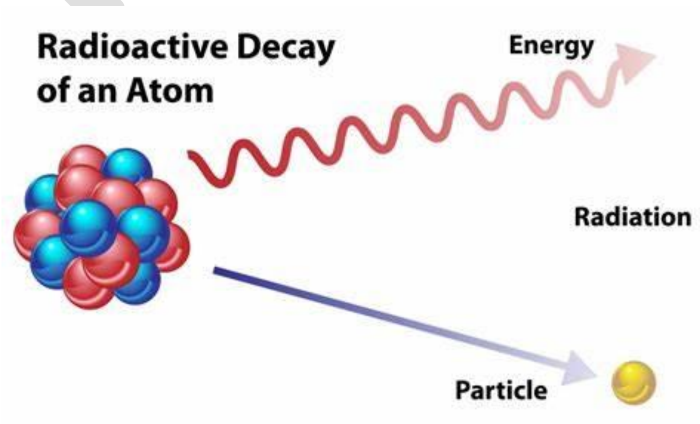
Edexcel IGCSE

Physics

CODE: (4MA1)

Unit 7

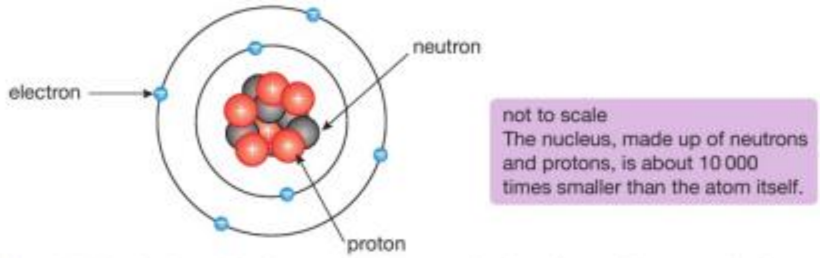
Radioactivity and particles



7.1 Atoms and radioactivity

Electrons protons and electrons

Atoms are made up of electrons, protons and neutrons. Figure 22.1 shows a simple model of how these particles are arranged.



▲ Figure 22.1 A simple model with protons and neutrons in the nucleus of the atom and electrons in orbits around the outside

Electrons are small, negative-charged particles orbiting the atom's nucleus, which is 10,000 times smaller than the atom's diameter. The nucleus consists of protons and neutrons, with protons having a positive charge and neutrons being electrically neutral. Protons and neutrons have similar masses but opposite charges.

The properties of these three atomic particles are summarised in the table below. Protons and neutrons are also called nucleons because they are found in the nucleus of the atom.

Atomic particle	Relative mass of particle	Relative charge of particle
electron	1	–1
proton	2000	+1
neutron	2000	0

The atom

An atom's nucleus is surrounded by electrons, moving rapidly in a cloud or shell. Electrons are electrically neutral, as the number of positive charges in the nucleus is balanced by the number of negative charges.

Atomic number, Z

The chemical behavior of an element is determined by its atomic number, which is the number of protons in its atoms. The atomic number, also known as the proton number, is unique to each element and is determined by the combination of atoms.

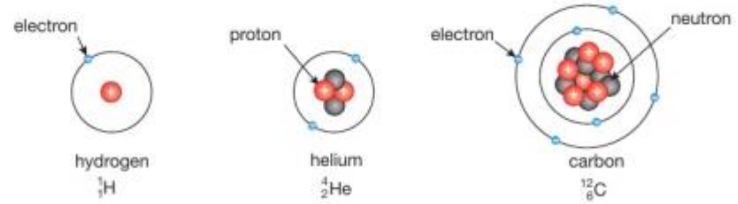
Atomic mass, A

Atomic mass is determined by the total number of protons and neutrons in the nucleus, with electrons' mass usually ignored. Protons have a mass of 1.7 x 10^{-27} kg, often referred to as the nucleon number.

Atomic notation – the recipe for an atom

Atoms have unique atomic numbers and mass numbers, based on the total number of nucleons in the nucleus. For example, oxygen has an atomic number of 8 and a mass number of 16, with eight protons and eight neutrons. The atom is electrically neutral, with eight orbiting electrons each with charge -1.

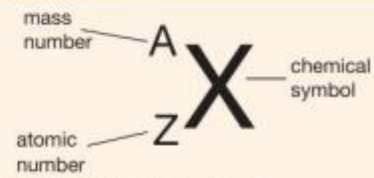
So, using this notation, an atom of oxygen is represented by:
$^{16}_{8}O$



▲ Figure 22.3 The hydrogen atom has one proton in its nucleus and no neutrons, so the mass number A = 1 + 0 = 1. As it has one proton, its atomic number, Z = 1. For helium, A = 4 (2 protons + 2 neutrons) and Z = 2 (2 protons). For carbon, A = 12 (6 protons + 6 neutrons) while Z = 6 (6 protons).

Figure 22.3 illustrates the notation used for hydrogen, helium, and carbon, indicating their atom structure, where the number of orbiting electrons equals the number of protons in the nucleus.

KEY POINT



▲ Figure 22.2 Atomic notation

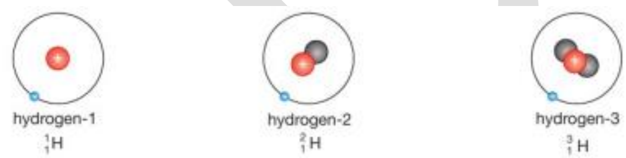
mass number, A = number of neutrons + number of protons, Z = number of nucleons

so

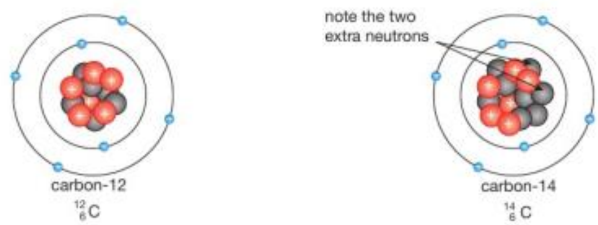
number of neutrons = number of nucleons − number of protons = A − Z

Isotopes

An atom's chemical behavior depends on its number of protons and electrons, which balance each other. Atoms with different neutron numbers, called **isotopes**, have the same atomic number but different mass numbers, with examples shown in Figures 22.4 and 22.5.



