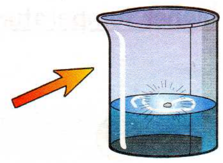
Energy Transfer in Reactions

Whenever chemical reactions occur energy is transferred to or from the surroundings.

In an Exothermic Reaction, Heat is Given Out

An EXOTHERMIC reaction is one which transfers energy to the surroundings, usually in the form of heat and usually shown by a rise in temperature.

1) The best example of an exothermic reaction is burning fuels — also called COMBUSTION. This gives out a lot of heat — it's very exothermic.
2) Neutralisation reactions (acid + alkali) are also exothermic — see page 65.
3) Many oxidation reactions are exothermic. For example, adding sodium to water produces heat, so it must be exothermic — see page 75. The sodium emits heat and moves about on the surface of the water as it is oxidised.



4) Exothermic reactions have lots of everyday uses. For example, some hand warmers use the exothermic oxidation of iron in air (with a salt solution catalyst) to generate heat. Self heating cans of hot chocolate and coffee also rely on exothermic reactions between chemicals in their bases.

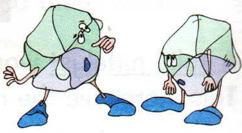
In an Endothermic Reaction, Heat is Taken In

An ENDOTHERMIC reaction is one which takes in energy from the surroundings, usually in the form of heat and is usually shown by a fall in temperature.

Endothermic reactions are much less common. Thermal decompositions are a good example:

Heat must be supplied to make calcium carbonate decompose to make quicklime.

$$CaCO_3 \rightarrow CaO + CO_2$$



Endothermic reactions also have everyday uses. For example, some sports injury packs use endothermic reactions — they take in heat and the pack becomes very cold. More convenient than carrying ice around.

Reversible Reactions Can Be Endothermic and Exothermic

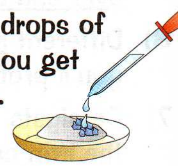
In reversible reactions (see page 55), if the reaction is endothermic in one direction, it will be exothermic in the other direction. The energy absorbed by the endothermic reaction is equal to the energy released during the exothermic reaction. A good example is the thermal decomposition of hydrated copper sulfate.

$$\text{hydrated copper sulfate} \underset{\text{exothermic}}{\overset{\text{endothermic}}{\rightleftharpoons}} \text{anhydrous copper sulfate + water}$$

"Anhydrous" just means "without water", and "hydrated" means "with water".

1) If you heat blue hydrated copper(II) sulfate crystals it drives the water off and leaves white anhydrous copper(II) sulfate powder. This is endothermic.

2) If you then add a couple of drops of water to the white powder you get the blue crystals back again. This is exothermic.



Right, so burning gives out heat — really...

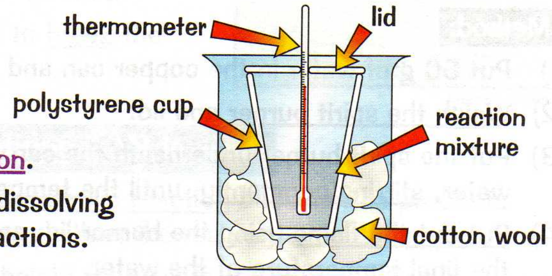
This whole energy transfer thing is a fairly simple idea — don't be put off by the long words. Remember, "exo-" = exit, "-thermic" = heat, so an exothermic reaction is one that gives out heat. And "endo-" = erm... the other one. Okay, so there's no easy way to remember that one. Tough.

Energy

Whenever chemical reactions occur, there are changes in energy. This means that when chemicals get together, things either hot up or cool right off. I'll give you a heads up — this page is a good 'un.

Energy Transfer can be Measured

1) You can measure the amount of energy produced by a chemical reaction (in solution) by taking the temperature of the reagents (making sure they're the same), mixing them in a polystyrene cup and measuring the temperature of the solution at the end of the reaction. Easy.
2) The biggest problem with energy measurements is the amount of energy lost to the surroundings.
3) You can reduce it a bit by putting the polystyrene cup into a beaker of cotton wool to give more insulation, and putting a lid on the cup to reduce energy lost by evaporation.
4) This method works for reactions of solids with water (e.g. dissolving ammonium nitrate in water) as well as for neutralisation reactions.



