Nuclear Radius

Mark Scheme

Name: ________________________

Class: ________________________

Date: ________________________

Time:	**98 minutes**
Marks:	**70 marks**
Comments:	

Mark schemes

1 **D**

[1]

2 **C**

[1]

3 C

[1]

4 B

[1]

5 (a) $^{27}_{13}\text{Al} + \alpha \rightarrow {}^{30}_{15}\text{P} + {}^{(1)}_{(0)}\text{n}$ ✓

1

(b) kinetic energy lost by the α particle approaching the nucleus is equal to the potential energy gain ✓

$$2.18 \times 10^{-12} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{13 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19}}{r}$$ ✓

$r = 2.75 \times 10^{-15}$ (m) ✓

3

[4]

6 **A**

[1]

7 (a) (i) electromagnetic / electrostatic / Coulomb (repulsion between the alpha particles and the nuclei) ✓

The interaction must be named not just described.

1

(ii) the scattering distribution remains the same (because the alpha particles interact with a nucleus) whose charge / proton number / atomic number remains the same or the (repulsive) force remains the same

The mark requires a described distribution <u>and the reason</u> for it.

Or

the scattering distribution changes / becomes less distinct because there is a mixture of nuclear <u>masses</u> (which gives a mixture of nuclear recoils) ✓ (owtte)

A reference must be made to mass and not density or size.

1

(b) (i) use of graph to find r_0

e.g. $r_0 = 6.0 \times 10^{-15} / 75^{1/3}$ ✓

(or $8.0 \times 10^{-15} / 175^{1/3}$)

($r_0 = 1.43 \times 10^{-15}$ m)

Substitution and calculation t must be shown.

Condone a gradient calculation on <u>*R against A*$^{1/3}$</u> *graph (not graph in question) as* $R \propto A^{1/3}$

1

(ii) **Escalate if clip shows $^{27}_{13}$Al in the question giving $R \approx 4 \times 10^{-15}$ m.**

(using $R = r_0 A^{1/3}$)

$R = 1.43 \times 10^{-15} \times 51^{1/3}$ ✓

$R = 5.3 \times 10^{-15}$ (m) ✓

($R = 5.2 \times 10^{-15}$ m from

$r_0 = 1.4 \times 10^{-15}$ m)

First mark for working.

Second mark for evaluation which must be 2 or more sig figs allow CE from (i) R = 3.71 × (i).

***Possible escalation**.*

2

(c) **Escalate if clip shows $^{27}_{13}$ in the question and / or the use of 27 in the working.**

density = mass / volume
$m = 51 \times 1.67 \times 10^{-27}$
($= 8.5 \times 10^{-26}$ kg)

Give the first mark for substitution of data into the top line or bottom line of the calculation of density.

$v = 4/3\pi\ (5.3 \times 10^{-15})^3$
($6.2(4) \times 10^{-43}$ m^3)

In the second alternative the mark for the substitution is only given if the working equation is given as well.

Or
density = $A \times$ u / $4/3\pi\ (r_0\ A^{1/3})^3$
= u /$4/3\pi\ (r_0\ )^3$

$51 \times 1.67 \times 10^{-27}$ would gain a mark on its own but 1.66×10^{-27} would need u / $4/3\ \pi(r_0)^3$ as well to gain the mark.

top line = 1.66×10^{-27}

bottom line = $4/3\pi\ (1.43 \times 10^{-15})^3$

✓ for one substitution

density = 1.4×10^{17} ✓
(1.37×10^{17})
kg m^{-3} ✓

Expect a large spread of possible answers. For example
If $R = 5 \times 10^{-15}$ $V = 5.24 \times 10^{-43}$ and density = 1.63×10^{17}.
***Possible escalation**.*

3

[8]

8 (a) 1eV = 1.6×10^{-19} J

kinetic energy = $1.6 \times 10^{-19} \times 4.9 \times 10^6 = 7.8(4) \times 10^{-13}$ J ✓

ke lost = pe gained = $7.8(4) \times 10^{-13}$ J ✓

2

(b) using $V = Q / 4\pi\varepsilon_0 r$ and $E_p = qV$

$r = qQ/4\pi\varepsilon_0 E_p$✓

$= (2 \times 1.6 \times 10^{-19})\ (79 \times 1.6 \times 10^{-19})/4\pi \times 8.85 \times 10^{-12} \times 7.84 \times 10^{-13}$✓

$r = 4.67(4.64) \times 10^{-14}$ m ✓

3

(c) $A = (R/R_0)^3$ ✓

$= (7.16 \times 10^{-15} / 1.23 \times 10^{-15}\ \text{m})^3$ ✓

= 197 placed on the dotted line ✓

3

(d) *r* gets smaller ✓

less force so needs to travel further to lose same initial ke ✓

Fewer protons means that r will be smaller when alpha particle has the same electrostatic potential energy (as initial kinetic energy)

2

[10]

9 (a) (i) momentum (= E/c)

$= 5.94 \times 10^{-11} / 3.00 \times 10^{8} = 2.0 \times 10^{-19}$ (kg m s^{-1})

(= 1.98×10^{-19} kg m s^{-1})

Or evidence of use of $E = hc / \lambda$ ✓

$\lambda = (h / mv = 6.63 \times 10^{-34} / 1.98 \times 10^{-19}) = 3.35 \times 10^{-15}$ (m) ✓

(allowable range 3.32×10^{-15} - 3.37×10^{-15} m)

3.348×10^{-15} m alone may score 1 mark

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

2

(ii) nuclear radius = $0.61\ \lambda / \sin\theta = 0.61 \times 3.35 \times 10^{-15} / \sin 42°$

$= 3.1 \times 10^{-15}$ (m) ✓ (allow 2.95 – 3.1×10^{-15} m which is a range incorporating 3.32×10^{-15} - 3.37×10^{-15} m and 42° – 43°)

(The answer must be to 2 sf or better

note 3.3×10^{-15} , 42° gives 3.008×10^{-15} 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

5 - 6

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)

these together suggest a 'solar system' configuration for the atom.

