AQA Physics – Atomic Structure Journey of Knowledge Part 1

Context and introduction to the unit: Ionising radiation is hazardous but can be very useful. Although radioactivity was discovered over a century ago, it took many nuclear physicists several decades to understand the structure of atoms, nuclear forces and stability. Early researchers suffered from their exposure to ionising radiation. Rules for radiological protection were first introduced in the 1930s and subsequently improved. Today radioactive materials are widely used in medicine, industry, agriculture and electrical power generation.

KS3: Yr. 7: Atoms, Elements, Compounds and Mixtures – Structure of the atom. Bonding of atoms. Forces – Electrostatic force. Particle Model – Internal energy of atoms. Cells – are made from atoms. Yr. 8: Electricity – revisits atomic structure and movement of electrons, Periodic Table – Atomic number and atomic mass.

CORE KNOWLEDGE

6.4.1.1 The structure of an atom

Atoms are very small, having a radius of about 1×10^{-10} metres. The basic structure of an atom is a positively charged nucleus composed of both protons and neutrons surrounded by negatively charged electrons. The radius of a nucleus is less than 1/10 000 of the radius of an atom. Most of the mass of an atom is concentrated in the nucleus. The electrons are arranged at different distances from the nucleus (different energy levels). The electron arrangements may change with the absorption of electromagnetic radiation (move further from the nucleus; a higher energy level) or by the emission of electromagnetic radiation (move closer to the nucleus; a lower energy level).

6.4.1.2 Mass number, atomic number and isotopes

In an atom the number of electrons is equal to the number of protons in the nucleus. Atoms have no overall electrical charge. All atoms of a particular element have the same number of protons. The number of protons in an atom of an element is called its atomic number. The total number of protons and neutrons in an atom is called its mass number. Atoms can be represented as shown in this example: (Mass number) (Atomic number) $^{23}_{11}Na$

Atoms of the same element can have different numbers of neutrons; these atoms are called isotopes of that element. Atoms turn into positive ions if they lose one or more outer electron(s). Students should be able to relate differences between isotopes to differences in conventional representations of their identities, charges and masses.

6.4.1.3 The development of the model of the atom (common content with chemistry)

New experimental evidence may lead to a scientific model being changed or replaced. Before the discovery of the electron, atoms were thought to be tiny spheres that could not be divided. The discovery of the electron led to the plum pudding model of the atom. The plum pudding model suggested that the atom is a ball of positive charge with negative electrons embedded in it. The results from the alpha particle scattering experiment led to the conclusion that the mass of an atom was concentrated at the centre (nucleus) and that the nucleus was charged. This nuclear model replaced the plum pudding model. Niels Bohr adapted the nuclear model by suggesting that electrons orbit the nucleus at specific distances. The theoretical calculations of Bohr agreed with experimental observations. Later experiments led to the idea that the positive charge of any nucleus could be subdivided into a whole number of smaller particles, each particle having the same amount of positive charge. The name proton was given to these particles. The experimental work of James Chadwick provided the evidence to show the existence of neutrons within the nucleus. This was about 20 years after the nucleus became an accepted scientific idea.

6.4.2.1 Radioactive decay and nuclear radiation

Some atomic nuclei are unstable. The nucleus gives out radiation as it changes to become more stable. This is a random process called radioactive decay. Activity is the rate at which a source of unstable nuclei decays. Activity is measured in becquerel (Bq). Count-rate is the number of decays recorded each second by a detector (e.g. Geiger-Muller tube). The nuclear radiation emitted may be: • an alpha particle (α) – this consists of two neutrons and two protons; it is the same as a helium nucleus • a beta particle (β) – a high speed electron ejected from the nucleus as a neutron turns into a proton • a gamma ray (γ) – electromagnetic radiation from the nucleus • a neutron (n).

Alpha α – penetrates skin/paper. High ionising power. <5 cm range in air.

Beta β – penetrates 3mm aluminium foil. Low ionising power. ≈ 1 m range in air.

Gamma γ – penetrates lead/concrete. Very low ionising power. > 1 km range in air.

Disciplinary knowledge

WS 1.1, 1.2,1.4, 1.5, 1.6, 4.1, 4.4

Vocabulary

Activity, alpha particle, becquerel, beta particle, Bohr model, count rate, half-life, ion, isotope, irradiation, radioactive contamination.

Reading is Power

Where next?

Electricity (part 1)

AQA Physics – Atomic Structure Journey of Knowledge Part 2

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CORE KNOWLEDGE

6.4.2.2 Nuclear equations

Nuclear equations are used to represent radioactive decay.
In a nuclear equation an alpha particle may be represented by the symbol: ${}^{4}_{2}He$ and a beta particle by the symbol: ${}^{0}_{-1}e$.
The emission of the different types of nuclear radiation may cause a change in the mass and /or the charge of the nucleus.
For example: ${}^{219}_{86}\text{radon} \rightarrow {}^{215}_{84}\text{polonium} + {}^{4}_{2}\text{He}$ So alpha decay causes both the mass and charge of the nucleus to decrease: ${}^{14}_{6}\text{carbon} \rightarrow {}^{14}_{7}\text{nitrogen} + {}^{0}_{-1}\text{e}$
So, beta decay does not cause the mass of the nucleus to change but does cause the charge of the nucleus to increase. The emission of a gamma ray does not cause the mass or the charge of the nucleus to change.