Example:
1) Place 25 cm^3 of dilute hydrochloric acid in a polystyrene cup, and record its temperature.
2) Put 25 cm^3 of dilute sodium hydroxide in a measuring cylinder and record its temperature.
3) As long as they're at the same temperature, add the alkali to the acid and stir.
4) Take the temperature of the mixture every 30 seconds, and record the highest temperature it reaches.

Reactions are Exothermic or Endothermic

See page 64 for more info on exothermic and endothermic reactions.

An EXOTHERMIC reaction is one which gives out energy to the surroundings, usually in the form of heat and usually shown by a rise in temperature.

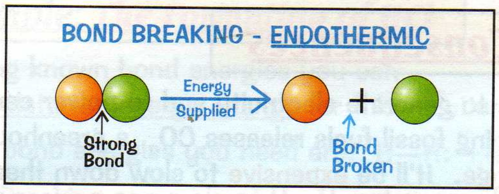
E.g. fuels burning or neutralisation reactions.

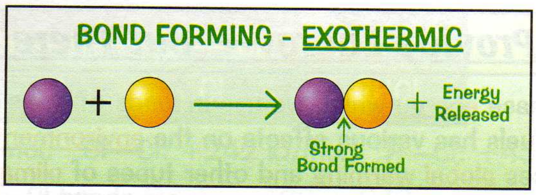
An ENDOTHERMIC reaction is one which takes in energy from the surroundings, usually in the form of heat and usually shown by a fall in temperature.

E.g. photosynthesis.

Energy Must Always be Supplied to Break Bonds... ...and Energy is Always Released When Bonds Form

1) During a chemical reaction, old bonds are broken and new bonds are formed.
2) Energy must be supplied to break existing bonds — so bond breaking is an endothermic process. Energy is released when new bonds are formed — so bond formation is an exothermic process.





3) In an endothermic reaction, the energy required to break old bonds is greater than the energy released when new bonds are formed.
4) In an exothermic reaction, the energy released in bond formation is greater than the energy used in breaking old bonds.

Save energy — break fewer bonds...

You can get cooling packs that use an endothermic reaction to draw heat from an injury. The pack contains two compartments with different chemicals in. When you use it, you snap the partition and the chemicals mix and react, taking in heat — pretty cool, I reckon (no pun intended).

Energy and Fuels

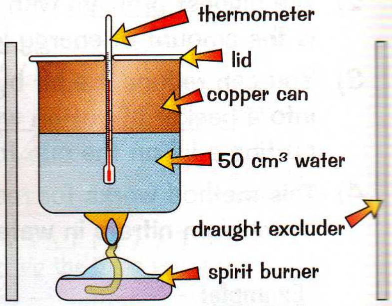
Burning fuels releases energy. Just how much energy you can find using calorimetry. Bet you can't wait.

Fuel Energy is Calculated Using Calorimetry

Different fuels produce different amounts of energy. To measure the amount of energy released when a fuel is burnt, you can simply burn the fuel and use the flame to heat up some water. Of course, this has to have a fancy chemistry name — calorimetry. Calorimetry uses a glass or metal container (it's usually made of copper because copper conducts heat so well).

Method:

1) Put 50 g of water in the copper can and record its temperature.
2) Weigh the spirit burner and lid.
3) Put the spirit burner underneath the can, and light the wick. Heat the water, stirring constantly, until the temperature reaches about 50 °C.
4) Put out the flame using the burner lid, and measure the final temperature of the water.
5) Weigh the spirit burner and lid again.



Example: to work out the energy per gram of methylated spirit (meths):

1) Mass of spirit burner + lid before heating = 68.75 g
2) Mass of spirit burner + lid after heating = 67.85 g

→ Mass of meths burnt = 0.9 g

3) Temperature of water in copper can before heating = 21.5 °C
4) Temperature of water in copper can after heating = 52.5 °C

→ Temperature change in 50 g of water due to heating = 31.0 °C

5) So 0.9 g of fuel produces enough energy to heat up 50 g of water by 31 °C.
6) It takes 4.2 joules of energy to heat up 1 g of water by 1 °C. This is known as the specific heat capacity of water.

You'll be told this in the exam.

