carbon-14.

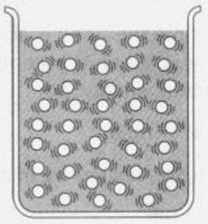
Radioactive isotopes These have atoms with unstable nuclei. The nuclei break up, emitting ***nuclear radiation***. The three main types of nuclear radiation are ***alpha*** particles, ***beta*** particles and ***gamma*** waves (see A6).

Solids, liquids and gases

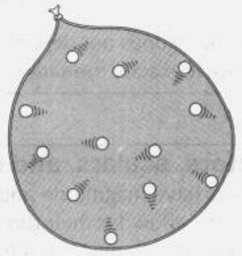
According to the ***kinetic theory***, matter is made up of tiny, randomly moving particles. Each particle may be a single atom, a group of atoms called a ***molecule***, or an ion. The three normal ***phases*** of matter are solid, liquid, and gas.



Solid The particles are held close together by strong forces of attraction. They vibrate, but about fixed central positions, so a solid keeps a fixed shape and volume.



Liquid The particles are held close together. But the vibrations are strong enough to overcome the attractions, so the particles can change positions. A liquid has a fixed volume, but it can flow to fill any shape.



Gas The particles move at high speed, colliding with each other and with the walls of their container. They are too spread out and fast-moving to stick together, so a gas quickly fills any space available. Its pressure is due to the impact of its particles on the container walls.

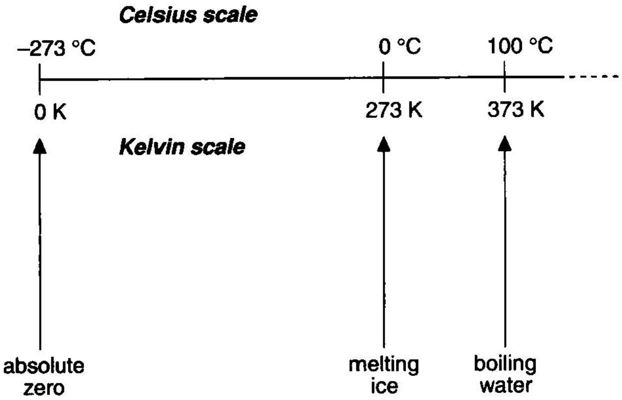
Temperature

The particles in, for example, a gas move at a range of speeds. However, the higher the temperature, the faster the particles move on average.

If two objects at the same temperature are in contact, there is no flow of heat between them. This is because the average kinetic energy of each particle due to its vibrating or speeding motion is the same in each object, so there is no overall transfer of energy from one object to the other.

Celsius scale On this scale, pure water freezes at 0 °C and boils at 100 °C (under standard atmospheric conditions).

Kelvin scale This has the same sized 'degree' as the Celsius scale, but its 'zero' is ***absolute zero*** (–273 °C), the temperature at which particles have the minimum possible kinetic energy. (The laws governing the behaviour of atoms do not permit zero energy).



Linking heat and temperature

If, say, a block of copper absorbs heat, its internal energy increases and its temperature rises.

Copper has a ***specific heat capacity*** of 390 J kg^{-1} K^{-1}. This means that 390 J of energy are required to raise the temperature of 1 kg of copper by 1 K.

Specific heat capacities, in J kg^{-1} K^{-1}

copper	390	aluminium	910
iron	470	ice	2100
glass	670	water (liquid)	4200

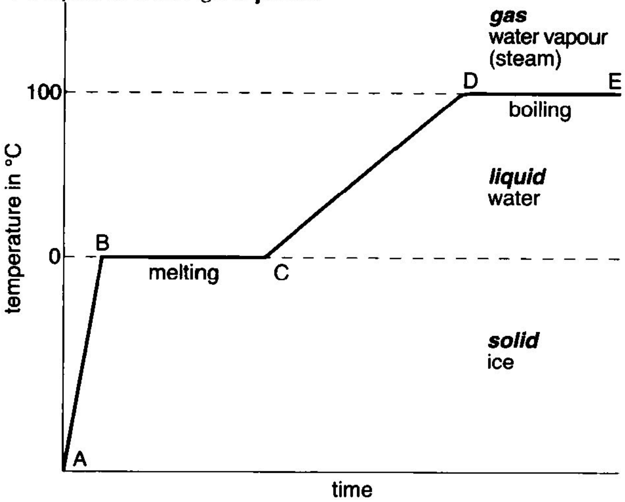
If a solid of mass m and specific heat capacity c is to increase its temperature by ΔT, then the heat input required is given by the following equation:

heat input = $mc\Delta T$

For example, to raise the temperature of 2 kg of copper by 10 K, the heat input required = 2 × 390 × 10 = 7800 J.

