IB · HL · Physics

2 hours 12 questions

Structured Questions

Structure of the Atom

Rutherford's Gold Foil Experiment / Nuclear Notation / Emission & Absorption Spectrum / Photon Energy / Rutherford Scattering & Nuclear Radius (HL) / Deviations from Rutherford Scattering (HL) / The Bohr Model of Hydrogen (HL)

Easy (4 questions)	/30
Medium (4 questions)	/57
Hard (4 questions)	/29
Total Marks	**/116**

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Easy Questions

1 (a) Match, by drawing a line, the words with their correct definitions.

Ionisation	Fundamental particles that make up all forms of electromagnetic radiation
Photon	A group of atoms containing the same number of protons and neutrons
Nuclide	The electron has gained enough energy to be removed from the atom entirely
Isotope	An atom of the same element that has an equal number of protons but a different number of neutrons

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(4 marks)

(b) The energy of a photon can be calculated using the equation

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

Define the following terms and give the unit:

(i) h

[2]

(ii) c

[2]

(iii) λ

[2]

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(6 marks)

(c) Calculate the wavelength of a photon with an energy of 1.44×10^{-19} J.

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(2 marks)

(d) (i) Complete the following sentences

Electrons in an atom can only occupy specific states called ....

The lowest state an electron can occupy is known as the ....

An electron can move to a higher state by .... a photon.

An electron can move to a lower state by .... a photon.

[4]

(ii) State the name of the process in which an electron is removed from an atom.

[1]

(5 marks)

2 (a) Outline how the density of a nucleus varies with nuclear radius.

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(2 marks)

(b) Calculate the nuclear radius of carbon-14 $\left(^{14}_{6}\text{C}\right)$, in m.

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(2 marks)

3 The density of a nucleus, ρ, is given by the equation:

$$\rho = \frac{3u}{4\pi R_0^3}$$

Where u is the atomic mass unit and R_0 is a constant of proportionality equal to approximately 1.20×10^{-15} m.

(i) State how the density of a nucleus changes after it undergoes radioactive decay.

[1]

(ii) Explain your answer to part (i).

[1]

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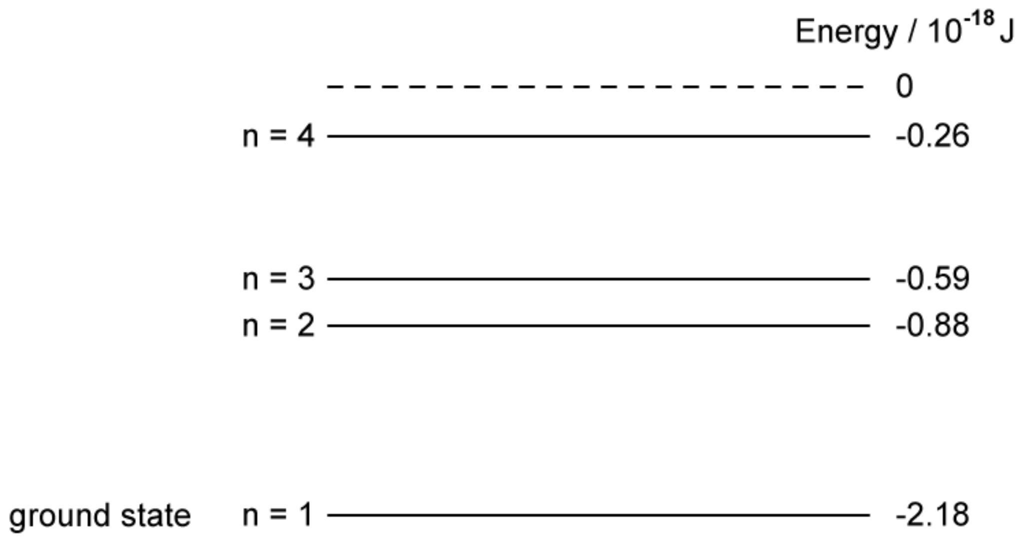
(2 marks)

4 (a) Fluorescent tubes operate by exciting the electrons of mercury atoms.

