Page 449 Test yourself on prior knowledge

1 The atom has a very small nucleus, of the order of 10^{-15} m in radius; the atom has a radius of order 10^{-10} m. The nucleus contains protons and neutrons, which comprise nearly all the mass of the atom. The number of protons, each with one positive charge, is balanced by an equal number of negatively charged electrons outside the nucleus.

2 Alpha particles travel about 5 cm through air and are stopped by pieces of paper or metal foils.
Beta particles travel several metres in air and can be stopped by an aluminium foil a few mm thick.
Gamma rays can travel an infinite distance in a vacuum, and are reduced in intensity by thick sheets of lead.

3 a) An element is determined by the number of protons in the nucleus. However, isotopes of an element have the same number of protons, but different number of neutrons.

b) $^{254}_{102}\text{No} \rightarrow {}^{250}_{100}\text{Fm} + {}^{4}_{2}\text{He}$

4 $^{85}_{36}\text{Kr} \rightarrow {}^{85}_{37}\text{Rb} + {}^{0}_{-1}\text{e} + \bar{\nu}_e$

Page 452 Test yourself

1 You need to make about six points here.

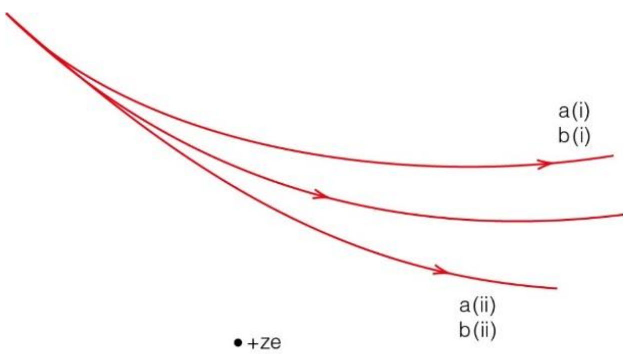
- Describe the apparatus (see Figure 24.1 on page 450).
- Describe how many particles were deflected through various angles: most by nearly nothing; a very small number – one or two in ten thousand – bounce back through very large angles.
- Bouncing back implies a region of positive charge with a large nuclear mass.
- A small fraction bouncing back through large angles implies small nucleus.

2 a) Alpha particles only travel about 5 cm through air.

b) A thicker foil will stop the alpha particles completely.

c) Alpha particles are stopped by the lead; they can only escape through the long narrow hole at the front. So they travel at a narrow range of angles – or in a well-directed beam.

3



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4 a) The 7.7 MeV is transferred to electrical potential energy at the point of closest approach:

$$eV = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r}$$

$$7.7 \times 10^6 \times 1.6 \times 10^{-19}\text{ J} = \frac{(13\times1.6\times10^{-19}\text{C})\times(2\times1.6\times10^{-19}\text{C})}{4\pi\times(8.85\times10^{-12}\text{Fm}^{-1})\times r}$$

$r = 4.9 \times 10^{-15}$ m or 4.9 fm

b) i) $$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

$$= \frac{(13\times1.6\times10^{-19}\text{C})\times(2\times1.6\times10^{-19}\text{C})}{4\pi\times(8.85\times10^{-12}\text{Fm}^{-1})\times(4.9\times10^{-15}\text{m})^2}$$

= 250 N

ii) a = F/m

$$= \frac{250\text{ N}}{6.8\times10^{-27}\text{kg}}$$

$= 3.7 \times 10^{28}$ m s^{-1}

Page 455 Test yourself

5 a) 7.5×10^{-15} m (or 7.5 fm)

b) m = ρ V

$$\rho = \frac{m}{V}$$

$$= \frac{238\times1.67\times10^{-27}\text{kg}}{\frac{4}{3}\pi\times(7.5\times10^{-15}\text{m})^3}$$

$= 2.3 \times 10^{17}$ kg m^{-3}

6 a) You should include the following ideas: electrons have a wavelength; fast moving electrons have a wavelength comparable to the nuclear diameter; nuclei scatter the electrons; and the position of diffraction minima can be related to the electron wavelength and nuclear diameter.

b) Electrons are scattered off the nuclei so give direct data about the nuclear size. In Rutherford scattering, the alpha particles do not reach the nucleus, so we just get a maximum possible size for the nucleus.

