Name: DAVE **/50**

Yr 12 Physics Light Duality Test 2016

Instructions

1. Answer all questions in the spaces provided.
2. Give all numerical answers to three significant figures, except where you are required to estimate values where two significant figures will be appropriate.
3. Show all working – marks may be awarded for logical working even when an incorrect final answer is arrived at.
4. If you require extra working space, write "PTO" on the bottom of the page and continue working on the back of the page.

48 marks for answering the questions, 2 marks for units and significant figures

Question 1 **(4 marks)**

Louis de Broglie thought that if a wave could behave like a particle, then perhaps a particle could behave like wave. He proposed that the wavelength of a material particle was related to its linear momentum $p = mv$.

Compare, through calculations, the de Broglie wavelengths for a 5.0kg ball travelling at 14m s^{-1} to that of an electron travelling at 5.9 x 10^{6}m s^{-1}.

From these results, determine which of these particles has a wavelength in the X-ray region of the electromagnetic spectrum.

$\lambda = \frac{h}{p} = \frac{h}{mv}$.

Ball : $\lambda = \frac{6.63 \times 10^{-34}}{(5 \times 14)} = \frac{6.63 \times 10^{-34}}{70}$

$= 9.47 \times 10^{-36}$ m

$\lambda_e = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31} \times 5.9 \times 10^{6})}$

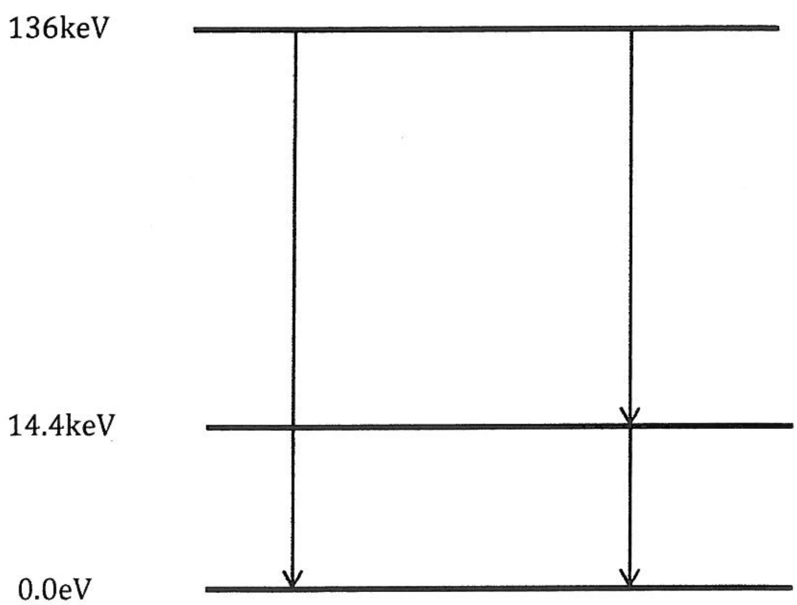
$= \frac{6.63 \times 10^{-34}}{5.3749 \times 10^{-24}} = 1.23 \times 10^{-10}$ m

↳ X-ray

Question 2 **(4 marks)**

When a radioactive isotope undergoes gamma decay, a nucleus in an excited state decays to a lower energy state of the same isotope by the emission of a photon. This decay is similar to the emission of light when an electron in an atom moves from a higher energy level to a lower level. The isotope Fe-57 can decay to the ground state in the two ways shown on the energy level diagram below.