The energy levels of a mercury atom are shown in the diagram below.



An electron is excited to the energy level n = 4.

On the diagram, draw all the possible transitions from n = 4 to the ground state n = 1.

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(4 marks)

(b) State and explain which energy transition will emit the photon with the lowest frequency.

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(3 marks)

Medium Questions

1 (a) In a HeNe laser, electrons collide with helium atoms. The ground state of a helium is labelled as 1*s* and the next energy level is labelled 2*s*.

When an electrons de-excite from 2*s* to 1*s* in helium, photons are emitted with a wavelength of 58.4 nm.

Calculate the energy difference of this transition, giving your answer in eV.

(3 marks)

(b) An electron collides with a helium in its ground state, causing an electron to transition from 1*s* to 2*s*. The electron initially has 45.0 eV of kinetic energy.

Calculate the electron's kinetic energy after the collision.

(2 marks)

(c) Explain why it is not possible for the same electron from (b) to collide with the ground state helium atom and be left with 40.0 eV of kinetic energy.

(3 marks)

(d) Helium and neon coincidentally have very similar energy gaps for certain transitions, allowing one atom to cause an excitation in the other.

The excited helium atom from part (b) then collides with a ground state neon atom. The neon atom becomes excited and subsequently emits two photons in order to return to its ground state.

(i) If the helium is left back in its ground state after the collision, determine the amount of energy transferred to the neon atom.

[1]

(ii) If one photon has an energy of 1.96 eV, calculate the wavelength of the other.

[4]

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(5 marks)

2 (a) Rutherford used the scattering of α particles to provide evidence for the structure of the atom. The apparatus includes a narrow beam of α particles fired at a very thin sheet of gold foil inside a vacuum chamber.

Explain why it is essential to use:

(i) a vacuum in the chamber

[1]

(ii) a very thin sheet of gold foil

[1]

(iii) a narrow beam of alpha particles

[1]

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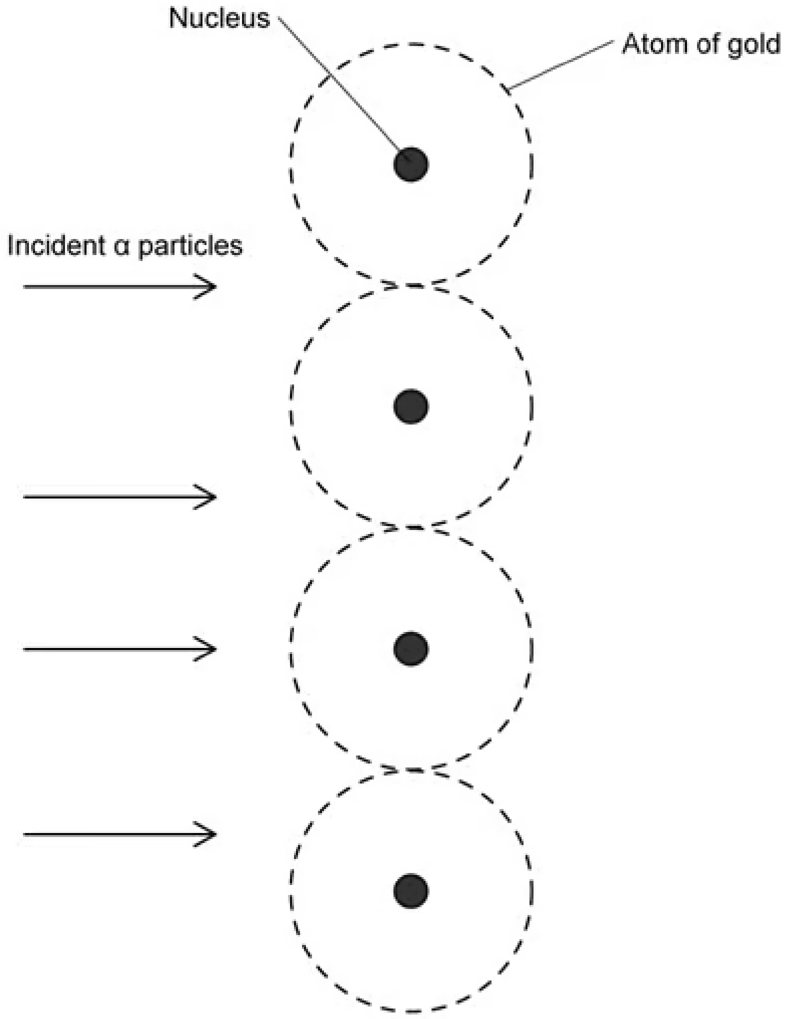
(3 marks)