▲ Figure 22.4 Isotopes of hydrogen – they all have the same atomic number, 1, and the same chemical symbol, H.



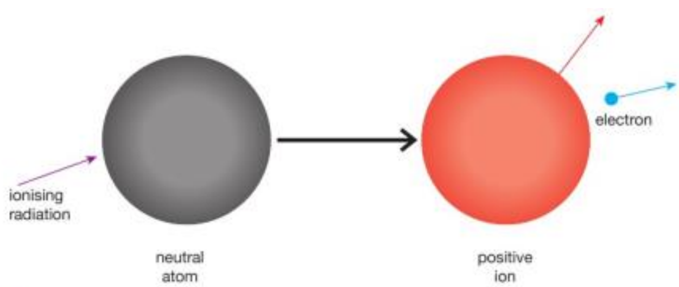
▲ Figure 22.5 Two isotopes of carbon – they are referred to as carbon-12 and carbon-14 to distinguish between them.

The stability of isotopes

Isotopes of an element have different physical properties from other isotopes of the same element. One obvious difference is the mass. Another difference is the stability of the nucleus.

Ionization radiation

Unstable nuclei decay, releasing ionising radiation, causing atoms to gain or lose charge. It's impossible to predict which nucleus or decay time in radioactive material. However, measurements can predict decay probability.



▲ Figure 22.6 When a neutral atom (or molecule) is hit by ionising radiation it loses an electron and becomes a positively charged ion.

There are three basic types of ionising radiation. They are alpha (α), beta (β) and gamma (γ) radiation.

Alpha (α) radiation

Alpha radiation is a type of ionising radiation originating from unstable nuclei. It consists of fast-moving particles, known as alpha particles, which are helium nuclei without their orbiting electrons. These particles have a large mass of four nucleons and a relatively high charge due to their two protons. They have a short range, only a few centimetres in air and a few millimetres in paper.

Beta radiation (β^+ and β-)

Beta minus particles (β-) are very fast-moving electrons that are ejected by a decaying nucleus. The nucleus of an atom contains protons and neutrons, so where does the electron come from? The stability of a nucleus depends on the proportion of protons and neutrons it contains.

Gamma rays (γ)

Gamma rays are short wavelength electromagnetic waves with no mass or charge, weakly ionizing and penetrating materials. They pass through dense materials easily, but it takes several centimetres of lead or concrete to stop gamma radiation.

Neutron radiation

Neutrons are emitted by radioactive material. They have roughly the same mass as a proton but have no electric charge. The symbol used for a neutron in radioactive decay equations is:

${}^{1}_{0}n$

Summary of the properties of ionization radiation

We have said that ionising radiation causes uncharged atoms to lose electrons. An atom that has lost (or gained) electrons has an overall charge. It is called an ion. The three types of radioactive emission can all form ions.

Radiation	Ionising power	Penetrating power	Example of range in air	Radiation stopped by
alpha, α	strong	weak	5–8 cm	paper
beta, β	medium	medium	500–1000 cm	thin aluminium
gamma, γ	weak	strong	virtually infinite	thick lead sheet

Alpha (α) decay

Hera is an example for an alpha decay:

$${}^{222}_{88}Ra \rightarrow {}^{218}_{86}Ra + {}^{4}_{2}He + \text{energy}$$

radium atom → radon atom + α particle + energy

The radioactive isotope radium-222 decays to the element radon by the emission of an alpha particle. The alpha particle is sometimes represented by the Greek letter a. Radon is a radioactive gas that also decays by emitting an alpha particle. Note that the atomic number for radon, 86, is two less than the atomic number for radium.

This is a balanced equation:

■ The total of the A numbers on each side of the equation is the same. (Remember that A is the total number of protons and neutrons.)
■ The total of the Z numbers on each side of the equation is the same. (Remember that the Z number tells us the number of protons in the nucleus - the number of positively charged particles.)

The general form of the alpha decay equation is:

$${}^{A}_{Z}Y \rightarrow {}^{A-4}_{Z-2}W + {}^{4}_{2}He + \text{energy}$$

alpha particle, α

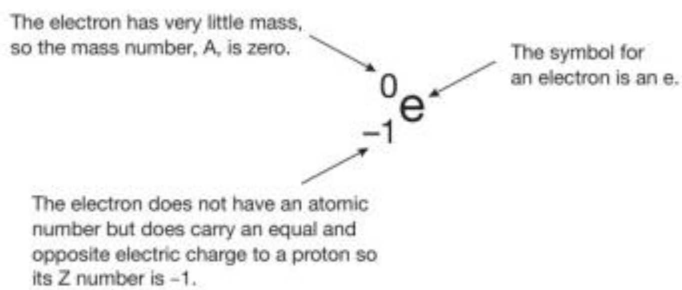
Beta (β-) decay

Hera is an example for a beta minus decay:

$${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \text{energy}$$

carbon-14 atom → nitrogen-14 atom + beta particle, β^- + energy (also an antineutrino)

The radioactive isotope of carbon, carbon-14, decays to form the stable isotope of the gas nitrogen, by emitting a beta particle. Remember that the beta minus particle is formed when a neutron splits to form a proton and an electron. Figure 22.10 shows the standard atomic notation for a beta particle (B-).



▲ Figure 22.10 A beta minus particle

The general form of the β mines decay is….

$${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e + \text{energy}$$

beta minus particle, β^-

Beta (β⁺) decay

You will not be asked about ß+ decay but the example here is included to show that the atomic mass numbers (A) and the atomic numbers (Z) on each side of the decay equation must balance. Here is an example of beta plus decay:

$${}^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + {}^{0}_{+1}e + \text{energy}$$

sodium-22 atom → neon-22 atom + beta particle, β^+ + energy (also a neutrino)

The radioactive isotope of sodium (Na), sodium-22, decays to form the stable isotope of the gas neon (Ne), by emitting a beta plus particle. Remember that the beta plus particle is formed when a proton splits to form a neutron and a positron. Figure 22.11 shows the standard atomic notation for a beta particle (B+).

