IB Physics SL Y2 – Option B (Quantum and Nuclear Physics) – Exam Study Guide Practice Problem Solutions

Objectives:

1. Describe the photoelectric effect. (B.1.1)

2. Describe the concept of the photon and use it to explain the photoelectric effect. (B.1.2)

3. Describe and explain an experiment to test the Einstein model. (B.1.3)

4. Solve problem involving the photoelectric effect. (B.1.4)
   a) Photoelectric emission takes place when ultraviolet light is incident on zinc but it does not take place when visible light is incident on zinc. However, photoelectric emission does take place when visible light is incident on potassium. The work function of zinc is 4.2 eV.
      i. Explain whether the work function for potassium is greater **or** less than 4.2 eV.
      Work function of potassium is smaller than 4.2 eV and any reasonable justification; 1
      e.g. energy of UV photon is greater than energy of visible photon
      Will NOT award mark for "smaller" without appropriate justification
      (1)
      ii. Ultraviolet light of wavelength 210 nm is incident on a zinc surface. Calculate the maximum kinetic energy, in eV, of a moving electron emitted from the surface.
      appropriate substitution into correct formula;
      e.g. energy = $\frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.1\times10^{-7}}$ *= 9.47 × 10^{-19} J*
      appropriate division by 1.6 × 10^{-19} to convert joules into eV;
      e.g. 9.47 × 10^{-19} J = 5.92 eV
      KE of electron = 5.92 – 4.2 eV = 1.72 eV 1.7 eV; 3 max
      (3)

5. Describe the de Broglie hypothesis and the concept of matter waves. (B.1.5)

6. Outline an experiment to verify the de Broglie hypothesis. (B.1.6)

7. Solve problems involving matter waves. (B.1.7)
   b) An electron is accelerated from rest through a potential difference of 850 V. For this electron
      i. calculate the gain in kinetic energy.
      KE = *Ve* = 850 × 1.6 × 10^{-19} J = 1.4 × 10^{-16} J; 1
      (1)
      ii. deduce that the final momentum is 1.6 × 10^{-23} Ns.
      use $E = \frac{p^2}{2m}$ to get $p = \sqrt{2mE}$;
      substitute $p = \sqrt{2\times9.1\times10^{-31}\times1.4\times10^{-16}}$ = 1.6 × 10^{-23} N s; 2
      (2)
      iii. determine the associated de Broglie wavelength. (Electron charge *e* = 1.6 × 10^{-19}C, Planck constant *h* = 6.63 × 10^{-34} Js).
      $\lambda = \frac{h}{p}$;
      substitute $\lambda = \frac{6.6\times10^{-34}}{1.6\times10^{-23}}$ = 4.1 × 10^{-11} m; 2
      (2)

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8. Outline a laboratory procedure for producing and observing atomic spectra. (B.1.8)

9. Explain how atomic spectra provide evidence for the quantization of energy in atoms. (B.1.9)

10. Calculate wavelengths of spectral lines from energy level differences and vice versa. (B.1.10)
    c) The Bohr model of the hydrogen atom can be extended to singly ionized helium atoms. The model leads to the following expression for the energy E_n of the electron in an orbit specified by the integer *n*.

$E_n = \frac{k}{n^2}$, where *k* is a constant.

In the spectrum of singly ionized helium, the line corresponding to a wavelength of 362 nm rises from electron transitions between the orbit *n* = 3 to the orbit *n* = 2. Deduce the value of the ionization energy of singly ionized helium atoms.

$E = \frac{hc}{\lambda} = \frac{k}{n^2}$;

$= k\left(\frac{1}{4} - \frac{1}{9}\right) = 0.139\,k$;

$k = \frac{hc}{0.14\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{362 \times 10^{-9} \times 0.139} = 3.95 \times 10^{-18}$ J;

Recognize that *k* is the ionization energy; 4

Allow use of 2 significant figures.

11. Explain the origin of atomic energy levels in terms of the “electron in a box” model. (B.1.11)

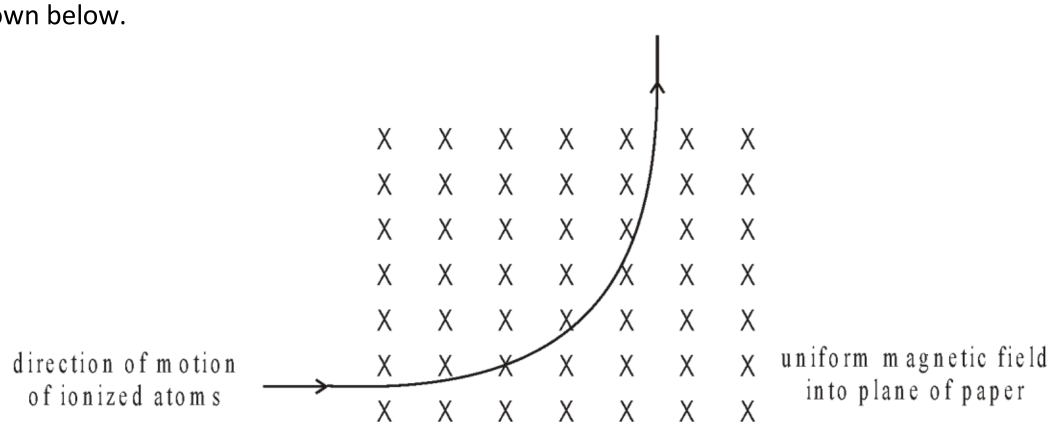
12. Outline the Schrödinger model of the hydrogen atom. (B.1.12)

