Physics ATAR - Year 12
Particles Waves and Quanta
2016

Name: SOLUTIONS	Mark: / 61 = %

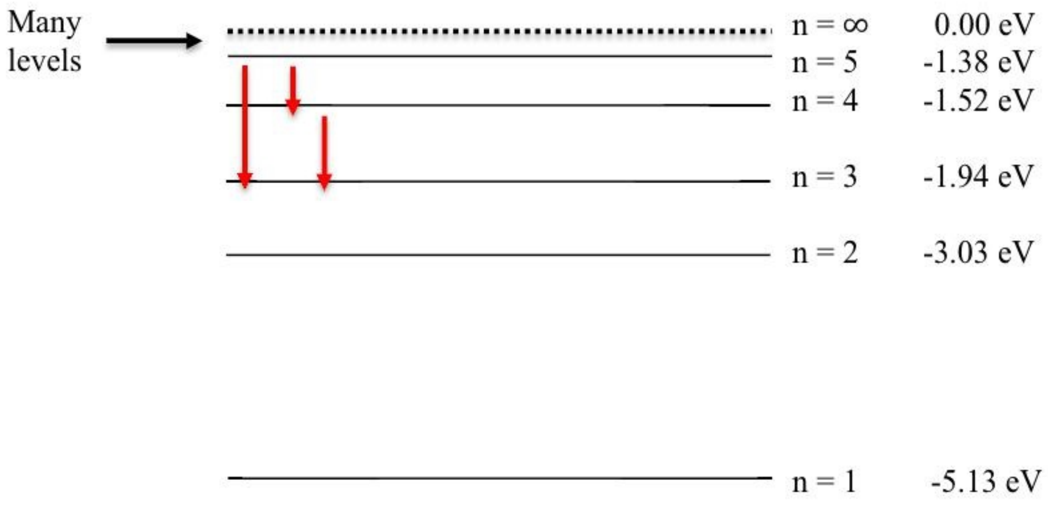
Time Allowed: 50 Minutes

Notes to Students:

1. You must include **all** working to be awarded full marks for a question.
2. Marks will be deducted for incorrect or absent units and answers stated to an incorrect number of significant figures.
3. **No** graphics calculators are permitted – scientific calculators only.

Question 1 **(13 marks)**

The diagram below represents a simplified energy level diagram (not to scale) of A neutral sodium atom



(a) Calculate the energy of the emitted photon when an excited electron decays from the n = 2 level to the n = 1 level.

(2 marks)

$E = E_2 - E_1$ (½)

$= -3.0 - (-5.13)$ (½)

$= 2.10$ eV (1)

Must show logic in arriving at 2.10 eV.

-1 mark for no unit.

(b) Calculate is the wavelength of this emitted photon.

(3 marks)

$E = \frac{hc}{\lambda} \quad \lambda = \frac{hc}{E}$ (1)

$= \frac{(6.63\times10^{-34})(3.00\times10^{8})}{2.10 \times 1.60 \times 10^{-19}}$ (1)

$= 5.92\times10^{-7}\ m$ (1)

-1 mark for no unit..

(c) Using the energy levels provided in the diagram above, show all of the possible transitions an excited electron could make to decay to the n = 3 energy level.

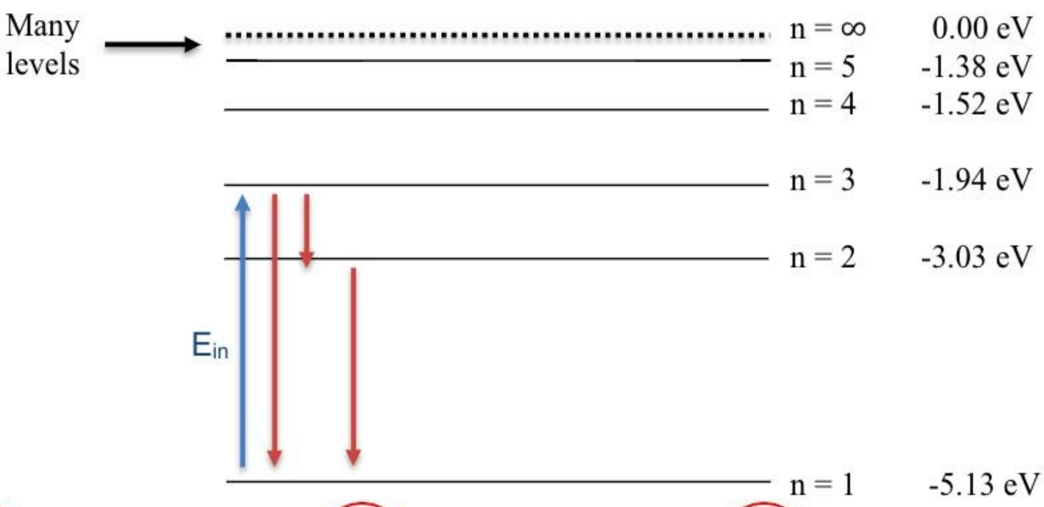
(2 marks)