Changing phase

The graph shows what happens when a very cold solid (ice) takes in heat at a steady rate. Melting and boiling are both examples of a change of ***phase***.



A to B The temperature rises until the ice starts to melt.

B to C Heat is absorbed, but with no rise in temperature. The energy input is being used to overcome the attractions between the particles as the solid changes into a liquid.

C to D The temperature rises until the water starts to boil.

D to E Heat is absorbed, but with no rise in temperature. The energy input is being used to separate the particles as the liquid changes into a gas (water vapour).

A liquid, such as water, starts to turn to gas well below its boiling point. This process is called ***evaporation***. It happens as faster particles escape from the surface.

Boiling is a rapid type of evaporation in which vapour bubbles, forming in the liquid, expand rapidly because their pressure is high enough to overcome atmospheric pressure.

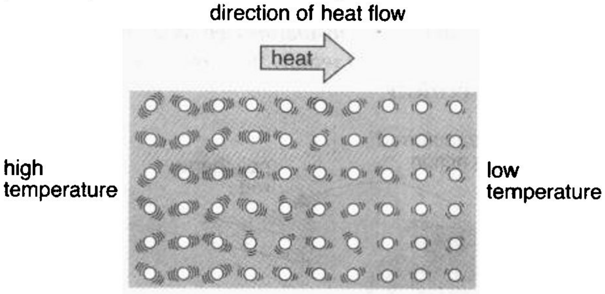
The heat required to change a liquid into a gas (or a solid into a liquid) is called ***latent heat***. When water evaporates on the back of your hand, it takes the latent heat it needs from your hand. That is why there is a cooling effect.

Latent heat is released when a gas changes back into a liquid (or a liquid changes back into a solid).

Heat transfer

Heat can be transferred by ***conduction***, ***convection***, and ***radiation***, as well as by evaporation.

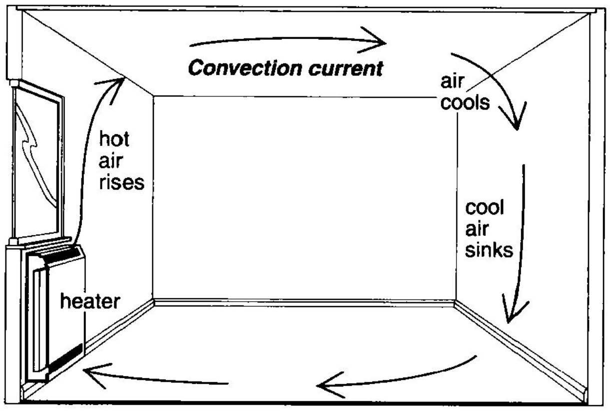
Conduction In all materials, fast-moving particles in one region can gradually pass on energy to neighbouring particles, and hence on to all the particles.



Metals are the best conductors of heat. This is because they have free electrons which can transfer energy rapidly from one part of the material to another. These same electrons also make metals good conductors of electricity.

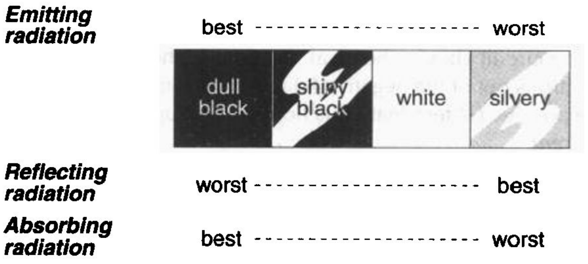
Non-metal solids and liquids are normally poor conductors of heat because they do not have free electrons. Bad conductors are called ***insulators***. Gases are especially poor conductors: most insulating materials rely on tiny pockets of trapped air for their effect.

Convection Heat is carried by a circulating flow of particles in a liquid or gas.



Most room heaters rely on convection. Hot air from the heater expands and floats upwards through the cooler air around it. Cooler air sinks to replace the hot air which has risen. In this way, a ***convection current*** is set up.

Radiation Hot objects radiate energy in the form of electromagnetic waves such as infrared (see A6). The higher the temperature, the more they emit. When this radiation is absorbed by other things, it produces a heating effect. So it is known as ***thermal radiation***.



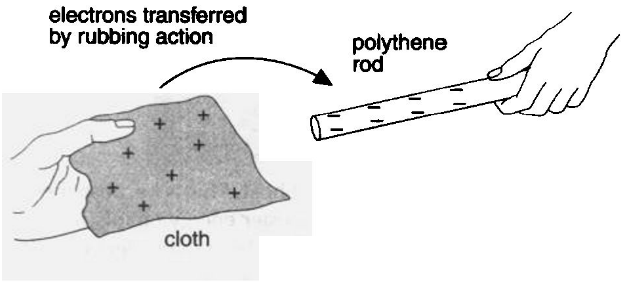
Black surfaces are the best emitters of thermal radiation and also the best absorbers. (They look black because they absorb light).

