Atomic structure and radioactivity

Model answers and marking points

GCSE science 6-mark questions

This topic online

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

1 Ideas about what an atom looks like changed a great deal between about 1900 and 1935 as new experimental evidence was found.

Describe how the model of the atom developed over this time, and the evidence that led to each change.

(6 marks)

Model answer

At first atoms were thought of as tiny solid spheres that could not be divided into anything smaller.

When the electron was discovered, this idea had to change, because atoms clearly contained smaller particles. The plum pudding model described the atom as a ball of positive charge with negative electrons spread through it.

Then scientists fired alpha particles at very thin gold foil. Most of them passed straight through, which showed that most of the atom is empty space. A few were deflected and a very small number bounced back. This showed there must be a tiny centre that is positively charged and contains most of the mass. This gave the nuclear model, with a small positive nucleus and electrons around it.

Niels Bohr then suggested that electrons orbit the nucleus at fixed distances, in energy levels. His calculations agreed with experimental observations.

Later experiments showed that the positive charge of the nucleus is made of smaller particles, called protons. About 20 years after the nucleus was proposed, James Chadwick found evidence for neutrons, which explained the extra mass in the nucleus. Each time, the model changed because new evidence did not fit the old one.

Marking points (credit any 6 relevant points, linked in a sensible order)

- before the electron was discovered, atoms were thought to be tiny spheres that could not be divided
- the discovery of the electron led to the plum pudding model: a ball of positive charge with negative electrons spread through it
- in the alpha scattering experiment, alpha particles were fired at very thin gold foil
- most alpha particles went straight through, showing that most of the atom is empty space
- a few were deflected and a very small number bounced back, showing a tiny, dense, positive centre
- this led to the nuclear model, with the mass concentrated in a small positive nucleus and electrons around it
- Bohr suggested electrons orbit the nucleus at fixed distances in energy levels, which matched observed results and theoretical calculations
- later experiments showed the positive charge of the nucleus is made up of smaller particles called protons
- Chadwick's work about 20 years after the nucleus was proposed gave evidence for neutrons in the nucleus, which accounted for the extra mass of the nucleus
- each model was replaced or changed because new evidence could not be explained by the old one

How it is marked

- 5-6 marks: describes the sequence from indivisible spheres to plum pudding, nuclear model, Bohr's energy levels, protons and neutrons, linking the key changes to the evidence, especially alpha scattering.
- 3-4 marks: describes at least two models in the right order with some evidence, for example plum pudding replaced after alpha scattering.
- 1-2 marks: names one or two models or describes the modern atom with no development.

What loses marks

- saying alpha particles bounced back because they hit electrons
- putting the models in the wrong order
- describing the experiment without saying what each result showed

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

2 A science technician at a school in Leicester stores three radioactive sources: one emits alpha particles, one emits beta particles and one emits gamma rays.

Compare alpha, beta and gamma radiation. Refer to what each one is, how far it travels, what stops it and how strongly it ionises.

(6 marks)

Model answer

An alpha particle is made of two protons and two neutrons, which is the same as a helium nucleus, so it has a positive charge. A beta particle is a fast-moving electron that comes from the nucleus when a neutron changes into a proton, so it is negative. A gamma ray is not a particle but electromagnetic radiation, so it has no mass and no charge.

Alpha particles are the most strongly ionising, beta particles are less ionising and gamma rays are the least ionising. Because alpha particles ionise so many atoms, they lose their energy very quickly.

This explains their ranges. Alpha travels only a few centimetres in air and is stopped by a sheet of paper or by the outer layer of skin. Beta travels around a metre in air and is stopped by a few millimetres of aluminium. Gamma rays travel a very long distance in air and pass through paper and aluminium. They are only reduced by thick lead or a lot of concrete.

So as you go from alpha to beta to gamma, the ionising power decreases and the penetrating power increases.

Marking points (credit any 6 relevant points, linked in a sensible order)

- an alpha particle is two protons and two neutrons, the same as a helium nucleus
- a beta particle is a high-speed electron emitted when a neutron in the nucleus turns into a proton
- a gamma ray is electromagnetic radiation emitted from the nucleus, with no mass and no charge
- alpha has a positive charge, beta has a negative charge, gamma is uncharged
- alpha travels only a few centimetres in air; beta travels about a metre; gamma travels a very long way in air
- alpha is stopped by a sheet of paper or the skin
- beta is stopped by a few millimetres of aluminium
- gamma is only reduced by thick lead or several metres of concrete
- alpha is the most strongly ionising, beta is less ionising, and gamma is the least ionising
- the more strongly ionising a radiation, the more quickly it loses energy, which is why alpha has the shortest range

How it is marked

- 5-6 marks: compares all three radiations on nature, range, what stops them and ionising power, and links strong ionisation to short range.
- 3-4 marks: compares the three on two or three of the features, with mostly correct details.
- 1-2 marks: gives one or two correct facts, such as alpha being stopped by paper.

