IMCC Yr 12 ATAR Physics

Quantum Physics and Atomic Test – 2018

Name: Answers.

Total Marks - 57

Q1. A synchrotron produces hard X-rays that travel along a beam line and impact on a sample of crystalline material.

a). **ESTIMATE** the energy of these hard X-rays in keV. [3 marks]

$\lambda_{typical} = 1 \times 10^{-10}$ m.

$E = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} \times 3\times10^{8}}{1\times10^{-10}} = 1.99\times10^{-15}$ J $\div 1.6\times10^{-19} = 1.24\times10^{4}$ eV

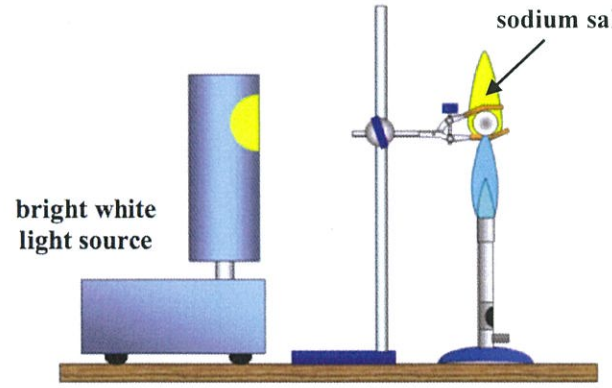
$\approx$ 12.4 keV.

b). How many of these hard X-rays would be produced each second by a 1.8 kW X-ray tube? [2 marks]

$E = P \times t = 1800 \times 1 = 1800$ J

$\therefore$ no. of X-rays; $1800 \div 1.99\times10^{-15} = 9.05\times10^{17}$.

Q2. The following arrangement produces a spectrum when viewed through a spectroscope.



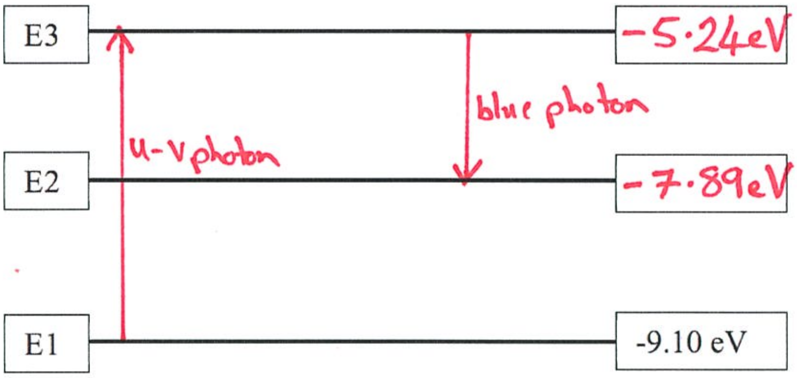
a) This type of spectrum is called a line absorption spectrum and an example is shown above. Describe how such a spectrum is produced. (4 marks)

- bright white light source produces all photons within visible spectrum and therefor generate a continuous spectrum
- some of these photons will have energy values which match transitions within the sodium atoms EXACTLY and $\therefore$ excite ground state electrons to an excited level
- as these electrons return to the ground state, they re-emit their energy in the form of emr photons, but in ALL directions
- so, certain wavelengths are missing from the spectrum which explain the dark lines.

Q3. Tonic water contains quinine and is a clear liquid under normal lighting conditions. When UV light shines onto tonic water it starts to glow with a distinct blue colour. This is because of the process of fluorescence. One of the atoms in quinine has a ground state energy level value of -9.10 eV. It is excited to Energy Level 3 (E3) by a UV photon of wavelength 322 nm. A blue photon of wavelength 469 nm is emitted in a de-excitation from E3 to E2.

a) On the diagram below show and label the electron transitions taking place that give rise to the observed phenomenon.

(2 marks)



b) Calculate the value of Energy Levels 2 and 3 (eV) and show them on the diagram. Show your working in the space below.