7 a) i) Transuranic means beyond or above uranium in the periodic table.

ii) Any element above uranium is unstable and must be artificially produced.

b) $r = r_0 A^{\frac{1}{3}}$

$= 1.2\text{ fm} \times 293^{\frac{1}{3}}$

= 8.0 fm

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8 a) p $= \frac{E}{c}$

$= \frac{890\times10^{6}\times1.6\times10^{-19}\text{J}}{3\times10^{8}\text{m s}^{-1}}$

$= 4.7 \times 10^{-19}$ kg m s^{-1}

b) λ $= \frac{h}{p}$

$= \frac{6.6\times10^{-34}\text{J s}}{4.7\text{ x }10^{-19}\text{kg m s}^{-1}}$

$= 1.4 \times 10^{-15}$ m

c) For gadolinium: θ = 15°

For calcium: θ = 24°

i) $\sin\theta = \frac{1.22\lambda}{d}$

d $= \frac{1.22\lambda}{\sin\theta}$

$= \frac{1.22\times1.4\times10^{-15}\text{m}}{\sin(15)}$

$= 6.6 \times 10^{-15}$ m

r = 3.3 fm

ii) d $= \frac{1.22\lambda}{\sin\theta}$

$= \frac{1.22\times1.4\times10^{-15}\text{m}}{\sin(24)}$

$= 4.2 \times 10^{-15}$ m

r = 2.1 fm

d) Figure 24.7 gives the following values:

gadolinium-160, r = 6.6 fm

calcium-40, r = 4.1 fm

These are both significantly larger than the values calculated in **c)**

Page 459 Test yourself

9 Yes, the electroscope still discharges. The alpha source produces positive and negative ions. Now the positive ions are attracted towards the negatively charged electroscope to discharge it.

10 a) Background radiation is ionising radiation which is present in the environment. It comes from a range of sources in nature including outer space and rocks surrounding us. A small amount of radiation is also produced in industrial processes (e.g. coal burning), medical treatment and by nuclear power stations.

b) You can set up a GM tube and counter. Then simply measure the background count over an hour.

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11 a) Use the left hand rule. This shows that the current is moving right to left.
Since the current carrying particles are moving left to right, they must be negatively charged.

b) For deflection in a field we can write:

$$Bqv = \frac{mv^2}{r}$$

$$\text{So } r = \frac{mv}{Bq}$$

So, faster-moving particles (v is velocity) move in a larger circle (r is the radius).
Hence, the ones deflected by 20°, which are moving in a larger circle, are travelling faster.

Page 460 Activity

Identification of radiations

1 Average background count = 330 counts/15 minutes = 22 counts per minute

2 There is a significant change to the count rate when paper is used as an absorber so α-particles produce a count rate of 5054 – 3294 ≈ 1 800 counts per minute.
There are no γ-rays from the source because the background count is all that is left when the lead absorbers are in place.
Therefore, β-particles produce the remaining count.

2 This source emits β-particles and γ-rays.
The lead reduces the radiation but does not stop it completely, showing γ-rays are emitted.
Aluminium also reduces the count rate, showing β-particles are emitted, but paper has no effect.

Pages 461–462 Required practical 12

Inverse square law for γ-radiation

1 and 2

GM count over 10 seconds	431	260	195	138	110	81	73	61
x/cm	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
Corrected count (I)	428	257	192	135	107	78	70	58
$I^{-\frac{1}{2}}$	0.048	0.062	0.072	0.086	0.096	0.113	0.120	0.131

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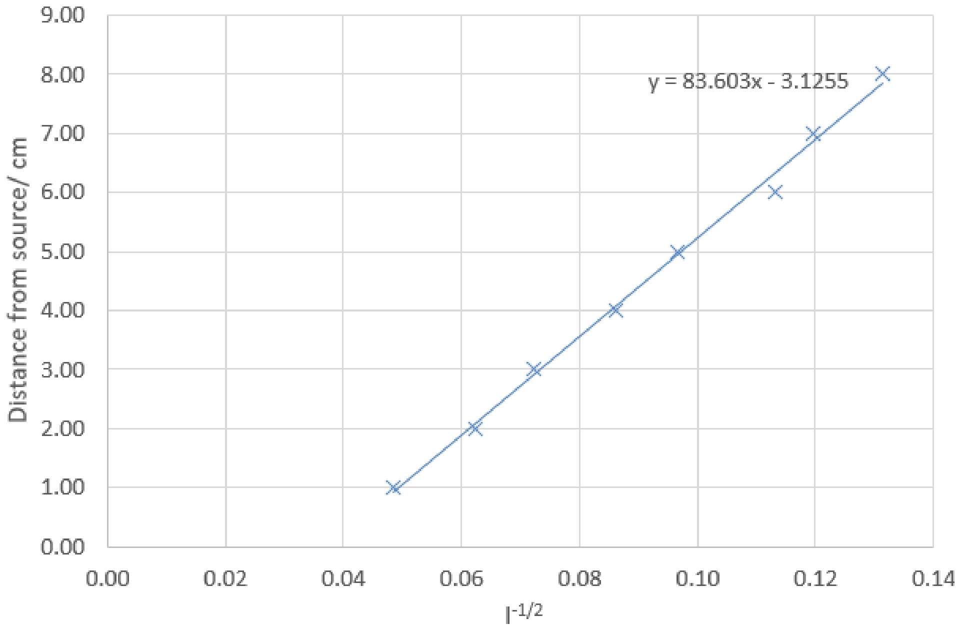
3 a) A graph of distance, *x*, against $I^{-1/2}$ is a straight line, confirming that $I \propto \frac{1}{(x+c)^2}$ to within a reasonable experimental error.



