UNIT 3 Atoms and Radioactivity

Recommended Prior Knowledge

Pupils will have heard about atoms and electrons but are very unlikely to have a very clear idea of what they are. It would be helpful if pupils had already encountered atoms as building-bricks in chemistry and had some conception of just how small they are. Similarly, pupils will have met electric charge in more domestic circumstances but this quantity is not properly encountered until the next unit and teachers should be aware that, for pupils, it is not necessarily a fully understood branch of the subject. Element, ionising and random are words which might well be used freely by the teacher whilst remaining something of a mystery to the pupils. The word radioactive will have been encountered mostly in negative and dangerous contexts. Furthermore, some pupils will not realise that the Sun is just an ordinary star and this ought to be stated specifically in the final sections.

Context

This unit deals with the structure of ordinary matter and as a result it presents ideas which are vital in many scientific contexts ranging from engineering and materials science to pharmacology. The ideas included will be fundamental to many other sections of the syllabus and if the numerical order of units is not followed, the first parts of this unit must be dealt with at an early stage.

Outline

The first half of this unit describes the structure of an atom and the evidence for the nuclear theory. Pupils learn about the three constituent particles which make up atoms and their arrangement within it. Terms like isotope will be explained. The second half deals with radioactivity and the properties of alpha-, beta- and gamma-radiation. The fission of large atoms and the fusion of hydrogen atoms in stars will be explained and, then, some elementary mathematics is needed for the definition of half-life and is used in calculations.

	Learning Outcomes	**Suggested Teaching Activities**	**Online Resources**	**Other resources**
27(a)	Describe the structure of the atom in terms of nucleus and electrons.	Pupils have probably heard of atoms and that there are roughly 90 different types which combine to make all substances. They have probably heard about electrons. State that these particles are small objects which carry negative charge. They are important in: ionisation (chemistry), electrostatics (unit 4), current electricity (unit 4), electrolysis (chemistry), beta-emission (26(a)) and thermionic emission (unit 10). There are electrons in all atoms.	Electrons: http://www.sciencemuseum.org.uk/on-line/electron/index.asp Atomic Structure: http://www.purchon.com/chemistry/atoms.htm	Electrons occur in: electrical conduction in gases and electrical and thermal conduction in metals (unit 5). Some of these effects are found in all substances. Electrons are fundamental particles.
27(b)	Describe how the Geiger-Marsden alpha scattering experiment provides evidence for the nuclear atom.	Describe the experiment. Three possible results: (1) Nearly all alpha particles pass straight through. The atom is almost entirely empty space. (2) A few particles are deflected through noticeable angles. There is something in the foil. (3) A very few particles rebound through very large angles. There is something in the foil which is very small, very dense and repels alpha particles (positive).	Geiger-Marsden Experiment: http://www.schoolscience.co.uk/content/4/physics/particles/particlesdiscover2.html Nucleus: www.physicslab.co.uk	Emphasise the extreme inequality in the distribution of matter within the atom. ~99.95% of the mass is concentrated in ~10^{-12} % of the volume. Use a **local** comparison, e.g.

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				a pea in a local football stadium.
27(c)	Describe the composition of the nucleus in terms of protons and neutrons.	Since the electrons are negative and easy to remove (electrostatics, ionisation, thermionic emission), they must be in the outer orbits and keep atoms apart. The nucleus is the dense and positive centre of the atom. State that the nucleus is made up of positive and neutral particles of very similar mass. These are protons and neutrons.	The nuclear atom: http://www.lancs.ac.uk/ug/cooked1/rutherford.htm	The helium nucleus is four times more massive than that of hydrogen but has only twice the charge. The neutral particles keeping the two protons apart also have mass.
27(d)	Define the terms proton number (atomic number), Z and nucleon number (mass number), A.	The proton number determines the number of electrons in the neutral atom and so it determines the chemical properties of that substance. It is the atomic number. All carbon atoms have 6 protons and all atoms with 6 protons are carbon and so on. The nucleon number determines the mass of the nucleus and is sometimes called the mass number. Avoid the term "neutron number".		
27(f)	Define the term isotope.	Two atoms with the same proton number may have a different number of neutrons. They have the same chemical properties but are not identical. They are different isotopes of the same atom.	Isotopes: http://www.southwest.com.au/~jfuller/chemistry/isotopes.htm or: http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/nucnot.html	Emphasise that the proton number alone determines the chemical properties ^{12}C and ^{13}C are identical chemically (or use another example).
27(g)	Explain, using nuclide notation, how one element may have a number of isotopes.			^{12}C and ^{13}C are **both** isotopes of carbon. Use the nuclide notation here before radioactivity is mentioned.
26(k)	Describe how radioactive materials are handled, used and stored in a safe way.	Explain dangers of nuclear radiation, include: burns, sickness, biological cell damage, cancer, cell mutation. Rules include: use the minimum activity, keep your	Radioactive safety: http://www.gcse.com/radio/safety.htm	Emphasise that alpha-, beta- and gamma-radiation do not make