What loses marks

- saying gamma is the most ionising because it is the most penetrating
- saying a beta particle comes from the electron shells
- listing facts about each one with no comparison words

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

3 Mr Adeyemi has a small tumour in his prostate gland. He lives on a farm about 80 km from the hospital in Norwich. His doctors offer him two treatments.

	Treatment A: external beam	Treatment B: implanted seeds
What happens	Gamma rays from a source in a hospital machine are aimed at the tumour from several different directions	About 80 tiny sealed metal capsules containing a radioactive isotope are placed inside the tumour during one operation and left there
Radiation reaching the tumour	High-energy gamma rays	Low-energy gamma rays, mostly absorbed within 1 cm of each seed
Half-life of the isotope in the patient	No isotope is placed in the patient	60 days
Hospital visits	20 short visits over 4 weeks	1 visit, with a general anaesthetic
Advice after treatment	None	Do not hold young children or sit close to pregnant women for 2 months

Evaluate the two treatments for Mr Adeyemi. Use the information and your own knowledge of radiation. Give a justified conclusion.

Separate science only

(6 marks)

Model answer

Both treatments use ionising radiation to damage the DNA in the cancer cells so that they die.

In treatment A the gamma rays come from outside the body, so they pass through healthy tissue on the way to the tumour and damage some healthy cells. Aiming the beam from several directions helps, because the tumour gets the full dose while each area of healthy tissue gets only part of it. Mr Adeyemi is irradiated but not contaminated, so he is not radioactive afterwards. However, he would need 20 return trips of about 160 km.

In treatment B the low-energy gamma rays are absorbed within about 1 cm of each seed, so nearly all the dose goes into the tumour. The seeds are sealed, so the radioactive material should not spread. He does become a source of radiation, so people close to him could be irradiated, which is why young children and pregnant women should keep away. With a half-life of 60 days, the activity halves every two months, and after a year it is only about 1/64 of the start. The operation and anaesthetic carry some risk.

I would choose B. It needs only one visit, which matters for someone living so far away, and it harms less healthy tissue, as long as he follows the advice.

Marking points (credit any 6 relevant points, linked in a sensible order)

- both treatments use ionising radiation to damage the DNA of the cancer cells so that they die
- in A the gamma rays come from outside the body, so they pass through healthy tissue and damage some healthy cells
- aiming the beam from several directions gives the tumour the full dose while each area of healthy tissue gets only part of it
- in A the patient is irradiated, not contaminated, so he is not radioactive afterwards and is no risk to other people
- in B the low-energy gamma is absorbed within about 1 cm, so nearly all the dose goes into the tumour and little reaches healthy tissue
- the seeds are sealed, so the radioactive material should not spread through his body or contaminate other people

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

- in B he becomes a source of radiation, so people close to him can be irradiated, which is why young children and pregnant women should keep away
- a 60-day half-life means the activity halves every two months and after a year (about 6 half-lives) is only about 1/64 of the starting value
- A needs 20 return trips of about 160 km; B needs one visit but the operation and anaesthetic carry their own risks
- a conclusion that follows from the points made, for example B suits Mr Adeyemi because of the distance and the smaller harm to healthy tissue, provided he follows the advice

How it is marked

- 5-6 marks: uses the information on both treatments to weigh damage to healthy tissue, risk to other people and the half-life, includes the travel problem, and reaches a conclusion that follows from these points.
- 3-4 marks: gives advantages and disadvantages of both treatments with some use of the table, but the radiation ideas are thin or the conclusion is only partly supported.
- 1-2 marks: picks a treatment with one simple reason, such as fewer visits, or copies facts from the table.

What loses marks

- saying the patient becomes radioactive after treatment A
- treating the sealed seeds as contamination that spreads around the body
- choosing a treatment without using the half-life or the travel information
- giving a conclusion that ignores the risk to other people

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

4 Dr Okafor works in a hospital laboratory that handles radioactive sources. Her colleague says: *Being irradiated and being contaminated are the same thing.*

Explain the difference between irradiation and contamination, why each is a hazard, and the precautions staff should take to reduce each risk.

(6 marks)

Model answer

The colleague is wrong. Irradiation means being exposed to radiation coming from a source outside the body. Once the person moves away from the source the exposure stops, and an irradiated person does not become radioactive.

Contamination means radioactive atoms actually get onto the skin or clothes, or into the body, for example by being breathed in or swallowed. The person keeps being exposed to radiation until the material is removed or has decayed.

