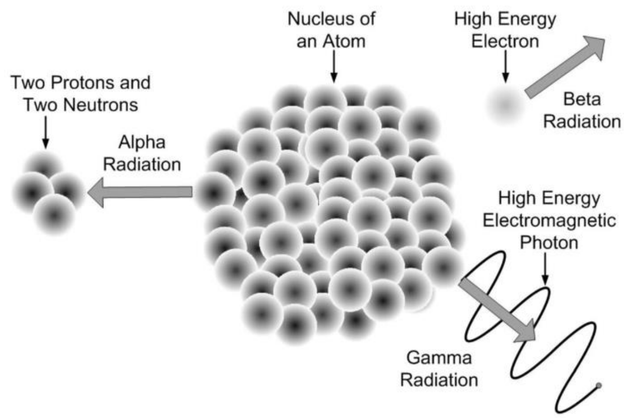
UNIT 10

RADIOACTIVITY AND NUCLEAR CHEMISTRY

teacher version



www.toppr.com

Contents

(a) Types of Radiation
(b) Properties of Radiation
(c) Dangers of Radiation
(d) Rates of radioactive decay
(e) Nuclear reactions and nuclear energy
(f) Applications of radioactivity

Key words: radioactive, radioactivity, radioactive decay, alpha particle, beta particle, gamma ray, nuclear reaction, nuclear equation, penetrating power, ionising power, Geiger-Muller tube, half-life, nuclear fission, nuclear fusion, nuclear power, atom bomb, hydrogen bomb, carbon-dating, tracers

Units which must be completed before this unit can be attempted:
Unit 1 – Atomic Structure and the Periodic Table
Unit 4 – Introduction to Physical Chemistry

Estimated Teaching Time: 4 hours

Lesson 1 – What is radioactivity?

(a) Types of Radiation

Summary Activity 1.1: What is a nucleus made of?

- Define the terms “atomic number”, “mass number” and “isotopes”
- Describe the main features of a proton, neutron and an electron
- Explain what is meant by the term “nucleon”
- Write the symbol for a nucleus with 8 protons and 10 neutrons; include the atomic number and mass number in the symbol
- Deduce the number of protons and neutrons present in $^{56}_{26}\mathrm{Fe}$
- What is meant by the term “ionisation”?

- number of protons, sum of number of protons and number of neutrons, atoms with the same atomic number but different mass numbers
- proton has mass 1 and charge 1; neutron has mass 1 and charge 0; electron has mass 0 and charge -1
- particle in the nucleus (ie proton or neutron)
- $^{18}_{8}\mathrm{O}$
- 26 protons, 30 neutrons
- Forming ions from atoms, usually by taking away electrons

- The mass of protons and neutrons changes depending on which nucleus they are in; protons and neutrons bonded together in nuclei always have a lower mass than free protons and free neutrons; when protons and neutrons bind together, the potential energy of the nucleus decreases and this results in a loss in mass; by measuring the exact mass of a nucleus it possible to calculate the “binding energy”; ie the lowering of potential energy resulting from the attraction between protons and neutrons in the nucleus; the greater the binding energy per nucleon, the more stable the nucleus

- Some nuclei have a low binding energy per nucleon and these nuclei are not stable; the stability of a nucleus depends on the balance between the number of protons and neutrons in the nucleus; nuclei with too many protons or too many neutrons are unstable; these nuclei will emit particles from their nucleus in order to become more stable; the spontaneous emission of particles from the nucleus of an atom is known as **radioactivity or radioactive decay**; atoms which emit particles from their nucleus are said to be **radioactive**

- Most elements have isotopes; in many cases one or more of these isotopes is radioactive, whilst others are not radioactive; for this reason, it is usual to refer to individual isotopes when describing radioactivity

  eg cobalt-60 is radioactive but cobalt-59 is not

UNIT 10 – RADIOACTIVITY AND NUCLEAR CHEMISTRY

- Generally, radioactive atoms will emit one of two different types of particle:

