

1

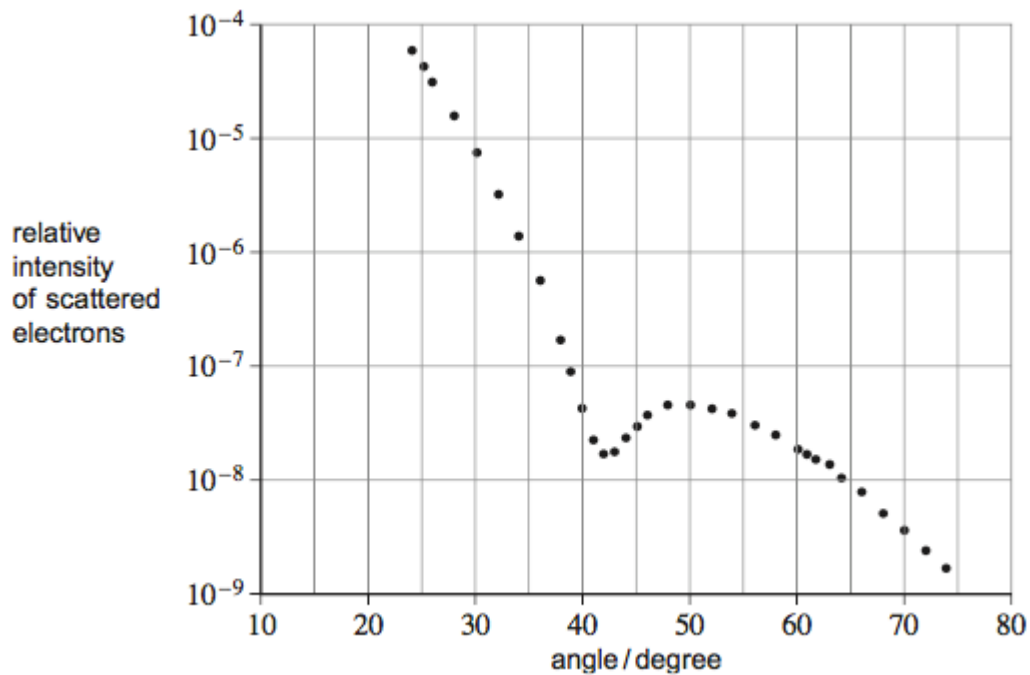
- (a) The radius of a nucleus may be determined by electron diffraction. In an electron diffraction experiment a beam of electrons is fired at oxygen-16 nuclei. Each electron has an energy of $5.94 \times 10^{-11} \text{ J}$.

The approximation, $\text{momentum} = \frac{\text{energy}}{\text{speed of light}}$ can be used for electrons at this energy.

- (i) Show that the de Broglie wavelength λ of each electron in the beam is about $3.3 \times 10^{-15} \text{ m}$.

(2)

- (ii) The graph shows how the relative intensity of the scattered electrons varies with angle due to diffraction by the oxygen-16 nuclei. The angle is measured from the original direction of the beam.



The angle θ of the first minimum in the electron-diffraction pattern is given by

$$\sin \theta = \frac{0.61\lambda}{\text{nuclear radius}}$$

Calculate the radius of an oxygen-16 nucleus using information from the graph.

radius = _____ m

(1)

- (b) Rutherford used the scattering of α particles to provide evidence for the structure of the atom.

- (i) Sketch a labelled diagram showing the experimental arrangement of the apparatus used by Rutherford.

(2)

- (ii) State and explain the results of the scattering experiment.
Your answer should include the following:

- the main observations
- the significance of each observation
- how the observations placed an upper limit on the nuclear radius.

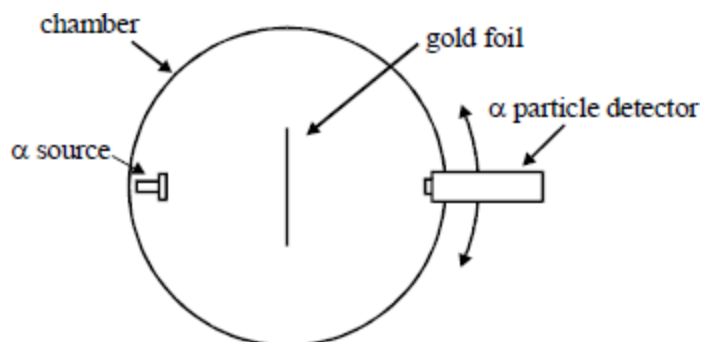
The quality of your written communication will be assessed in your answer.

