Chapter 4: Atomic structure

Lesson 4.1 Atomic structure

1 88 electrons

2 92 protons, 238 – 92 = 146 neutrons

3 The number of electrons is the same; the number of protons is the same; the number of neutrons is different.

4 Uranium: 92 protons, 238 – 92 = 146 neutrons

Thorium: 90 protons, 234 – 90 = 144 neutrons

5a 7 protons and 14 - 7 = 7 neutrons.

5b 92 protons and 235 - 92 = 143 neutrons.

6 Nuclear radiation can knock electrons off atoms. These atoms become positive ions since they have lost negative charge. Once the electrons have been knocked off, these can join onto other atoms. These atoms become negative ions because they have gained negative charge.

Lesson 4.2 Radioactive decay

1 150 × 20 = 3000 counts

2 They are all unstable and form radioisotopes.

3 You can't predict when a particular nucleus is going to decay.

4 The nitrogen nucleus has one more proton and one fewer neutron than the carbon nucleus.

5a The nucleus loses 2 protons and 2 neutrons.

5b One of the neutrons in the nucleus becomes a proton.

6 This is beta decay.

7 A nucleus has a lot of energy after it has undergone alpha or beta decay. This energy is enough for gamma radiation to be released.

Lesson 4.3 Background radiation

1 Radon and thoron from soil, rocks and building materials; gamma rays from rocks and soil; radiation from living things and food; cosmic rays from outer space; medical; fallout from nuclear weapons testing and other forms such as air travel; work related; nuclear power industry.

2 All of the forms of background radiation apart from medical, work related, nuclear fallout, nuclear industry and air travel are natural. Therefore, the total percentage = 37 + 19 + 17 + 14 = 87 %.

3a The types of rock are different in different areas so some areas are exposed to more background radiation than others.

3b For example, nuclear fallout will vary depending on which way the wind is blowing. Cosmic background radiation increases when the sun is particularly active.

4 Beta particles can pass through a few metres of air and paper but they are stopped by a few mm of low density metals such as aluminium. Beta particles are more ionising than gamma rays but are less ionising than alpha particles.

5 Gamma radiation

6 Radon is an alpha emitter and alpha particles are very ionising and therefore dangerous if the inside of the body is exposed to them. Radon is also a gas so you can breathe it in.

7 It is likely that they would receive a higher amount of radiation. Pilots and cabin crew spend much of the time in the air at a higher altitude. The atmosphere will not have absorbed as much cosmic radiation at this altitude so the pilots and cabin crew will receive more cosmic radiation than people who spend more time at ground level

8 The alpha radiation would be absorbed before it passes outside the body. Therefore it would not be detected.

Lesson 4.4 Nuclear equations

1 They both have to be balanced.

2 A chemical equation only has one set of numbers that need to be balanced, a nuclear equation has two sets of numbers.

3a ${}^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$

3b ${}^{219}_{86}\mathrm{Rn} \rightarrow {}^{215}_{84}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$

4a ${}^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}\mathrm{e}$

4b ${}^{32}_{15}\mathrm{P} \rightarrow {}^{32}_{16}\mathrm{S} + {}^{0}_{-1}\mathrm{e}$

5a ${}^{24}_{11}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}\mathrm{e}$

5b The particle emitted is a beta particle (an electron).

6a An alpha particle is emitted.

6b A = 228, Z = 88

7a platinum-190 → osmium-186 + alpha particle

${}^{190}_{78}\mathrm{Pt} \rightarrow {}^{186}_{76}\mathrm{Os} + {}^{4}_{2}\mathrm{He}$

7b rhenium-187 → tantalum-183 + alpha particle

${}^{187}_{75}\mathrm{Re} \rightarrow {}^{183}_{73}\mathrm{Ta} + {}^{4}_{2}\mathrm{He}$

7c copper-66 →zinc-66 + beta particle

${}^{66}_{29}\mathrm{Cu} \rightarrow {}^{66}_{30}\mathrm{Zn} + {}^{0}_{-1}\mathrm{e}$

