AWEsome Education
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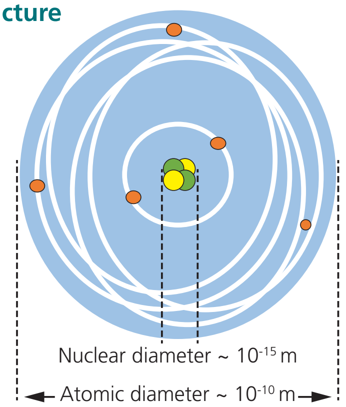
Inspiring Great Minds
of the Future

Radioactivity and Nuclear Power

This resource can be used in support of the following KS4 curricula:
AQA: GCSE Science and additional – P2 **OCR:** Gateway P2 and P4 21st century P2 and P6
Edexcel: GCSE, mixed and individual P2 and P3

For Students:
Revision Notes

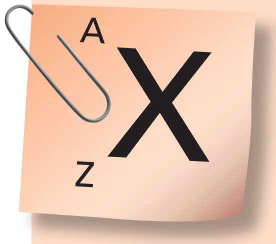
Atomic structure



What is a nucleus?

The nucleus of the atom is made up of tightly-bound protons and neutrons, so the nucleus itself is positively charged. Negatively charged electrons surround the nucleus.
This structure was discovered by **Ernest Rutherford** in 1911. He fired a stream of positively-charged particles (called alpha particles) towards a film of gold. He found that while most of the particles went straight through, a small number bounced back! This result suggested that atoms were mostly empty space, but with a small positive 'ball' at the centre.

You're going to try a version of Rutherford's experiment yourself later, but for now, let's discuss the structure….



Proton number (Z): This is called the **atomic number**. It is the number of protons in the nucleus of an atom.

Nucleon number (A): This is the total number of nucleons (protons plus neutrons) in the nucleus of an atom. It is also known as mass number.

Isotopes of an element have the same number of protons but different numbers of neutrons in the nucleus. Some isotopes are more stable than others - Carbon 12 is incredibly stable, because it has an equal number of protons as neutrons. Carbon 14 has two extra neutrons, making it unstable and radioactive – it can **decay** (or break down) emitting radiation.

How does the nucleus decay?

Radioactive decay occurs because a nuclei is unstable. The nucleus can emit different forms of radiation to become more stable. Radioactive decay is a random process, so we work in probabilities. The probability that a nucleus will decay per second is called the decay constant. The half-life is the time it takes for half of the nuclei to decay.

Type of decay	α	β^-	γ
Change in no. of protons	-2	+1	0
Change in no. of neutrons	-2	-1	0

α decay: The unstable parent nuclei emits an alpha particle (equivalent to a helium nucleus = 2 protons and 2 neutrons). α-particles can be easily stopped, even by a thin layer of skin.

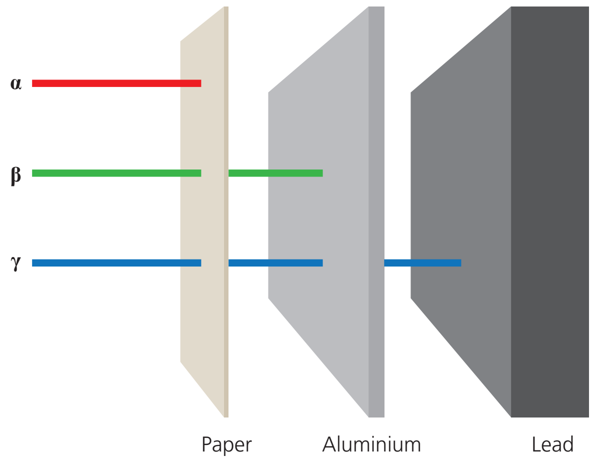
β^- decay: In the parent nuclei, a neutron changes into a proton and emits a beta, β^-, particle (equivalent to an electron).

γ decay: Gamma rays are waves, not particles. They have no mass and no charge, which makes them extremely difficult to stop.

All radioactive material must be handled with caution

- A radioactive substance that emits **alpha particles** can be safely handled with rubber gloves.
- Sources that emit **beta particles** must be held with long handled tongs and pointed away from the body.
- It is almost impossible to stop **gamma rays** completely. Lead lined clothing can reduce the number of waves reaching the body.