(6)

(Total 11 marks)

2

The diagram below shows the apparatus used to investigate Rutherford scattering, in which α particles are fired at a gold foil.



- (a) Why is it essential for there to be a vacuum in the chamber?

(2)

- (b) What observations made with this apparatus support each of the following conclusions?
No explanation is required.

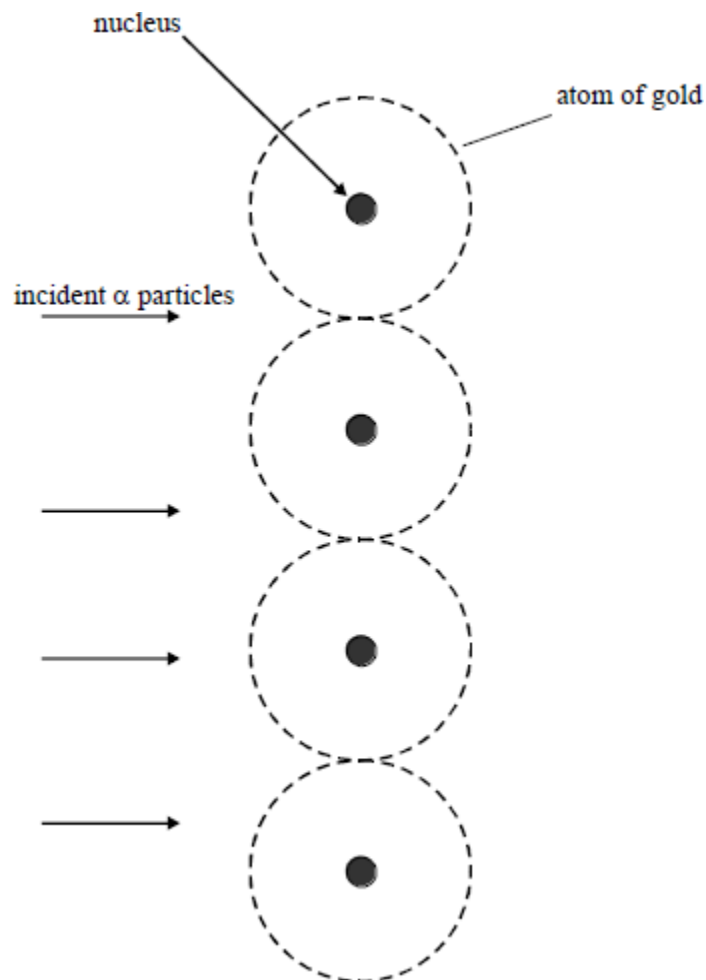
- (i) The nuclear radius of gold is much smaller than its atomic radius.

- (ii) Most of the mass of an atom of gold is contained in its nucleus.

(3)

- (c) The drawing below shows α particles incident on a layer of atoms in a gold foil.

On this figure draw the complete path followed by **each** of the α particles shown.



(3)

(Total 8 marks)

3

- (a) (i) Why is it necessary to remove the air from the chamber in a Rutherford scattering experiment?

- (ii) Give **two** conclusions that can be deduced about the nucleus from the results of such an experiment.

conclusion 1 _____

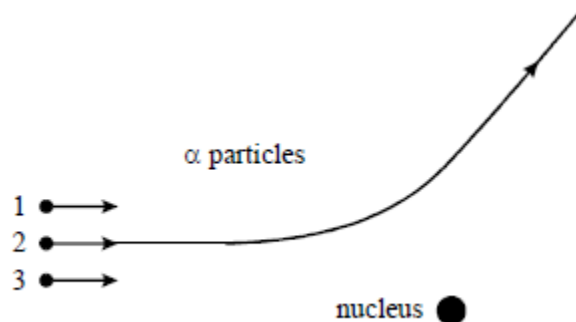
conclusion 2 _____

(iii) What force or interaction is responsible for Rutherford scattering?