$Q = mc\Delta T$ → ENERGY TRANSFERRED (in J) Q = MASS OF WATER (in g) m × SPECIFIC HEAT CAPACITY OF WATER (= 4.2) c × TEMPERATURE CHANGE (in °C) ΔT

7) Therefore, the energy produced in this experiment = 50 × 4.2 × 31 = 6510 joules.
8) So 0.9 g of meths produces 6510 joules of energy...
... meaning 1 g of meths produces 6510/0.9 = 7233 J or 7.233 kJ

Energy's wasted heating the can, air, etc. — so this figure will often be much lower than the actual energy content.

You can use pretty much the same method to calculate the amount of energy produced by foods. The only problem is that when you set food on fire, it tends to go out after a bit.

Fuels Provide Energy — But There are Consequences

Fuels release energy which we use in loads of ways — e.g. to generate electricity and to power cars. Burning fuels has various effects on the environment. Burning fossil fuels releases CO_2, a greenhouse gas. This causes global warming and other types of climate change. It'll be expensive to slow down these effects, and to put things right. Developing alternative energy sources (e.g. tidal power) costs money.

Crude oil is running out. We use a lot of fuels made from crude oil (e.g. petrol and diesel) and as it runs out it will get more expensive. This means that everything that's transported by lorry, train or plane gets more expensive too. So the price of crude oil has a big economic effect.

Energy from fuels — it's a burning issue...

Alrighty. A bit of method, a few sums and some social 'n' environmental gubbins to round it off. A useful thing to remember is that energy values can be measured in calories instead of joules (1 calorie = 4.2 joules). More importantly though, make sure you're familiar with the equation $Q = mc\Delta T$ — you're bound to need it.

Bond Energies

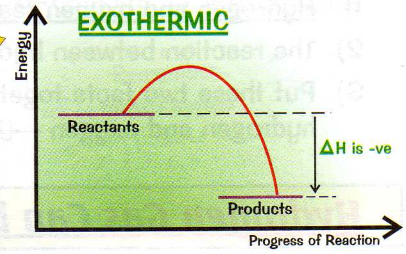
This is about calculating the stuff that you found by experiment on the previous page.

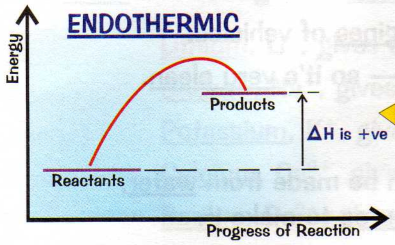
Energy Level Diagrams Show if it's Exo- or Endo-thermic

In exothermic reactions ΔH is –ve

ΔH is the energy change.

1) This shows an exothermic reaction — the products are at a lower energy than the reactants. The difference in height represents the energy given out in the reaction (per mole). ΔH is –ve here.
2) The initial rise in the line represents the energy needed to break the old bonds. This is the activation energy.



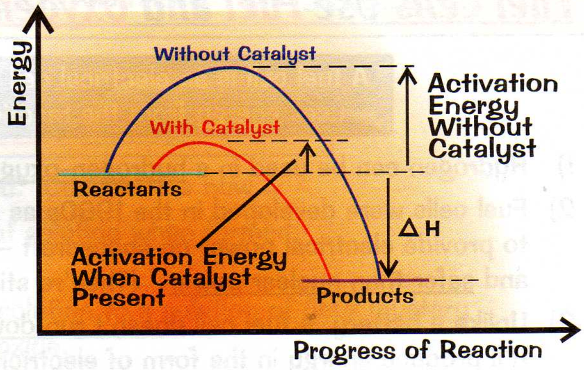


In endothermic reactions ΔH is +ve

1) This shows an endothermic reaction because the products are at a higher energy than the reactants, so ΔH is +ve.
2) The difference in height represents the energy taken in during the reaction (per mole).

The Activation Energy is Lowered by Catalysts

1) The activation energy represents the minimum energy needed by reacting particles to break their bonds.
2) A catalyst provides a different pathway for a reaction that has a lower activation energy (so the reaction happens more easily and more quickly).
3) This is represented by the lower curve on the diagram showing a lower activation energy.
4) The overall energy change for the reaction, ΔH, remains the same though.



Bond Energy Calculations — Need to be Practised

1) Every chemical bond has a particular bond energy associated with it. This bond energy varies slightly depending on what compound the bond occurs in. Don't worry — you'll be given the ones you need.
2) You can use these known bond energies to calculate the overall energy change for a reaction. You need to practise a few of these, but the basic idea is really very simple...