13. Outline the Heisenberg uncertainty principle with regard to position–momentum and time–energy. (B.1.13)

14. Explain how the radii of nuclei maybe estimated from charged particle scattering experiments. (B.2.1)

15. Describe how the masses of nuclei may be determined using a Bainbridge mass spectrometer. (B.2.2)

    d) A beam of singly ionized atoms moving at speed *v* enters a region of magnetic field strength *B* as shown below.



The magnetic field is directed into the plane of the paper. The ions follow a circular path. Given that the radius *r* of the circular path is given by

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$$r = \frac{mv}{Bq}$$

where m and q are the mass and charge respectively of the ions.

In one particular experiment, the beam contains singly ionized neon atoms all moving at the same speed. On entering the magnetic field, the beam divides in two. The path of the ions of mass 20 u has radius 15.0 cm.

i. Calculate in terms of u, the mass of the ions having a path of radius 16.5 cm.

$$\frac{16.5}{15} = \frac{\frac{m_{16.5}v}{Bq}}{\frac{m_{15}v}{Bq}} = \frac{m_{16.5}}{m_{15}}$$;

hence $\frac{16.5}{15} = \frac{m_{16.5}}{20}$ $m_{16.5} = 22u$;

(2)

16. Describe one piece of evidence for the existence of nuclear energy levels. (B.2.3)

17. Describe β^+ decay, including the existence of the neutrino. (B.2.4)

18. State the radioactive decay law as an exponential function and define the decay constant. (B.2.5)

19. Derive the relationship between decay constant and half-life. (B.2.6)

20. Outline methods for measuring the half-life of an isotope. (B.2.7)

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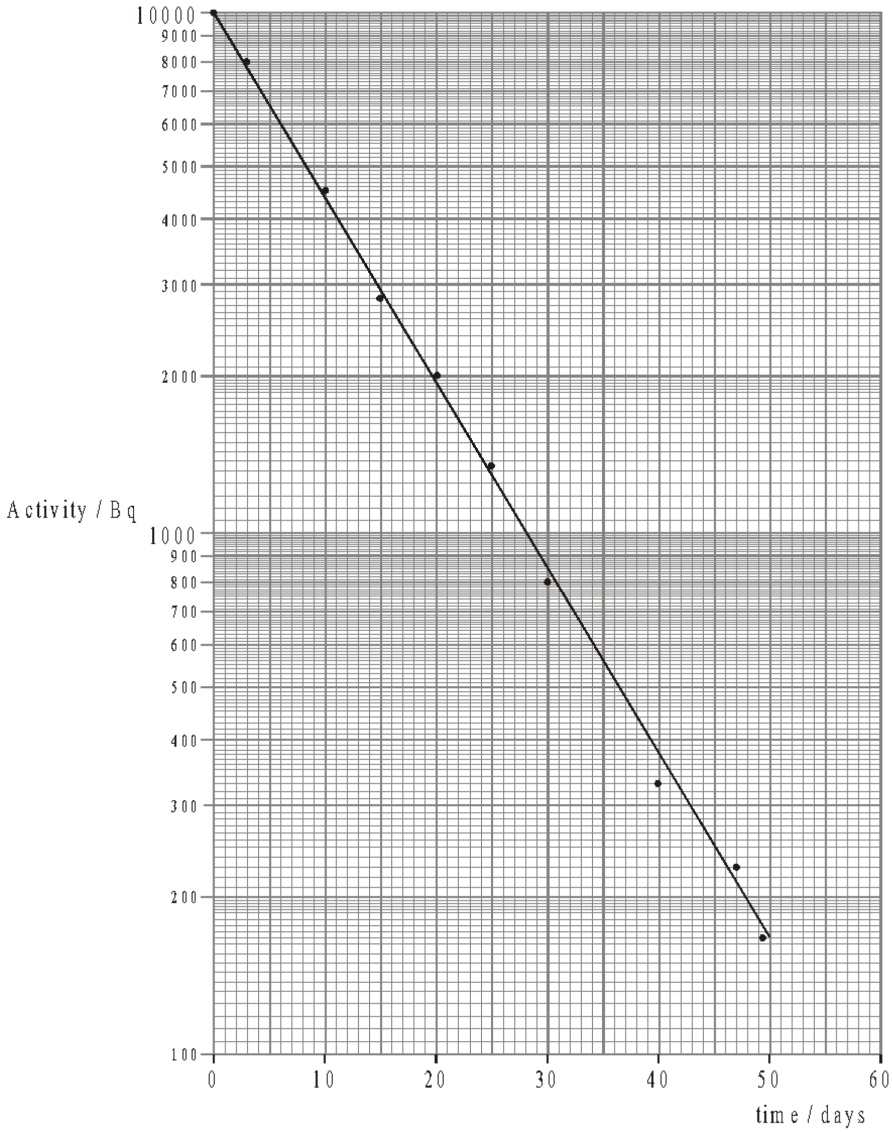
21. Solve problems involving radioactive half-life. (B.2.8)