7d nickel-66 → copper-66 + beta particle

$^{66}_{28}\text{Ni} \rightarrow ^{66}_{29}\text{Cu} + ^{0}_{-1}\text{e}$

7e rhodium-105 → palladium-105 + beta particle

$^{105}_{45}\text{Rh} \rightarrow ^{105}_{46}\text{Pd} + ^{0}_{-1}\text{e}$

7f osmium-186 → tungsten-182 + alpha particle

$^{186}_{76}\text{Os} \rightarrow ^{182}_{74}\text{W} + ^{4}_{2}\text{He}$

Lesson 4.5 Radioactive half-life

1 Because radioactive decay is random.

2 It is the time it takes for the activity of a sample to fall to half of its current amount.

3a 40 counts per minute

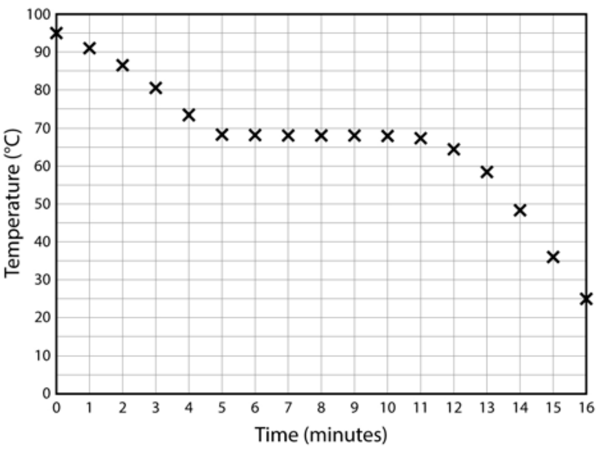
3b 20 counts per minute

3c 10 counts per minute

3d 5 counts per minute

4 8 minutes

5a & 5b



5c Time taken to halve from 100 Bq to 50 Bq = 1 minute

Time taken to halve from 40 Bq to 20 Bq = 2.4 – 1.4 = 1 minute

Time taken to halve from 32 Bq to 16 Bq = 2.7 – 1.7 = 1 minute

So the average of these three measurements = (1 + 1 + 1) / 3 = 1 minute.

6 It takes 1 half-life to decrease from 100 Bq to 50 Bq and a further half-life to decrease from 50 Bq to 25 Bq. Therefore 4 hours is 2 half-lives which means that 1 half-life = 2 hours.

7 Number of half-lives = 24 / 6 = 4. So the amount remaining is ½ × ½ × ½ × ½ = 1/16th of the original amount.

8 80 minutes = 10 half-lives. 2^{10} = 1024, so the fraction remaining = 1/1024.

Lesson 4.6 Hazards and uses of radiation

1 When a radioactive material is somewhere where it isn't wanted.

2 Radioactive materials produce ionising radiation which is harmful to health. Ionising radiation can kill cells and can cause cancer.

3 Gamma (since it has the weakest ionising power)

4 Alpha particles are very ionising which means that they are more likely to kill cells or cause cancer. However, they are not very penetrating so if they are outside the body they can't get in and cause the damage.

5a You need to make sure that your measurements are a true measure of the activity of the tracer rather than that of the background radiation.

5b Background radiation is random and its activity can be higher at some times than at others. You need to use an accurate average.

6 The isotope with the half-life of 6 hours. 6 seconds would mean that the isotope has decayed to unmeasurable levels before the tracer can be monitored and 6 days would mean the patient would remain radioactive long after the procedure had taken place which would add unnecessary risk.

7 A gamma emitter. Gamma radiation has the weakest ionising power so it does the least harm to the body. It is also the most penetrating so it can pass from the inside of the body where the tracer is, to the outside where it can be detected.

8 Inject the tracer into the blood. Leave enough time for the tracer to be carried by the blood through the body. Examine the patient with a gamma camera. If there is a large signal at a particular place in the vessel then it is likely that there is a blockage in that place.

Lesson 4.7 Irradiation

1 Irradiation is when you expose an object to nuclear radiation.

2 We receive much more irradiation from the food than from the air (it's about 500 times more).

3 Accurate repair, cell death, misrepair

4 If a sperm cell or an egg cell is misrepaired then this change of genetic material could be passed onto offspring.

5 Irradiation is exposing someone to nuclear radiation. Contamination is when radioactive material is actually present on the person (which will continue to irradiate them).

6 The people doing the experiments might have made mistakes. If other people carrying out an experiment agree with the findings, then the findings are more likely to be true.

7 Once the pigeons move away from something that is irradiating them then they are no longer exposed to the radiation. However, if they are contaminated with radioactive material then they will continue to be irradiated for as long as the material in them remains radioactive. This is much more likely to cause them serious harm.

Lesson 4.8 Uses of radiation in medicine

1 They are both types of electromagnetic waves.

2 Many manufactured radioisotopes are used in medicine. Some of these are used to destroy cancerous cells from the radiation they produce; others are used as tracers to help diagnose problems with a patient in order to treat them.