(b) The diagram shows α particles incident on a layer of atoms in a gold foil.

On the diagram, draw and complete the paths followed by **each** of the α particles shown.



(3 marks)

(c) Outline the results of the scattering experiment by explaining:

(i) the main observations of the scattering experiment

[2]

(ii) the significance of each observation

[3]

(5 marks)

(d) The Thomson model of the atom preceded Rutherford's model. In the Thomson model, the atom was imagined as a sphere of positive charge of diameter 10^{-10} m containing electrons moving within the sphere.

Thomson's model could explain some of the results of the Rutherford experiment, but not all.

Explain

(i) why, at small deflections, Rutherford's experiment can be explained by Thomson's model but not at large deflections

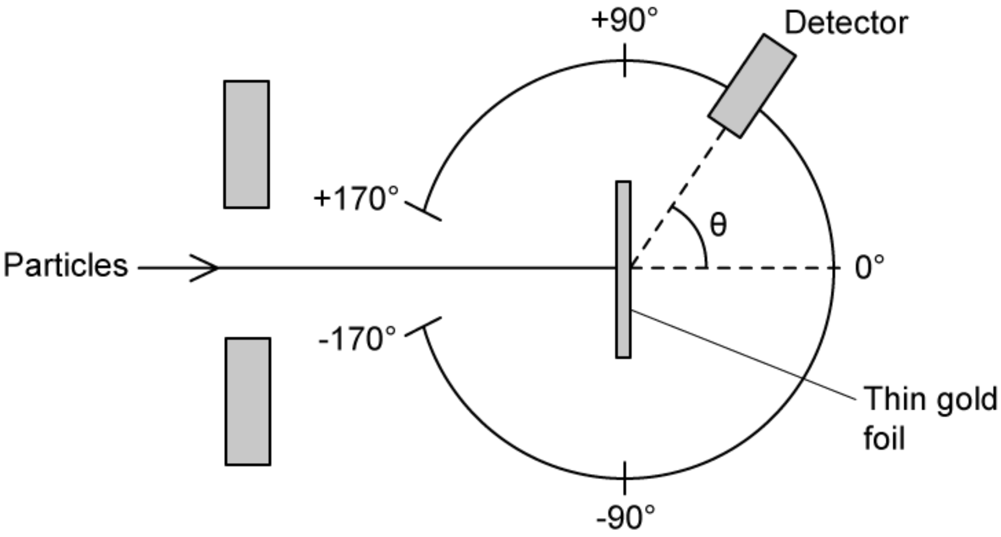
[3]

(ii) why Rutherford's model of the atom can account for the results at both small and large deflections

[3]

(6 marks)

3 (a) In the Rutherford scattering experiment, alpha particles are fired at a thin gold foil target using the experimental setup shown below.



Some of the alpha particles are backscattered.

Outline how the results of the Rutherford scattering experiment can be used to estimate the radius of a gold nucleus. Include a relevant equation.

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(4 marks)

(b) An alpha particle with an initial speed one-tenth that of the speed of light is fired head-on at a stationary gold nucleus $\left({}^{197}_{79}\mathrm{Au}\right)$.

Calculate the minimum separation between the alpha particle and the centre of the gold nucleus.

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(3 marks)

(c) Estimate the number of nucleons in a gold nucleus based on the value of separation that you calculated in **(b)**.

Comment on your answer in relation to:

- the actual size of a gold nucleus
- the accuracy of the Rutherford scattering method for determining nuclear radii.

(4 marks)

(d) The target nucleus is changed to one that has fewer protons. The alpha particle is fired with the same speed as before.