Shiny surfaces are poor emitters and also poor absorbers. They reflect most of the radiation that strikes them.

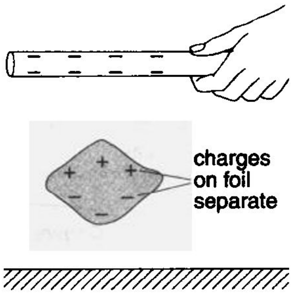
A4 Charges and circuits

Static electricity

If two materials are rubbed together, electrons may be transferred from one to another. As a result, one gains negative charge, while the other is left with an equal positive charge. If the materials are ***insulators*** (see right), the transferred charge does not readily flow away. It is sometimes called ***static electricity***.

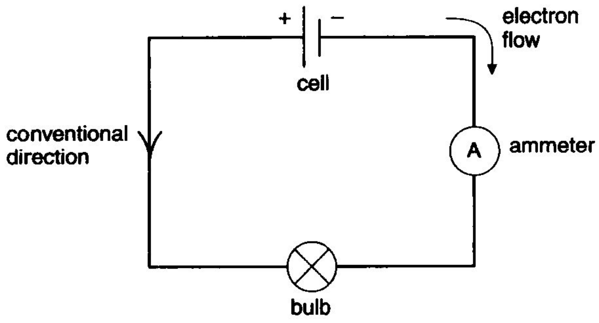


A charged object will attract an uncharged one. On the right, the charged rod has extra electrons. Being uncharged, the foil has equal amounts of – and + charge. The – charges are repelled by the rod and tend to move away, while the + charges are attracted. However, the force of attraction is greater because of the shorter distance.



Charge which collects in one region because of the presence of charge on another object is called ***induced*** charge.

Current



In the circuit above, chemical reactions in the cell push electrons out of the negative (–) terminal, round the circuit, to the positive (+) terminal. This flow of electrons is called a ***current***.

An arrow in the circuit indicates the direction from the + terminal round to the –. Called the ***conventional direction***, it is the *opposite* direction to the actual electron flow.

The SI unit of current is the ***ampere*** (A).

A current of 1 A is equivalent to a flow of 6×10^{18} electrons per second. However, the ampere is not defined in this way, but in terms of its magnetic effect (see B17).

Current may be measured using an ***ammeter*** as above.

Conductors and insulators

Current flows easily through metals and carbon. These materials are good ***conductors*** because they have free electrons which can drift between their atoms (see A3).

Most non-metals are ***insulators***. They do not conduct because all their electrons are tightly held to atoms and not easily moved. Although liquids and gases are usually insulators, they do conduct if they contain ions.

Semiconductors, such as silicon and germanium, are insulators when cold but conductors when warm.

Charge

Charge can be calculated using this equation:

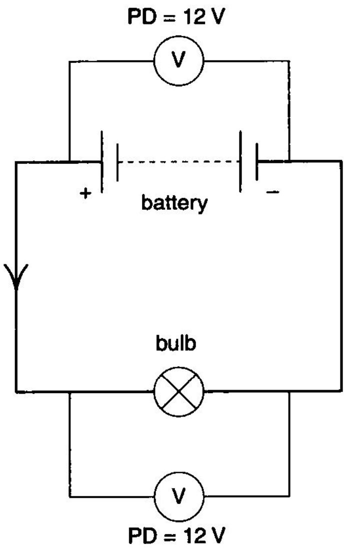
charge = current × time

The SI unit of charge is the ***coulomb*** (C).

For example, if a current of 1 A flows for 1 s, the charge passing is 1 C. (This is how the coulomb is defined.) Similarly, if a current of 2 A flows for 3 s, the charge passing is 6 C.

Voltage (PD and EMF)

In the circuit below, several cells have been linked in a line to form a ***battery***. The ***potential difference*** (**PD**) across the battery terminals is 12 volts (V). This means that each coulomb (C) of charge will 'spend' 12 joules (J) of energy in moving round the circuit from one terminal to the other.



The PD across the bulb is also 12 V. This means that, for each coulomb pushed through it, 12 J of electrical energy is changed into other forms (heat and light energy).

PD may be measured using a ***voltmeter*** as shown above.

PD, energy, and charge are linked by this equation:

energy transformed = charge × PD

For example, if a charge of 2 C moves through a PD of 3 V, the energy transformed is 6 J.

The voltage produced by the chemical reactions inside a battery is called the ***electromotive force*** (**EMF**). When a battery is supplying current, some energy is wasted inside it, which reduces the PD across its terminals. For example, when a torch battery of EMF 3.0 V is supplying current, the PD across its terminals be might be only 2.5 V.