(4)

- (b) The figure shows three α particles, all with the same kinetic energy, directed at a nucleus. The path followed by α particle 2 is given.

Draw lines on the figure to show the paths followed by α particles 1 and 3.

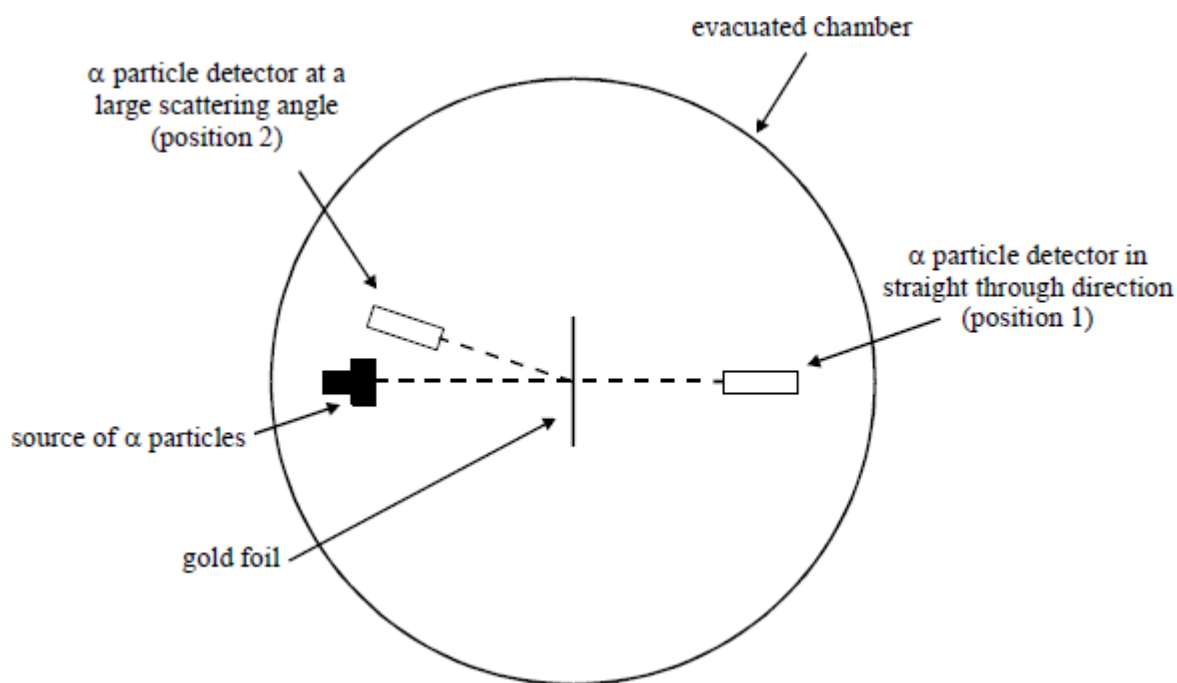


(2)

(Total 6 marks)

4

The figure below represents an experiment on Rutherford scattering in which α particles are directed at a gold foil. The detector is shown in two positions in the evacuated chamber.



- (a) Why is it necessary to remove the air from the apparatus?

- (b) Explain why the gold foil should be very thin.

- (c) Explain why the count rate from the α particle detector in position 1 is much greater than that in position 2.

What can be deduced from this observation about the structure of the atom and the properties of the nucleus of gold?

(Total 6 marks)

5

- (a) An α particle source of half-life 3420 years has a rate of decay of 450 kBq. Calculate

- (i) the decay constant, in s^{-1} ,

- (ii) the number of radioactive atoms in the source.

(4)

- (b) A narrow beam of α particles is directed at a thin gold foil target in an evacuated vessel. Only a very small proportion of the α particles scatter backwards at an angle greater than 90° to the direction from which they came

- (i) Describe what happens to the majority of the α particles incident on the gold foil.

- (ii) Several deductions may be made about the structure of gold atoms from the results of α^- particle scattering. Write down **two** of these deductions.

(3)

(Total 7 marks)

6 In an experiment to investigate the structure of the atom, α particles were aimed at thin gold foil in a vacuum. A detector was used to determine the number of α particles deflected through different angles.

