12.2 Nuclear Physics

Question Paper

Course	DP IB Physics
Section	12. Quantum & Nuclear Physics (HL only)
Topic	12.2 Nuclear Physics
Difficulty	Easy

Time allowed: 90

Score: /72

Percentage: /100

Question 1a

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

[2]

[2 marks]

Question 1b

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

[2]

[2 marks]

Question 1c

Carbon-14 is unstable and decays to nitrogen by beta minus emission.

In living tissue, such as plants and animals, the ratio of carbon-14 to carbon-12 atoms is constant.

(c)
State and explain what will happen to this ratio after the living tissue dies.

[3]

[3 marks]

Question 1d

When carbon-14 undergoes beta-minus decay, the energy gained by the emitted particles varies.

(d)
Nitrogen-14 is one of the products of this decay.

(i)
State the other **two** particles that are emitted.

[1]

(ii)
One of the emitted particles is very difficult to detect. Explain why, and outline the evidence that made the presence of this particle in beta decay necessary by completing the following sentences:

___________ are hard to detect because they are electrically ____________ and have an extremely small ______.

The energy released in beta decay must be ________________ the two particles emitted. Without the presence of the ___________, the emitted ____________ would be expected to carry away the same amount of energy with each decay.

Energy distributions for beta decay are _________, as opposed to alpha decays which are _________.

[3]

[4 marks]

Question 2a

(a)
Outline what is meant by the term decay constant.

[2]

[2 marks]

Question 2b

A sample of 2.5 mol of the radioactive nuclide plutonium-239 decays into uranium-235 with the production of another particle.

$$^{239}_{94}Pu \rightarrow \, ^{235}_{92}\mathrm{U} + \mathrm{X}$$

(b)

(i)
Identify particle X.

[1]

(ii)
The radioactive decay constant of plutonium-239 is 9.5×10^{-13} s^{-1}. Determine the time required to produce 1 mol of uranium-235.

[4]

[5 marks]

Question 2c

Thorium-227 is one of the isotopes formed after a uranium-235 nucleus has undergone a series of decays.

(c)
One sample of thorium-227 has a decay constant of 0.037 day^{-1} and an initial activity of 46 Bq.

(i)
State what is meant by the activity of a sample.

[2]

(ii)
Calculate the activity of the sample after one week.

[3]

[5 marks]

Question 2d

Particle X has an initial kinetic energy of 7.5 MeV after the decay in (b). In a scattering experiment, particle X is aimed head-on at a stationary gold-197 nucleus $\left({}^{197}_{79}\mathrm{Au}\right)$.

(d)
Particle X transfers all its kinetic energy to another form as it approaches the gold nucleus. At the distance of closest approach, *d*, to the gold nucleus:

(i)
State the energy transfer taking place in particle X and the gold nucleus.

[1]

(ii)
Write an expression for the total energy in terms of the Coulomb constant, *k*, the elementary charge, *e*, and distance, *d*.

[1]

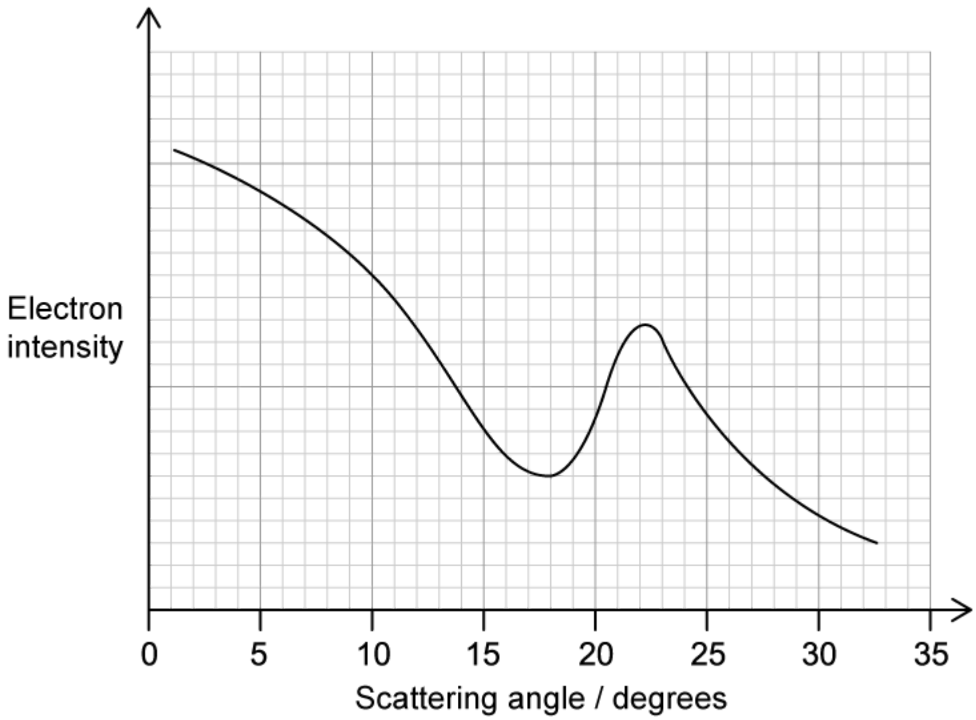
(iii)
Calculate the distance, *d*, between particle X and the gold nucleus at this point.