Both are hazards because nuclear radiation is ionising. It can damage cells and the DNA inside them, which can cause cell death or lead to cancer.

For irradiation, beta and gamma radiation are the biggest risk because they can pass through the skin. For contamination inside the body, alpha is the most dangerous because it is so strongly ionising and all of its energy is absorbed by nearby cells.

To reduce irradiation, staff should store sources in lead-lined boxes, use tongs to keep a distance, work behind shielding and spend as little time near sources as possible. To reduce contamination, they should wear gloves and lab coats, never eat or drink in the lab and wash their hands afterwards. Wearing a dosimeter badge lets them check their dose.

Marking points (credit any 6 relevant points, linked in a sensible order)

- irradiation is being exposed to radiation from a source outside the body
- an irradiated person or object does not become radioactive
- contamination is when radioactive atoms get onto or into a person or object
- a contaminated person keeps being exposed until the radioactive material is removed or decays
- radiation is ionising, so it can damage cells and DNA and may cause cancer
- for irradiation, gamma and beta from outside the body are most dangerous as they can penetrate the skin
- for contamination inside the body, alpha is most dangerous because it is strongly ionising and is absorbed by nearby cells
- to reduce irradiation: keep sources in lead-lined boxes, stand behind shielding, keep a distance, use tongs, limit time near sources
- to reduce contamination: wear gloves and lab coats, do not eat or drink near sources, wash hands
- staff wear dosimeter badges to monitor the dose they receive

How it is marked

- 5-6 marks: defines both terms clearly, explains why each is harmful including which radiation is most dangerous in each case, and gives suitable precautions linked to each.
- 3-4 marks: gives a clear difference between the two and some precautions, but the explanation of the hazard is limited.
- 1-2 marks: gives a partial definition of one term or lists one or two safety measures.

What loses marks

- saying irradiated objects become radioactive
- saying alpha is harmless in every situation
- listing precautions without linking them to irradiation or contamination

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.

5 **Higher tier**

Rhys measures the count rate from a radioactive sample over 8 hours. The background count rate in the laboratory is 20 counts per minute.

Time in hours	0	2	4	6	8
Measured count rate in counts per minute	820	420	220	120	70

Use the data to find the half-life of the sample. Then predict the count rate from the sample alone after 12 hours, and express the net decline from the start to 12 hours as a ratio. (6 marks)

Model answer

First I need to subtract the background count rate of 20 counts per minute from each reading, because some of the counts are not from the sample.

Corrected count rates: 800, 400, 200, 100 and 50 counts per minute.

The corrected count rate halves every 2 hours: 800 to 400, 400 to 200, and so on. Half-life is the time taken for the count rate from a sample to fall to half, so the half-life is 2 hours. If I had used the raw values, 820 to 420 is not exactly half, so the background has to be removed first.

12 hours is 12 / 2 = 6 half-lives.

After 6 half-lives the count rate from the sample = 800 / 2^6 = 800 / 64 = 12.5 counts per minute. The detector would actually read about 12.5 + 20 = 32.5 counts per minute because of background radiation.

The net decline is from 800 to 12.5 counts per minute. As a ratio of final to initial count rate this is 12.5 : 800, which simplifies to 1 : 64.

Because decay is random, real readings would vary a little around these values.

Marking points (credit any 6 relevant points, linked in a sensible order)

- the background count rate must be subtracted from each measured value
- corrected count rates are 800, 400, 200, 100 and 50 counts per minute
- the corrected count rate halves every 2 hours
- half-life is the time for the count rate (activity) to fall to half, so the half-life is 2 hours
- using the raw values would give the wrong half-life, because the counts do not halve exactly
- 12 hours is 12 / 2 = 6 half-lives
- after 6 half-lives the count rate is 800 / 2 to the power 6 = 800 / 64 = 12.5 counts per minute
- the measured count rate after 12 hours would be about 12.5 + 20 = 32.5 counts per minute
- the net decline is from 800 to 12.5, so the ratio of final to initial is 1 : 64
- radioactive decay is random, so real counts would vary around these values

How it is marked

- 5-6 marks: corrects for background, finds a half-life of 2 hours, predicts 12.5 counts per minute after 12 hours and gives the ratio 1 : 64, with clear working.
- 3-4 marks: finds the half-life correctly (with or without the background correction explained) and makes some progress with the prediction or ratio.
- 1-2 marks: describes the count rate falling or attempts a half-life without correcting for background.

What loses marks

- forgetting to subtract the background count
- dividing by 6 instead of by 2 six times
- writing the ratio the wrong way round without saying which is which

Free for classroom and home use: print, photocopy and share. Not for resale or re-hosting.