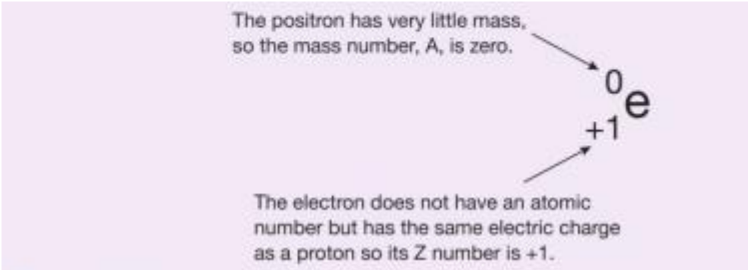


Figure 22.11 A beta plus particle

The general form of the of β plus decay is....

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + \text{energy}$$

beta plus particle, β^{+}

Neutron decay

Here is an example of neutron decay:

$$^{5}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

helium-5 atom → helium-4 atom + neutron

As a neutron has no electric charge, the total positive charge is unchanged by the emission of a neutron - the Z number is 2 before and after the decay. The total number of particles (protons and neutrons) in the nucleus of the helium atom has decreased by 1 because of emission of the neutron.

Gamma (γ) decay

Gamma radiation is high-energy electromagnetic radiation emitted by unstable nuclei after alpha or beta particle emission, without mass or charge, and does not alter the nucleus's atomic number or mass number.

7.2 Radiation and half - life

Detecting ionization radiation

Using photographic films

Wilhelm Röntgen discovered x-rays in 1895, while Henri Becquerel discovered radioactivity by observing uranium ore on photographic plates. The becquerel (Bq) unit measures the number of unstable nuclei disintegrating per second. More practical units include the kBq (1000 disintegrations per second) and MBq (1,000 disintegrations per second). Photographic film can still detect radioactivity, with scientists wearing fogged badges to monitor radiation exposure.

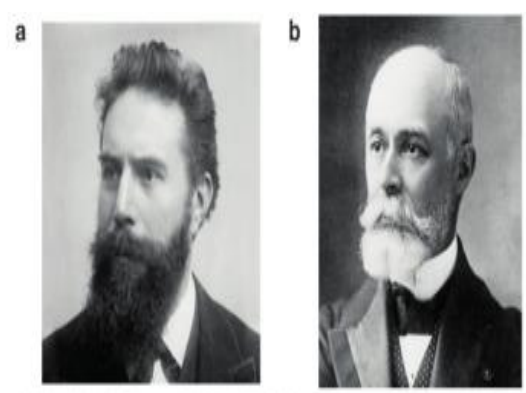
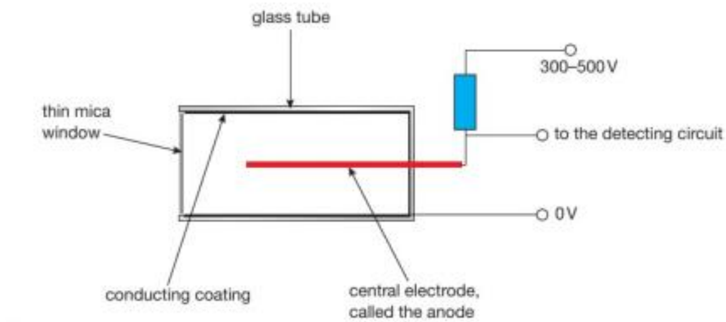


Figure 23.1 a Wilhelm Röntgen (1845–1923), b Henri Becquerel (1852–1908). Nobel prize winners in 1901 and 1903

The Geiger – muller (GM) tube

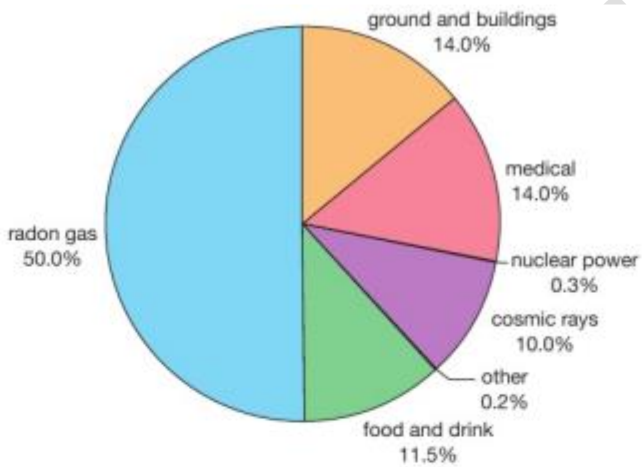
A **Geiger-Müller** tube is a glass tube with an electrically conducting surface and mica window. It contains a low-pressure gas mixture. An **electrode**, connected to a high-voltage supply, forms ions when ionizing radiation enters the tube. This current flows from the electrode to the conducting layer, detected by an electronic circuit.



▲ Figure 23.2 A Geiger–Müller tube is used to measure the level of radiation.

Background radiation

Background radiation is low-level ionising radiation that is produced all the time. This background radiation has several sources. Some of these are natural and some are artificial.



▲ Figure 23.3 Sources of background radiation in the UK. These are the average values – the true amounts and proportions vary from place to place.

Natural background radiation from the earth

Radiation from Earth's crust comes from radioactive isotopes, some of which decay quickly, and others produce radiation. Uranium, a slow-decaying element, produces radon and thoron gases, which build up in basements of buildings. The amount of background radiation produced varies depending on the Earth's crust's concentration, with higher amounts in certain areas like Cornwall, UK, where granite rock contains uranium, increasing the risk of exposure to radon gas.

Natural background radiation from space

Violent nuclear reactions in stars and exploding stars called **supernovae produce cosmic rays** (very energetic particles) that continuously hit the Earth. Lower energy cosmic rays are given out by the Sun. Our atmosphere gives us good protection from cosmic rays, but some still reach the Earth's surface.

Artificial radiation

Nuclear power stations generate electricity, releasing radioactive materials into the environment. Major incidents, such as Three Mile Island in 1979 and Chernobyl in 1986, have caused significant damage. The

Fukoshima disaster in 2011 also caused radioactive material release, making land unsafe. Testing nuclear weapons has increased radioactive isotope levels on Earth.

Radioactive **tracers** are used in industry and medicine. Radioactive materials are also used to treat certain forms of cancer.

Radioactive decay

Radioactive decay is a random, unpredictable process, like throwing a coin. It's impossible to predict which nuclei will disintegrate at any given time. However, if a thousand coins were thrown as heads, the proportion of heads would be around 500, which is considered unusual. If the proportion is much higher, it's considered unfair.