Calculate the wavelength and frequency of the photon emitted in the transition from the level with energy of 136 keV to the level with energy of 14.4 keV.



$$E = hf$$

$$f = \frac{E}{h} = \frac{(136 - 14.4)}{h} = \frac{121.6 \times 1.6 \times 10^{-16}}{6.63 \times 10^{-34}}$$

$$= \frac{194.56 \times 10^{-16}}{6.63 \times 10^{-34}}$$

$$(2) \quad = 2.93 \times 10^{19}\ \text{Hz}$$

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^{8}}{2.93\ldots \times 10^{19}}$$

$$= 1.02 \times 10^{-11}\ \text{m} \quad (2)$$

Question 3

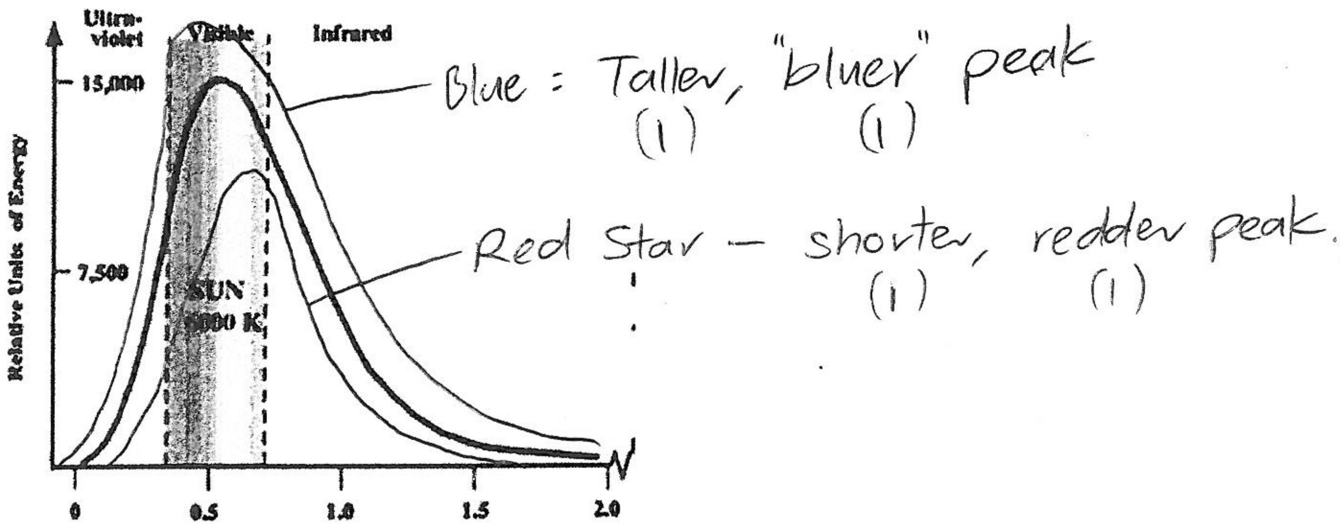
(4 MARKS)

The diagram below shows the spectrum of the (blackbody) EMR emitted by the sun.

One the diagram, sketch and label the general curve for

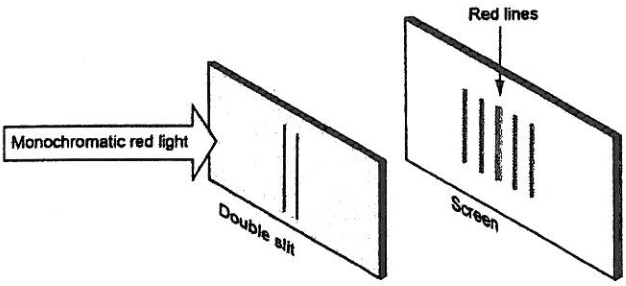
a) a cooler, red star (2 marks)

b) a warmer, blue star (2 marks)



Question 4

(3 marks)



The pattern observed when monochromatic light passes through a piece of cardboard with twin slits close together is often considered evidence for the wave theory of light. A diagram of an experimental set up is shown to the left.

Explain how the pattern of red lines is formed on the screen and why this is considered to be evidence for the wave theory of light.

1. Each slit is a source of new, circular waves.

2. The waves from these sources interact, interfering constructively and destructively.

3. This results in a series of bright, high intensity lines, interspersed by dark, low intensity bands, similar to patterns produced by water and other mechanical waves.