(4 marks)

$E_{u\text{-}v} = \frac{hc}{\lambda} = 6.63\times10^{-34}\times3\times10^{8}/(322\times10^{-9})$

$= 6.18\times10^{-19}\,J \div 1.6\times10^{-19} = \underline{3.86\,eV}.$

$\therefore -9.10 + 3.86 = \underline{-5.24\,eV}$ = energy level, E_3

$E_{blue} = \frac{hc}{\lambda} = 6.63\times10^{-34}\times 3\times10^{8}/(469\times10^{-9})$

$= 4.24\times10^{-19}\,J \div 1.6\times10^{-19} = \underline{2.65\,eV}$

$\therefore -5.24 - 2.65 = \underline{-7.89\,eV}$

c) Determine the wavelength (nm) of the other photon that can be emitted in this fluorescence process by a transition from E2 and state whether it is visible or not. (refer to the data sheet to justify your answer)

(4 marks)

ΔE (from 2−1) $= 9.10 - 7.89 = 1.21\,eV \times 1.6\times10^{-19} = 1.936\times10^{-19}\,J$

$\therefore E = \frac{hc}{\lambda}\quad \therefore \lambda = hc/E = 6.63\times10^{-34}\times3.0\times10^{8}/1.936\times10^{-19}$

$\therefore \lambda = \underline{1.03\times10^{-6}\,m}.$ $\therefore$ NOT visible! (it is infra-red).

(or $1.03\,\mu m$).

Q4. When demonstrating the photoelectric effect, a beam of light is shone onto a clean metal surface. If the light is above a certain threshold frequency it causes electrons to be ejected from the surface.

a). Explain if this indicates that light is behaving as a particle or a wave. (3 marks)

- it indicates the particle nature of light
- if it behaved as a wave, then any frequency of incident light would build up over time and eventually cause photoelectric emission – as stated above, this is NOT the case!

b). In an experiment to determine Planck's Constant, the following data was achieved while determining the stopping potential required to prevent the flow of electric current in a circuit containing a photodiode which produces photoelectrons when irradiated with visible light.

Stopping potential (V)	wavelength, λ (nm)	frequency, f x10^{14} (Hz)
2.95	420	7.14
2.32	534	5.62
2.08	598	5.02
1.93	642	4.67
1.82	680	4.41

i). Complete the table by calculating the missing frequency values. (1 mark)

ii). Use the grid opposite to plot a graph of stopping potential versus frequency. (4 marks)

iii). Calculate the gradient of your graph (with units) **and** use it to determine a value for Planck's Constant. (4 marks)

gradient $= (2.8-1)/(6.75\times10^{14}-2.5\times10^{14}) = 1.8/(4.25\times10^{14}) = 4.24\times10^{-15}$ Vs