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		distance, and insert protective layers. It is essential to state the rules and to **obey** them.		other materials radioactive when they are absorbed.
26(a)	Describe the detection of alpha-particles, beta-particles and gamma-rays by appropriate methods.	Where possible, bring radioactive samples near to a GM tube or a spark counter. Use an old, luminous watch or altimeter or suitable rocks if educational samples are not available. Such substances are emitting something. The radiations can also be detected by a variety of devices. Only one method of detection needs to be learnt by the pupils.	Detecting Radiation: http://www.bbc.co.uk/schools/gcsebitesize/physics/radioactivity/detectingradiationrev2.shtml	State that some substances cause the exposure of nearby photographic plates – this was how radioactivity was discovered. Describe the tracks in a cloud chamber.
26(c)	State for radioactive emissions, their nature, relative ionising effects and relative penetrating powers.	Where possible use a mixed source and show that there are three types of emission which have distinct properties: (1) heavily ionising but easily absorbed, (2) less ionising but less easily absorbed, (3) weakly ionising but difficult to absorb completely.	Radiation properties: http://www.physics.isu.edu/radinf/properties.htm	Tabulate the properties of the three types of radiation. Include: • particle/wave, • charge, • mass, • ionising strength, • penetration strength, • nature, • behaviour in electric and magnetic fields.
26(d)	Describe the deflection of radioactive emissions in electric fields and magnetic fields.			
26(b)	State and explain the random emission of radioactivity in direction and time.	Measure the count-rate from a source (background radiation will do). Notice that it varies about an average value. Emphasise that whilst random events are utterly unpredictable individually, on a sufficiently large scale, the behaviour is very accurately predictable (half-life ideas	Random emission: http://www.physicsdaily.com/physics/Random or:	Life assurance works on a similar basis. Individual deaths are unpredictable but with a large enough number of

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		lead pupils to imagine that the number of atoms falls in some manner such as this: 160 → 80 → 40 → 20 → 10 → what happens now? With numbers this small, of course, the behaviour is unpredictable).	http://serc.carleton.edu/quantskills/activities/PennyDecay.html	customers, the likely number of deaths in a given time varies very little.
26(e)	Explain what is meant by radioactive decay.	Pupils should know that radioactive decay is the random emission of alpha-, beta- or gamma-radiation from unstable nuclei. The emissions are unaffected by temperature, pressure and chemical combination.	Radioactive decay: http://www.walter-fendt.de/ph11e/lawdecay.htm Radioactive series: http://www.walter-fendt.de/ph11e/decayseries.htm	Consider only two types of radioactive decay: alpha and beta. Then explain that these may occur on their own, or with gamma.
27(e)	Explain the term nuclide and use the notation $^{A}_{Z}X$ to construct equations where radioactive decay leads to changes in the composition of the nucleus.	When explaining this notation, make it clear that the element X determines what the number Z is and vice versa. E.g. if Z = 7, then X is always an N (nitrogen). The equation for the alpha decay of, say, $^{238}_{92}U$ is fairly straightforward. Emphasise that in beta emission a nuclear reaction occurs first: $n \rightarrow p^{+} + e^{-}$. Hence, the superscript and subscript, in $^{0}_{-1}e$, are present to balance the equation. A beta-particle is not made of −1 proton.	Nuclide notation: http://www.jghs.edin.sch.uk/mathscience/chemistrynotes/topic3.html	Emphasise that after the emission of an alpha- or beta-particle, the nucleus may rearrange itself and emit an electromagnetic wave (gamma-ray). No particle is emitted. Notation such as $^{0}_{0}\gamma$ confuses pupils.
26(f)1	Explain the processes of fission.	State that $^{236}_{92}U$ is explosively radioactive. Bombarding $^{235}_{92}U$ with neutrons may produce this isotope which may lead to a chain reaction. Do not explain fission and fusion together. The terms are very similar but the processes are essentially the reverse of each other.	Fission: http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/fission.html	The chain reaction can be modelled with a vertical array of horizontal matches. Light the lowest match but it is too far away from the ones above to ignite them. If a second array of matches interpenetrates the first, distances are reduced and they can all ignite from the bottom