- (a) State **two** observations about the α particles detected coming from the foil.

(2)

- (b) State **two** features of the structure of the atom which can be deduced from these observations.

(2)

(Total 4 marks)

Mark schemes

1

- (a) (i) momentum ($= E/c$)
 $= 5.94 \times 10^{-11} / 3.00 \times 10^8 = 2.0 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$
 $(= 1.98 \times 10^{-19} \text{ kg m s}^{-1})$
 Or evidence of use of $E = hc / \lambda$ ✓
 $\lambda = (h / mv = 6.63 \times 10^{-34} / 1.98 \times 10^{-19}) = 3.35 \times 10^{-15} \text{ (m)}$ ✓
 (allowable range $3.32 \times 10^{-15} - 3.37 \times 10^{-15} \text{ m}$)

$3.348 \times 10^{-15} \text{ m}$ alone may score 1 mark

A completed calculation to at least 3 sf must be seen for 2nd mark

2

- (ii) nuclear radius $= 0.61 \lambda / \sin \theta = 0.61 \times 3.35 \times 10^{-15} / \sin 42^\circ$
 $= 3.1 \times 10^{-15} \text{ (m)}$ ✓ (allow $2.95 - 3.1 \times 10^{-15} \text{ m}$ which is a range
 incorporating $3.32 \times 10^{-15} - 3.37 \times 10^{-15} \text{ m}$ and $42^\circ - 43^\circ$)
 (The answer must be to 2 sf or better
 note 3.3×10^{-15} , 42° gives $3.008 \times 10^{-15} \text{ m}$ i.e. 3.0×10^{-15})

1

- (b) (i) diagram to show a labelled α source, foil target and detector (which is not simply a forward facing screen so there must be some indication it can move around the target e.g. a curved arrow / positioned at an angle / or screen curved round target or detectors shown in at least two positions) ✓

with evacuated vessel or an item to collimate the beam ✓ (the evacuated vessel does not have to be drawn so a simple label of 'in a vacuum' will gain the mark.) (A tube or a plate(s) must be drawn with a collimator label or a label on an emergent alpha beam from the drawn item (which is distinct from the source) will gain a mark)

'detector' has alternatives e.g. fluorescent screen / scintillator / zinc sulphide

2

- (ii) The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).

Descriptor

High Level – Good to Excellent

Both observations should be given ie most α particles pass straight through the foil and that some α 's are backscattered. Again both of these must be explained. Additionally one approach to finding the upper limit to the radius must be given and interpreted.

The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.

6 marks = all 3 bullet points covered in full.

5 marks = Same as 6 marks but one explanation is omitted or poorly expressed

Intermediate Level – Modest to Adequate

Both observations should be given ie most α particles pass straight through the foil and that some α 's are backscattered. Both of these observations can be explained or one of them explained along with the observation necessary to obtain the upper limit to the nuclear radius but without the explanation of how to use the data.

The grammar and spelling may have a few shortcomings but the ideas must be clear.

4 marks = for first two bullet points covered in full.

Alternatively both observations given but only one explained along with an observation necessary to find the upper limit to the nuclear radius.

3 marks = for both observations given but only one explained

3 - 4

Low Level – Poor to Limited

Any two observations or interpretations but an interpretation must come with the appropriate observation.

There may be many grammatical and spelling errors and the information may be poorly organised.

2 marks for two observations or one observation along with its interpretation.

1 mark = Any observation..

1 - 2

The description expected in a competent answer should include:

1. most α particles pass straight through
2. which suggests an atom is composed of mainly open space
3. α particles can be backscattered or scattered by more than 90°
4. which suggests
 - i. they have collided with something more massive than themselves (using momentum considerations)
 - ii. they have been repelled by a concentrated positive charge (using coulomb repulsion)
5. these together suggest a 'solar system' configuration for the atom.
6. Consider the proportion of α 's passing straight through the foil, i.e. how much of the straight through beam is stopped by the foil.

Or

Appreciate that scattering of α 's close to 180° takes place which means the α 's have not touched the nuclear surface.

