

4.4

Atomic structure

Exam-style questions — answers and mark schemes

100 questions • 226 marks

Written in the style of AQA papers, including the required practicals, maths and working scientifically.

How to use this booklet

Each answer gives the creditworthy points; one mark per point unless stated.

Alternative correct wording is credited — these are marking points, not model answers.

Calculations: the equation and the substitution each earn a mark, so a wrong final answer can still score. Error carried forward applies where stated.

Examiner notes flag the mistakes that actually lose marks in real examinations.

Command words used

State, Give, Name, Write down — a short factual answer, no explanation needed

Describe — say what happens, in order, without needing a reason

Explain — give a reason; 'because', 'so' or 'therefore' should appear

Calculate — show your working and give a unit

Determine — use data given, often from a graph or table

Estimate — an approximate value from reasonable assumptions

Suggest — apply what you know to an unfamiliar situation

Compare — say how things are similar and different, in the same sentence

Evaluate — give both sides, then a conclusion

Design, Plan — set out a method others could follow

Questions are labelled beside the marks where they are Higher Tier only, Separate Physics only, or Working scientifically — the apparatus, variables, accuracy, evaluation and maths skills that carry around a third of the marks in every AQA paper.

4.4.1 Atoms and isotopes

1 An atom of lithium is written as ${}^7_3\text{Li}$.

a State the number of protons, neutrons and electrons in this atom. [3]

Protons 3 (1); neutrons $7 - 3 = 4$ (1); electrons 3 (1)

b Give the relative charges of a proton, a neutron and an electron. [2]

Proton +1 and electron -1 (1); neutron 0 (1)

c Explain why the atom has no overall charge. [2]

It has equal numbers of protons and electrons (1); their charges are equal and opposite, so they cancel (1)

d State the approximate radius of an atom and of a nucleus. [2]

Atom about 1×10^{-10} m (1); nucleus less than 1/10 000 of that, about 1×10^{-14} m (1)

e The lithium atom loses one electron. Give the charge on the ion formed. [1]

+1 (1)

2 Carbon has two common isotopes, carbon-12 and carbon-14.

a Define the term isotope. [2]

Atoms of the same element with the same number of protons (1); but a different number of neutrons (1)

b State how many neutrons each isotope contains. Carbon has atomic number 6. [2]

Carbon-12 has 6 neutrons (1); carbon-14 has 8 neutrons (1)

Examiner note: Examiners stress that any numbers quoted must be correct; a statement such as 'carbon-12 has 12 neutrons' scores nothing.

c Explain why the two isotopes have identical chemical behaviour. [2]

They have the same number of protons and so the same number of electrons (1); chemical behaviour depends on the electrons (1)

d Carbon-14 is radioactive but carbon-12 is not. Suggest why. [1]

The nucleus of carbon-14 is unstable because of the different ratio of neutrons to protons (1)

3

Describe how the model of the atom changed as a result of the alpha scattering experiment.

- a** State what the plum pudding model suggested. [2]

The atom is a ball of positive charge (1); with negative electrons embedded in it (1)

- b** Describe the three observations made in the alpha scattering experiment. [3]

Most alpha particles passed straight through the gold foil (1); some were deflected through small angles (1); a very small number were deflected through more than 90° , bouncing back (1)

- c** Explain what each observation showed about the structure of the atom. [3]

Most passing through shows the atom is mostly empty space (1); deflections show a concentration of positive charge that repels the positive alpha particles (1); the few bouncing back show the mass and charge are concentrated in a tiny, dense nucleus (1)

- d** Describe the two further changes to the model after the nuclear model was accepted. [2]

Bohr proposed that electrons orbit the nucleus at fixed distances, which agreed with experimental observations (1); later work showed the positive charge is made up of protons, and about 20 years later Chadwick provided evidence for the neutron (1)

- e** Explain why scientific models are changed over time. Working scientifically [2]

New experimental evidence is obtained that the existing model cannot explain (1); so the model is modified or replaced, after being checked by other scientists through peer review (1)

4.4.2 Atoms and nuclear radiation

4

A radioactive source emits alpha, beta and gamma radiation.