Stopping decay products



Radioactivity causes ionisation, and the ions formed can then be detected:

- A photographic film badge will darken when exposed to radiation. By including thin windows of paper, aluminium and lead on the badge, you can work out the type of radioactivity detected.
- A Geiger-Müller tube is filled with argon gas. When radiation enters the tube, it splits the argon molecules into ions and electrons. The flow of electrons produce a pulse of electricity that can be measured on a meter.

Nuclear Energy

Mass and energy are related to each other by Einstein's very famous equation. It tells us that a small amount of mass can contain large amounts of energy, and that it is possible to convert mass into energy, and energy into mass.

$$E = mc^2$$

E = energy measured in joules (J), **m =** mass measured in kilograms (kg), **c =** the speed of light 3×10^8 ms^{-1}

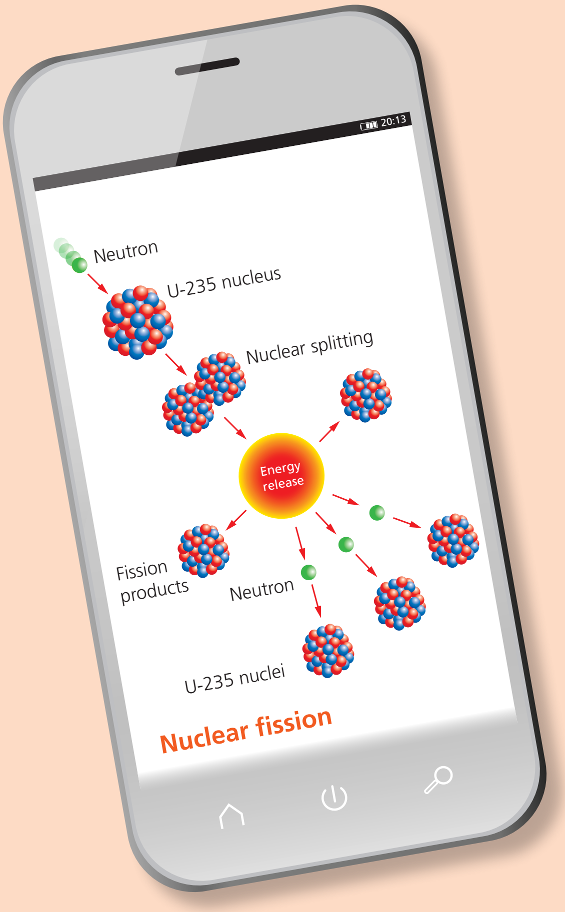
There are two ways in which nuclei can be converted to energy – nuclear fusion and nuclear fission. Because uranium-235 can undergo induced fission (basically, it can be forced to decay), it is commonly used in nuclear applications.

Fusion: This involves two atomic nuclei joining to form a larger nucleus. Energy is released when this happens.

This is what happens in stars - two hydrogen atoms are pushed together to fuse and make a helium atom. This also releases massive amounts of energy!

Fission: Nuclear fission of uranium-235 can be triggered by the nucleus absorbing a neutron. The uranium splits into two lighter nuclei (also radioactive), and two neutrons are released.

If there is enough uranium present (the so called 'critical mass'), these two neutrons can collide with other uranium nuclei, leading to further fission… this is called a **chain reaction** and it is the process used in nuclear power plants.



Nuclear Power

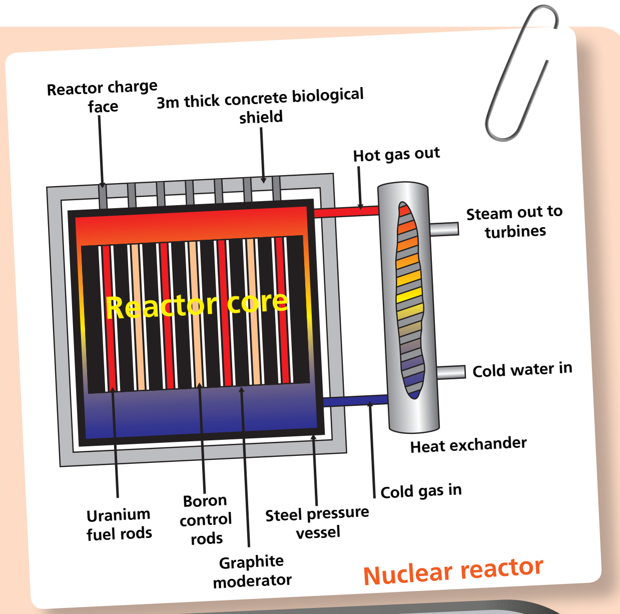
The **fuel rods** in a reactor contain uranium. The neutrons produced during fission are fast moving, and so to increase the probability of a neutron entering a nucleus, they must be slowed down by a **moderator**. Slow moving neutrons are called **thermal neutrons**.

