12.2 Nuclear Physics

Question Paper

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

Time allowed: 60

Score: /49

Percentage: /100

Question 1a

(a)
Show that all nuclei have the same density.

[3]

[3 marks]

Question 1b

A beam of neutrons is fired normally at a thin foil sheet made from tin. The beam has energy 75 MeV and the first diffraction minimum is observed at an angle of 15° relative to the central bright fringe.

(b)
Calculate an estimate for the radius of the tin nucleus.

[4]

[4 marks]

Question 1c

The tin ($^{50}\mathrm{Sn}$) foil was replaced by thin aluminium ($^{13}\mathrm{Al}$) foil.

(c)
Deduce and explain the expected difference in the observations between the two experiments.

[2]

[3 marks]

Question 1d

An isotope of tin has a half-life of 129 days. It undergoes beta-minus decay to a meta-stable isotope of antimony.

(d)
Calculate the percentage of the sample which will consist of antimony after 2 years.

[2]

[2 marks]

Question 2a

Iodine-131 $\left({}^{131}_{53}\mathrm{I}\right)$ has a half-life of 8.02 days.

(a)
Calculate the decay constant of ${}^{131}_{53}\mathrm{I}$.

[2]

[2 marks]

Question 2b

The initial activity of the sample of Iodine–131 is 6.5×10^4 Bq.

(b)
Determine the activity after 16 days.

[2]

[2 marks]

Question 2c

(c)
Determine the mass of the iodine–131 in the sample after 16 days.

[2]

[2 marks]

Question 2d

Iodine–131 decays through a number of decay modes. Two of these are β^- decay of 606 keV and gamma emission of 364 keV. The product of the β^- decay is ${}^{131}_{54}\mathrm{Xe}$.

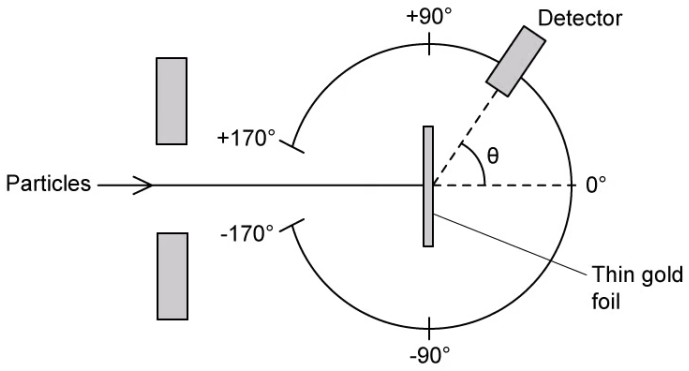
(d)
Sketch a nuclear energy level diagram to represent these decays.

[2]

[2 marks]

Question 3a

Ernest Rutherford was able to deduce a relationship for the size of the nucleus using the Rutherford scattering experiment shown below:



A radioisotope has a nuclear radius of 7.41 fm

(a)
Determine the nucleon number of the isotope.

[2]

[2 marks]

Question 3b

A beam of high-energy neutrons is directed at the nucleus and a pattern is formed on a detector screen.

(b)
Explain the pattern which is observed.

[3]

[3 marks]

Question 3c

The neutrons are accelerated to a speed of 2.88×10^{8} m s^{-1}.

(c)
Determine the angle of the first minimum.

[2]

[2 marks]

Question 3d

The decay constant of the isotope is 9.72×10^{-10} yr^{-1}. The mass of a sample of this isotope is 600 g.

(d)
Determine the activity of the sample.

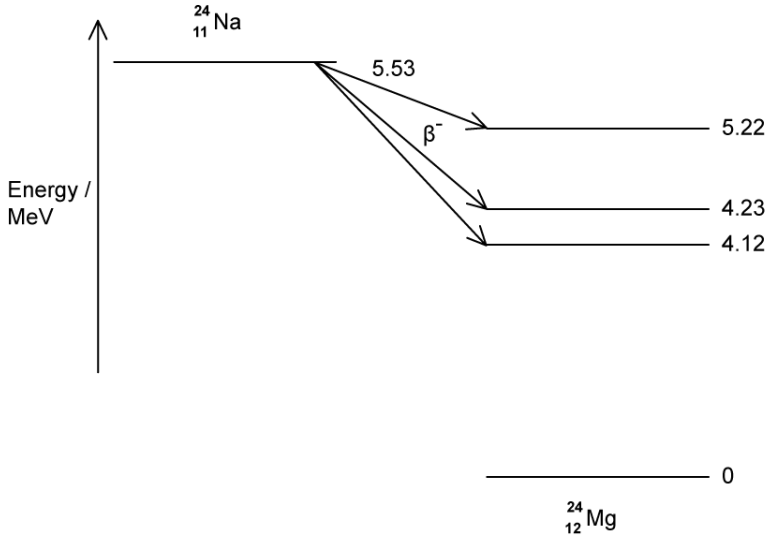
[3]