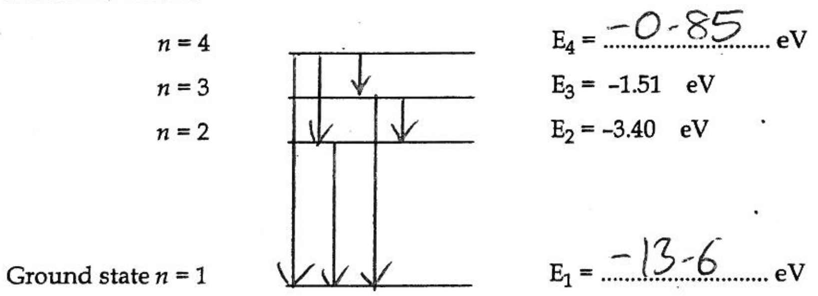
QUESTION 5 (13 MARKS)

A hydrogen atom, in an excited energy level, undergoes relaxation by emitting a photon. The energy values are given by $E_n = -\frac{13.6}{n^2}$ eV. The initial state of the electron is in energy level $n = 4$ and the final state after relaxation is ground state ($n = 1$).

(a) Does the average radius of the electron orbital remain the same, increase or decrease in value during this transition? Circle the correct answer. [1]

remains the same   increases   (decreases)

(b) Use the formula $E_n = -\frac{13.6}{n^2}$ eV to complete the energy level diagram below. The diagram is **not** drawn to scale. [2]



(c) On the diagram above, draw in all the possible transitions when an electron undergoes relaxation from $n = 4$ to the ground state. 6 possible : −1 for each not shown. [3]

(d) (i) Calculate the wavelength of the photon emitted from the E_3 to E_2 transition. Show **all** workings. [4]

$E_{photon} = 3.40 - 1.51 = 1.89\ eV = \frac{hc}{\lambda}$

$\therefore \lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{(1.89\times1.60\times10^{-19})} = \frac{1.989\times10^{-25}}{3.024\times10^{-19}}$

$= 6.58\times10^{-7}$ m

(ii) The transitions of E_4 to E_2 and E_3 to E_2 produce red and green photons. Explain which transition produces which colour. [3]

(1) $E_4 \rightarrow E_2$: Green and $E_3 \rightarrow E_2$: Red.

(1) Green light carries more energy per photon.

(1) The $E_4 \rightarrow E_2$ transition releases more energy ⇒ green.

Question 6 **(6 marks)**

There are five general types of spectra that may be observed through a spectroscope. By discussing the appearance and mode of production, compare and contrast the spectra observed when:

a) a sample of monatomic gas is highly heated.

Black background with coloured lines. (1)
The coloured lines show the photons emitted (1) as electrons excited by heating move to lower energy levels.

b) a sample of cold monatomic gas has broad spectrum light shone through it

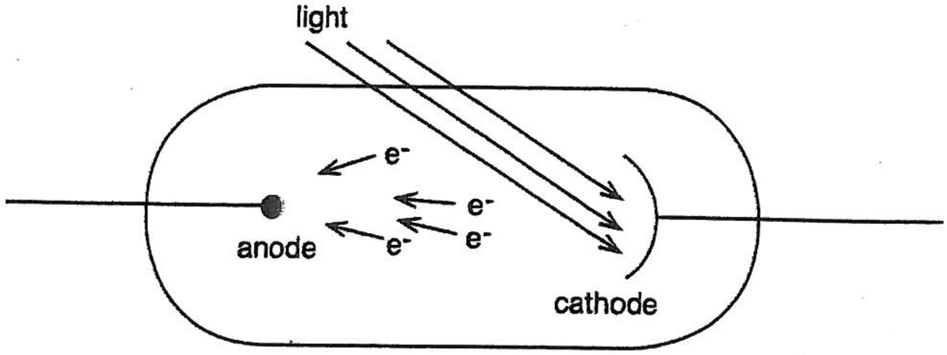
A full spectrum with black lines. (1)
The black lines indicate the wavelength of light (1) absorbed by electrons as they move to higher energy levels.

c) a chunk of metal is heated to 6000K

A continuous spectrum showing all visible light (1
Metal is dense with many overlapping electron energy levels - heating means energised electrons can jump up and down between these levels emitting all wavelengths in the visible range. (1)

Question 7 **(14 marks)**

A group of students set up a photocell to investigate the photoelectric effect and determine a value for Planck's constant.