b) Comparing $x + c = \left(\frac{k}{I}\right)^{\frac{1}{2}}$ with the equation of a straight line shows that the gradient is $k^{\frac{1}{2}}$ and the intercept on the *y*-axis is –*c*. The intercept is −3.1255 so
c = 3.1 cm

Page 463 Test yourself

12 You need to summarise the activity in which radiations were identified by using various absorbers described in the Activity on page 460.

13 $I \propto \frac{1}{x^2}$ which can be written $\frac{I_2}{I_1} = \frac{{x_1}^2}{{x_2}^2}$

So, count rate at 0.5m, I_2 = 200 Bq × $\left(\frac{0.2\text{ m}}{0.5\text{ m}}\right)^2$

= 32 Bq

14 a) E = hf

$= \frac{hc}{\lambda}$

$= \frac{6.6\times10^{-34}\text{J s}\times3\times10^{8}\text{m s}^{-1}}{2\times10^{-7}\text{m}}$

= 9.9×10^{-19} J

= (9.9×10^{-19} /1.6×10^{-19}) eV = 6.2 eV

b) Molecules can be ionised with energies of a few eV. So, ultraviolet light can ionise molecules in the skin, thus changing their chemical behaviour. Chemical changes can damage our cells.

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15 a) Ionising radiation produces ion pairs in material through which it travels.

b) When a molecule is ionised, it behaves in a different chemical way. Chemical change can damage our cells – leading to illnesses such as cancer.

16 a) The gamma source is more dangerous. The γ-rays can penetrate through the lead and reach people. Alpha particles can only travel 5 cm through air so do not reach the pupils.

b) i) Radon gas can be inhaled. So alpha particles can be emitted by the gas inside our lungs. Alpha particles are highly ionising and so cause more damage.

ii) Although γ-rays can reach people from rocks because they are so penetrating, γ-rays are less ionising than alpha particles and so cause less damage to our bodies.

Pages 464–466 Practice questions

1 C

2 C

3 D

4 B

5 A

6 D

7 B

8 D

9 C

10 A

11 a) $R = 1.2 \times 138^{1/3} \times 10^{-15}$ m

$= 6.2 \times 10^{-15}$ m [1]

Volume $= \frac{4}{3}\pi R^3$

$= \frac{4}{3}\pi \times (6.2 \times 10^{-15})^3$

$= 1.0 \times 10^{-42}$ m^3 [1]

Density $= \frac{\text{mass}}{\text{volume}}$

$= \frac{138 \times 1.67 \times 10^{-27}\ \text{kg}}{1.0 \times 10^{-42}\ \text{m}^3}$

$= 2.3 \times 10^{17}$ kg m^{-3} [1]

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b) Volume $= \frac{\text{mass}}{\text{density}}$

$= \frac{4 \times 10^{30}\ \text{kg}}{2.3 \times 10^{17}\ \text{kg m}^{-3}}$

$= 1.73 \times 10^{13}\ \text{m}^3$ [1]

Volume $= \frac{4}{3}\pi R^3$

$r^3 = \frac{3V}{4\pi}$

$r = \left(\frac{3V}{4\pi}\right)^{\frac{1}{3}}$ [1]

$= \left(\frac{3 \times 1.73 \times 10^{13}\ \text{m}^3}{4\pi}\right)^{\frac{1}{3}}$

= 16 000 m or 16 km [1]

12 Place a gamma source a distance x from a GM tube. [1]

Record counts for different values of x. [1]

Correct the counts for background. [1]

Since the GM tube may not detect near its window, but detecting inside the tube, the length also needs to be corrected. [1]

So $I = \frac{k}{(x+c)^2}$ [1]

Plot x against $I^{-1/2}$ to see if it is a straight line. [1]

(Full marks could still be awarded if you suggest plotting I against $\frac{1}{x^2}$)

13 a) Any two points from: [2]

- Protect the patient with lead to cover parts of the body not to be exposed to radiation.
- Calculate the dose carefully.
- Direct the dose accurately; direct the dose from different directions towards the cancer so that it passes through different parts of the body, thereby minimises damage to healthy tissue.

b) Any two points from: [2]

- The radiographer should handle the source remotely with tongs or a machine.
- The radiographer should be protected by a screen.
- The radiographer should be a long way from the source while the dose is given.
- The source is immediately stored in its lead case once the dose is given.