The role of the **control rods** (usually made from boron or cadmium) is to absorb neutrons. By moving them in and out of the core, the rate of nuclear fission can be controlled.

The **coolant** in the reactor removes the heat energy from the reactor and transfers it to the water in the heat exchanger, generating steam.

Thick concrete walls and steel are used to provide shielding from the ionising radiation produced in power plants.

Unlike conventional power stations, nuclear power stations do not release carbon dioxide, so they do not contribute to global warming while in use.



Nuclear reactor

Exam Question

Q1: Global warming is seen by many as a major threat to many countries. Nuclear power is seen by some as a solution to the energy needs of a country, without causing further global warming.

Explain why this is the case. (2 marks)

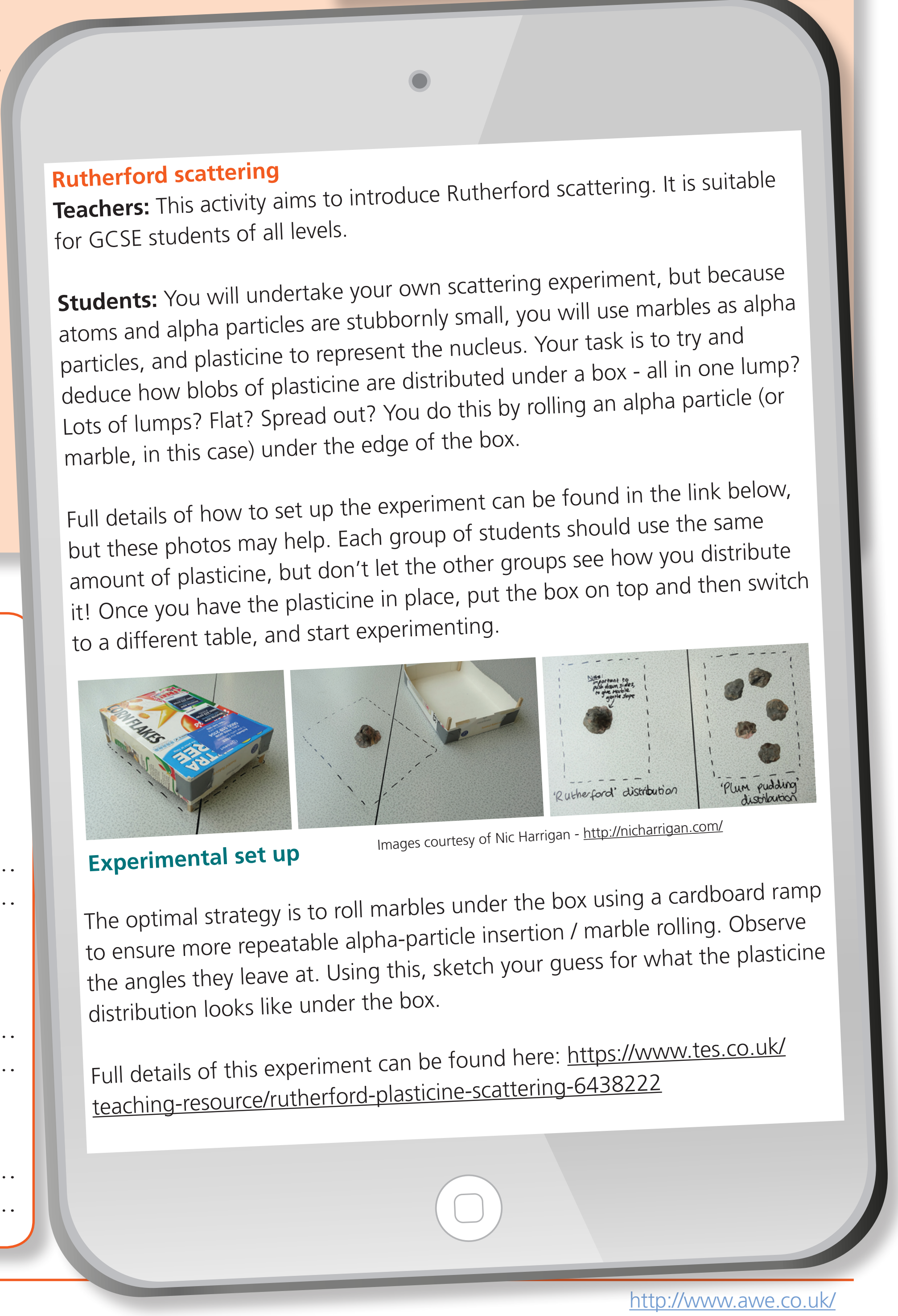
Q2: Using 1 tonne of uranium in a nuclear power station produces 1600 000 000kWh of energy. How much uranium would be needed to fuel a 2400MW nuclear power station for 24 hours?

