ALL SAINTS' COLLEGE

Year 12 Physics – ATAR
Wave particle duality and quantum physics test
July 2016

Time allowed: 50 minutes
Total marks available: 50
Show calculation answers to 3 significant figures

Student Name: Solutions

1. Consider Young's double slit experiment; when a coherent green light source is projected through 2 small slits that are several hundred nanometres apart; an image is produced on a screen.

a) Explain why the image on the screen is regions of light and dark bands.

(2)

The light diffracts to circular wave fronts through the slits ✓
The light and dark bands are the interference pattern ✓ (light =constructive and dark =destructive).

b) This indicates that light is behaving as a: *(circle a response)* particle [✓ wave]

(1)

2. Describe 2 ways that an atom in its ground state can become "excited".

(2)

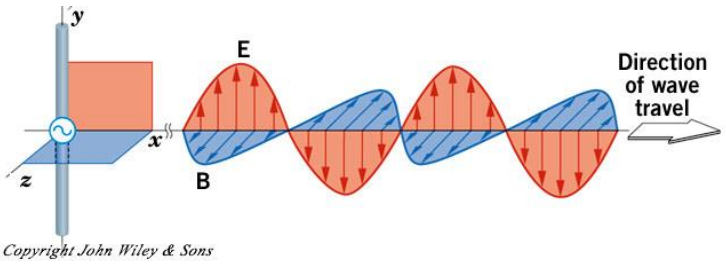
Thermal excitation -via particle collisions to transfer energy into atomic electron✓

Photon absorption where photon energy matches E level diff ✓

By bombardment of atomic electron by external particle e.g. electrons accelerated by an electric field transfer KE to atomic electron.
Any 2 reasonable answers with a description rather than just a list

3. A light wave is often depicted as 2 waves propagating perpendicular to each other. Explain the meaning of the 2 waves in this diagram.

(2)



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The EM wave is composed of two components ✓
electric field (E)
and magnetic field (B) ✓
which are perpendicular to each other and to the direction of wave propagation.

4. Consider the photoelectric effect. Blue light of wavelength 445 nm shines on a metal whose work function is 1.80 eV.

a) Calculate the maximum kinetic energy of the ejected electrons

(3)

$$f = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{445 \times 10^{-9}}$$

$f = 6.74157 \times 10^{14} Hz$ ✓ $W = 1.80 \times 1.60 \text{ x } 10^{-19} = 2.88 \text{x } 10^{-19}$ J

$$E_{KE\,Max} = hf - W$$

$$E_{KE\,Max} = (6.63 \times 10^{-34} \times 6.74157 \times 10^{14}) - 1.80 \times 1.60 \text{ x } 10^{-19} \checkmark$$

$$E_{KE\,Max} = 1.59 \times 10^{-19} J \checkmark$$

b) Red light of wavelength 770 nm is shone onto the same metal. Will the photoelectric effect occur in this instance? Explain briefly.

(4)

$$W = hf_o$$

$$1.80 \times 1.60 \text{ x } 10^{-19} = 6.63 \times 10^{-34} \times f_o$$

$$f_o = 4.343 \times 10^{14} \text{ Hz} \checkmark$$

$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{4.343\times10^{14}}$ ✓

$\lambda = 6.90 \text{ x } 10^{-7} = 690\ nm$ ✓

770 nm is longer than 690 nm which is less energetic so will NOT occur✓

OR, calculates E photon = 1.61 eV which is less than 1.80 eV
(2.58E-19 J vs 2.88E-19 J)
OR, calculates f photon as 3.896 x 10^{14} Hz which is less than threshold f

5. A green light emitting diode (LED) emits monochromatic light with a wavelength of 532 nm. The LED has a power rating of 40.0 mW.

a) Calculate the photon energy of the LED (2)

Consider photon

$E = h.f = h.c / \lambda = 6.63 \times 10^{-34} \times 3 \times 10^{8} / 532 \times 10^{-9}$ ✓

$E = 3.74 \times 10^{-19}$ J ✓

b) Calculate how many photons are emitted when the LED illuminates for 180 milliseconds. (3)

Consider a pulse

$E = P \times t = 0.040 \times 0.180 = 7.20 \times 10^{-3}$ J ✓

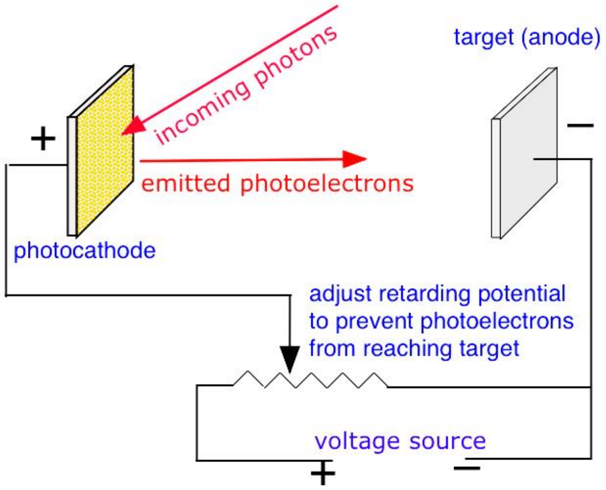
#photons = E (pulse) / E (photon) = $7.20 \times 10^{-3} / 3.74 \times 10^{-19}$ ✓