e) The activity of a sample of Iodine-131 is plotted as a function of time as shown below. The activity scale is logarithmic.



The half-life of Iodine-131 is close to

A. 180 days.

B. 55 days.

C. 28 days.

D. 8 days.

f) The activity *A* of a freshly prepared sample of the iodine isotope is 6.4×10^5 Bq and its half-life is 8.0 days.

i. Using the axes, draw a graph to illustrate the decay of this sample.

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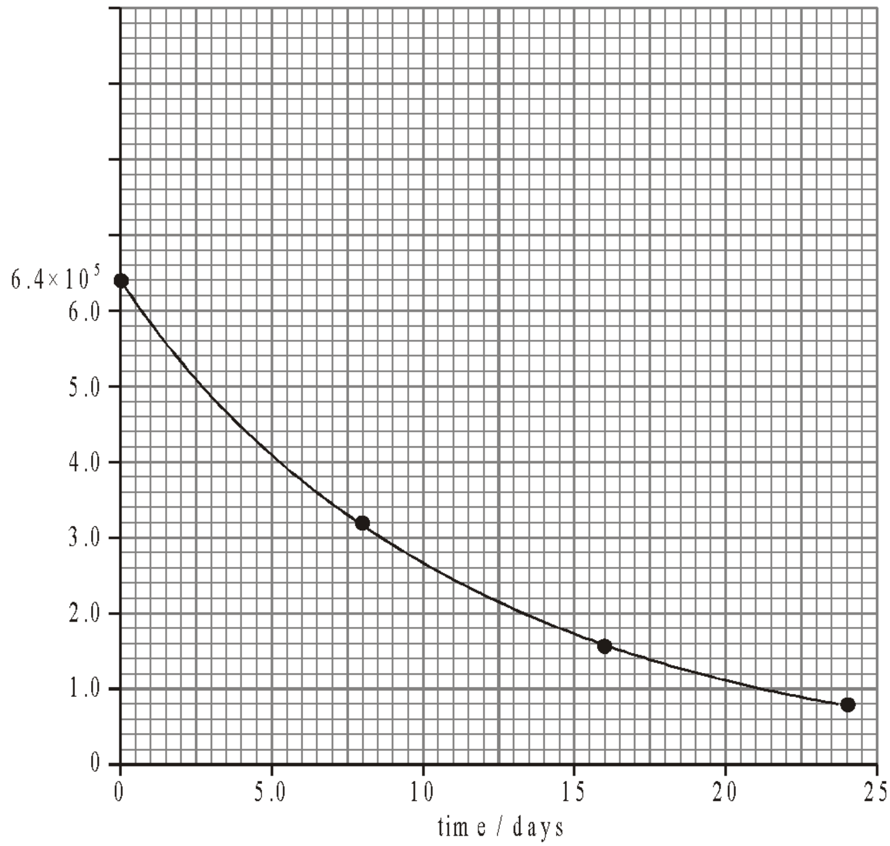

shown on graph at least the 0, 8 and 16 day data points;
exponential shape;
scale on *y*-axis / goes through 24 day point;

(3)

ii. Determine the decay constant of the isotope I-131

$\lambda = \frac{0.69}{T}$; (*accept ln 2 for 0.69*)
$= 0.086\ d^{-1}$ / $0.87\ d^{-1}$ / $1.0 \times 10^{-6}\ s^{-1}$;

(2)

iii. The sample is to be used to treat a growth in the thyroid of a patient. The isotope should not be used until its activity is equal to 0.5×10^5 Bq. Calculate the time it takes for the activity of a freshly prepared sample to be reduced to an activity of 0.5×10^5 Bq.

$0.5 = 6.4e^{-0.086t}$;
to give $t = 30d$ / 2.6×10^6 s / $29d$ / 2.5×10^6 s;

(2)

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