  - **alpha-particles (α-particles)** consist of two protons and two neutrons; α-particles therefore have a mass number of 4 and a charge of +2; they are identical to the nucleus of a typical He atom; they are therefore given the symbol ${}^{4}_{2}\mathrm{He}$ or ${}^{4}_{2}\alpha$; the superscript 4 denotes the mass number of the particle and the subscript 2 indicates the charge on the particle
  - α-particles are emitted when a nucleus has too many protons to be stable; after an α-particle has been emitted, the new nucleus has two protons and two neutrons fewer than it did before; it is therefore an atom of a different element; this change can be written in the form of a **nuclear equation:**

    eg: ${}^{232}_{90}\mathrm{Th} \rightarrow {}^{228}_{88}\mathrm{Ra} + {}^{4}_{2}\alpha$ ^{232}Th emits an α-particle and becomes ^{228}Ra

    eg ${}^{224}_{88}\mathrm{Ra} \rightarrow {}^{220}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$ ^{224}Ra emits an α-particle and becomes ^{220}Rn

  - **beta-particles (β-particles)** consist of a high-energy electron; β-particles have a mass number of 0 and a charge of -1; they are therefore given the symbol ${}^{0}_{-1}\mathrm{e}$ or ${}^{0}_{-1}\beta$; an electron is emitted when a neutron changes into a proton and an electron; the proton remains in the nucleus but the electron is emitted: ${}^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\mathrm{e}$
  - β-particles are emitted when a nucleus has too many neutrons to be stable; after a β-particle has been emitted, the new nucleus has one proton more and one neutron fewer than it did before; it is therefore an atom of a different element; this change can also be written in the form of a nuclear equation:

    eg: ${}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}\beta$ ^{60}Co emits a β-particle and becomes ^{60}Ni

    eg ${}^{214}_{82}\mathrm{Pb} \rightarrow {}^{214}_{83}\mathrm{Bi} + {}^{0}_{-1}\beta$ ^{214}Pb emits a β-particle and becomes ^{214}Bi

- The emission of an α-particle or a β-particle from a nucleus is an example of a **nuclear reaction**; a nuclear reaction results in the change in the composition of a nucleus and therefore result in the formation of new atoms with different atomic numbers; chemical reactions, by contrast, no not change the composition of a nucleus – they only involve the rearrangement of the electrons in orbitals and therefore do not result in the formation of new atoms

- For this reason, nuclear equations always include atomic numbers and mass numbers of every particle, as they change during the reaction; chemical reactions do not usually include atomic numbers and mass numbers as these do not change during chemical reactions; mass numbers are shown as a superscript before the atomic symbol and atomic numbers are shown as a subscript before the atomic symbol:

  Eg ${}^{60}_{27}\mathrm{Co}$ this is cobalt-60; cobalt atoms have 27 protons

- In nuclear equations, the sum of the mass numbers of the reactants must equal the sum of the mass numbers of the products, and the sum of the atomic numbers of the reactants must equal the sum of the atomic numbers of the products:

  Eg ${}^{232}_{90}\mathrm{Th} \rightarrow {}^{228}_{88}\mathrm{Ra} + {}^{4}_{2}\alpha$ (sum of mass numbers = 232; sum of atomic numbers = 90)

- The emission of an α or β-particle often results in a much more stable nucleus with a much lower potential energy; the potential energy is converted into a high-energy photon of electromagnetic radiation known as a **gamma ray** (γ-ray); γ-rays are only emitted at the same time as α or β-particles; they have no charge and no mass and they do not themselves change the composition of the nucleus

- α-particles, β-particles and γ-rays are collectively known as "nuclear radiation"; many radioactive isotopes occur naturally; radiation emitted from naturally occurring isotopes is known as "natural radiation"

Test your knowledge 1.2: Describing radiation and radioactivity

(a) Describe an alpha particle; explain what happens to a nucleus after it emits an alpha particle
(b) Describe a beta particle; explain what happens to a nucleus after it emits a beta particle
(c) Explain why gamma rays are sometimes emitted at the same time as an alpha or beta particle
(d) Write a balanced nuclear equation to show:
  (i) the emission of an alpha particle from thorium-228
  (ii) the emission of a beta particle from oxygen-19

(a) two protons and two neutrons; atomic number decreases by 2 and mass number decreases by 4
(b) an electron emitted from the nucleus; atomic number increases by 1
(c) emission of alpha and beta particles reduce potential energy of nucleus; excess energy is emitted as a gamma ray
(d) (i) ${}^{228}_{90}\mathrm{Th} \rightarrow {}^{224}_{88}\mathrm{Ra} + {}^{4}_{2}\alpha$; (ii) ${}^{19}_{8}\mathrm{O} \rightarrow {}^{19}_{9}\mathrm{F} + {}^{0}_{-1}\beta$

Lesson 2 – What are the main features of radiation and radioactivity?