#photons = 1.93×10^{16} ✓

c) If the LED had the same power rating but was blue instead of green how many photons would it emit in comparison? Circle a response (1)

Greater number Same number [✓ Lesser number] Impossible to know

6. Some students conduct an experiment with the photoelectric effect equipment shown in the diagram. Yellow light of wavelength 555 nm is shone onto the photocathode and current flows. They adjust the voltage source to find the stopping voltage that prevents photoelectrons reaching the anode. This occurs at -0.61 V.



a) Calculate the speed of the fastest moving electrons when they are emitted from the cathode.

(3)

$$qV_0 = E_{KE\,Max} = \frac{1}{2}mv^2$$

$$(-1.60 \times 10^{-19} \times -0.61) \checkmark = \frac{1}{2} 9.11 \text{ x } 10^{-31} \times v^2 \checkmark$$

$$v = 4.63 \times 10^5\ m\ s^{-1} \checkmark$$

b) Calculate the work function of the metal stating your answer in eV.

(3)

$$qV_0 = E_{KE\,Max} = hf - W$$

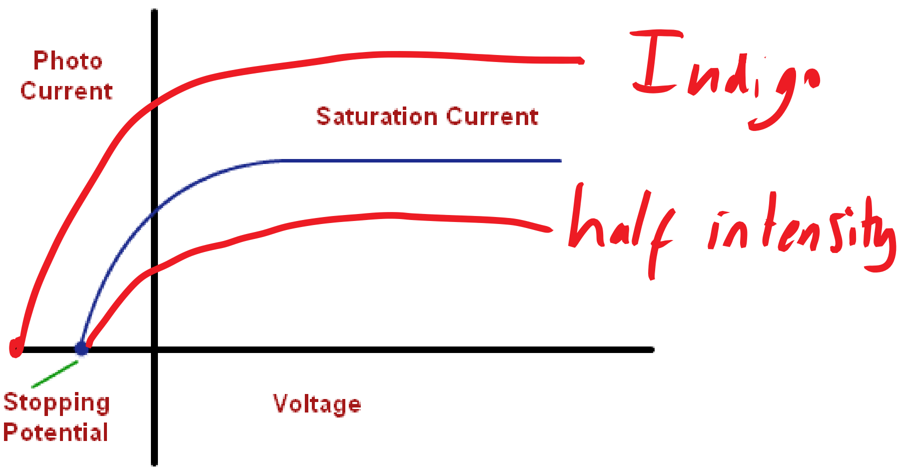
$$W = hf - q.V_0$$

$$W = \frac{hc}{\lambda} - q.V_0$$

$$W = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{555 \times 10^{-9}} - (-1.60 \times 10^{-19} \times -0.61) \checkmark$$

$$W = 2.60778 \times 10^{-19} J \checkmark = \frac{2.60778 \times 10^{-19}}{1.60 \times 10^{-19}} \text{ eV} = 1.63 \text{ eV} \checkmark$$

The students plot a curve of photocurrent versus voltage for the yellow light and obtain the curve below.



c) Explain why the curve flattens on the section labelled “saturation current”.

(2)

As the voltage increases from negative to positive all photo-electrons are brought across the plate gap. Current = flow of these charges✓
For a given intensity of light there is a maximum number of photoelectrons corresponding to the number of photons in the beam. ✓ (per second)

d) Sketch the approximate shape of the curve if the yellow light is halved in intensity and label it “half intensity”.

(1)

Shows same stopping voltage lower saturation current✓

e) Sketch the approximate shape of the curve obtained if indigo light at a higher intensity is used instead of yellow light. Label this curve “indigo”

(1)

Shows more negative stopping voltage higher saturation current✓

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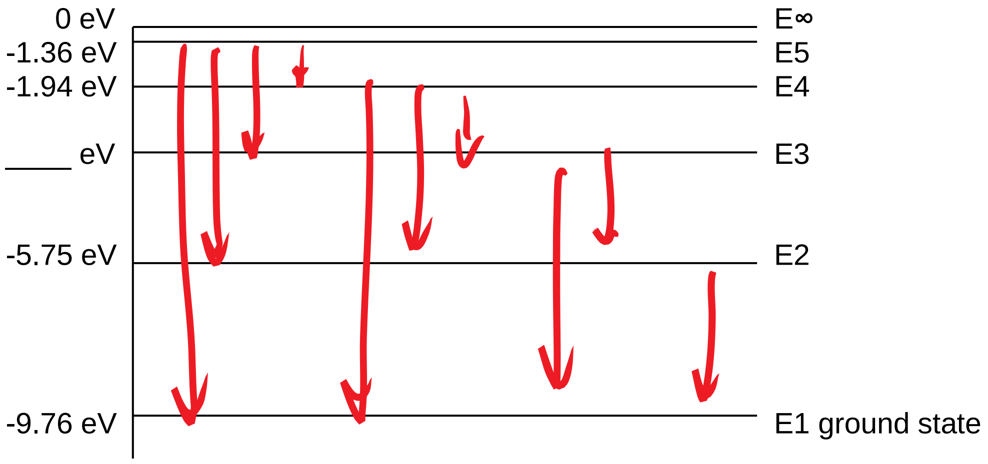
7. The diagram below details some of the energy levels for the Waugium atom.