[2]

[4 marks]

Question 3a

A beam of electrons each of de Broglie wavelength 2.8 × 10^{-15} m is incident on a thin film of iron-56 $\left({}^{56}_{26}Fe\right)$. The variation in the electron intensity of the beam with scattering angle is shown.



(a)
Use the graph to determine the nuclear radius of iron-56.

[3]

[3 marks]

Question 3b

(b)
Using the result from part (a):

(i)
Show that the constant of proportionality, R_0, is equal to 1.2 fm

[2]

(ii)
Calculate the nuclear radius of radium-222 $\left({}^{222}_{88}Ra\right)$

[1]

[3 marks]

Question 3c

Two students debate whether beams of electrons or alpha particles, of the same energy, would be better for investigating the size of a nucleus.

(c)
Complete the sentences below to outline which student is correct.

Beams of ____________ would be better for investigating the size of a nucleus.

This is because a beam of ____________ would provide a greater resolution since their de Broglie wavelength is _________ than the de Broglie wavelength of ____________.

Another reason is that ____________ are leptons meaning they are not subject to the ____________ force, therefore, they are ______ likely to interact with the nucleus being investigated.

[3]

[3 marks]

Question 3d

The graph shows how the number of alpha particles that are observed at a fixed scattering angle, *N*, depends on alpha particle energy, *E*, according to Rutherford's scattering formula.

Deviations from Rutherford scattering are detected in experiments carried out at high energies.

(d)

(i)
Outline an assumption of the Rutherford scattering formula.

[1]

(ii)
Indicate the deviations from Rutherford scattering on the axes provided above.

[1]

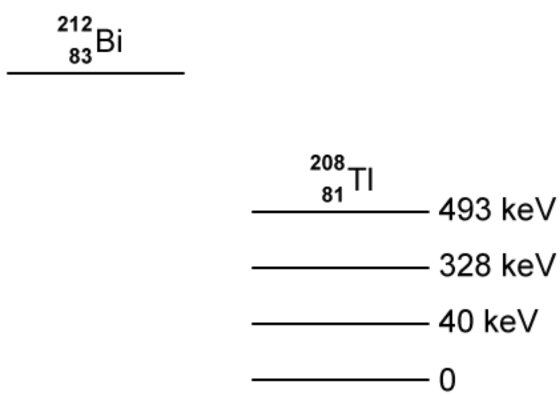
(iii)
Explain what these deviations provide evidence for.

[3]

[5 marks]

Question 4a

The isotope bismuth-212 undergoes α-decay to an isotope of thallium-208. In this decay, a gamma-ray photon is also produced.



(a)

(i)
Complete the nuclear energy level diagram to indicate the alpha decay of Bi-212 into Tl-208, followed by the emission of a photon of energy 0.493 MeV.

[2]

(ii)
Outline how the alpha particle spectrum and the gamma spectrum of the decay of bismuth-212 give evidence for the existence of discrete nuclear energy levels, by completing the following sentences:

The emitted alpha particles have _________ energies.

The emitted gamma rays have __________ energies.

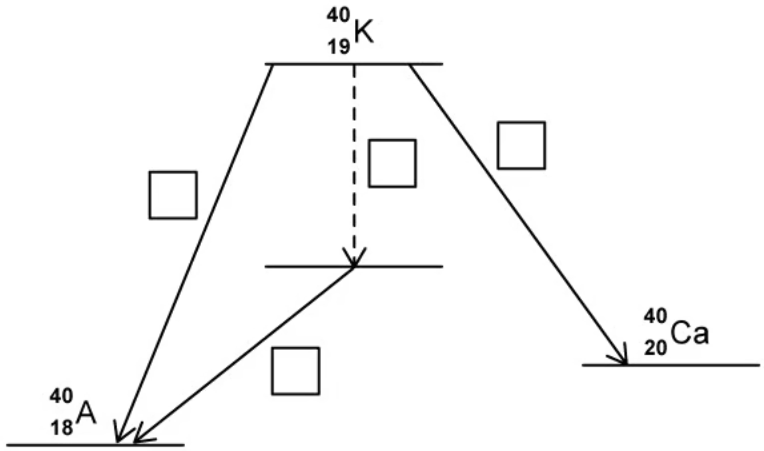
Therefore, nuclear energy levels must be discrete because the energies of the alpha particles and the gamma photons are determined by _______________________________________.