(b) Properties of Radiation

- α-particles collide easily with other particles, pulling electrons away from them until the α-particle has gained two electrons and become a stable helium atom; as a result α-particles are very strongly ionising – any particles they hit are likely to lose electrons and become ionised; because of this, α-particles are very quickly destroyed; they generally travel no further than 4 cm in air and are easily stopped by a thin piece of paper

- β-particles are much smaller and so collide less easily with other particles; when they do collide with other particles, they transfer energy to them and this can result in other electrons being lost from that atom; as a result β-particles are also ionising, although much less so than α-particles; eventually the β-particle will slow down and be absorbed into the electron shells of another atom; β-particles have more penetrating power than α-particles; they can travel a long distance through air and can pass through paper but can be stopped by a thin sheet of metal

- γ-rays have no charge and no mass; they therefore do not cause ionisation in other particles and often pass through them completely without being absorbed; as a result γ-rays have a very low ionising power but a very high penetrating power; they cannot be completely stopped and a few centimetres of lead or several metres of concrete is needed to significantly reduce their concentration

Type of radiation	A	B	γ
penetrating power	Low – stopped by 4 cm of air or a piece of paper	Medium – stopped by a thin sheet of metal	High – intensity reduced by a few centimetres of lead or a few metres of concrete
Ionising power	High	Medium	Low

- The ionising properties of radiation mean that it can be detected by a piece of equipment known as a **Geiger-Muller tube**; this contains gaseous particles which become ionised by the radiation, creating a current which can be detected; each radioactive particle or ray produces one pulse; the total concentration of radiation in a particular location can be measured from the number of pulses per second; a Geiger-Muller tube does not distinguish between alpha, beta and gamma radiation

(c) Dangers of radiation

- All three types of radiation are high in energy and if living cells are exposed to significant quantities of radiation they can be seriously damaged; sometimes the cells are killed (they are effectively burned); sometimes the cells will mutate and become cancerous; either way, high levels of exposure to radiation can be fatal

- Exposure to low levels of radiation is not harmful and we are constantly being exposed to low levels of radiation from the air, the soil and the sun, as well as some human activity; this is not dangerous – the danger comes from exposure to unusually high levels of radiation, over a long or short period

- The relative dangers of alpha, beta and gamma radiation are directly linked to their ionizing power, their penetrating power and how the exposure takes place:
    - alpha and beta radiation is highly ionising but cannot penetrate skin; external alpha and beta radiation is therefore not considered dangerous unless it is present in large quantities and very close, in which case it will kill skin cells (burn the skin); if radioactive atoms are ingested, injected or inhaled, however, they can be very dangerous as they release ionising radiation inside the body; this can kill healthy cells or turn them into cancerous cells
    - gamma radiation is less ionising but can pass through the body; due to its low ionising power, small quantities of gamma radiation are not considered dangerous; in fact small quantities of gamma radiation can come from space and is emitted by rocks, soil and as a result of human activity (this is known as background radiation; large quantities of gamma radiation can be dangerous wherever it is; you can be harmed or killed by gamma radiation without inhaling, injecting or ingesting radioactive material

Test your knowledge 2.1: Describing the properties and dangers of radiation

(a) State, with a reason, which type of radiation is the most ionising and which type is the least ionising
(b) State, with a reason, which type of radiation is the most penetrating and which type is the least penetrating
(c) Describe two ways in which exposure to excessive radiation can be harmful to living cells
(d) Explain why gamma-rays are generally considered more dangerous than alpha or beta particles
(e) State the circumstances under which alpha and beta particles would be very dangerous

(a) Alpha is the most ionising – it is large and has a +2 charge; gamma is the least ionising – it has no charge
(b) Gamma is the most penetrating as it has no mass so does not collide with particles; it has no charge so is not strongly ionising; alpha is the least penetrating because it is strongly ionising and is destroyed when it ionises another particle
(c) It can kill/burn cells or cause them to mutate and become cancerous
(d) Their penetrating power means that they cannot be stopped by skin, containers or walls
(e) If they get inside the body through inhalation, ingestion or injection

(d) Rate of Radioactive Decay and Half-Life

- The rate of chemical reactions depends on various factors including temperature, pressure or concentration, surface area the presence of a catalyst (see Unit 4 – Introduction to Physical Chemistry)