Explain, without further calculation, the effect this has on the minimum separation.

Ignore any recoil effects.

(3 marks)

4 (a) The Bohr model was developed in order to explain the atomic spectrum of hydrogen.

Outline the Bohr model and give a limitation of it.

(4 marks)

(b) The Bohr model for hydrogen can also be applied to a helium atom which has lost one of its electrons through ionisation.

The one remaining electron has a mass of *m* and moves in a circular orbit of radius *r*. Deduce an expression for

(i) the kinetic energy E_k of the electron

[2]

(ii) the electric potential energy E_p

[1]

(iii) the total energy E_T of the atom

[1]

(4 marks)

(c) Using your answer to **(b)**, describe the predicted effect on the orbital radius of the electron when it

(i) absorbs an electromagnetic wave

[1]

(ii) emits an electromagnetic wave.

[1]

(2 marks)

(d) The radius of the electron's orbit in the helium atom is 2.43×10^{-10} m.

Determine the principal quantum number of the energy level occupied by the electron.

(3 marks)

Hard Questions

1 (a) Bohr modified the Rutherford model by introducing the condition:

$$mvr = n\frac{h}{2\pi}.$$

The total energy E_n of an electron in a stable orbit is given by:

$$E_n = -\frac{ke^2}{2r}$$

Where $k = \frac{1}{4\pi\varepsilon_0}$

(i) Discuss one issue posed by Rutherford's model and one issue solved by Bohr's modification.

[2]

(ii) Use Bohr's modification with the expression for total energy to derive the equation

$$E_n = \frac{K}{n^2}$$

[3]

(iii) State and explain what physical quantity is represented by the constant, *K*

[1]

(6 marks)

(b) In 1908, the physicist Friedrich Paschen first observed the photon emissions resulting from transitions from a level n to the level n = 3 of hydrogen and deduced their wavelengths were given by:

$$\lambda = \frac{An^2}{n^2 - 9}$$

where A is a constant.

Justify this formula on the basis of the Bohr theory for hydrogen and determine an expression for the constant A.

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(3 marks)

2 (a) In a scattering experiment, a metal foil of thickness 0.4 μm scatters 1 in 20 000 alpha particles through an angle greater than 90°.

(i) Considering the metal foil as a number of layers of atoms, *n*, explain why the probability of an alpha particle being deflected by a given atom is approximately equal to

$$\frac{1}{20\,000n}$$

[2]

(ii) Estimate the diameter of the nucleus. Consider the nuclei as cubes and the atoms in the foil as cubes of side length 0.25 nm.

[3]

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(5 marks)

(b) Deviations from Rutherford scattering are observed when high-energy alpha particles are incident on nuclei.

Outline the incorrect assumption used in the Rutherford scattering formula and suggest an explanation for the observed deviations.

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(3 marks)

(c) In a scattering experiment, alpha particles were directed at five different thin metallic foils, as shown in the table.

Metal	Symbol
Silver	${}^{108}_{47}\text{Ag}$
Aluminium	${}^{27}_{13}\text{Al}$
Gold	${}^{197}_{79}\text{Au}$
Tin	${}^{119}_{50}\text{Sn}$
Tungsten	${}^{184}_{74}\text{W}$

Initially, all alpha particles have the same energy. This energy is gradually increased.

Predict and explain the differences in deviations from Rutherford scattering that will be observed.

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(3 marks)

(d) Outline why the particles must be accelerated to high energies in scattering experiments.

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(3 marks)

3 The isotope beryllium-10 is formed when a nucleus of deuterium $\left({}^{2}_{1}\text{H}\right)$ collides with a nucleus of beryllium-9 $\left({}^{9}_{4}\text{Be}\right)$. The radius of a deuterium nucleus is 1.5 fm.

(i)

Determine the minimum initial kinetic energy, in J, that the deuterium nucleus must have in order to produce the isotope beryllium-10.

[2]

(ii) Outline an assumption made in this calculation.

[1]

(3 marks)

4 Show that all nuclei have the same density.

(3 marks)