Figure 23.4 Throwing a coin

Experimental demonstration of nuclear decay

We could, if we had the time, take 1000 coins and throw them. We could then remove all the coins that came down heads, note the number of coins remaining and then repeat the process. If we did this for, say, six trials we would begin to see the trend. A set of typical results is shown in the following table and in Figure 23.5.

Trial	Number of coins remaining
0	1000
1	519
2	264
3	140
4	72
5	33
6	19

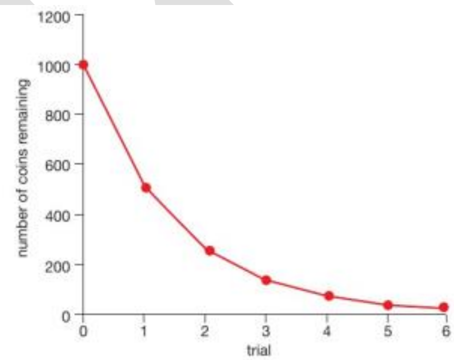


Figure 23.5 Coin-throwing experiment. Each time the coins are thrown about 50% of them land as 'heads' and are removed from the pile. The graph decreases steeply at first but then does so more and more slowly.

half – life

The coin-tossing model of radioactive decay shows a slow-moving graph with fewer throws as time passes. The **half-life**, the average time taken for half the original mass to decay, is used to measure the half-life of an isotope. The model's reliability decreases as the number of coins decreases.

Figure 23.6 shows what this means. After one half-life period, ty, the amount of the original unstable element has halved. After a second period, ty, the amount has halved again, and so on.

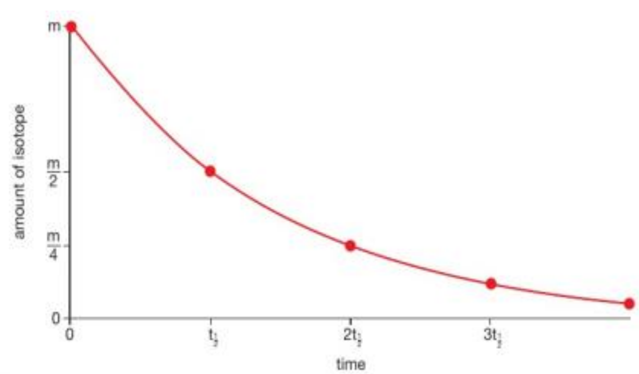


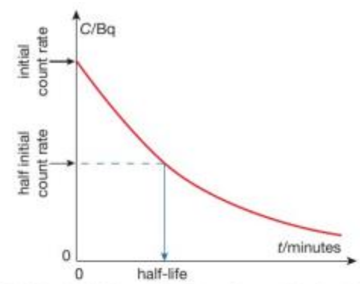
Figure 23.6 Graph showing the half-life period for a radioactive isotope

Measuring the half – life of a radioactive isotope

To measure the half-life of a radioactive material (**radioisotope**). We must **subtract** the background radiation measurement from measurements taken from the sample, so we know the radiation produced by the sample itself. We then measure the rate of decay of the sample at regular time intervals. The rate of decay is shown by the count rate on the rate meter. The results should be recorded in a table like the one shown below.

The rate of decay, C, corrected for background radiation, is proportional to the amount of radioactive isotope present. If we plot a graph of C against time, t, we can measure the half-life from the graph, as shown in Figure 23.7.

Average background radiation measured over 5 min = x Bq		
Time, *t*/min	Count rate/Bq	Corrected count rate, *C*/Bq
0	y_0	$y_0 - x$
5	y_5	$y_5 - x$



▲ Figure 23.7 You can find the half-life by reading from the graph the time taken for the count rate to halve.

As we have already mentioned, different isotopes can have very different half- lives. Some examples of different half-lives are shown in the table below.

Isotope	Half-life	Decay process
uranium-238	4.5 billion years	α particle emission
radium-226	1590 years	α particle emission, γ ray emission
radon-222	3.825 days	α particle emission

Half – life equations

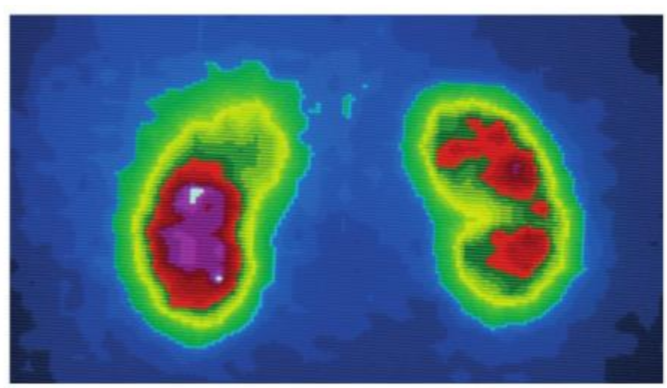
Graphs of activity, in becquerels, against time can be used to find the half-life of an isotope, and this half-life information can be used to make predictions of the activity of the radioisotope later.

7.3 Applications of radioactivity

The use of radioactivity in medicine

Using tracers in diagnoses

Radioactive isotopes are used as tracers by doctors to identify diseased organs. These gamma radiation-emitting compounds are taken orally or injected, followed by a gamma ray camera. Different compounds are chosen for different



▲ Figure 24.1 This scan shows the kidneys in a patient's body.

diagnostic tasks. Iodine-123, for example, decays and emits gamma radiation, allowing a clear image of the thyroid gland. Its short half-life is crucial.

Radiation

Isotope radiation can have various effects on cells, with low doses having no lasting effect, higher doses leading to abnormal growth and cancer, and very high doses killing living cells. Cancer treatment involves surgery and chemicals containing radioactive isotopes, which can kill healthy and diseased cells. Iodine-131, a radioisotope used for thyroid gland diseases, has a half-life of eight days and decays by beta particle emission.

Sterilization using radiation

Gamma radiation can kill **bacteria** and viruses. It is therefore used to kill these microorganisms on surgical instruments and other medical equipment. The technique is called irradiation. The items to be **sterilised** are placed in secure bags to ensure that they cannot be re-contaminated before use. The gamma radiation will pass through the packaging and destroy bacteria without damaging the item.