Example: The Formation of HCl

Using known bond energies you can calculate the energy change for this reaction:

$$H—H + Cl—Cl \rightarrow 2H—Cl$$
$$H_2 + Cl_2 \rightarrow 2HCl$$

The bond energies you need are: H—H: +436 kJ/mol; Cl—Cl: +242 kJ/mol; H—Cl: +431 kJ/mol.

1) Breaking one mole of H—H and one mole of Cl—Cl bonds requires 436 + 242 = 678 kJ
2) Forming two moles of H—Cl bonds releases 2 × 431 = 862 kJ
3) Overall more energy is released than is used to form the products: 862 – 678 = 184 kJ/mol released.
4) Since this is energy released, if we wanted to show ΔH we'd need to put a negative sign in front of it to indicate that it's an exothermic reaction, like this: ΔH = –184 kJ/mol

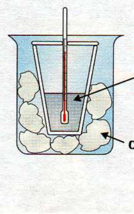
Energy transfer — make sure you take it all in...

I admit — it's a bit like maths, this. But think how many times you've heard energy efficiency mentioned — well, this kind of calculation is used in working out whether we're using resources efficiently or not.

Revision Summary for Chemistry 3b

Whenever anything at all happens, energy is either taken in or released. So it's amazingly important. If that doesn't inspire you to learn the stuff about it, the fact that you're likely to get exam questions on it should. There's also titration and bagloads of chemical tests in this section too. There's no easy way to remember it all — you just have to do some good old-fashioned memorising. Anyway, enough words of wisdom, try these questions:

1) Name a suitable indicator you could use in the titration of sulfuric acid and sodium hydroxide.
2)* In a titration, 49 cm^3 of hydrochloric acid was required to neutralise 25 cm^3 of sodium hydroxide with a concentration of 0.2 moles per dm^3.
   Calculate the concentration of the hydrochloric acid in: a) mol/dm^3 b) g/dm^3
3) An acid and an alkali were mixed in a polystyrene cup, as shown to the right.
   The acid and alkali were each at 20 °C before they were mixed.
   After they were mixed, the temperature of the solution reached 24 °C.
   a) State whether this reaction is exothermic or endothermic.
   b) Explain why the cotton wool is used.

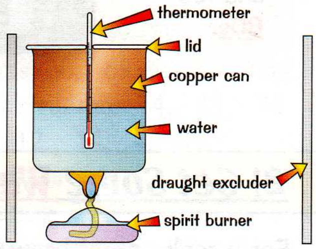


4) Is energy released when bonds are formed or when bonds are broken?
5) The apparatus below is used to measure how much energy is released when pentane is burnt. It takes 4.2 joules of energy to heat 1 g of water by 1 °C.
   a)*Using the following data, and the equation $Q = mc\Delta T$, calculate the amount of energy per gram of pentane.

Mass of empty copper can	64 g
Mass of copper can + water	116 g

Initial temperature of water	17 °C
Final temperature of water	47 °C

Mass of spirit burner + pentane before burning	97.72 g
Mass of spirit burner + pentane after burning	97.37 g



   b) A data book says that pentane has 49 kJ/g of energy. Why is the amount you calculated different?
6) Explain why the price of bananas might rise if we keep burning so much fuel.
7) a) Draw energy level diagrams for exothermic and endothermic reactions.
   b) Explain how bond breaking and forming relate to these diagrams.
8) What is the activation energy for a reaction? Mark it on your exothermic energy level diagram from Q7.
9) How does a catalyst affect: a) activation energy, b) overall energy change for a reaction?
10)*a) Calculate the energy change for the following reaction:
   $2H_2 + O_2 \rightarrow 2H_2O$ $2H—H + O—O \rightarrow 2H—O—H$
   You need these bond energies: H–H: +436 kJ/mol, O=O: +496 kJ/mol, O–H: +463 kJ/mol
   b) Is this an exothermic or endothermic reaction?
11) Give an advantage of using hydrogen as a fuel in a car engine.
12) Give a disadvantage of using hydrogen as a fuel in a car engine.
13) What is a fuel cell?
14) Why is the car industry researching fuel cells?
15) Describe two ways of testing for metal ions.
16) How would you distinguish between solutions of: a) magnesium sulfate and aluminium sulfate,
   b) sodium bromide and sodium iodide, c) copper nitrate and copper sulfate?

* Answers on page 100.