5. 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 <u>and</u> (foil) thickness Or alpha KE to PE giving r Or if α's touch surface SNF stops scattering.

[11]

10 (a) R (= $r_0A^{1/3}$) = $1.3 \times 10^{-5} \times (238)^{1/3}$ **(1)**
= $8.0(6) \times 10^{-15}$m **(1)**

2

(b) (use of inverse square law e.g. $\frac{I_1}{I_2} = \left(\frac{x_1}{x_2}\right)^2$ gives)

$10 = \left(\frac{x_2}{0.03}\right)^2$ **(1)**

x = 0.095 m **(1)**
(0.0949 m)

2

(c) (use *of* $A = A_0 exp(-\lambda t$ gives) 0.85 = 1.0 exp ($-\lambda$52) **(1)**

$\lambda = \frac{\ln(100/0.85}{52}$ **(1)**

= $3.1(3) \times 10^{-3}$s^{-1} **(1)**

3

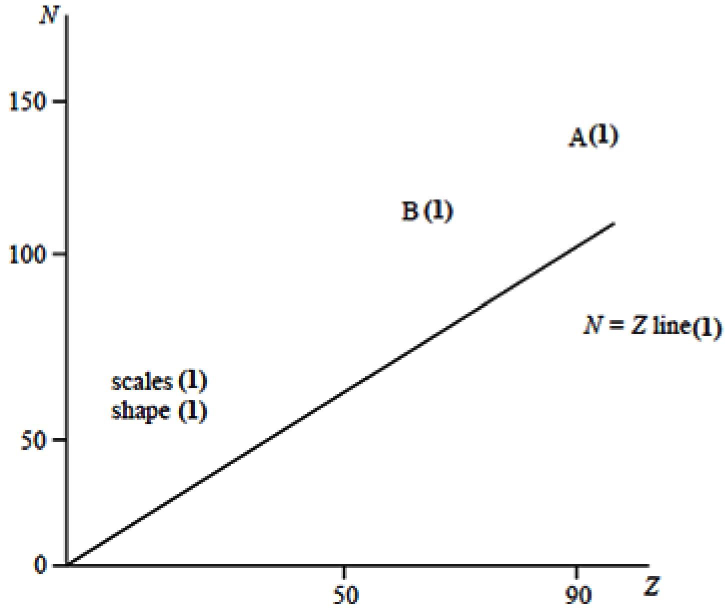
(d) it only emits γ rays **(1)**
relevant properties of γ radiation e.g. may be detected outside the body/weak ioniser and causes little damage **(1)**
it has a short enough half-life and will not remain active in the body after use **(1)**
it has a long enough half-life to remain active during diagnosis **(1)**
the substance has a toxicity that can be tolerated by the body **(1)**
it may be prepared on site **(1)**

any three **(1)(1)(1)**

3

[10]

11 (a)



(5)

(b) (i) α emitter: $N \downarrow 2$, $Z \downarrow 2$ **(1)**

(ii) β^- emitter: $N \downarrow 1$, $Z \uparrow 1$ **(1)**

(2)

(c) density = $\frac{\text{mass}}{\text{volume}}$ **(1)**

mass $\propto A$

volume $\propto R^3$ and $R \propto A^{\frac{1}{3}}$ hence volume $\propto A$ **(1)**

hence density = $\frac{\text{mass}}{\text{volume}}$ is independent of A **(1)**

(3)

[10]

12 (a) $(R^3 = R_0^3 A)$

plot R^3 against A with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$R^3/10^{-45}$ m^3
carbon	2.66	12	18.8
silicon	3.43	28	40.4
iron	4.35	56	82.3
tin	5.49	120	165.5
lead	6.66	208	295

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient

e.g. gradient = $\frac{1}{3}$ **(1)** (= 1.41×10^{-45} m^3)

r_0 (= gradient)$^{1/3}$ **(1)**

= $(1.41 \times 10^{-45})^{1/3} = 1.1(2) \times 10^{-15}$ m **(1)**

alternative:

plot R against $A^{1/3}$ with axes labelled **(1)**
units on axes **(1)**
scales chosen to use more than 50% of page **(1)**

element	$R/10^{-15}$ m	A	$A^{1/3}$
carbon	2.66	12	2.29
silicon	3.43	28	3.04
iron	4.35	56	3.83
tin	5.49	120	4.93
lead	6.66	208	5.93

calculate data for table **(1)**
plot data **(1)(1)** lose one mark for each error
calculation of gradient

e.g. gradient = $\frac{6.72 \times 10^{-15}}{6.0}$ **(1)** = ($1.1(2) \times 10^{-45}$ m^3)

r_0 = gradient **(1)**
= $1.1(2) \times 10^{-15}$ m **(1)**
[or plot ln$R$ against ln$A$...]

(max 8)

(b) assuming the nucleus is spherical
ignoring the gaps between nucleons
assuming all nuclei have same density
assuming total mass is equal to mass of constituent nucleus
any one assumption **(1)**

$M = \frac{4}{3}\pi R^3 \rho$ **(1)**

$\left(\therefore M = \frac{4}{3}\pi R_0^3 a\rho\right)$

$\left(\therefore \rho = \frac{3m}{4\pi R_0^3}\right) = \frac{3 \times 1.67 \times 10^{-27}}{4\pi \times (1.12 \times 10^{-15})^3}$ **(1)**

= 2.8×10^{17} kg m^{-3} **(1)**

(4)

[12]