- a** Describe the nature of an alpha particle. [2]

Two protons and two neutrons (1); the same as a helium nucleus (1)

- b** Describe the nature of a beta particle. [2]

A high-speed electron (1); emitted from the nucleus when a neutron turns into a proton (1)

- c** Describe the nature of a gamma ray. [1]

Electromagnetic radiation emitted from the nucleus (1)

- d** Compare the penetrating power of the three radiations. [3]

Alpha is stopped by paper or a few centimetres of air (1); beta is stopped by a few millimetres of aluminium (1); gamma is only reduced by thick lead or several metres of concrete (1)

- e** Compare the ionising power of the three radiations. [2]

Alpha is the most strongly ionising, then beta, then gamma (1); the order is the reverse of the order of penetration (1)

- f** Explain why alpha radiation is the most ionising. [2]

It has the largest charge, +2, and the largest mass (1); so it interacts most strongly with atoms it passes, knocking off electrons (1)

5

Complete and explain the following nuclear decays.

- a Radium-226 (atomic number 88) emits an alpha particle. Give the mass number and atomic number of the nucleus formed.

Maths skill [2]

Mass number 222 (1); atomic number 86 (1)

- b Write the full nuclear equation for this decay.

[2]

$${}_{88}^{226}\text{Ra} \rightarrow {}_{86}^{222}\text{Rn} + {}_2^4\text{He}$$
 (1 for the daughter nucleus, 1 for the alpha particle correctly written) (2)

- c Carbon-14 (atomic number 6) emits a beta particle. Write the nuclear equation.

[2]

$${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + {}_{-1}^0\text{e}$$
 (1 for the daughter nucleus, 1 for the beta particle) (2)

- d State the effect of gamma emission on the mass number and atomic number.

[1]

Neither changes (1)

- e A nucleus emits a neutron. State the effect on the mass number and atomic number.

[2]

The mass number decreases by 1 (1); the atomic number is unchanged (1)

- f Explain how you know a nuclear equation is balanced.

[2]

The total mass numbers on each side are equal (1); and the total atomic numbers on each side are equal (1)

6

A student measures the count rate near a radioactive source using a Geiger-Müller tube.

- a Explain why the student measures the count rate with no source present before starting.

Working scientifically [2]

To measure the background radiation (1); which must be subtracted from every reading to find the count rate due to the source alone (1)

- b Give two sources of background radiation.

[2]

Radon gas from rocks and soil, or building materials (1); cosmic rays from space, food and drink, or medical procedures (1)

- c The background count is 25 counts per minute. The detector reads 865 counts per minute beside the source. Calculate the corrected count rate.

Maths skill [1]

 $865 - 25 = 840$ counts per minute (1)

- d Explain why the count rate measured varies slightly even when nothing is changed.

Working scientifically [2]

Radioactive decay is a random process (1); so the number of decays in a given time varies, and the count rate fluctuates about a mean (1)

- e Describe two precautions the student should take when handling the source.

Working scientifically [2]

Handle it with tongs and keep it at arm's length, pointing away from people (1); limit the time of exposure and return it to a lead-lined container when not in use (1)

7

A source has a half-life of 6 hours and an initial corrected count rate of 1600 counts per minute.

Time in hours	0	6	12	18	24
Count rate in counts per minute	1600	800	400	200	100

- a** Define the term half-life. [2]

The time taken for the number of unstable nuclei in a sample to halve (1); or the time for the count rate from a sample to fall to half its initial value (1)

Examiner note: Examiners report that 'the time for the radioactivity to halve' is insufficient; candidates must say what is halving.

- b** Determine the count rate after 30 hours. Maths skill [2]

30 h is five half-lives (1); $1600 \div 32 = 50$ counts per minute (1)

- c** Calculate how long it takes for the count rate to fall to one eighth of its initial value. Maths skill [2]

One eighth is three half-lives (1); $3 \times 6 = 18$ hours (1)

- d** Express the net decline after 24 hours as a ratio. Higher Tier only [2]

$100 : 1600$ (1); $= 1 : 16$ (1)

- e** Plot a graph of count rate against time on the grid provided, and draw a curve of best fit. Working scientifically [4]

Sensible scales using over half the grid (1); axes labelled with quantity and unit (1); all points plotted correctly (1); smooth curve of best fit (1)

- f** Use your graph to determine the count rate after 9 hours. Working scientifically [2]

Line drawn on the graph at 9 hours (1); reading between 540 and 580 counts per minute (1)

8

Use the grid to plot the decay data from the previous question.