- The rate at which a nucleus emits α-particles and β-particles does not depend on temperature, surface area or any catalyst; it depends only on how many radioactive atoms are present in the sample; **the rate of radioactive decay of a particular isotope is directly proportional to the number of atoms of that isotope in the sample and does not depend on any other factors**

- As a result of this, the time taken for half of a sample radioactive isotope to decay is fixed for every radioactive isotope; it does not even depend on the number of atoms of that isotope present; the time taken for half of the atoms to decay is called the **half-life** of that isotope; the half-life of radioactive isotopes can vary from fractions of a second to millions of years

  Eg ^{90}Kr has a half-life of 33 s
  Eg ^{108}Ag has a half-life of 2.4 min
  Eg ^{131}I has a half-life of 8 days
  Eg ^{238}U has a half-life of 160,000 years

- After one half-life, 50% of a sample will have decayed and 50% will be remaining; after two half-lives, 75% of a sample will have decayed and 25% will be remaining; after three half-lives, 87.5% of a sample (7/8^{ths})will have decayed and 12.5% (1/8th) will be remaining

Example:	cobalt-60 has a half-life of 5.3 years; starting with 1000 atoms of cobalt-60, how many atoms will have decayed after 10.6 years and how many will remain?
Answer:	10.6 years = 10.6/5.3 = 2 half-lives, so 75% will have decayed (750) and 25% will be remaining (250)

Example:	A sample contains 400 atoms of carbon-14; 17,190 years later, only 50 atoms of carbon-14 remain; what is the half-life of carbon-14?
Answer:	50/400 = 1/8; this is three half-lives so one half-life = 17190/3 = 5730 years

- The more stable a nucleus, the longer its half-life; the less stable a nucleus, the shorter its half-life; nuclei which are completely stable (ie non-radioactive) do not have a half-life (they have an infinite lifetime)

- Radioactive isotopes with a long half-life are considered more of an environmental hazard than those with a short half-life, as they remain active in the environment for a much longer time

Test your knowledge 2.2: Using half-lives

(a) Define the term "half-life"
(b) ^{108}Ag has a half-life of 2.4 minutes; calculate the percentage of a sample of ^{108}Ag which will have decayed after 7.2 minutes
(c) It is found that the activity of a sample of ^{212}Bi falls to 25% of its original value after 121 minutes; calculate the half-life of ^{90}K
(d) Calculate the time it will take for the activity of a sample of ^{131}I, which has a half-life of 8 days, to form to 12.5% of its original value

(a) The time taken for the amount or activity of a sample to fall to half of its original value
(b) 7.2 mins = 3 half-lives so 87.5% decayed
(c) 121 mins = 2 half-lives so half-life = 60.5 mins
(d) 12.5% of value = 3 half-lives = 24 days

Lesson 3 - How can radioactivity and nuclear reactions be useful?

(e) Nuclear reactions and nuclear energy

- The emission of an α-particle or a β-particle from a nucleus (known as radioactive decay) is just one example of a **nuclear reaction**; there are two other important types of nuclear reaction:

(i) nuclear fission

- Nuclear fission is the break-up of a large nucleus to form two or more smaller nuclei; it does not occur spontaneously and only happens when a nucleus is bombarded with a neutron:
  Eg $^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{141}_{56}\mathrm{Ba} + ^{92}_{36}\mathrm{Kr} + 3^{1}_{0}\mathrm{n}$

- The two smaller nuclei are usually more stable than the original large nucleus, so a lot of heat energy and gamma rays are released during nuclear fission; in addition, the neutrons produced can collide with more ^{235}U atoms and cause further fission, starting a **nuclear chain reaction**

- Most nuclear fission reactions are man-made and the products are often radioactive isotopes; radiation emitted from isotopes produced by man-made nuclear reactions is called "artificial radiation"

- Nuclear fission is carried out in **nuclear reactors** to produce **nuclear energy**:
  - most nuclear reactors use ^{235}U; this is present in small quantities in naturally-occurring uranium; uranium needs to be "enriched", which means increasing the amount of ^{235}U, before it is used in nuclear reactors
  - the ^{235}U atoms are bombarded with neutrons and break up (ie they undergo nuclear fission); the process produces a large amount of heat as well as extra neutrons
  - the heat is used to boil water, which is used to drive a turbine which powers a generator and produces electricity
  - the reaction must be carefully controlled to prevent a chain reaction taking place which will cause the reactor to overheat and explode; boron rods are inserted into the reactor to absorb neutrons and control the speed of the reaction