The use of radioactivity in industry

Gamma radiography

Gamma ray cameras, like x-ray cameras used at airports, **scan** objects using gamma radiation. They pass through more objects than x-rays and can be used to check for faults in casting or welding. Gamma radiography is advantageous as it can be small and does not require a power source or large equipment, making it a valuable tool for detecting metal defects.

▲ Figure 24.4 A gamma camera image used to view inside a valve

Gauging

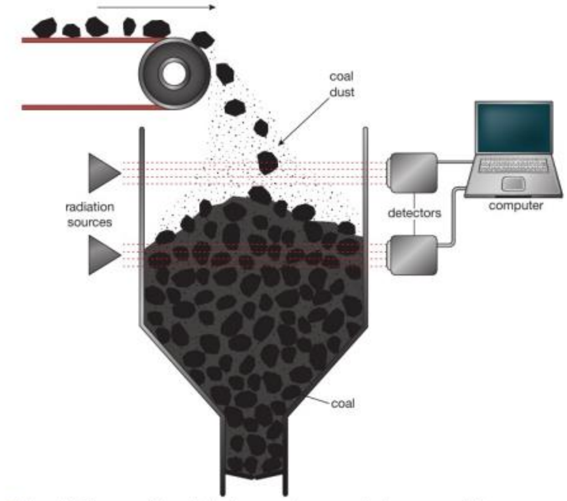
Industrial processes store raw materials and fuel in hoppers, which are gauged using radioactive isotopes. Coal absorbs radiation, resulting in small readings on the lower detector and high readings on the upper detector. This method offers advantages like no contact with the material, and the gamma ray system remains effective.

Tracing measuring the flow of liquids and gases

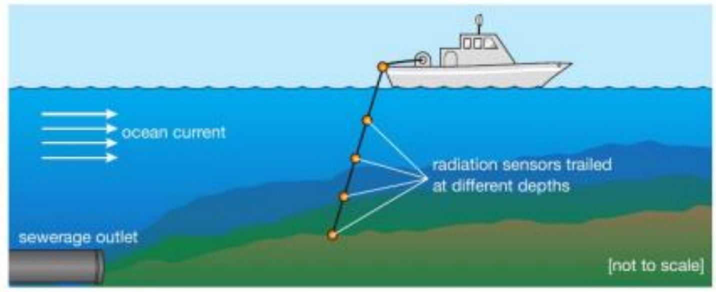
Radioisotopes are used to check the flow of liquids in industrial processes. Very tiny amounts of radiation can easily be detected. Complex piping systems, like those used in in power stations, can be monitored for leaks. Radioactive tracers are even used to measure the rate of spread of sewage (human waste) (Figure 24.6)!

Radioactive dating

A variety of different methods involving radioisotopes are used to date minerals and organic matter. The most widely known method is radiocarbon dating. This is used to find the age of organic matter - for example, from trees and animals - that was once living. We shall also look at techniques that are used to find the age of inorganic material like rocks and minerals.



▲ Figure 24.5 The amount of coal in the hopper can be measured using gamma radiation.



▲ Figure 24.6 Radioactive tracers released with the sewage allow its spread to be monitored to make sure the concentration does not reach harmful levels in any area.

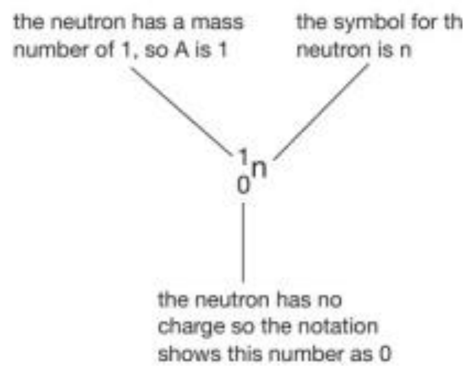
Radiocarbon dating

Radiocarbon dating measures carbon-14 isotope levels in the atmosphere due to cosmic rays causing atoms to break apart and undergo nuclear transformations. This process, triggered by collisions with other elements, can transform elements into different isotopes.

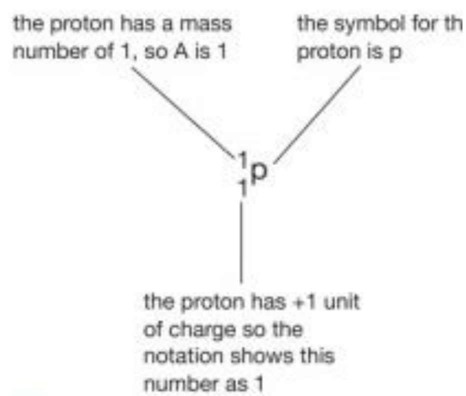
(Nitrogen forms nearly 80% of our atmosphere.) The nuclear equation for this process is:

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}p$$

Carbon-14 atoms react with oxygen in the atmosphere to form carbon dioxide, which is absorbed by plants through **photosynthesis**. This radioactive carbon is present in plants and animals, and decays over time. When an organism dies, the replacement process stops, and the proportion of radioactive carbon decreases. The half-life for carbon-14 decay is approximately 5600 years, causing the proportion of carbon-14 in dead material to halve every 5600 years.



▲ Figure 24.7 The neutron



▲ Figure 24.8 The proton

The dangerous to health of ionizing radiation

Ionising radiation can damage cells, leading to cell mutation and some types of cancer. Different types of radiation present different risks. Alpha particles have the greatest ionising effect but cannot pass through many materials, making them less risky. Exposure to alpha radiation is more severe if taken into the body, where it is close to various cell types. Radon gas, a decay product of radium, is an alpha emitter and poses a serious health risk. Beta and gamma radiation pose serious health risks, with gamma radiation being the most penetrating. Workers in the nuclear industry wear badges to indicate their exposure levels, which can be foggy or **thermoluminescent**. Regular checks of these badges help measure overall radiation exposure.

Safe handling of radioactive materials

Schools and colleges use small radioactive isotope samples to limit risk to teachers. These samples are stored in lead-lined containers, labeled as radiation hazards, and handled using tongs. In the nuclear industry and research laboratories, larger amounts of radioactive material are handled with care, using lead shields, concrete, and thick glass viewing panels. Neutron radiation is absorbed by lighter elements, and waste materials are stored under water until safe levels are reached.

▲ Figure 24.9 Radioactive samples are stored in lead-lined containers and are handled with tongs or protected fingers.