$E_K = eV_s = hf - W \quad \therefore V_s = \frac{h}{e}f - \frac{W}{e}$

$y = mx + c$

$\therefore$ gradient $= h/e \quad \therefore h =$ gradient $\times e$

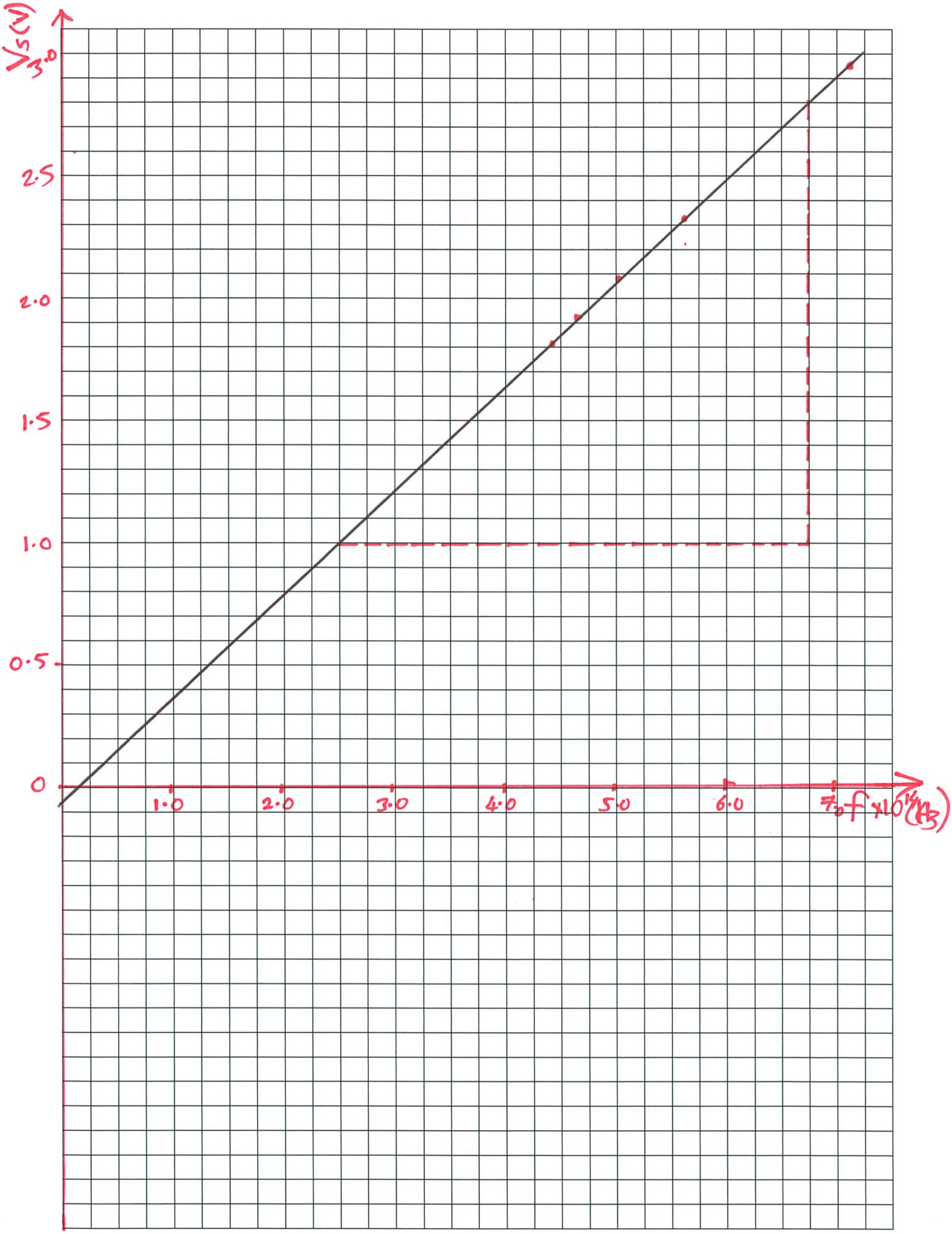
$\therefore h = 4.24\times10^{-15} \times 1.6\times10^{-19} = 6.78\times10^{-34}$ Js

iv). Use your y-intercept value to determine the work function, W (in electron-volts, eV) for the metal surface used within the photodiode.

(3 marks)

y-intercept $= 0.06$ V $= \frac{W}{e}$

$\therefore W = 0.06$ eV (or 9.6×10^{-21} J)



V_s (V)
3.0
2.5
2.0
1.5
1.0
0.5
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
f ×10^14 (Hz)

Q5. The following describe features largely associated with phenomena related to quantum and atomic physics.

a). Oscillating charges produce electromagnetic waves of the same frequency as the oscillation; electromagnetic waves cause charges to oscillate at the frequency of the wave. Examples of this are electromagnetic radio waves which are received by an antenna / aerial before being converted into sound waves by a radio. What is the principle called whereby waves vibrating at a particular frequency cause particles to vibrate in an object **at exactly the same** frequency?

Resonance (1 mark)

b). Transverse waves and longitudinal waves both share a number of common properties, such as reflection, refraction, diffraction, interference, etc. Outline a property you have studied which clearly differentiates between the two wave types. Give an everyday example where this particular property is evident. (3 marks)

~~• wave-like behaviour would be diffraction and interference~~
~~• the fringe pattern (bright and dark fringes) produced in Young's Double slit experiment is a~~

• only transverse waves can be polarised, longitudinal waves can not. Polaroid sunglasses remove glare by removing most of the planes of light from sunlight, which consists of unpolarised light.

c). Define an electromagnetic wave and use a diagram to aid your definition. (3 marks)

e/m waves are transverse waves consisting of mutually perpendicular electric and magnetic fields.

d). A stream of electrons travelling at $5.60 \times 10^5\ ms^{-1}$ can produce interference patterns similar to those produced by visible light waves in Young's Double Slit Experiment. Calculate the de Broglie wavelength of this stream of electrons. (3 marks)