Use this equation:

Energy transferred (kWh) = power (kW) x time (hour)

Note: 1MW = 1000 kW

a) 0.00036 tonnes
b) 0.000625 tonnes
c) 0.36 tonnes
d) 2.78 tonnes



Rutherford scattering

Teachers: This activity aims to introduce Rutherford scattering. It is suitable for GCSE students of all levels.

Students: You will undertake your own scattering experiment, but because atoms and alpha particles are stubbornly small, you will use marbles as alpha particles, and plasticine to represent the nucleus. Your task is to try and deduce how blobs of plasticine are distributed under a box - all in one lump? Lots of lumps? Flat? Spread out? You do this by rolling an alpha particle (or marble, in this case) under the edge of the box.

Full details of how to set up the experiment can be found in the link below, but these photos may help. Each group of students should use the same amount of plasticine, but don't let the other groups see how you distribute it! Once you have the plasticine in place, put the box on top and then switch to a different table, and start experimenting.

Experimental set up

Images courtesy of Nic Harrigan - http://nicharrigan.com/

The optimal strategy is to roll marbles under the box using a cardboard ramp to ensure more repeatable alpha-particle insertion / marble rolling. Observe the angles they leave at. Using this, sketch your guess for what the plasticine distribution looks like under the box.

Full details of this experiment can be found here: https://www.tes.co.uk/teaching-resource/rutherford-plasticine-scattering-6438222

Discussion points

- *What kind of force 'repels' the marbles from the plasticine? What force does the equivalent when an alpha particle is fired at an atom?*

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- *What could you vary in order to discover how high a mound of plasticine was?*

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- *In the atomic world, explain why the alpha particle changes direction*