▲ Figure 24.10 Industrial sources of radioactivity must be handed with a lot of care.

7.4 Fission and fusion

Nuclear reactions as a fuel of energy

Nuclear reactions involve atoms changing their properties, either through fission or fusion. The missing mass is converted into energy. Radioactive isotopes in Earth's core, such as uranium, thorium, and potassium, contribute significantly to Earth's heat through radioactive decay.

In the Sun, hydrogen is converted into helium in a **fusion reaction** providing us with a continuous supply of energy in the form of heat and other electromagnetic radiation.

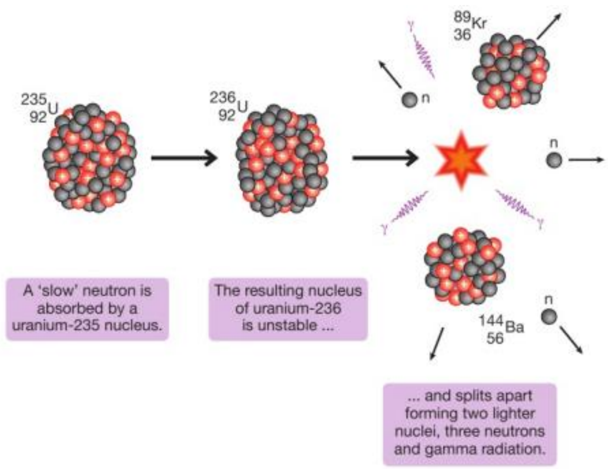
Nuclear fission

Uranium-235 is used as fuel in a nuclear reactor. It is used because its nuclei can be split by a neutron. The process of splitting an atom is called fission.

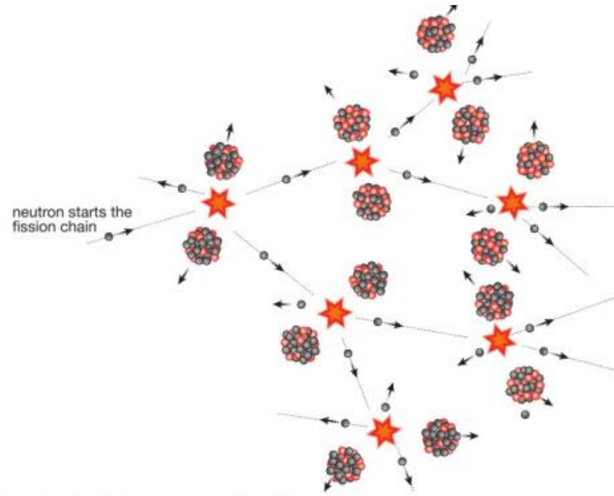
The resulting nucleus of uranium-236 is unstable and splits apart. The fragments of this decay are the two daughter nuclei of barium-144 and krypton-89. The decay also produces gamma radiation and three more neutrons. The equation for this decay is:

$$^{236}_{92}\text{U} \rightarrow {}^{144}_{56}\text{Ba} + {}^{89}_{36}\text{Kr} + 3\,{}^{1}_{0}\text{n} + \gamma \text{ radiation}$$

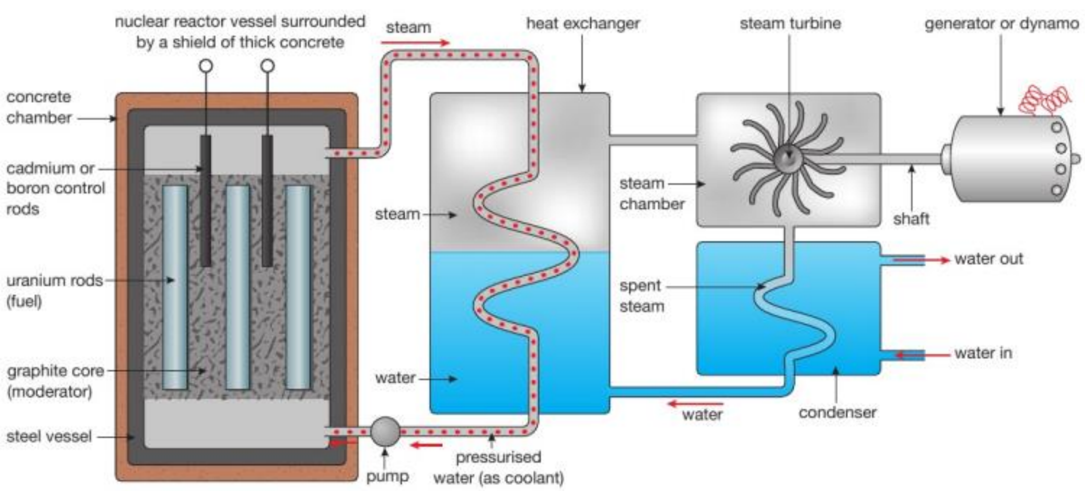
A nuclear reactor overheats, causing a nuclear explosion with massive heat energy and radiation release. The process is controlled to release heat over time, using it to heat water and drive turbines and generators. The reactor core contains fuel rods of enriched uranium, with graphite acting as a moderator.



▲ Figure 25.1 One example of fission of uranium-235



▲ Figure 25.2 A chain reaction in uranium-235

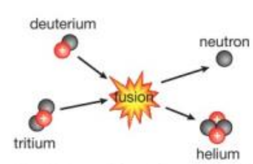


▲ Figure 25.3 A nuclear reactor controls a chain reaction so that heat energy is released slowly.

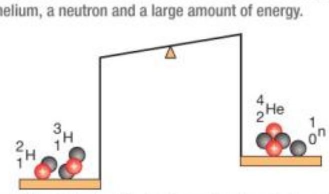
In the nuclear reactor there are also **control rods**, made of boron or cadmium. These absorb the neutrons and take them out of the fission process completely. When the control rods are fully inside the core, the chain reaction is almost completely stopped and the rate of production of heat is low. As the control rods are withdrawn, the rate of fission increases producing heat at a greater rate.

Nuclear fusion

The fusion process, which involves the collision of deuterium and tritium isotopes at high speeds, is used in nuclear fusion reactor projects. This process produces a helium nucleus, a neutron, and energy, and is the energy source for the Sun and all stars. However, high temperatures and high pressure are required to overcome the repulsive force between the nuclei.