The photocell works when incident light falls on a metal cathode and causes electrons to be ejected with a certain kinetic energy from the metal. These electrons then move across the cell to the anode. The kinetic energy of an ejected electron is equal to the energy of the incident light minus the work function W (the energy required to remove the electron from the metal).

$$E_k = hf - W$$

To determine the kinetic energy of the electrons, a reverse voltage is applied to the anode and cathode so that it will just completely stop the electrons from reaching the anode. This is called the 'stopping voltage'. At this point, the work done by the electric field must equal the kinetic energy of the ejected electrons:

$$E_k = q_e V$$

The students then shone incident light that had passed through a filter of known wavelength onto a photocell. The photocell was connected to a circuit that allowed the students to adjust the stopping voltage so that zero current flowed through the tube.

The students combined several relationships to produce the following equation:

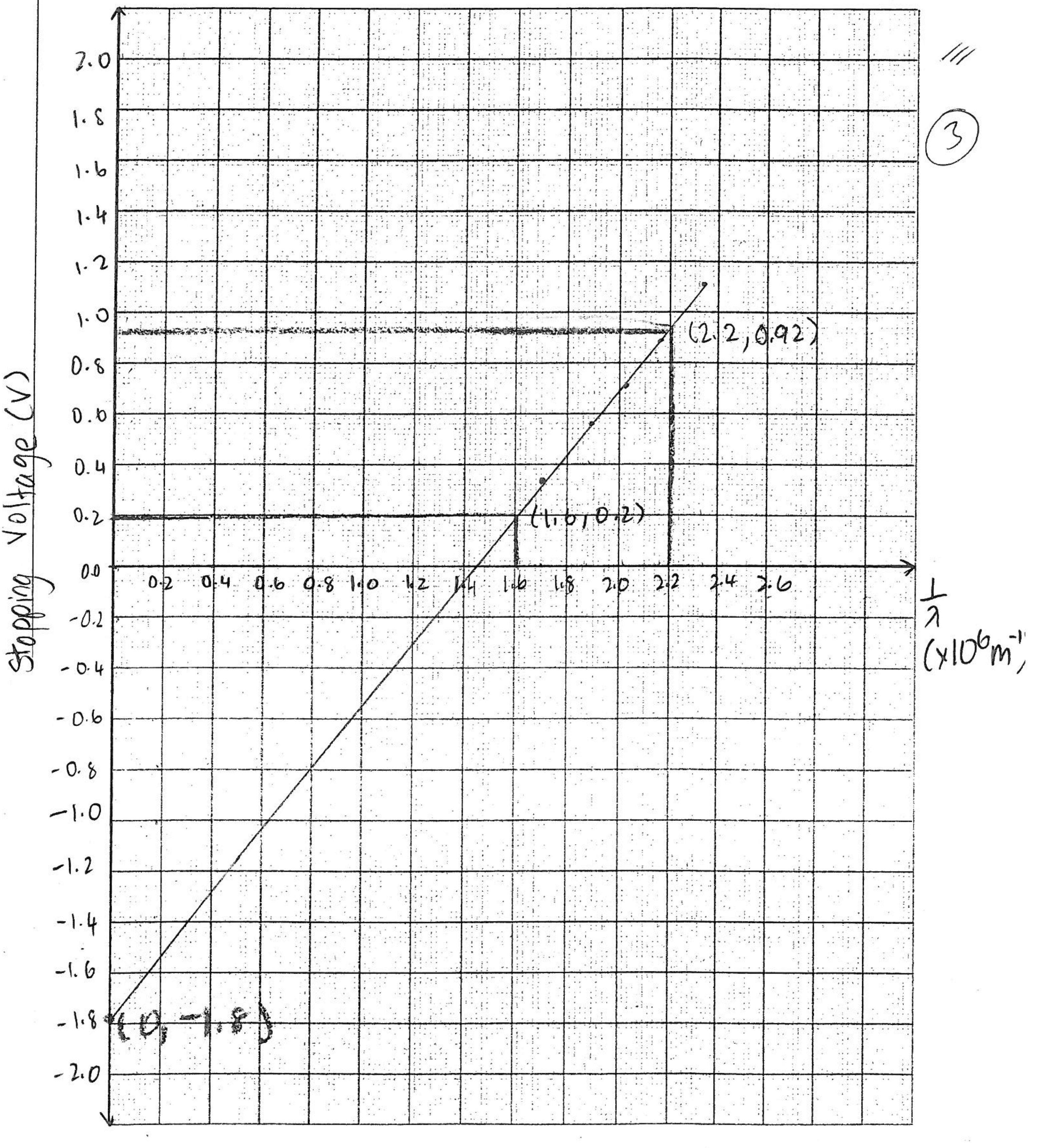
$$q_e V = \frac{hc}{\lambda} - W$$

The data was recorded and processed in the table below.

Filter colour	Wavelength (nm)	$\frac{1}{\lambda}$ (m^{-1})	Stopping voltage (V)
Blue	426	2.35×10^6	1.12
Green	464	2.16×10^6	0.88
Yellow	493	2.03×10^6	0.72
Orange	534	1.87×10^6	0.57
Red	589	1.70×10^6	0.33

of a photocell
stopping Voltage ^ required for varying wavelengths of light.