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63\times10^{-34}}{9.11\times10^{-31} \times 5.6\times10^{5}}$$

$$= \underline{1.30\times10^{-9}\ m} \quad (130\ nm)$$

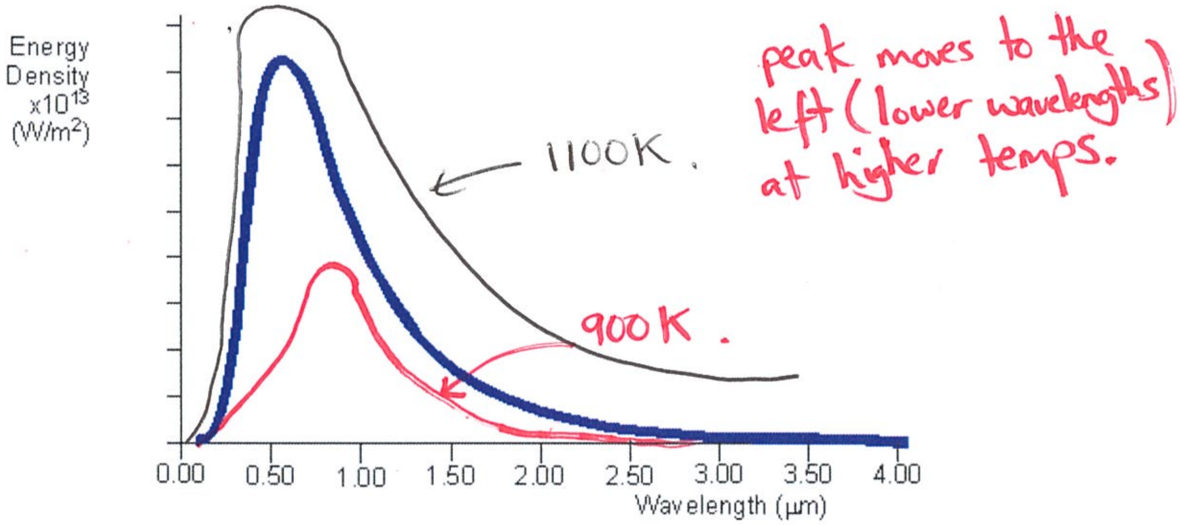
e). A *Black Body* emits radiation, often referred to as *Black Body Radiation* (BBR).

i). Define the terms in italics. (3 marks)

Black Body: a body that is a perfect absorber and emitter of electromagnetic radiation – none of the incident radiation is reflected.

Black Body Radiation: the radiation emitted by a black body which remains in thermal equilibrium with its surroundings.

ii). An example of a black body is heated to a temperature of 1000 K and generates radiation according to the continuous spectrum shown by the graph below.



Add two further spectra to this graph, one showing the radiation generated at a temperature of 1100 K and the other showing the radiation generated at 900 K, clearly indicating which curve represents the higher temperature and which represents the lower temperature.

(4 marks)

f). Ultra violet photons of wavelength 5.4×10^{-8} m irradiate a polished zinc metal plate. Zinc has a work function value, W = 4.3 eV. Calculate:

i). the threshold frequency for zinc metal (2 marks)

$W = hf_0 \therefore f_0 = \frac{W}{h} = \frac{4.3 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}}$

$\therefore f_0 = 1.04 \times 10^{15}$ Hz.

ii). the maximum kinetic energy of the ejected photoelectrons (2 marks)

$E_k = hf - W = \frac{hc}{\lambda} - W = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{5.4 \times 10^{-8}} - (4.3 \times 1.6 \times 10^{-19})$

$= 3.68 \times 10^{-18} - 6.88 \times 10^{-19} = 3.00 \times 10^{-18}$ J.

iii). the velocity of these fastest moving photoelectrons (2 marks)

$E_k = \frac{1}{2} m_e v^2 \therefore v = \sqrt{\frac{2 \times 3 \times 10^{-18}}{9.11 \times 10^{-31}}}$

$\therefore v = \sqrt{(6.58 \times 10^{12})} = 2.56 \times 10^{6}$ ms^{-1}.