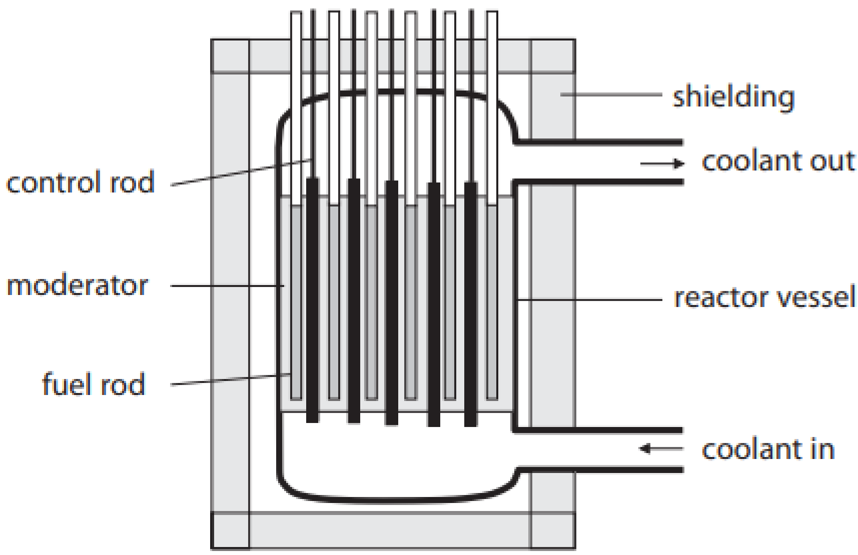
▲ Figure 25.4 Here a nucleus of deuterium collides with a nucleus of tritium. They undergo fusion to form the nucleus of helium, a neutron and a large amount of energy.



▲ Figure 25.5 The mass of the products of fusion is smaller than the two hydrogen nuclei.

Revision questions

(1) The diagram shows the main parts of a nuclear reactor.



(a) Draw a line linking each part of the reactor with its main function. The first one has been done for you.

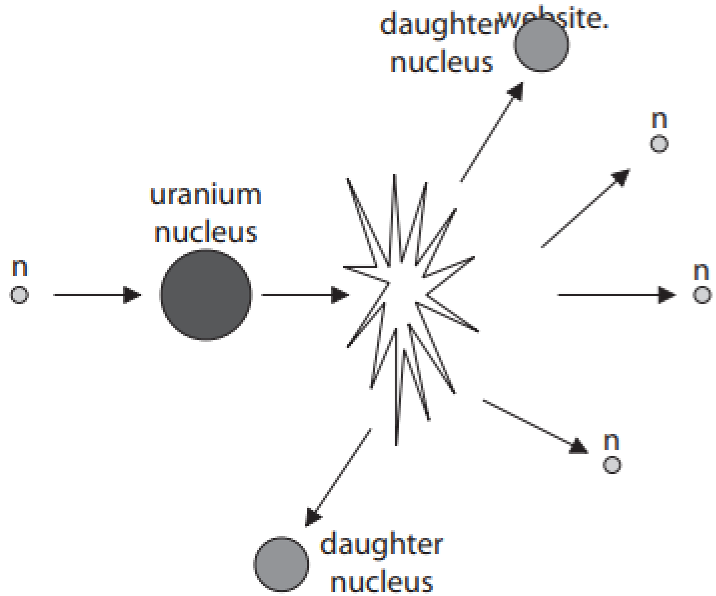
part of reactor	main function
control rod	controls the rate of fission
coolant	absorbs dangerous radiation
fuel rod	contains uranium for fission
shielding	removes energy from the reactor

(b) State the type of energy released in a fission reaction.

(c) Explain the role of the moderator in a fission reaction

(d) Explain, in terms of neutrons, what is meant by controlled nuclear fission.

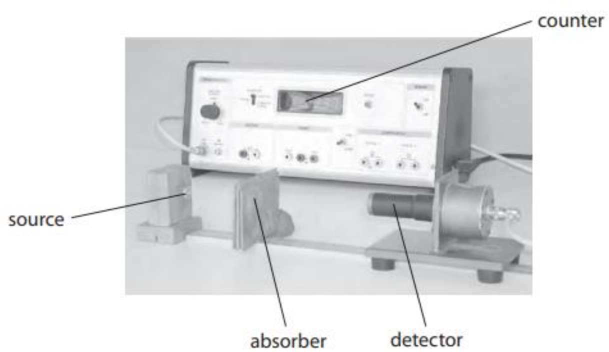
2) A student finds this representation of nuclear fission on a website



a) Describe what happens when nuclear fission of uranium occurs

(b) The daughter nuclei move off with high speed. Name the type of energy that this gives them.

(3). A teacher uses this apparatus to demonstrate radioactivity to his students.



(a) The teacher needs to take some safety precautions. Put one tick on each row to show whether the safety precaution is needed or not. Two have been done for you.

safety precaution	needed	not needed
not touch the source with bare hands	✓	
use tongs		
wear gloves		✓
wear goggles		
students sit at least two metres away		
wear a lead apron		
store source in a lead box		

(b) The teacher uses this method to investigate radioactivity.

- place the detector 10 cm from the radioactive source

- record the count with different absorbent materials between the source and the detector
- repeat the investigation using a different radioactive source
- also repeat the investigation without a source The table shows his results.

Source used	**Counts in 30 s for each material**					
	5 mm of aluminium	**5 mm of lead**	**0.2 mm of paper**	**5 mm of plastic**	**5 mm of stone**	**5 mm of wood**
barium-133	3 843	1 989	not taken	4 551	10 408	4 557
strontium-90	14	15	42 770	182	13	331
none	15	15	14	15	14	15

(i) State why the teacher keeps the distance constant between the source and the detector.
(ii) Explain why there is a reading when no source is used
(iii) Explain which of the materials the teacher used is the best absorber of radiation.
(iv) A student makes this conclusion

'Stone is the worst absorber of radiation.'