Do not allow transition from n = ∞ as electrons have been ionized and would not interact further.

(d) The sodium atom is bombarded with electrons, each having an energy of 3.50 eV. Calculate:

i. the energies of the emitted photons when the bombarding electrons interact with atoms in their ground state. (another diagram has been provided to assist you)

(3 marks)



$E = E_3 - E_1$ ½
$= -1.94 - (-5.13)$
$= 3.19$ eV ½

$E = E_3 - E_2$ ½
$= -1.94 - (-3.03)$
$= 1.09$ eV ½

$E = E_2 - E_1$ ½
$= -3.03 - (-5.13)$
$= 2.10$ eV ½

- ½ marks for each quanta if no logic / equation shown
-1 mark for no unit..

ii. the energies of the scattered bombarding electrons if they interact with atoms in their ground state.

(3 marks)

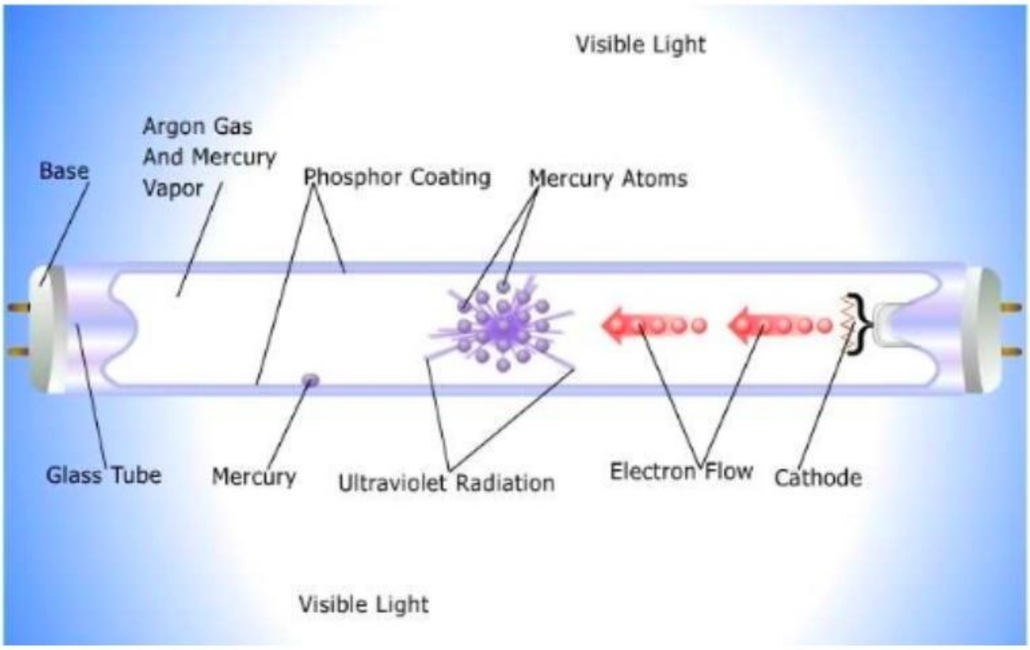
3.50 – 3.19 = 0.31 eV 1.5

3.50 – 2.10 = 1.40 eV 1.5

- ½ marks for each quanta if no logic / equation shown
-1 mark for no unit..