6.4.2.3 Half-lives and the random nature of radioactive decay

Radioactive decay is random. The half-life of a radioactive isotope is the time it takes for the number of nuclei of the isotope in a sample to halve, or the time it takes for the count rate (or activity) from a sample containing the isotope to fall to half its initial level. Students should be able to explain the concept of half-life and how it is related to the random nature of radioactive decay. Students should be able to determine the half-life of a radioactive isotope from given information.
(HT only) Calculate the net decline, expressed as a ratio, in a radioactive emission after a given number of half-lives.

6.4.2.4 Radioactive contamination

Radioactive contamination is the unwanted presence of materials containing radioactive atoms on other materials. The hazard from contamination is due to the decay of the contaminating atoms. The type of radiation emitted affects the level of hazard. Irradiation is the process of exposing an object to nuclear radiation. The irradiated object does not become radioactive.
Compare the hazards associated with contamination and irradiation: Irradiation and contamination both are hazardous to the human body. When the body is exposed to either form of radiation, cells can change their behaviour, be damaged or completely destroyed.

Eyes	High doses can cause cataracts.
Thyroid	Radioactive iodine can build up and cause cancer, particularly during growth.
Lungs	Breathing in radioisotopes can damage DNA.
Stomach	Radioactive isotopes can sit in the stomach and irradiate for a long time.
Reproductive organs	High doses can cause sterility or mutations.
Skin	Radiation can burn skin or cause cancer.
Bone marrow	Radiation can cause leukaemia and other diseases of the blood.

Suitable precautions must be taken to protect against any hazard that the radioactive source used in the process of irradiation may present.
It is important for the findings of studies into the effects of radiation on humans to be published and shared with other scientists so that the findings can be checked by peer review.

Disciplinary knowledge
WS 1.1, 1.2,1.4, 1.5, 1.6, 4.1, 4.4

Vocabulary
Activity, alpha particle, becquerel, beta particle, Bohr model, count rate, half-life, ion, isotope, irradiation, radioactive contamination.

Reading is Power

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AQA Physics – Atomic Structure Journey of Knowledge Part 3 SEPS Only

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CORE KNOWLEDGE

4.4.3 Hazards and uses of radioactive emissions and of background radiation

4.4.3.1 Background radiation (Physics only)

Background radiation is around us all of the time. It comes from: • natural sources such as rocks and cosmic rays from space • man-made sources such as the fallout from nuclear weapons testing and nuclear accidents. The level of background radiation and radiation dose may be affected by occupation and/or location.
Radiation dose is measured in sieverts (Sv) 1000 millisieverts (mSv) = 1 sievert (Sv)

4.4.3.2 Different half-lives of radioactive isotopes (Physics only)

Radioactive isotopes have a very wide range of half-life values. Explain why the hazards associated with radioactive material differ according to the half-life involved. Sources with longer half-lives remain radioactive for longer periods of time and so this means that there is a greater hazard posed. This is because longer exposure to a radioactive substance increases the risk of causing damage to, or destroying, cells.

4.4.3.3 Uses of nuclear radiation (Physics only)

Nuclear radiations are used in medicine for the: • exploration of internal organs • control or destruction of unwanted tissue.
Injected radioactive sources (such as technetium-99) can be used as tracers to make soft tissues, such as blood vessels or the kidneys, show up through medical imaging processes. An isotope emits gamma rays that easily pass through the body to a detector outside the body, for example an x-ray machine or a 'gamma camera'. In this way, the radioactive isotope can be followed as it flows through a particular process in the body. Changes in the amount of gamma emitted from different parts would indicate how well the isotopes are flowing, or if there is a blockage. In medical applications that involve injecting radioactive sources, efforts are made to ensure that contamination does not cause any long-term effects. This is done by choosing isotopes that: have very short half-lives (sources used typically have half-lives of hours so after a couple of days there will hardly be any radioactive material left in a person's body) or are not poisonous.

4.4.4.1 Nuclear fission (Physics only)

Nuclear fission is the splitting of a large and unstable nucleus (e.g. uranium or plutonium). Spontaneous fission is rare. Usually, for fission to occur the unstable nucleus must first absorb a neutron. The nucleus undergoing fission splits into two smaller nuclei, roughly equal in size, and emits two or three neutrons plus gamma rays. Energy is released by the fission reaction. All of the fission products have kinetic energy. The neutrons may go on to start a chain reaction. The chain reaction is controlled in a nuclear reactor to control the energy released. The explosion caused by a nuclear weapon is caused by an uncontrolled chain reaction.

4.4.4.2 Nuclear fusion (Physics only)

Nuclear fusion is the joining of two light nuclei to form a heavier nucleus. In this process some of the mass may be converted into the energy of radiation.

Disciplinary knowledge

WS 1.1, 1.2,1.4, 1.5, 1.6, 4.1, 4.4

Vocabulary

Activity, alpha particle, becquerel, beta particle, Bohr model, count rate, half-life, ion, isotope, irradiation, radioactive contamination.

Reading is Power

Incredible Science
Nuclear Power

Where next?

Electricity (part 1)