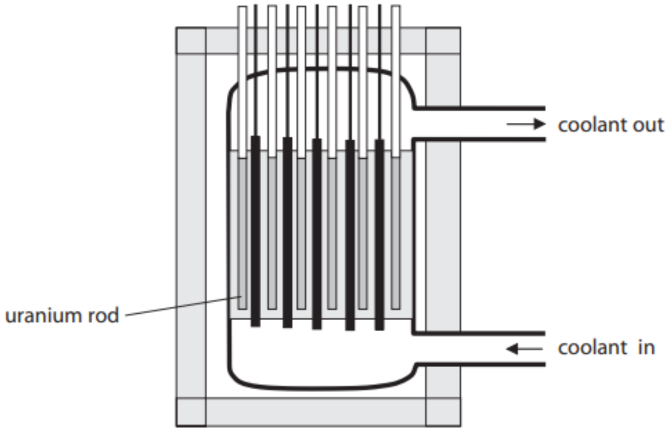
Evaluate this conclusion
(v) Explain what type of radiation strontium-90 emits
(vi) Suggest why the teacher does not take a reading for barium-133 and paper.
(vii) Barium-133 and strontium-90 both have a half-life of over 10 years. Suggest why isotopes with a much shorter half-life are not suitable for this investigation.

(4) Sodium-24 is a radioactive isotope. (a) What are isotopes?
(b) Sodium-24 decays by emitting beta particles.
(i) Describe the nature of a beta particle.
(ii) Name a piece of equipment that can be used to detect beta particles
(iii) Describe how a detector can be used with sheets of lead, aluminium and paper to show that a sample of sodium-24 emits beta particles
(c) Granite is a rock. It contains a radioactive isotope of uranium that decays very slowly.
(i) Explain how scientists can use this radioactivity to find the age of a piece of granite
(ii) Suggest why the age of a piece of granite could not be found using a uranium isotope with a half-life of 15 hours.

(5) In a nuclear reactor, a uranium-235 nucleus absorbs a neutron and fission occurs.
(a) Complete the equation below that shows a typical fission reaction.

$$ {}^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{142}_{\square}\mathrm{Ba} + {}^{\square}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} $$

(b) Explain how nuclear fission can lead to a chain reaction.
(c) The diagram shows a nuclear reactor.



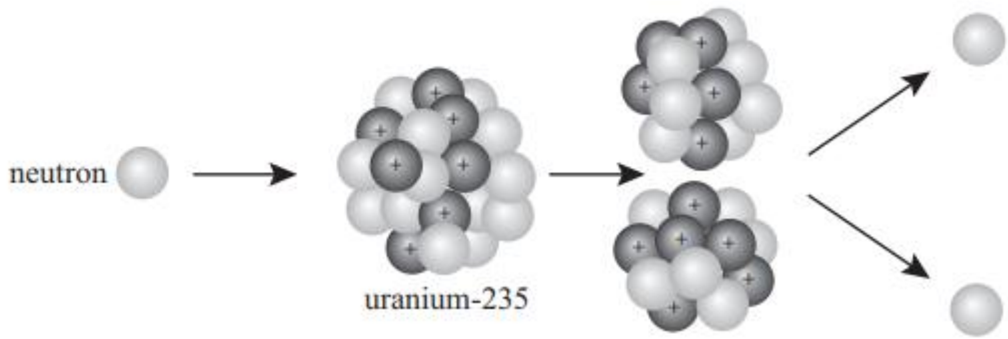
(i) On the diagram, label the control rods and the shielding.
(ii) Explain why the shielding is needed

(6) A scientist placed a radioactive source in front of a Geiger-Muller detector and measured the count rate every 20 minutes. The table shows her data

Time in minutes	Count rate in counts per minute	Corrected count rate in counts per minute
0	660	630
20	462	432
40	330	300
60	240	210
80	180	150
100	142	112

(a) The scientist corrects the count rate readings to allow for background radiation.
(i) State two sources of background radiation
(ii) Describe how the scientist should measure the background radiation and correct the count rate readings
(b) The radioactive nuclei in the source emit beta radiation.
What effect does the emission of a beta particle have on a nucleus?
(c) The scientist needs to reduce the risks when working with radioactive sources.
(i) Explain why radioactive sources can be dangerous
(ii) Describe how the risks of working with radioactive sources can be reduced.

(7) The diagram shows a neutron colliding with a nucleus of uranium-235, producing several products
(a) Name the process shown in the diagram
(b) Explain how the process shown in the diagram can lead to a chain reaction.
(c) This process releases energy. Explain the form that this energy takes

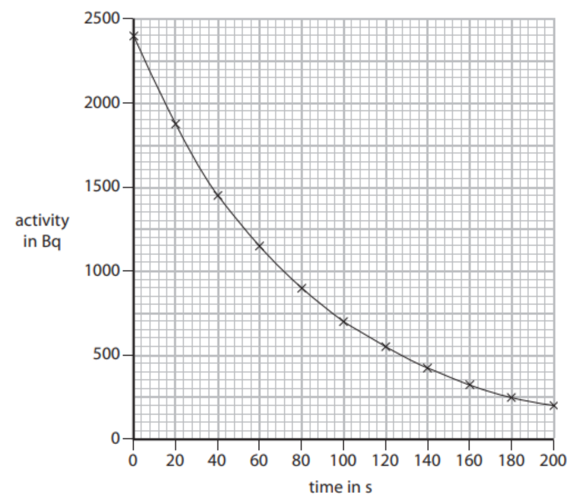


(8) A teacher investigates the half-life of a radioactive isotope that decays quickly.

(a) The teacher measures the background activity. Explain how this value should be used in the investigation.

(b) Explain what is meant by the term half-life.

(c) The graph shows how the activity of a sample of the radioactive isotope changes with time.



(i) Use the graph to find the half-life of the isotope

ii) The teacher takes a new reading every 20 s. Suggest why the teacher measures the activity so frequently.

(9) An unstable isotope of strontium has a half-life of 28.8 years. It is a beta emitter and can be represented by this symbol

$$^{90}_{38}\text{Sr}$$

(a) (i) What is the mass number of this isotope?

(ii) Explain the meaning of the term half-life

(iii) A person can absorb strontium atoms, which stay in their bones. Explain why strontium-90 in the bones a serious health hazard is.

(b) When a strontium-90 nucleus emits a beta particle, it decays to form yttrium-90. (i) Complete the equation for this decay

$$^{90}_{38}\text{Sr} \rightarrow \, ^{\square}_{39}\text{Y} + \, ^{\square}_{\square}\beta^-$$

(ii) Yttrium-90 is also an unstable isotope. Explain why strontium-90 and yttrium-90 can both be described as isotopes, even though they have different numbers of protons.