7.1 Discrete Energy & Radioactivity

Question Paper

Course	DP IB Physics
Section	7. Atomic, Nuclear & Particle Physics
Topic	7.1 Discrete Energy & Radioactivity
Difficulty	Hard

Time allowed: 50

Score: /40

Percentage: /100

Question 1a

Transitions between three energy levels in a particular atom give rise to three spectral lines. In decreasing magnitudes, these are f_1, f_2 and f_3.

The equation which relates f_1, f_2 and f_3 is:

$$f_1 = f_2 + f_3$$

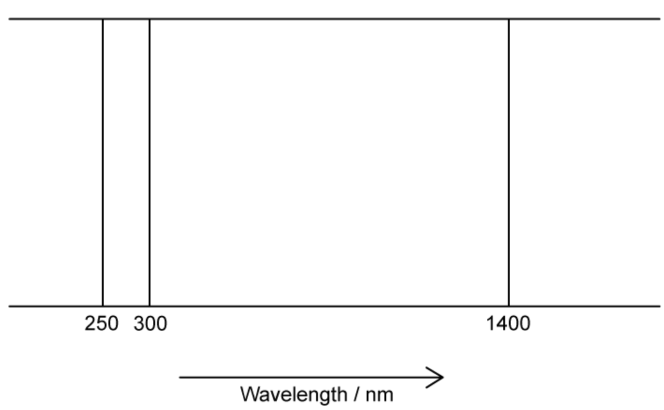
(a)
Explain, including through the use of a sketch, how this equation relates f_1, f_2 and f_3.

[3]

[3 marks]

Question 1b

A different atom has a complete line emission spectra with a ground state energy of -10.0 eV. is:



(b)
Sketch and label a diagram of the possible energy levels for the atomic line spectra shown.

[5 marks]

[5 marks]

Question 1c

(c)
Explain the significance of an electron at an energy level of 0 eV.

[3]

[3 marks]

Question 1d

(d)

(i)
Explain the statement 'the first excitation energy of the hydrogen atom is 10.2 eV'

[1]

(ii)
The ground state of hydrogen is –13.6 eV. Calculate the speed of the slowest electron that could cause this excitation of a hydrogen atom.

[2]

[3 marks]

Question 2a

A radioactive nucleus $^{229}_{85}\mathrm{X}$ undergoes a beta-minus decay followed by an alpha decay to form a daughter nucleus $^{A}_{Z}\mathrm{Y}$.

(a)
Write a decay equation for this interaction and hence determine the values of A and Z.

[2]

[2 marks]

Question 2b

Thorium, $^{90}_{232}\mathrm{Th}$ decays to an isotope of Radium (Ra) through a series of transformations. The particles emitted in successive transformations are:

$$\alpha \;\; \beta \;\; \beta \;\; \gamma \;\; \alpha$$

(b)
Determine the resulting nuclide after these successive transformations.

[3]

[3 marks]

Question 2c

Through a combination of successive alpha and beta decays, the isotope of any original nucleus can be formed.

(c)
Explain the simplest sequence of alpha and beta decays required to do this

[3]

[3 marks]

Question 2d

A nucleus of Bohrium $^{X}_{Y}\mathrm{Bh}$ decays to Mendelevium $^{255}_{101}\mathrm{Md}$ by a sequence of three alpha particle emissions.

(d)
Determine the number of neutrons in a nucleus of $^{X}_{Y}\mathrm{Bh}$

[2]

[2 marks]

Question 3a

The table shows some of the isotopes of phosphorus and, where they are unstable, the type of decay.

Isotope	$^{29}_{15}\mathrm{P}$	$^{30}_{15}\mathrm{P}$	$^{31}_{15}\mathrm{P}$	$^{32}_{15}\mathrm{P}$	$^{33}_{15}\mathrm{P}$
Type of decay	β^+	β^+	stable		β^-

(a)
State whether the isotope $^{32}_{15}\mathrm{P}$ is stable or not. If not, determine, with a reason, the type of decay it experiences.

[3]

[3 marks]

Question 3b

The isotope of phosphorus $^{30}_{15}\mathrm{P}$ decays into an isotope of silicon, $^{A}_{Z}\mathrm{Si}$.

(b)
Write a decay equation for this decay, finding the values of A and Z, and explain why each emission product occurs.

[3]

[3 marks]

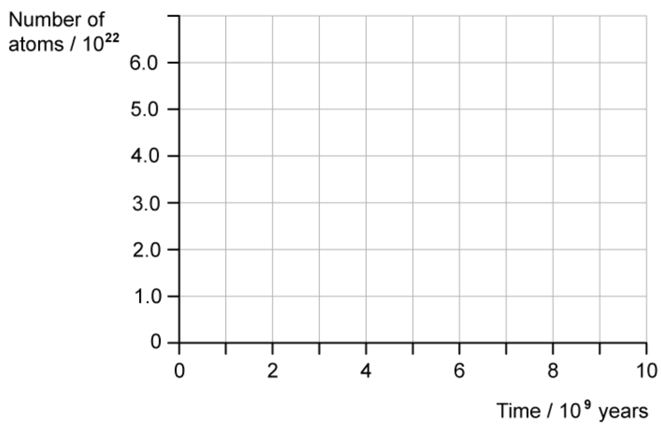
Question 4a

The radioactive isotope uranium–238 decays in a decay series to the stable lead–206.

The half–life of $^{238}_{92}U$ is 4.5×10^9 years, which is much larger than all the other half–lives of the decays in the series.

A rock sample, when formed originally, contained 6.0×10^{22} atoms of $^{238}_{92}U$ and no $^{206}_{82}Pb$ atoms. At any given time, most of the atoms are either $^{238}_{92}U$ or $^{206}_{82}Pb$ with a negligible number of atoms in other forms in the decay series.

(a)
Sketch on the axes below the variation of number of $^{238}_{92}U$ atoms and the number of $^{206}_{82}Pb$ atoms in the rock sample as they vary over a period of 1.0×10^{10} years from its formation. Label your graphs U and Pb.



[2]

[2 marks]

Question 4b

A certain time, *t*, after its formation, the sample contained twice as many $^{238}_{92}U$ atoms as $^{206}_{82}Pb$ atoms.

(b) Show that the number of $^{238}_{92}U$ atoms in the rock sample at time *t* was 4.0×10^{22}.

[2]

[2 marks]

Question 4c

The ratio of the number of lead nuclei N_{Pb} to the number of uranium nuclei N_U at some time *t* is given by:

$$\frac{N_{Pb}}{N_U} = e^{\lambda t} - 1$$

λ is the decay constant and has a value of 1.54×10^{-10} years.

(c)
Calculate the time taken (in years) for there to be twice as many $^{238}_{92}\text{U}$ atoms as $^{206}_{82}\text{Pb}$ atoms.

[2]

[2 marks]

Question 4d

Lead–214 is an unstable isotope of lead–206. It decays by emitting a β^- particle to form bismuth–214 (Bi)

Bismuth is also unstable and has two decay modes:

- Emitting an α particle to form thallium–210 (Tl) + energy
- Emitting a β particle to form polonium–214 (Po) + energy

(d)
Write decay equations for the decay chain of lead–214 to thallium–210 and to polonium–214. Comment on the nature of the energy released.

[4]

[4 marks]