3 X-rays are only produced when needed. You can control the energy of the x-rays that you produce.

4 Bracytherapy uses the radioactive source right next to (or inside) the tumour rather than the radiation coming from outside the body.

5 You need to make sure that you can extract all of the radioactive source so you don't contaminate the patient. Placing the radioactive source near the tumour might need invasive surgery which can lead to problems with infection.

6 Alpha particles wouldn't penetrate very far into the tumour (and probably wouldn't even be able to leave the protective casing). Many gamma rays would pass through the tumour so there would be a large dose applied to tissue outside of the tumour. Beta particles would penetrate into the tumour and deposit most of their energy within the tumour. Therefore, the tumour would get the biggest dose with a beta emitter.

Lesson 4.9 Using nuclear radiation

1 The patients have cancer and are therefore likely to suffer much more if they are left untreated. The benefits of the cancer treatment outweigh the risks of side effects from the treatment.

2 Compare the amount of radiation produced from the radioactive iodine with an image produced by a normal thyroid gland. If the patient is suffering from hypothyroidism then the image will show less radiation since the gland would not have as absorbed as much iodine.

3 Radiotherapy has a risk of harm to the patient. Although surgery is also dangerous, it is the safer option once the tumour has been reduced in size.

4 Not all of the cancer cells would have been removed from the tumour and these could go on to cause further cancer. The radiotherapy is used to kill all of the remaining cancer cells.

5a Activity is the number of decays per second.

5b Dose is a measure of harm that a particular procedure does to the patient.

6 It is more important to consider the dose as this is a measure of the direct harmful effect that the procedure has on the patient. A high activity of one source might actually be less harmful than a low activity of another source.

7a The heart scan.

7b Over this time interval you would receive the same amount of radiation from background radiation as you would from the scan.

7c The patient might have a had a radiation dose previously and this scan might make them go over the maximum allowed radiation dose.

Lesson 4.10 Nuclear fission

1 Nuclear fission is the splitting up of a large nucleus into two smaller daughter nuclei and a few neutrons.

2 Fission is made to happen when a neutron is absorbed whereas radioactive decay happens spontaneously. The nucleus splits into two approximately equally sized parts in fission whereas only a small part of the nucleus is ejected (if any) in radioactive decay.

3 Fission can be induced by absorbing a neutron. Fission also releases a few neutrons which can then go on to cause further nuclei to fission. Thus a chain reaction can build up.

4 The similarities are that they both heat up water to produce steam, which turns a turbine and a generator. The steam turns back into water using cooling towers. A nuclear power station differs from a coal-fired one in that it uses uranium as a fuel rather than coal. Also you only have to replace the uranium every few years whereas you have to continually feed a coal fired power station with coal. The amount of fuel you need in a coal fired power station is much more than you need in a nuclear power station.

5 A coolant (e.g. a gas) is made to flow through the nuclear reactor. This heats up the gas. The hot gas then passes by some cold water and energy is transferred to the water by conduction. This turns the water into steam.

6 The moderator slows down the neutrons. Slower moving neutrons are more likely to cause fission.

7 Raising the control rods increases the temperature and lowering them decreases the temperature. When the rods are raised, more neutrons per fission go on to cause further fissions so the number of fissions happening at a particular time increases and energy is released more quickly. When the control rods are lowered then fewer neutrons go on to cause further fission so the number of fission reactions at any given time decreases. When, on average, one neutron in a fission reaction goes on to cause a further fission then the temperature remains constant.

Lesson 4.11 Nuclear fusion

1 They both release energy from changes in the structure of a nucleus. However, fission involves a large nucleus splitting into smaller ones whereas fusion is the joining of two small nuclei to form a larger one.

2 High temperatures and high pressures. The nuclei need to get very close together before fusion can take place. A large force is needed to do this because the nuclei repel each other (since they are both positively charged). Both high pressure and high temperature provide the conditions for the nuclei to get close enough to fuse.

3 There is plenty of available fuel and the waste products do not harm the environment.

4 The work is shared so that the work can be checked to see if everyone agrees with the results. Also other people can continue the work and use it in further developments in science.

5 You don't need to generate electricity from a hydrogen bomb. Therefore, you don't need to control the rate that energy is released from a hydrogen bomb. You can create the conditions needed for nuclear fusion using a fission bomb within a hydrogen bomb – it would not be possible to do this safely in a domestic fusion reactor.