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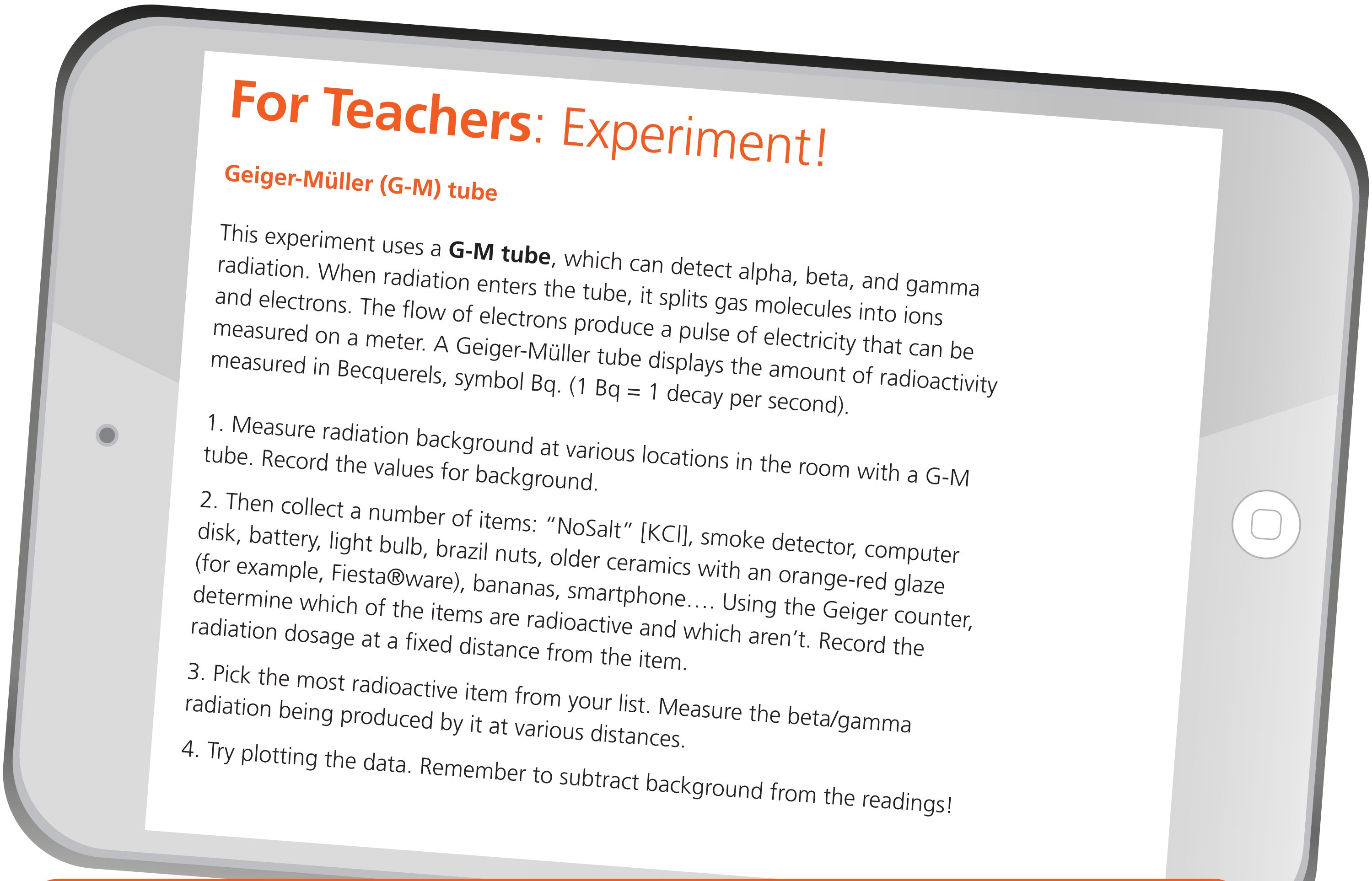

For Teachers: Experiment!

Geiger-Müller (G-M) tube

This experiment uses a **G-M tube**, which can detect alpha, beta, and gamma radiation. When radiation enters the tube, it splits gas molecules into ions and electrons. The flow of electrons produce a pulse of electricity that can be measured on a meter. A Geiger-Müller tube displays the amount of radioactivity measured in Becquerels, symbol Bq. (1 Bq = 1 decay per second).

1. Measure radiation background at various locations in the room with a G-M tube. Record the values for background.
2. Then collect a number of items: "NoSalt" [KCl], smoke detector, computer disk, battery, light bulb, brazil nuts, older ceramics with an orange-red glaze (for example, Fiesta®ware), bananas, smartphone…. Using the Geiger counter, determine which of the items are radioactive and which aren't. Record the radiation dosage at a fixed distance from the item.
3. Pick the most radioactive item from your list. Measure the beta/gamma radiation being produced by it at various distances.
4. Try plotting the data. Remember to subtract background from the readings!

Discussion points

- *Where is background radiation coming from?*

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- *How does distance affect radiation?*

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Did you know?
The annual dose level from discharges at AWE is currently less than 0.001 millisieverts (mSv). This is extremely low – putting it in context, a dose of 1mSv is less than the equivalent radiation dose likely to be received from a single medical CT scan and the average annual background radiation dose in the UK is approximately 2.7 mSv.

Learn more!

- IOP worksheet on nuclear decay: https://www.tes.co.uk/teaching-resource/nuclear-equations-6041997
- More Geiger experiments: https://www.nuc.berkeley.edu/sites/default/files/events/teachers-workshop/meter-exercises/teachers_guide.pdf
- BBC's Bang Goes the Theory talk about Brazil nuts: https://www.youtube.com/watch?v=Pt-SMAVN898