- An **atom bomb** is a device which releases a large amount of energy very quickly as a result of a nuclear fission reaction, causing an explosion; usually plutonium-239 or uranium-235 is used and the reaction is started by firing neutrons at the sample; because nuclear fission produces radioactive isotopes as products, atom bombs can leave behind radioactive material long after they have exploded

(ii) nuclear fusion

- Nuclear fusion is the joining together of two smaller nuclei to form a single, larger nucleus:

  Eg $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n}$

- The larger nucleus is usually more stable than the two smaller nuclei, and so a lot of heat energy and gamma rays are released during nuclear fusion

- Nuclear fusion takes place naturally in the sun – especially the fusion of hydrogen into helium; nuclear fusion reactions are the source of the sun's energy; it is not currently possible to produce energy commercially using nuclear fusion reactions because very high temperatures are needed

- Nuclear fusion does not generally produce radioactive products; as a result it is considered much safer than nuclear fission

- A **hydrogen bomb** is a device which releases a large amount of energy very quickly as a result of the nuclear fusion of hydrogen atoms; due to the large amount of energy required to start nuclear fusion, a nuclear fission reaction is used to create the heat necessary for the nuclear fusion reaction to start

Test your knowledge 3.1: Understanding nuclear fission and nuclear fusion

(a) Explain the meaning of the term "nuclear fission"; in one nuclear fission reaction, uranium-235 breaks up to give barium-139, one other nucleus and two neutrons; identify the other nucleus and write a nuclear equation for the reaction

(b) Explain the meaning of the term "nuclear fusion"; in one nuclear fusion reaction, two nuclei of deuterium (hydrogen-2) are combined to give one nucleus of helium-3; identify the other product and write a nuclear equation for the reaction

(c) Explain how electricity can be made from nuclear fission

(d) Explain why it is not currently possible to make electricity from nuclear fusion

(e) Explain the difference between an atom bomb and a hydrogen bomb

(a) Breaking up of a nucleus into two or more smaller nuclei; $^{235}_{92}\text{U} \rightarrow ^{139}_{56}\text{Ba} + ^{94}_{36}\text{Kr} + 2^{1}_{0}\text{n}$

(b) Joining of two or more nuclei to make a single nucleus; $^{2}_{1}\text{H} + ^{2}_{1}\text{H} \rightarrow ^{3}_{2}\text{He} + ^{1}_{0}\text{n}$

(c) Heat released when nucleus breaks up; this boils water which drives a turbine which drives a generator

(d) Very high temperature needed to start the reaction

(e) Atom bomb – energy released as a result of nuclear fission; hydrogen bomb - most energy released as a result of nuclear fusion

(f) Applications of Radioactivity

- Although the radiation emitted by radioactive atoms can be dangerous, it also has a number of useful applications:

(i) carbon-dating

- Naturally occurring carbon exists as three isotopes; most carbon atoms are either carbon-12 or carbon-13, neither of which are radioactive; a small proportion of carbon atoms, however, are carbon-14, which is radioactive with a half-life of 5730 years; carbon atoms in living organisms are constantly being replaced due to the carbon cycle and so the proportion of carbon existing as carbon-14 in living organisms is fairly constant

- When cells die, the carbon atoms in those cells are no longer replaced and so the amount of carbon-14 in those cells gradually decreases over time as the carbon-14 decays
  5730 years after death, the % of carbon-14 in tissue is 50% of that in living tissue
  11460 years after death, the % of carbon-14 in tissue is 25% of that in living tissue
  17190 years after death, the % of carbon-14 in tissue is 12.5% of that in living tissue

- It is therefore possible to estimate how many years ago a sample of tissue died, and this can be used to estimate the age of fossils, skeletons and some fabrics; the technique is known as **carbon-dating**

Example:	An ancient manuscript is discovered and the carbon-14 content in its fibres is found to be 25% of that expected in living tissue; estimate the age of the manuscript
Answer:	25% is two half-lives; one half-life is 5730 years to two half-lives is 11460 years

Lesson 4 – How is radioactivity used in medicine, agriculture and industry?