6 There is plenty of fuel for fusion and the waste produces are clean so this would solve many of the future problems that we are currently facing in energy production. Also the fuel is available everywhere so this limits potential for wars over gaining resources in the future. However, fusion is very difficult to achieve and we might spend lots of money trying to develop fusion power with no success. This money could be spent on developing energy resources that we know will work. Also fusion power will turn buildings radioactive so there will be hazards associated with fusion power.

Lesson 4.12 Key Concept: Developing ideas for the structure of the atom

1 No it only includes the electrons. The rest of the atom was a positively charged sphere.

2 Yes – although it is unclear how they are balanced.

3 The results were very surprising and other scientists needed to peer review the work to check that they had not made any mistakes. The work is useful for other scientists to develop in order to produce further scientific theories.

4 The experimental results could not be explained by the current model of the atom.

5 Rutherford's model explained why most of the alpha particles went through the gold foil and only a few bounced back. It also went on to explain what was happening in radioactive decay.

6 More people do experiments to test whether the results agree with the predictions of the scientific theory. If the theory correctly predicts the results of many experiments over a long period of time it becomes gradually accepted. However just one experiment's results can force a theory to be changed as shown by Geiger and Marsden's experiment.

Lesson 4.13 Maths Skills: Using ratios and proportional reasoning

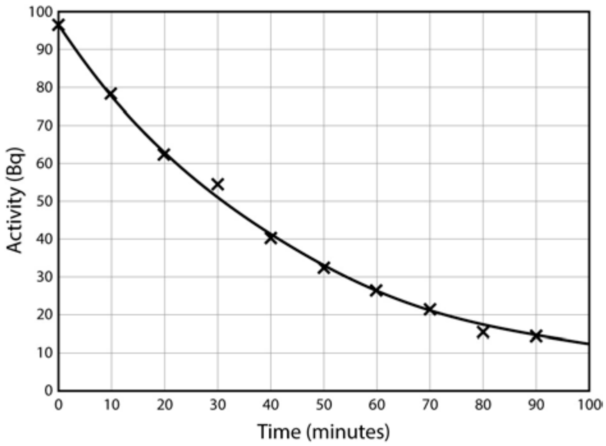
1 200 Bq → 100 Bq: 70 – 10 = 60 seconds

100 Bq → 50 Bq: 145 – 70 = 75 seconds

50 Bq → 25 Bq = 230 – 145 = 85 seconds

Average = (60 + 75 + 85) / 3 = 73 seconds

2a



2b 92 Bq → 46 Bq: 34 – 2 = 32 minutes

60 Bq → 30 Bq: 53 – 22 = 31 minutes

40 Bq → 20 Bq: 70 – 40 = 30 minutes

Average = 31 minutes.

3 6 hours = 3 half-lives.

Fractional decrease in activity = 1/8.

So activity after 6 hours = 160 / 8 = 20 Bq

4 200 / 12.5 = 16

So fractional decrease is 1/16 which corresponds to 4 half-lives.

So 21 years = 4 half-lives.

1 half-life = 21 / 4 = 5.25 years.

5 1/16 decrease in activity corresponds to 4 half-lives.

So 1 half-life = 24 / 4 = 6 hours.

6a Number of half-lives = 2.

So the activity = 640 ÷ 2 ÷ 2 = 160 Bq

6b Net decline = 160 / 640 = 0.25 = 1/4

7a Number of half-lives = 32 / 8 = 4

So count rate = 1800 ÷ 2 ÷ 2 ÷ 2 ÷ 2 = 112.5 Bq

7b Net decline = 112.5 / 1800 = 0.0625 = 1/16

8 The number of atoms of polonium that have decayed equals the number of atoms of lead that are formed. After two half-lives ¼ of the original polonium atoms would be remaining and ¾ would have turned into lead atoms. Therefore at this time there will be three times as many lead atoms as polonium atoms. So it takes two half-lives = 2 × 138 = 276 days.

End of Chapter Questions

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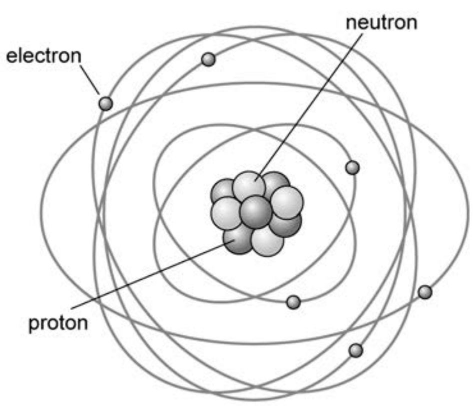

An atom contains a nucleus with protons and neutrons in it. Electrons are located further out. [1 mark]

2 Alpha, beta and gamma radiation. [1 mark for one of these correct, 2 marks if all three are correct.]

3 The time it takes for the activity to fall to half of its present value. [1 mark]

4 Any **two** from rocks/building materials, living things/food/soil, cosmic rays/outer space/the Sun, nuclear weapons/nuclear power stations. [2 marks]

5 A large proportion of background radiation comes from rocks [1 mark]. The type of rock changes from place to place and some are more radioactive than others [1 mark].