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				upwards.
26(g)	Describe with the aid of a block diagram one type of fission reactor for use in a power station.	A nuclear power station is like a standard steam turbine station powered by coal, oil or gas. It is simply that the mechanism for boiling the water is different.	Nuclear power stations: http://www.nucleartourist.com	
26(m)	Discuss the origins and effect of background radiation.	Measure the count-rate in the laboratory. It is never zero. Two sources: • natural background radiation – rocks and space • manmade exposure – medical diagnosis (include X-rays but emphasise that they are not nuclear in origin), medical treatment, power stations, military tests, flying, travel to areas with higher levels and so on. There are small risks with all levels of exposure and the risk increases with the absorbed dose. Even the highest natural levels seem to pose few health risks.	Background radiation: http://www.darvill.clara.net/nucrad/sources.htm or: http://www.ansto.gov.au/edu/nuclear_age/nuclear_age_biol.htm	Pupils find it difficult to understand that risky procedures are used in hospitals until it is pointed out that most medical procedures involve some risk but that the treatment is less hazardous than the disease.
26(i)	Explain what is meant by the term half-life.	Quote a specific example: 1 kg of $^{238}_{92}U$ contains ~2.5×10^{24} atoms and has an activity of ~1.2×10^{7} Bq. 2 kg is made of ~5.0×10^{24} atoms and has an activity of ~2.4×10^{7} Bq etc. Therefore A α N. Draw the graph of N → t. As the value of N falls so does the rate at which it is falling. This graph has the familiar property of halving in a certain constant time.	Half-life: http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/halfli.html or: http://www.bbc.co.uk/schools/gcsebitesize/physics/radioactivity/radioactivedecayandhalfliferev1.shtml	Emphasise that the constant time for halving does not depend on the start point. It also takes one half-life to fall from 80% to 40% or from 96% to 48%. Consequently in half-life experiments, the clock can be started at any convenient value.
26(j)	Make calculations based on half-life which might involve information in tables or shown by decay curves.	Carry out a standard school laboratory determination of half-life or show videos/DVDs of such experiments. Pupils plot the graph and calculate the answer. Paint one face of a large number of small cubes a distinct colour. Model decay by throwing the cubes from a beaker on to the desk and removing those which land with the painted face upwards. Repeat many times. Plot number of cubes left → number of the throw. Carry out calculations. Only use	Half-life calculations: http://www.darvill.clara.net/nucrad/hlife.htm	Plot height of water in a burette → time after opening tap (this does not give a particularly good curve but the height does decrease at a decreasing rate).

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		whole numbers of half-lives but problems which require a background count correction should be included. Half-lives encompass a very wide range of values: billions of years to milliseconds		
26(l)	Discuss the way in which the type of radiation emitted and the half-life determine the use for the material.	There are many examples but these include: • Alpha emitters are used to deliver radiation locally in medical procedures (e.g. to a tumour inside the brain) and in smoke detectors. • Beta emitters are used when determining the thickness of paper as it is manufactured and the level of fruit juice in a carton. • Gamma emitters are used when radiation has to leave the human body to be detected for diagnosis or when treating internal organs from outside. The half-life must be long enough for the procedure to be accurate but not so long that is constitutes a health hazard.	Uses of radiation: http://www.bbc.co.uk/schools/gcsebitesize/physics/radioactivity/radioactivedecayandhalfliferev1.shtml	There are so many examples that it is important to make it clear why a certain procedure needs the particular properties of the radiation chosen and why the others would not be effective.
26(n)	Discuss the dating of objects by the use of ^{14}C.	Emphasise that ^{14}C is continuously produced in the upper atmosphere and passes into living things through photosynthesis and digestion; it only occurs in things which were once alive including: wood, bones, seeds. Pupils can be unsure about which things were once alive. Its half-live is ~5730y and after about 20 000y, the dating is less accurate as little ^{14}C is left.	Radiocarbon dating: http://www.c14dating.com	The process has to be corrected for fluctuations in the prevailing level of ^{14}C. This is done using the tree rings of ancient redwood trees – dendrochronology.
26(f)2	Explain the processes of fusion.	Emphasise that the Sun and all stars have burnt for too long and given off too much energy for their power source to be chemical. It is now known that it is powered by four hydrogen atoms merging into one helium atom. This process is highly exothermic. Pupils should know that H + H → He + energy	Nuclear fusion: http://www.jet.efda.org/pages/content/fusion1.html or: http://en.wikipedia.org/wiki/Nuclear_fusion	Emphasise that both the fusion of small nuclei and the fission of large ones release energy. A different rule applies at the two ends of the periodic table.
26(h)	Discuss theories of star formation and their energy production by fusion.	Stars are formed when clouds of gas and dust collapse under gravity, the temperature increases until the hydrogen nuclei can fuse. Stars are in balance when the pressure caused by the fusion reaction balances that	Star formation: http://www.gcse.com/eb/star1.htm	

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		caused by gravitational attraction.		