(ii) tracers

- Because gamma radiation can travel through walls and earth, it is possible to track the location of gamma-emitting radioactive material by detecting the gamma rays; this is known as **tracing**

- Tracers are used in industry to locate blockages in underground or underwater pipes; a sample of radioactive material is inserted into the pipe and its progress is followed by tracking the radiation it emits; radiation will accumulate at a blockage and disperse at a leak; this can be used by engineers to find leaks and blockages without opening up the entire pipe

- Tracers are used in agriculture to monitor how and how fast plants are able to absorb certain nutrients from the soil; plants absorb water and other elements from the soil; if radioactive isotopes of these elements are placed in the soil, their rate of absorption can be measured by how much radioactivity is detected in the plant; the precise location of the radioactivity can identify how and why the plant absorbs those nutrients

- Tracers are used in medicine to monitor the digestive system, respiratory system or circulatory system; radioactive material can be inhaled, ingested or injected and its progress through the body can be monitored

- Cancer cells also absorb certain atoms (for example thyroid cancer absorbs iodine) so radioactive iodine will concentrate in the cancerous area, allowing the cancer to be located

(iii) treating cancer

- Exposure to large quantities of radiation is known to kill cells or cause them to mutate and become cancerous; radiation can also be used to kill cancerous cells; cancerous cells are more easily killed by radiation than healthy cells and so a targeted dose of radiation can kill cancerous cells without harming healthy cells

- Gamma radiation can be applied externally; the gamma rays can be pointed directly at the cancerous cells from a range of different angles to stop the same healthy cells from receiving too much radiation

- If the cancer absorbs certain atoms, then alpha or beta-emitting radioactive isotopes of those atoms can be ingested or injected; they will accumulate in the cancerous area and emit radiation, hopefully killing the cancerous cells (eg iodine-131 is used to locate and treat thyroid cancer

Test your knowledge 4.1: Using radioactivity

(a) Carbon-14 has a half-life of 5730 years; a fossil was tested for carbon-14 and found to contain 6.25% of the amount of carbon-14 expected in living matter; calculate the age of the fossil
(b) Give an example of the use of radioactive tracers in (i) agriculture; (ii) industry; (iii) medicine
(c) Explain how gamma rays can be used to treat cancer

(a) 6.25% is four half-lives, so fossil is 5730 x 4 = 22920 years old
(b) Monitoring how fast plants take up certain nutrients; identifying blockages and leaks in underground pipes; locating blockages in digestive or circulatory system
(c) They are directed at the cancer externally using lots of different angles; cancer cells are more easily killed by radiation than healthy cells

4.2 END-OF-UNIT QUIZ
UNIT 10 – RADIOACTIVITY AND NUCLEAR CHEMISTRY

1. Explain why gamma rays are more penetrating than alpha and beta particles and explain how this makes them more dangerous
2. Write a nuclear equation to show the emission of:
   (i) an alpha particle from bismuth-210
   (ii) a beta particle from sodium-24
3. Carbon-14 has a half-life of 5730 years; estimate the age of a fossil which contains 12.5% of the carbon-14 content of living tissue
4. Uranium-235 can undergo fission to produce caesium-144 and rubidium-90; deduce the number of neutrons released and write a nuclear equation for the reaction
5. Describe how the sun obtains its energy
6. Describe how iodine-131 can be used to detect and treat thyroid cancer

UNIT 10 – RADIOACTIVITY AND NUCLEAR CHEMISTRY

1. They have no mass or charge so do not interact with other materials; as a result it is very difficult to protect oneself against them
2. (i) ${}^{210}_{83}\mathrm{Bi} \rightarrow {}^{206}_{81}\mathrm{Tl} + {}^{4}_{2}\alpha$; (ii) ${}^{24}_{11}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}\beta$
3. 12.5% is three half-lives so age = 5730 x 3 = 17190 years
4. ${}^{235}_{92}\mathrm{U} \rightarrow {}^{144}_{55}\mathrm{Cs} + {}^{90}_{37}\mathrm{Rb} + {}^{1}_{0}\mathrm{n}$ (1 neutron released)
5. From nuclear fusion; the sun fuses hydrogen into helium; eg ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$
6. Detection: use iodine-131 as a tracer; it is absorbed by thyroid cancers, when absorbed the gamma radiation it emits can be detected, making it possible to identify and locate a tumour; if injected into the tumour it can release alpha radiation into the tumour which will help kill it