Question 2 **(14 marks)**

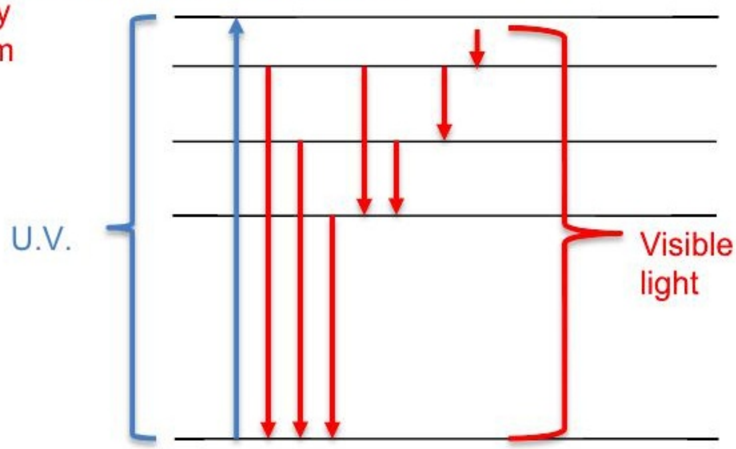
A fluorescent tube is filled with low-pressure mercury vapour which, when excited by the electron flow, emits radiation in the ultra-violet region. The tube is coated in a Phosphor coating that emits visible light.



(a) Explain, with the aid of a diagram, how the ultra-violet light is converted to visible light when it strikes the phosphor coating.

(4 marks)

- The UV light is absorbed by the phosphor coating, exciting electrons to higher levels
- The electrons then cascade back down to the ground state
- Releasing photons with energy within the visible light spectrum



(b) Examining the spectral emission of a fluorescent tube reveals a prominent spectral line with energy 3.00 eV. Calculate the energy of these photons in Joules.

(2 marks)

$E = qV$ (½)

$= 3.00 \times 1.60 \times 10^{-19}$ (½)

$= 4.80 \times 10^{-19}$ J (1) -1 mark for no unit.

(c) Calculate the wavelength of the 3.00 eV photon.

(3 marks)

$E = \frac{hc}{\lambda} \quad \lambda = \frac{hc}{E}$ (1)

$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{4.80 \times 10^{-19}}$ (1)

$= 4.14 \times 10^{-7}$ m (1) -1 mark for no unit.

Or 414 nm

(c) State the colour this photon is likely to be.

(1 mark)

blue – indigo - violet

(d) The Rutherford model of the atom described the electrons as analogous to planets that orbited the sun (the nucleus). Further experimental evidence contradicted this model resulting in acceptance of the Bohr model of the atom. Explain why the Rutherford model needed to be changed and how the Bohr model provides a better fit with the experimental evidence.

(4 marks)

- Accelerating electrons were shown to emit energy in EMR
- this would decrease the orbital speed of the electron and see it spiral into the nucleus.
- The Bohr model postulate added was that electrons could only exist in discrete orbital levels.
- And could only release a fixed quantum of EMR according to allowed energy level transitions

Question 3 **(10 marks)**

A 1.50×10^2 m long spaceship rushes past a stationary observer at a speed of 2.70×10^8 ms^{-1}.

(a) Calculate the length of the spaceship as it appears to the stationary observer as it rushes past.

(3 marks)

$\frac{v}{c} = \frac{2.7 \times 10^8}{3.00 \times 10^8} = 0.90$ (1)

$L = L_0\sqrt{1 - \frac{v^2}{c^2}}$ (½)

$= 1.50 \times 10^3 \sqrt{1 - 0.9^2}$ (½) $= 65.4$ m (1) -1 mark for no unit.

(b) The stationary observer and the pilot of the space ship have a disagreement over the length of the spaceship, each arguing that their measurement of the space ship is correct and the other person is wrong. Explain which person, if either, is correct.

(3 marks)

- Both observer's measurements are correct
- From their frame of reference.
- Einstein's postulate of special relativity states that no single inertial reference frame is better than any other

(c) Explain, using the following equation from Einstein's theory of relativity and one of Newton's laws, why faster than light travel is considered impossible.