14 a) When the alpha particle reaches the end of its track it has slowed down. [1]
It spends more time near each atom so it is more effective at producing ions. [1]

b) This is the area under the graph which is about 36 large squares [1]
and equivalent to about 36 × 1000 ion-pairs per mm × 5 mm, i.e. about 180 000 ion-pairs. [1]

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c) Energy of the alpha particle is:

30 eV per ion-pair × 180 000 ion-pairs

= 5 400 000 eV or 5.4 MeV

15 a) Fraction of the gamma rays passing through the tube is:

$\frac{3.2 \times 10^{-4}\ \mathrm{m}^2}{4\pi \times (0.15)^2} = 1.13 \times 10^{-3}$ [1]

So the fraction of the total detected is:

$\frac{1.13 \times 10^{-3}}{500} = 2.26 \times 10^{-6}$ [1]

Count rate = 2.26×10^{-6} × total emissions per second. [1]

So total emissions per second:

$\frac{38\ \mathrm{Bq}}{2.26 \times 10^{-6}} = 1.7 \times 10^{7}$ Bq [1]

b) Energy emitted per second is:

E $= 1.7 \times 10^{7}$ Bq × 1.2 MeV [1]

$= 1.7 \times 10^{7}\ \mathrm{s}^{-1} \times 1.2 \times 10^{6} \times 1.6 \times 10^{-19}\ \mathrm{J} = 3.2 \times 10^{-6}\ \mathrm{J\ s}^{-1}$ [1]

c) Count rate $= \frac{k}{x^2}$

$c_1 x_1^2 = c_2 x_2^2$

$c_2 = \frac{c_1 x_1^2}{x_2^2}$

$= 38\ \mathrm{Bq} \times \left(\frac{0.15}{0.10}\right)^2$

= 86 Bq

16 a) $F \propto \frac{1}{r^2}$ [1]

so the force on A is 4 times that on B. [1]

b) A is travelling faster. [2]
It experiences four times the force on B, but bends along the same radius of path. [2]

17 a) ${}^{27}_{13}\mathrm{Al} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{30}_{15}\mathrm{P} + {}^{1}_{0}\mathrm{n}$

A neutron is produced. [1]

b) $\mathrm{PE} = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$ [1]

$r = \frac{q_1 q_2}{4\pi\varepsilon_0 E}$

$= \frac{(13 \times 1.6 \times 10^{-19}\ \mathrm{C}) \times (2 \times 1.6 \times 10^{-19}\ \mathrm{C})}{4\pi \times 8.85 \times 10^{-12}\ \mathrm{Fm}^{-1} \times 10^{-12}\ \mathrm{J}}$ [1]

$= 6.0 \times 10^{-15}$ m [1]

c) The nuclear force is very short range so it does not act over larger distances. Slower alpha particles are repelled by the electrostatic force from the nucleus. [1]

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Pages 466–467 Stretch and challenge

18 a) Number of atoms $= \dfrac{\text{thickness of foil}}{\text{diameter of one atom}}$

$= \dfrac{2 \times 10^{-6}\,\text{m}}{1.5 \times 10^{-10}\,\text{m}}$

= 13 000 atoms (2sf)

b) If probability scattering ∝ number of atoms

$$\frac{P_2}{P_1} = \frac{n_2}{n_1}$$

so $P_2 = \dfrac{1\text{ atom}}{13000\text{ atoms}} \times \dfrac{1}{20\,000}$

= 1 in 2.6×10^8 (i.e. one in 260 million)

c) This probability corresponds to the ratio of the cross-sectional areas:

$$\frac{A_{atom}}{A_{nucleus}} = 2.6 \times 10^8$$

d) Since $A \propto d^2$

$$\frac{d_{atom}}{d_{nucleus}} = \sqrt{2.6 \times 10^8}$$

$$d_{nucleus} = \frac{1.5 \times 10^{-10}\,\text{m}}{\sqrt{2.6 \times 10^8}}$$

$d_{nucleus} = 9.3 \times 10^{-15}$ m

The nucleus is likely to be smaller than this because the particles will be scattered before they actually make contact with the nucleus.

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