No answer is required here — the grid is for your graph. [0]

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9

A sample of a radioactive isotope has an activity of 4800 Bq. After 20 days the activity is 300 Bq.

- a** State the unit of activity and what it means. [2]

The becquerel, Bq (1); one decay per second (1)

Examiner note: A common incorrect unit given is the sievert, which measures radiation dose, not activity.

- b** Calculate the half-life of the isotope. Maths skill [3]

4800 → 2400 → 1200 → 600 → 300 is four halvings (1); $20 \div 4$ (1); = 5 days (1)

- c** Predict the activity after a further 15 days. Maths skill [2]

15 days is three more half-lives (1); $300 \div 8 = 37.5$ Bq (1)

- d** Explain why it is impossible to predict when any particular nucleus will decay. [2]

Radioactive decay is a random process (1); the half-life only describes the average behaviour of a very large number of nuclei (1)

4.4.3 Hazards and uses of radiation

10

A hospital uses radioactive sources for both diagnosis and treatment.

- a** Explain the difference between irradiation and contamination. Separate Physics only [3]

Irradiation is exposure to radiation from a source outside the object or person (1); the object does not become radioactive (1); contamination is having the radioactive material itself on or inside the object (1)

- b** Explain why contamination is usually more dangerous in the long term. Separate Physics only [2]

The source remains with the person and continues to decay (1); so exposure continues until the material is removed or has decayed (1)

- c** A medical tracer is a gamma emitter with a short half-life. Explain why both properties are important. Separate Physics only [4]

Gamma radiation passes out of the body so it can be detected externally (1); and is weakly ionising so it does less damage to tissue (1); a short half-life means the activity falls quickly after the scan (1); so the patient's total dose is kept low (1)

- d** Explain why a source used in radiotherapy to destroy a tumour is used differently from a tracer. Separate Physics only [3]

Radiotherapy needs to damage cells, so a high dose of gamma radiation is directed at the tumour (1); the beam is rotated around the patient, or several beams are used, so the tumour receives the full dose (1); while surrounding healthy tissue receives much less (1)

- e** Explain why the findings of studies into the effects of radiation on humans must be published and peer reviewed. Working scientifically · Separate Physics [2]

Other scientists check the methods and conclusions for errors or bias (1); so the evidence used to set safety limits is reliable (1)

11

A smoke alarm contains a source that emits alpha radiation.

- a** Explain why an alpha source is suitable for a smoke alarm.

Separate Physics only [3]

Alpha radiation ionises the air strongly, which is what the detector relies on (1); it is stopped by a few centimetres of air, so it cannot escape the device (1); and it cannot pass through the casing to reach people (1)

- b** Explain why a gamma source would be unsuitable.

Separate Physics only [2]

Gamma radiation would pass out of the alarm and expose people to radiation (1); and it ionises too weakly to be detected reliably by the alarm (1)

- c** Suggest why a source with a long half-life is used.

Separate Physics only [2]

The activity stays almost constant over many years (1); so the alarm continues to work without the source being replaced (1)

12

Describe the problems of disposing of radioactive waste from a nuclear power station, and how the risks are reduced.

Give your answer.

Separate Physics only [4]

Some isotopes have half-lives of thousands of years, so the waste stays dangerously radioactive far beyond human timescales (1); it must be sealed in glass or concrete to prevent leaks (1); and stored deep underground in stable rock, away from groundwater (1); sites must be monitored indefinitely, and there is public opposition to storage locations (1)

Examiner note: Examiners credited 'bury it underground' and 'bury it in landfill' but not 'keep it away from people', which is insufficient.

4.4.4 Nuclear fission and fusion

13

A nuclear power station uses the fission of uranium-235.

- a** Define nuclear fission. Separate Physics only [2]

The splitting of a large, unstable nucleus into two smaller nuclei (1); usually after it absorbs a neutron (1)

- b** State what else is released in a fission reaction. Separate Physics only [2]

Two or three neutrons (1); and energy (1)

- c** Describe how a chain reaction occurs. Separate Physics only [3]

The neutrons released by one fission are absorbed by other uranium-235 nuclei (1); causing further fissions, which release more neutrons again (1); so the number of fissions increases rapidly unless controlled (1)

- d** Explain the role of the control rods. Separate Physics only [3]

Control rods, usually boron, absorb neutrons (1); lowering them absorbs more neutrons, so fewer fissions occur and the rate slows (1); raising them allows the rate to increase, so the reaction is kept steady (1)