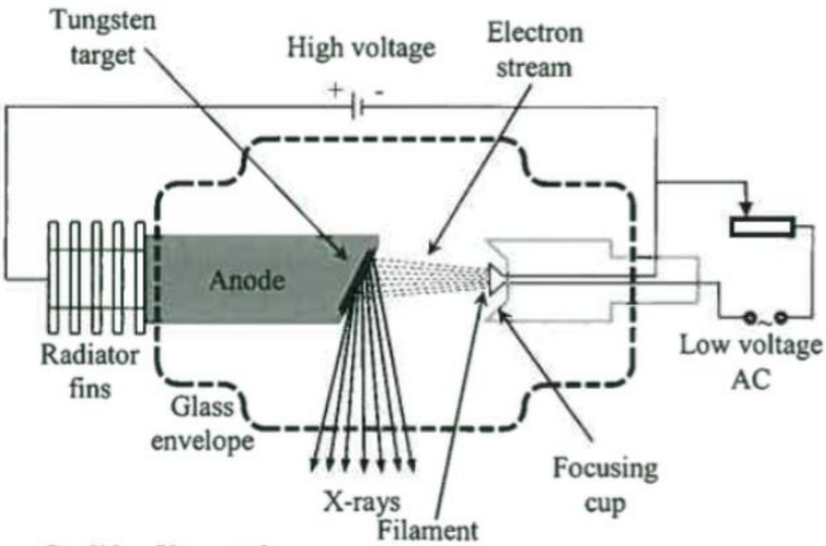
(4 marks)

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- As the speed of an object approaches c, the relativistic mass approaches infinity.
- Newton's 2^{nd} law states F = ma
- Which implies that as mass approaches infinity, the required force approaches infinity.
- Which is not possible.

Question 4 **(12 marks)**

The following diagram shows a simple type of X-ray tube. It can be used to produce either hard X-rays (with short wavelengths) or less penetrating soft X-rays (with longer wavelengths).



Coolidge X-ray tube

(a) State what adjustment could be made to vary the wavelength of the X-rays produced.

(1 marks)

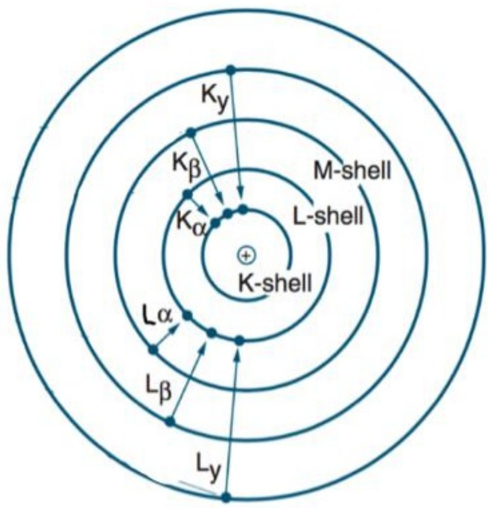
Vary the voltage between the anode and cathode

Or Change the metal on the anode.

(b) A proportion of the X-ray photons produced will be characteristic of the Tungsten target. Explain, with the inclusion of a diagram, how these photons are related to the structure of the Tungsten atoms.

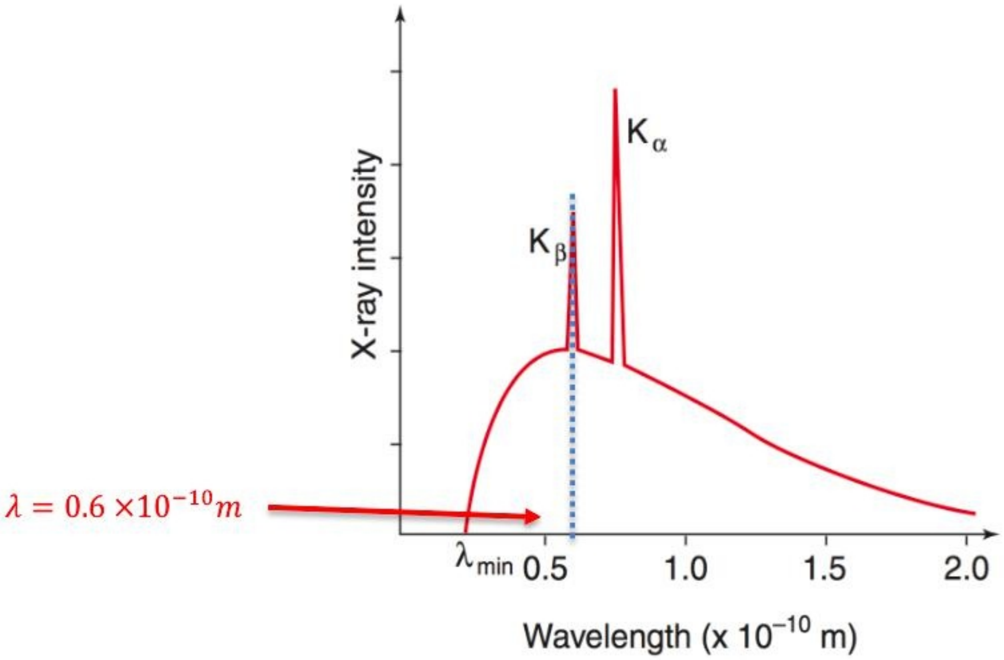
(3 marks)