(a) Plot stopping voltage on the y-axis against $\frac{1}{\lambda}$ on the grid below. Draw the x-axis in the middle of the grid, and extend the y-axis to ± 2 volts. (3 marks)



///
③

(b) Given the aim of the experiment, explain why the students graphed $\frac{1}{\lambda}$. (1 mark)

to determine "h" : $qV = \frac{hc}{\lambda} - W$; ie $V = \frac{hc}{q\lambda} - \frac{W}{q}$

this leads to grad = $\frac{hc}{q}$

since c and q are constants, h can be determi

(c) Determine the gradient of the line of best fit and give its units. (3 marks)

USE POINTS ON GRAPH → Shown (1)

$m = \frac{y_2 - y_1}{x_2 - x_1}$ = approx $1{\cdot}2 \times 10^{-6}$ Vm

(1) (1)

(d) Use the gradient from part (c) to determine the experimental value in J s for Planck's constant. (2 marks)

ie $1{\cdot}2 \times 10^{-6} = \frac{hc}{q}$ (1) $\therefore h = \frac{1{\cdot}2 \times 10^{-6} \times q}{c}$

$= \frac{1{\cdot}2 \times 10^{-6} \times 1{\cdot}6 \times 10^{-19}}{3{\cdot}0 \times 10^{8}}$

(1) $= 6{\cdot}4 \times 10^{-34}$ J s

(e) Use the graph to determine the work function, and give its units. (3 marks)

Y int. $= -\frac{W}{q}$ (from (b)) (1)

ie $-\frac{W}{q} = -1{\cdot}8$ $\therefore W = q \times 1{\cdot}8 = 1{\cdot}6 \times 10^{-19} \times 1{\cdot}8$

$= 2{\cdot}9 \times 10^{-19}$ J

or 1·8eV !

(f) Explain what information the intercept with the x-axis provides and how this supports Einstein's theory that light is made up of photons. (2 marks)

(1) The maximum wavelength that will eject photo-electrons (with 0J).

(1) It implies that long λ light, no matter how intense, will never eject electrons; crushing the classical explanations of light energy.