- e** Explain why a reactor is surrounded by thick concrete. Separate Physics only [2]

The concrete absorbs the neutrons and gamma radiation produced (1); protecting workers and the environment from ionising radiation (1)

- f** Define nuclear fusion and explain why extreme conditions are needed. Separate Physics only [4]

Fusion is the joining of two light nuclei to form a heavier nucleus (1); releasing energy, as some mass is converted into energy (1); the nuclei are both positively charged and repel each other (1); so very high temperatures and pressures are needed for them to get close enough to fuse (1)

14

Each fission of a uranium-235 nucleus releases 3.2×10^{-11} J of energy.

- a** Calculate the number of fissions needed each second for a power output of 1.6×10^9 W. Separate Physics · HT only [3]

Number per second = power $\div$ energy per fission (1); $= 1.6 \times 10^9 \div 3.2 \times 10^{-11}$ (1); $= 5.0 \times 10^{19}$ (1)

- b** Burning 1 kg of coal releases about 3×10^7 J. Compare this with nuclear fuel. Separate Physics only [3]

1 kg of uranium-235 releases of the order of 10^{14} J, roughly a million times more (1); a chemical reaction only rearranges electrons, releasing a few electronvolts per atom (1); fission changes the nucleus, converting a small amount of mass into a very large amount of energy (1)

Working scientifically

15

A student investigates how the count rate from a source changes with the thickness of aluminium placed between the source and the detector.

Thickness in mm	0	1	2	3	4	5
Count rate in counts per minute	720	410	238	140	86	60

- a Name the independent and dependent variables.

Working scientifically [2]

Independent: thickness of aluminium (1); dependent: count rate (1)

- b State two variables that must be controlled.

Working scientifically [2]

The distance between the source and the detector (1); the source used and the counting time (1)

- c The background count rate is 20 counts per minute. Calculate the corrected count rate at 3 mm.

Maths skill [1]

$140 - 20 = 120$ counts per minute (1)

- d Describe the pattern shown by the corrected results.

Working scientifically [2]

The count rate decreases as the thickness increases (1); by a roughly constant proportion for each extra millimetre, so the decrease is not linear (1)

- e Deduce which type of radiation the source emits, and justify your answer.

Working scientifically [3]

Beta (1); the count rate falls steeply as aluminium is added, so the radiation is being absorbed by a few millimetres of aluminium (1); alpha would have been stopped by the air or by the first sheet, and gamma would barely be reduced (1)

- f Explain why each reading is taken over a full minute rather than ten seconds.

Working scientifically [2]

Decay is random, so short counts vary a great deal (1); counting over a longer time reduces the effect of this random variation on the rate calculated (1)

16

Two students measure the half-life of the same source. Student A obtains 5.8 minutes, 6.1 minutes and 5.9 minutes. Student B obtains 4.9 minutes, 7.2 minutes and 6.0 minutes.

- a Calculate the mean of each student's results.

Maths skill [2]

A: $(5.8 + 6.1 + 5.9) \div 3 = 5.9$ minutes (1); B: $(4.9 + 7.2 + 6.0) \div 3 = 6.0$ minutes (1)

- b State which set of results is more precise, and explain why.

Working scientifically [2]

Student A (1); the repeated values are much closer together (1)

- c Explain why repeating the measurement is especially important for radioactive decay.

Working scientifically [2]

Decay is a random process, so individual measurements vary considerably (1); taking a mean of repeats gives a more reliable value (1)

- d Suggest why neither student can eliminate all variation.

Working scientifically [2]

The randomness of decay is a property of the process itself, not a fault in the method (1); so some variation remains however carefully the measurements are taken (1)

17

A newspaper reports: 'Living near a nuclear power station doubles your risk of cancer.' The study was based on 20 people living in one village.

- a** Give two reasons why this conclusion may not be reliable.

Working scientifically [2]

The sample size of 20 is very small, so the result could be due to chance (1); only one location was studied, and other factors such as age, smoking or occupation were not controlled (1)

- b** Describe how a more reliable study could be designed.

Working scientifically [3]

Use a much larger sample, from several locations near power stations (1); compare with a control group of similar age, lifestyle and occupation living further away (1); and measure the actual radiation dose received rather than assuming it (1)

- c** Explain why the study should be published in a peer-reviewed journal rather than only in a newspaper.