- Electrons are removed from K and L shells due to incident electron interaction.
- Photons emitted are produced from electrons transitioning into K and L orbital shells.



(Diagram must show a transition from an outer shell to an inner shell.)

The following X-ray spectrum was produced using a 50.0 kV tube with a Tungsten target.



(c) Calculate the energy, in eV, of the photons emitted in the K_β peak.

(4 marks)

$E = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E}$ (1)

$= \frac{(6.63x10^{-34})(3.00\times10^{8})}{0.6\times10^{-10}}$ (1)

$= 3.315 \times 10^{-15}$ J (1) $\div 1.60 \times 10^{-19}$ $= 2.07 \times 10^{4}$ eV

-1 mark for no unit..

(d) Explain, using an appropriate calculation, why no X-rays with wavelength less than 0.25×10^{-10} m are produced.

(4 marks)

- maximum energy of photons would be equal to 50 keV
- since $E = \frac{hc}{\lambda}$ $E \propto \frac{1}{\lambda}$
- the minimum wavelength possible is:

$\lambda = \frac{hc}{E}$

$= \frac{(4.14\times10^{-15})(3.00\times10^{8})}{50\times10^{3}}$ (2 marks for appropriate equation)

$= 2.49 \times 10^{-11}$ m

Question 5 **(12 marks)**

A sub-atomic particle called a Kaon (K^-) can be created in high energy particle accelerators before decaying into 3 smaller sub-atomic particle called 'pions'. The mean life-time (the time before it decays) of a Kaon at rest is 1.24×10^{-8} s and, in a series of experiments, is emitted at a speed of 95% the speed of light. Classical mechanics suggests that the Kaon can only travel 3.53 m, however, in experiment, the Kaon is detected to have travelled much further before decaying.

(a) Explain why the Kaon is detected to have travelled further.

(3 marks)

- The Kaon is emitted at relativistic speed (0.95c)
- Time dilation effects occur to a stationary observer
- Meaning the Kaon is observed to last longer relative to a stationary observer.

(b) Calculate the distance the Kaon travels when relativistic effects are to be considered.

(4 marks)

$\frac{v}{c} = 0.95\ c$ (½)

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1.24 \times 10^{-8}}{\sqrt{1-0.95^2}} = 3.97 \times 10^{-8} s$$

(½) (½) (½)

(½)

$S = v\,t$ (½)

$= (0.95 \times 3.00 \times 10^8) \times 3.97 \times 10^{-8}$

$= 11.3$ m (1)

- ½ mark for no unit.

(c) During an experiment, two Kaons are fired towards each other, each with a speed of 0.90 c with respect to a stationary observer positioned at a detector between the two Kaons. Calculate the magnitude of the speed of one Kaon from the reference frame of the other.

(4 marks)

K^- = 0.90c → stationary Observer ← K^- = - 0.90c

K- frame ← v = -0.90 c Observer ← K^- = u' = -0.90c

(diagram not necessary)

$$u = \frac{v + u'}{1 + \frac{v.u'}{c^2}}$$ (½)

$$= \frac{-0.9c+(-0.9c)}{1+\frac{(0.9c)(0.9c)}{c^2}} = \frac{-1.8c}{1+0.81} = 0.994c$$

(½) (½) (1)

$u = 0.993 \times 3.00 \times 10^8$ (½)

$= 2.98 \times 10^8\ ms^{-1}$ (1)