6 X-rays and gamma rays are both ionising forms of radiation, which means they can kill cells or turn them into cancer cells [1 mark]. However, x-rays and gamma rays can also be used to treat cancer by killing cancer cells / they can help to diagnose illnesses that can then be treated more effectively [1 mark].

7 It is the number of protons in the nucleus. [1 mark]

8 A photographic plate / a fluorescent screen / a Geiger counter / a gamma camera [1 mark]

9 Fusion is the joining of two small nuclei to form a larger one [1 mark]. Fission is the splitting of a large nucleus to form two smaller ones (and some neutrons) [1 mark].

10a 23 is the mass number (or the nucleon number) which is the total number of protons and neutrons in the nucleus. 11 is the atomic number which is the total number of protons in the nucleus. [1 mark]

10b An isotope of an element contains the same number of protons but a different number of neutrons (from other isotopes of the same element). [1 mark]

11a Iodine-131 because it has a shorter half-life [1 mark]. After a few weeks it will no longer be contaminating the body (whereas the activity of the Carbon-14 would not have decreased very much at all) [1 mark].

11b The benefits of using a tracer is that it might diagnose a condition that can be treated and so make the patient better. The risks of using a tracer is that it might harm the patient by causing cancer. [1 mark]

The benefits must be likely to greatly outweigh the risks before a tracer is used. [1 mark]

12 Ionising radiation that is around us all the time. [1 mark]

13 Irradiation is exposing someone to nuclear radiation. Contamination is when radioactive material is actually present on the person (which will continue to irradiate them). [1 mark]

14 $^{219}_{86}Rn \rightarrow ^{215}_{84}Po + ^{4}_{2}He$ [1 mark for all the top numbers correct and 1 mark for all the bottom numbers correct.]

15 The radioactive sample took 3 half-lives to decay from 400 Bq to 50 Bq (400 Bq → 200 Bq → 100 Bq → 50 Bq). [1 mark]

Therefore 60 minutes = 3 half-lives. So the half-life = 60 / 3 = 20 minutes. [1 mark]

16a Radioactivity is a random process [1 mark]. Therefore, all of the points would show considerable scatter and you would have to draw a curve of best fit [1 mark].

16b Time to halve from 2000 counts/min to 1000 counts/min = 8 minutes

Time to halve from 800 counts/min to 400 counts/min = 18.5 – 10.5 = 8 minutes

Therefore average half-life = 8 minutes.

[1 mark for obtaining a value of the half-life to be between 7.5 and 8.5 minutes, 1 mark for finding more than one half-life and obtaining an average.]

17 Any two marks from:

Alpha particles consist of 2 protons and 2 neutrons; beta particles are electrons; gamma rays are electromagnetic rays. [1 mark]

Alpha particles are heavily ionising; beta particles are less ionising and gamma rays are very weakly ionising. [1 mark]

Alpha particles are stopped by paper / a few cm of air; Beta particles are stopped by a few mm of aluminium / a few m of air; Gamma rays can even pass through a few cm of lead. [1 mark]

18 Any two marks from:

- Geiger and Marsden used a radioactive source to fire alpha particles at a thin piece of gold foil
- Most of the particles passed straight through
- A very few of them bounced straight back

Any one mark from:

- This showed that most of the atom consisted of empty space
- This showed that there must be a small / dense, positively charged nucleus at the centre

Any one mark from:

- The evidence contradicted the predictions from Thomson's plum pudding model
- Rutherford proposed a new nuclear model of the atom which was consistent with the evidence from the experiment.

19

- The tracer needs to be a gamma emitter (so it can be detected easily) [1 mark]
- It needs to have a sensible half-life (e.g. a few hours / days) so that it lasts long enough to be useful but it doesn't contaminate the water after the procedure is over. [1 mark]
- You need to place the tracer in the pollution that you suspect might be contaminating the water. [1 mark]
- You can collect samples from the water source and examine them using e.g. a gamma camera to see if there are any signs of the tracer. [1 mark]