Working scientifically [2]

Peer review means other scientists check the method and conclusions before publication (1); a newspaper may simplify or exaggerate the findings to make a story (1)

18

The table shows data about four radioactive isotopes.

Isotope	Radiation emitted	Half-life
A	alpha	4.5 billion years
B	beta	6 hours
C	gamma	5 days
D	alpha	3 minutes

- a** Identify the isotope most suitable as a medical tracer, and justify your answer.

Separate Physics only [3]

Isotope C (1); gamma radiation passes out of the body and is weakly ionising (1); and a half-life of 5 days is long enough for the scan but short enough that the activity falls soon afterwards (1)

- b** Explain why isotope A is unsuitable for use in a hospital.

Separate Physics only [2]

Its half-life is extremely long, so it remains radioactive effectively for ever (1); and alpha radiation would be absorbed in the body, causing heavy ionisation of tissue (1)

- c** Isotope D has a half-life of 3 minutes. Calculate the fraction of the original nuclei remaining after 15 minutes.

Maths skill [2]

$15 \div 3 = 5$ half-lives (1); fraction = $1/32$ (1)

- d** Explain why a source with a very short half-life has a high activity to begin with.

[2]

A short half-life means nuclei decay quickly (1); so a large number of decays occur each second, which is a high activity (1)

19

A student is asked to find out whether a source emits beta or gamma radiation. The student says: 'I will hold a sheet of paper in front of it. If the count rate drops, it is beta.'

- a** Explain why this method would not work.

Working scientifically [2]

Paper stops alpha radiation, not beta (1); both beta and gamma pass through paper, so the count rate would barely change for either (1)

- b** Describe a method that would work.

Working scientifically [3]

Place a few millimetres of aluminium between the source and the detector (1); if the count rate falls almost to the background level, the source emits beta (1); if it is only slightly reduced, the source emits gamma, and thick lead would be needed to reduce it further (1)

- c** Explain why the background count rate must be measured and subtracted.

Working scientifically [2]

Background radiation is always present (1); without subtracting it the count rate would never fall to zero, and the comparison would be misleading (1)

20

Uranium-238 decays through a series of steps. In one step, thorium-234 (atomic number 90) emits a beta particle.

- a** Give the atomic number and mass number of the nucleus formed.

Maths skill [2]

Atomic number 91 (1); mass number 234 (1)

- b** Explain, in terms of the particles in the nucleus, what happens during beta decay.

[2]

A neutron in the nucleus changes into a proton and an electron (1); the electron is emitted at high speed as the beta particle, so the proton number rises by one while the total number of nucleons is unchanged (1)

- c** The nucleus formed then emits an alpha particle. Give the atomic number and mass number of the next nucleus.

Maths skill [2]

Atomic number 89 (1); mass number 230 (1)

21

A sample of carbon-14 in a piece of ancient wood has an activity of 3.0 counts per minute per gram. Living wood has an activity of 24 counts per minute per gram. The half-life of carbon-14 is 5730 years.

- a** Calculate the age of the wood.

Maths skill [3]

$24 \rightarrow 12 \rightarrow 6 \rightarrow 3$ is three half-lives (1); age = 3×5730 (1); = 17 190 years (1)

- b** State one assumption made in this calculation.

Working scientifically [1]

That the activity of carbon-14 in living wood was the same in the past as it is now (1)

- c** Explain why this method is unreliable for very old samples.

Working scientifically [2]

After many half-lives the activity is very low (1); so it is close to the background count rate and the random variation in counts becomes significant compared with the measurement (1)

- 22** Explain why alpha radiation is the most dangerous type if the source is inside the body, but the least dangerous if the source is outside the body.

Give your answer.

Separate Physics only [4]

Outside the body, alpha radiation is stopped by a few centimetres of air or by the dead outer layer of skin (1); so it does not reach living tissue (1); inside the body it is absorbed directly by living cells (1); and because it is strongly ionising it causes a great deal of damage over a short distance (1)

- 23** A technician measures the count rate at different distances from a gamma source.

Distance in cm	10	20	30	40	50
Corrected count rate in counts per second	400	100	44	25	16

- a** Describe the relationship between count rate and distance.

Working scientifically [2]

The count rate decreases as the distance increases (1); doubling the distance reduces the count rate to roughly a quarter, so it follows an inverse square relationship (1)

- b** Predict the count rate at 100 cm.