6. First alternative data can be related to how much of the beam is intercepted by nuclei. Using the number of atomic layers / thickness of foil and the nuclear cross-sectional area the upper limit to the radius may be found

Or If second alternative is used some detail is needed to gain this point.

Either a discussion of the loss KE = gain PE to find upper limit to the radius

Or the idea that backscattering is not observed / falls off if the alpha comes close to the nucleus because the strong nuclear force (SNF) takes over and so provides an upper limit to the radius.

(owtte)

Do not award 'large space between atoms'.

The question is a QWC and not all the points are expected to be given as detailed on the left. This check list gives a brief idea of the main parts expected.

(note the pairing of 1 and 2, 3 and 4, 5 and 6 where the second of each pair cannot be given in isolation but the first of each pair does not have to perfect)

If it is obvious the candidate is talking about an alpha particle but calls it something different do not over penalise. E.g. miss out a pairing of marks then mark as if alpha)

Quick check list.

1. Most alpha's go straight on
2. Because an atom has mainly empty space
3. A few alpha's are backscattered
4. Because of nuclear positive charge or large nuclear mass
5. Method suggested to find R (drop in straight on beam Or backscattering means α 's have not touched nucleus)
6. Some detail such as ref. to (nuclear) area and (foil) thickness Or alpha KE to PE giving r Or if α 's touch surface SNF stops scattering.

[11]

2

- (a) to prevent the α particles being absorbed or scattered (1)
by air molecules (1)

(2)

- (b) (i) little or no deflection **(1)**
by a majority of α particles **(1)**
- (ii) some α particles suffer large deflection
[or backscattering occurs] **(1)**
- (3)
- (c) **first** path continues undeflected **(1)**
third path shows backscattering (inside the dotted circle) **(1)**
second path undeflected or deflected downwards and
fourth path undeflected or deflected upwards **(1)**
- (3)

[8]

3

- (a) (i) to prevent absorption/deflection/interaction/collision
of the α particle (by the air) **(1)**
- (ii) (nucleus) has a positive charge
(or same charge sign as an α particle
(nucleus) contains most of the mass (or is very dense) **(1) (1)** (any two)
(nucleus) is small compared to the separation between nuclei
- (iii) electromagnetic or electrostatic or Coulomb **(1)**
- (b) (particle 1) path is straighter than path of particle 2 **(1)**
(particle 3) path is bent more than path of particle 2, with
minimum radius of curvature near the minimum separation
and in front of the nucleus **(1)**

4

2

[6]

4

- (a) α particles have a short range in air (3–5 cm) **(1)**
(or to minimise collisions between α particles and air molecules) **(1)**
- (b) the α particles must not be absorbed by the foil **(1)**
(or the α particles must only be scattered once) **(1)**
- (c) a majority of α particles pass straight through **(1)**
most α particles do not pass close enough to be deflected
(or few pass close enough to be deflected significantly) **(1)**
- atoms consist mainly of open space **(1)**
nuclei are very small (or nucleus much smaller than the atom) **(1)**
the nucleus is massive (or most of the mass of the atom is contained in the nucleus)
the nucleus is positively charged
- (or the nucleus and the α particle have the same charge) **(1)**

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part.

[6]

5

(a) (i) $\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3420 \times 365 \times 24 \times 3600} \quad (1)$
 $= 6.43 \times 10^{-12} \text{ (s}^{-1}\text{)} \quad (1)$

(ii) $N = \frac{1}{\lambda} \frac{dN}{dt} = \frac{450 \times 10^3}{6.43 \times 10^{-12}} \quad (1)$

$= 7.0 \times 10^{16} \quad (1)$

(4)

(b) (i) pass through with no [or very small] deflection **(1)**

(ii) volume of nucleus << volume of atom (*)
 [or nucleus small and atom mostly empty space] (*)
 most of mass in nucleus (*)
 nucleus has positive charge (*)
 size of nucleus << separation (*)
 (*) any two **(1) (1)**

(3)

[7]**6**

(a) alpha particles undeflected **(1)**
 some through small angles **(1)**
 (very) small (but significant) number deflected through > 90° **(1)**

max 2

(b) atom mostly empty space **(1)**
 positive charge concentrated **(1)**
 in a volume much less than total volume [or radius] **(1)**

max 2

[4]