[3 marks]

Question 4a

A nucleus of sodium–24 decays into a stable nucleus of magnesium–24. It decays by β^- emission followed by the emission of γ-radiation as the magnesium–24 nucleus de-excites into its ground state.

The sodium–24 nucleus can decay to one of three excited states of the magnesium–24 nucleus. This is shown in the diagram below:



The energies of the excited states are shown relative to the ground state.

(a)
Calculate the maximum possible speed of the emitted beta particle in MeV.

[2]

[2 marks]

Question 4b

The excited magnesium nucleus de-excites through production of gamma radiation of discrete wavelengths.

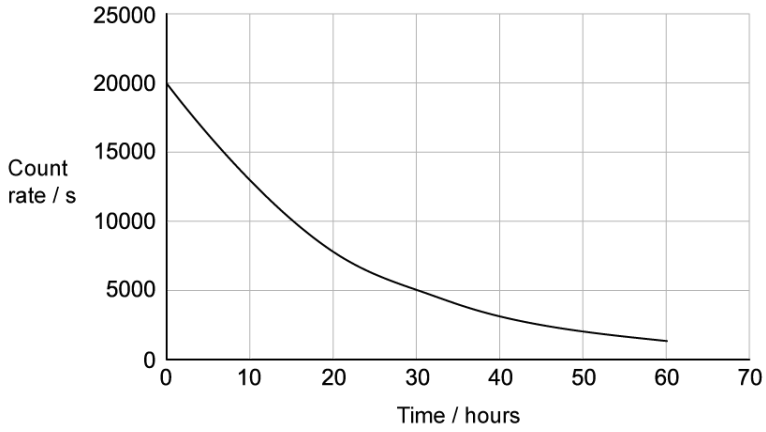
(b)
Calculate the shortest wavelength of emitted radiation.

[3]

[3 marks]

Question 4c

The graph shows the activity of a sample of sodium–24 with time.



(c)
Use the graph to calculate the decay constant of sodium–24.

[2]

[2 marks]

Question 4d

The detector in this experiment measures 4% of the activity from the sample.

(d)
Determine the activity of sample after 27 hours from the start of the recording,

[3]

[3 marks]

Question 5a

Americium-241 has a half-life of 432 years. A small sample is held in a school for use in experiments.

The teacher uses a Geiger-Müller counter to measure the count rate at close range. The relationship between activity and count rate is a ratio of 6:1. Over 5 minutes, the count is 13 600.

(a)
Determine the activity of the sample.

[2]

[2 marks]

Question 5b

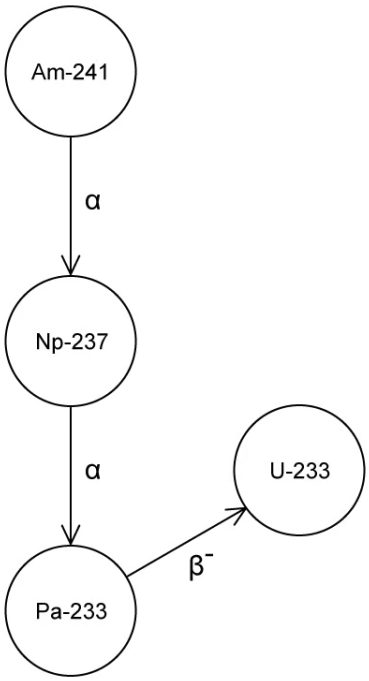
(b)
Determine the activity of the americium sample after 748 years.

[2]

[2 marks]

Question 5c

Americium–241 decays through a series of decays to uranium-233.



The energies from each decay path are recorded.

(c)
Explain the differences between the energy profiles for the alpha decays and the beta decays.

[2]

[3 marks]

Question 5d

The beta decay of protactinium–233 to uranium–233 has a half–life of 27 days. A sample of protactinium has an activity of 3879 Bq.

(d)
Determine the number of protactinium–233 nuclei in the sample.

[2]

[2 marks]