Maths skill [2]

100 cm is twice 50 cm, so the count rate falls to about a quarter (1); $16 \div 4 = 4$ counts per second (1)

- c** Explain how this relationship is used as a safety precaution.

Working scientifically [2]

Keeping a greater distance from a source greatly reduces the dose received (1); so sources are handled with tongs at arm's length rather than held (1)

- d** Suggest why the reading at 30 cm does not fit the pattern exactly.

Working scientifically [2]

Radioactive decay is random, so counts vary (1); and the distance may not have been measured exactly from the source itself (1)

- 24** Explain what is meant by the activity of a radioactive source, and describe how activity and half-life are related.

- a** Define activity and give its unit.

[2]

The rate at which nuclei in a sample decay (1); measured in becquerels, Bq, where 1 Bq is one decay per second (1)

- b** Explain why a source with a short half-life has a high initial activity for the same number of nuclei.

[2]

A short half-life means each nucleus is more likely to decay in a given time (1); so more decays occur each second, giving a higher activity (1)

- c** Explain why the activity of any source decreases with time.

[2]

The number of undecayed nuclei remaining falls (1); so fewer decays occur each second (1)

25

In 1911 Rutherford's model of the atom replaced the plum pudding model. In 1932 Chadwick discovered the neutron.

- a** Explain why the acceptance of a new scientific model usually takes time. Working scientifically [3]

Other scientists must repeat the experiments and check that the results can be reproduced (1); the work is peer reviewed before publication (1); and the new model must explain the existing evidence as well as the new observations (1)

- b** Suggest why the discovery of the neutron did not overturn the nuclear model. Working scientifically [2]

The neutron fitted within the existing nuclear model rather than contradicting it (1); it explained the mass of the nucleus and the existence of isotopes, so the model was refined rather than replaced (1)

26

A student says: 'An atom that has lost an electron is called an isotope.'

- a** Explain why the student is wrong, and give the correct term. [2]

An atom that has lost or gained electrons is an ion, which has an overall charge (1); isotopes differ in the number of neutrons, not electrons (1)

- b** State what happens to the mass number of an atom when it loses an electron. [1]

It is unchanged, because the mass number counts only protons and neutrons (1)

- c** Explain how an atom can become a positive ion. [2]

It loses one or more electrons (1); so there are more protons than electrons and the overall charge is positive (1)

Extended response

27

A school keeps three sealed sources: one alpha, one beta and one gamma emitter.

Describe an investigation to identify which source is which, and explain the safety precautions needed. You should refer to the equipment used and the results you would expect. [6]

Level 3 (5–6 marks): a complete method with expected results for all three sources and relevant precautions. Level 2 (3–4 marks): a workable method with some results or precautions. Level 1 (1–2 marks): simple statements.

Indicative content: measure the background count rate first, with no source present, and subtract it from all readings; place each source a fixed distance from a Geiger-Müller tube; record the count rate with nothing, then paper, then a few millimetres of aluminium, then thick lead between source and detector; the alpha source is stopped by the paper; the beta source passes through paper but is stopped by aluminium; the gamma source is only reduced by the lead; repeat each reading and count over a long enough period because decay is random; keep the distance and counting time the same for a fair comparison; handle sources with tongs, keep them at arm's length pointing away from people, limit exposure time and return them to a lead-lined container.

28

Compare nuclear fission and nuclear fusion as ways of generating electricity.

Your answer should refer to the process, the conditions required, the waste produced and the current practicality of each.

[6]

Level 3 (5–6 marks): a detailed comparison covering all four areas. Level 2 (3–4 marks): several points covering two or three areas. Level 1 (1–2 marks): isolated statements.

Indicative content: fission splits a large unstable nucleus, usually uranium-235, after it absorbs a neutron; fusion joins two light nuclei, such as isotopes of hydrogen, to form a heavier one; both convert a small amount of mass into a large amount of energy; fission occurs readily at ordinary temperatures once a neutron is absorbed, and is controlled with control rods and a moderator; fusion requires temperatures and pressures like those inside a star, because the positive nuclei repel one another; fission produces radioactive waste that stays dangerous for thousands of years, and carries a risk of a serious accident; fusion produces far less radioactive waste and its fuel is readily available from water; fission is used commercially now, whereas no fusion reactor yet produces more energy than it consumes, so it remains experimental.