PHYSICS 12

Atomic Physics Topic Test 2019

Question/Answer Booklet

CORPUS CHRISTI COLLEGE

SEQUERE DOMINUM

NAME: Solutions

Time allowed for this paper

Reading time before commencing work: ~~4~~ 3 minutes
Working time for paper: ~~38~~ ~~40~~ 42 minutes

STRUCTURE OF THE PAPER

Section	No. of questions	No. of questions to be attempted	No. of marks out of 41	
A: Short Answers	5	ALL	11	
B: Problem Solving	3	ALL	30	
C: Comprehension				

Section A: Short Answer
Marks Allocated: 11 marks out of 41 total marks.
This section has 5 questions. Answer the questions in the spaces provided.

Question 1 (3 marks)
Photons of wavelength 290 nm are incident on a metal plate. The work function of the metal is 4.1 eV. Calculate the maximum kinetic energy of the emitted electrons.

$\lambda = 290 \times 10^{-9}$ m

$\phi = 4.1$ eV $= 4.1 \times 1.6 \times 10^{-19}$ J $= 6.56 \times 10^{-19}$ J (1)

(1) $E_{KE} = hf - \phi = \frac{(6.63 \times 10^{-34})(3 \times 10^{8})}{290 \times 10^{-9}} - 6.56 \times 10^{-19}$

$= 6.86 \times 10^{-19} - 6.56 \times 10^{-19}$

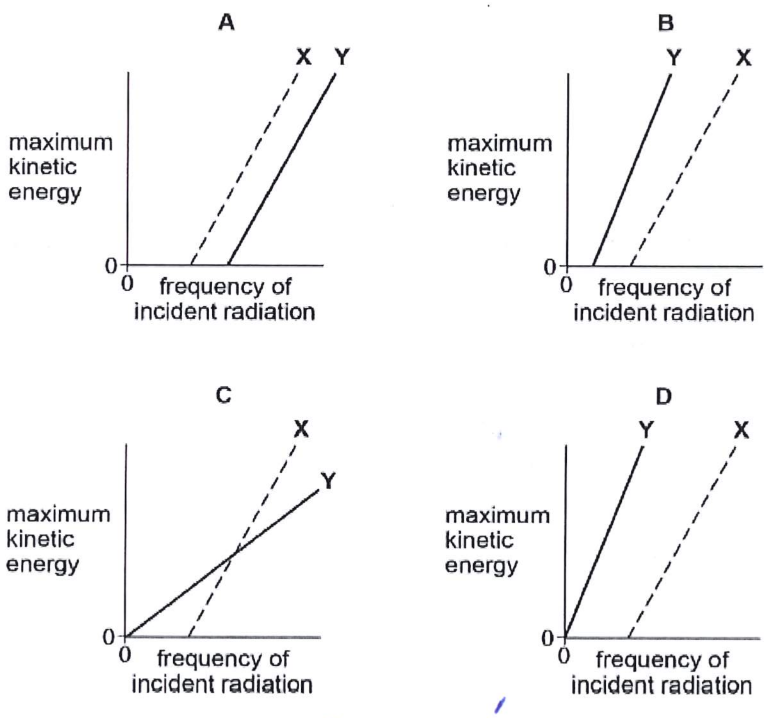
$= 2.99 \times 10^{-20}$ J $(= 0.19$ eV$)$

(1)

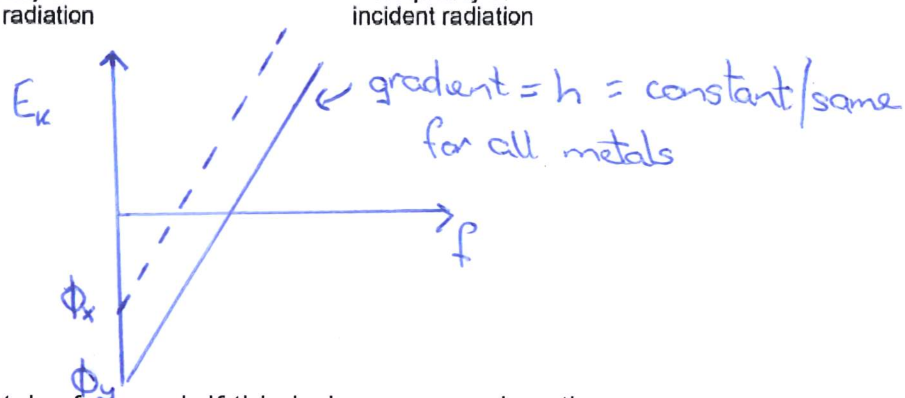
Question 2 (3 marks)