a) The ground state atom absorbs a 185 nm photon which causes an excitation to E3. Determine the energy of E3 in electron volts to 3 significant figures.

(4)

$\lambda = 185 \times 10^{-9}$ m

$$E = \frac{h.c}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{185 \times 10^{-9}}$$ ✓

$E = 1.0751 \times 10^{-18}$ J✓

E (eV) = $1.0751 \times 10^{-18} / 1.60 \times 10^{-19}$

E (eV) = 6.72 eV✓

E3 = E1 + 6.72

E3 = -9.76 + 6.72 = -3.04 eV✓ (on the diagram)

b) State the minimum photon energy in eV that could ionise the atom in its ground state.

(1)

9.76 eV ✓

c) Which energy level transition is responsible for the longest wavelength (nm) possible in the emission spectrum of Waugium as the ionised electron returns to its ground state?

(1)

E5 to E4 ✓

d) Which area of the electromagnetic spectrum does a 185 nm photon belongs to? *(Remember that the SCSA F&C sheet is a rough guide only).*

(1)

Ultraviolet ✓

e) An atomic electron is at E5. How many lines in the emission spectrum would be possible for the energy levels considered above if it returns to the ground state?

(1)

Number of lines = 10

f) A **single** Waugium atom in the ground state is bombarded by **one** electron of kinetic energy of 4.50 eV. Detail in the table below the possible photon energies observable on de-excitation and the possible bombarding electron energy after passing through the Waugium atom.

(2)

Possible photon energies on de-excitation (eV)	Bombarding electron energy after colliding with atomic electron (eV)
9.76 – 5.75 = 4.01 eV ✓	4.50 - 4.01 = 0.49 eV ✓

g) Can the ground state atom absorb a 7.88 eV photon? Explain briefly

(1)

No, there are no energy level differences that equal this value✓
Correct explanation required for mark

h) Can the ground state atom absorb a 14.8 eV photon? Explain briefly

(1)

Yes, can ionise and have a balance of 14.8 -9.76 eV as KE✓
Correct explanation required for mark

Continued on next page

8. A proton is travelling at 85% of the speed of light. Calculate the de Broglie wavelength of the proton. (momentum = mass x velocity)

(3)

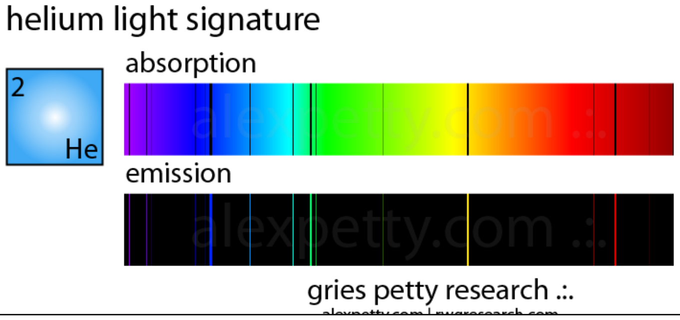
$m = 1.67 \times 10^{-27}$ kg $v = 0.85 \times 3 \times 10^{8}$ m s^{-1} ✓

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

$$\lambda = \frac{6.63\times10^{-34}}{1.67 \text{ x } 10^{-27} \times 0.85 \text{ x } 3 \text{ x } 10^{8}} \checkmark$$

$$\lambda = 1.56 \times 10^{-15}\, m \checkmark$$

9. The diagram shows an absorption spectrum for helium when viewed through a spectroscope. Black lines are shown on an otherwise continuous background. Explain how this absorption spectrum is formed.



(3)

White/Continuous (black body) spectrum of light is incident on relatively cool helium gas ✓

Photon absorption of only those photons whose energies correspond to energy level differences used for excitation of atomic electrons in helium✓

These wavelengths removed from spectrum seen as black lines – all other wavelengths pass through and are observed. ✓

Any 3 reasonable points.

Can also mention on de-excitation photons are scattered in random directions.

10. Calculate the momentum of 622 nm orange photon.

(2)

$$\lambda = 622 \times 10^{-9}$$

$$\lambda = \frac{h}{p} \qquad p = \frac{h}{\lambda}$$

$$p = \frac{6.63\times10^{-34}}{622 \times10^{-9}} \checkmark$$

$$p = 1.07 \times 10^{-27}\, kg\, m\, s^{-1} \checkmark$$

End of test