[3]

[5 marks]

Question 4b

The isotope potassium-40 can decay via different decay modes to form isotopes of argon-40 or calcium-40.



(b)

(i)
Complete the nuclear energy level diagram to indicate the different modes of decay.

[3]

(ii)
Outline how the β spectrum of the decay of potassium-40 led to the existence of the neutrino being postulated, by completing the following sentences:

The total energy released in any beta decay is __________, however, the majority of beta particles are found to have energies ________ than this value.

The distribution of energy values for the beta particles is not _________, it is found to be a ____________ spectrum.

The existence of the neutrino was postulated to account for the _________________.

The total energy of the decay process must be divided between the _____________ and _________________.

[2]

[5 marks]

Question 4c

The isotope potassium-40 occurs naturally in many rock formations. The composition of a particular rock sample is found to be 33% potassium-40 atoms out of the total number of argon and potassium-40 atoms.

The half-life of potassium-40 is 1.3×10^9 years.

(c)
Determine the age of the rock sample.

[4]

[4 marks]

Question 4d

Bismuth-212 is a short-lived isotope with a half-life of 1 hour.

(d)
Briefly outline experimental methods which can measure the half-life of:

(i)
Bismuth-212

[3]

(ii)
Potassium-40

[3]

[6 marks]

Question 5a

Particles can be used in scattering experiments to estimate nuclear radius.

(a)
Outline how these experiments are carried out by completing the following sentences:

High ______________ particles have wave-like properties such as a ____________ wavelength and the ability to ____________ when incident on a thin _______________.

The ____________ of the _______________ particles can be measured using a detector.

A graph of intensity against _______________ can be obtained.

The ________________ of the first _____________ can be used to determine the nuclear radius of the atoms in the _________________.

The nuclear radius can then be determined using the equation ____________________.

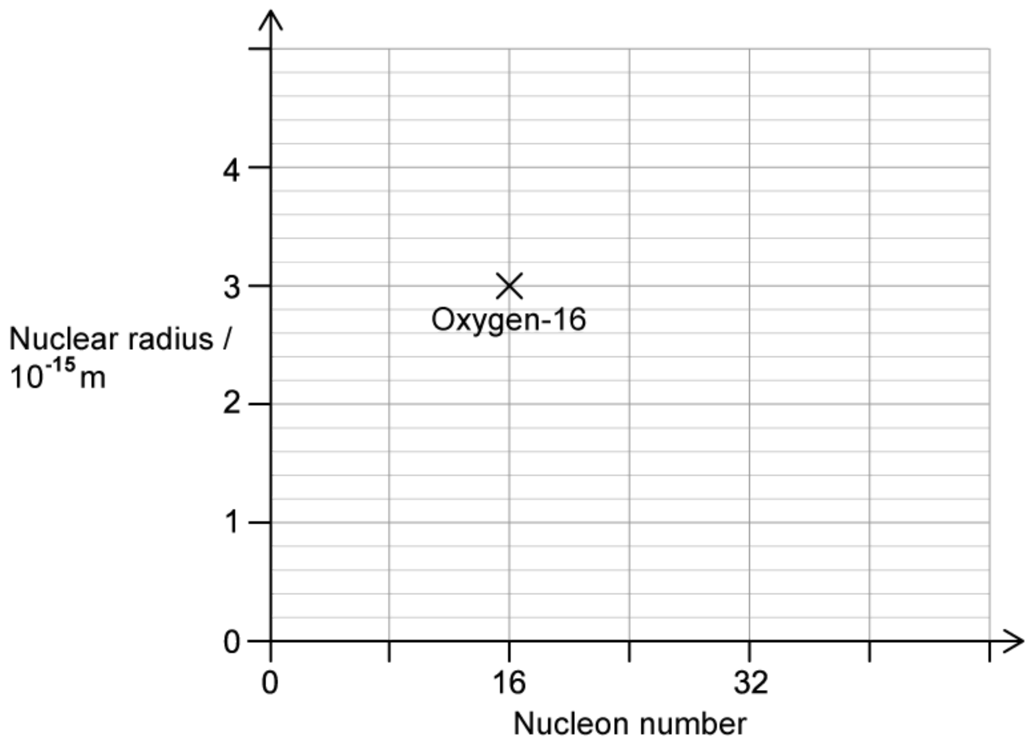
[5]

[5 marks]

Question 5b

Electron scattering experiments indicate that the nuclear radius of oxygen-16 is 3.02 fm

The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the oxygen-16 has been plotted.



(b)
Plot the position of sulphur-32 on the graph.

[2]

[2 marks]

Question 5c

(c)

Draw a line on the graph to show how nuclear radius varies with nucleon number.

[2]

[2 marks]

Question 5d

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.

(d)

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

[1]

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

[1]

[2 marks]