Line **X** on the graphs below shows how the maximum kinetic energy of emitted photoelectrons varies with the frequency of incident radiation for a particular metal.

Which graph shows the results for a metal **Y** that has a higher work function than **X**?



- **A** ☑
- **B** ☐
- **C** ☐
- **D** ☐



Explain your choice. Include a sketch of a graph if this helps your explanation.

- $E_K = hf - W = hf - \phi$
- The straight line graph of E_K versus f will have a constant gradient, given by Planck's constant

$$\begin{array}{ccccccc} E_K & = & h & f & - & \phi \\ \uparrow & & \uparrow & \uparrow & & \uparrow \\ y & = & m & x & + & c \end{array}$$

- The work function is given by the intercept value, which in graph A, intercept for line X < line Y

Question 3 (3 marks)

A line emission and a line absorption spectrum of a particular gas were observed. Describe the differences observed between these two spectra.

- A line emission spectrum is seen as individual coloured lines on an otherwise black background, corresponding to emmission of photons at discrete frequencies
- A line absorption spectrum is seen as black lines corresponding to missing frequencies on an otherwise continious spectraum
- There are more lines in the emission spectrum than on the absorption spectrum

Question 4 (1 mark)

Which statement suggests that electrons have wave properties?
Tick (✓) the correct answer.

Electrons are emitted in photoelectric effect experiments.	☐
Electrons are released when atoms are ionised.	☐
Electrons produce dark rings in diffraction experiments.	☑
Electron transitions in atoms produce line spectra.	☐

Question 5 (1 mark)

In an experiment to demonstrate the photoelectric effect, a charged metal plate is illuminated with light from different sources. The plate loses its charge when an ultraviolet light source is used but not when a red light source is used.

What is the reason for this?

A	The intensity of the red light is too low.	☐
B	The wavelength of the red light is too short.	☐
C	The frequency of the red light is too high.	☐
D	The energy of red light photons is too small.	☑

Section B: Problem Solving
Marks Allocated: 30 marks out of 41 total marks
This section has 3 questions. Answer the questions in the spaces provided.

Question 6 (10 marks)
(a) Light has a dual wave-particle nature. State and **outline a piece of evidence** for the wave nature of light and a piece of evidence for its particle nature. For each piece of evidence, outline a characteristic feature that has been **observed or measured** and give a short **explanation** of its relevance.

• Wave-like:

→ Wave property is interference and/or diffraction

→ Experiment / Evidence: Description of Young's Double Slits

→ Interference pattern of dark / bright fringes observed corresponding to waves being in phase / out of phase

- Particle Theory would predict 2 single bright fringes

• Particle-like

→ Property = photoelectric effect

→ Threshold frequency of incident light required for instant emission of electrons

→ Energy of photon is discretized according to $E = hf$ and description / explanation of reference to work function

→ Wave Theory predicts emission at all light frequencies OR delayed emission for low intensity light

(b) For a proton of kinetic energy 5.0 MeV,

(i) calculate its speed

$E_K = 5.0\times10^{6}\times1.6\times10^{-19}$

more space

$E_K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2\times5.0\times1.6\times10^{-13}}{1.67\times10^{-27}}}$

$= 3.1\times10^{7}\ \mathrm{m\,s^{-1}}$

(2)

(ii) calculate its de Broglie wavelength.

$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63\times10^{-34}}{1.67\times10^{-27}\times3.1\times10^{7}} = 1.3\times10^{-14}\ \mathrm{m}$

(other calculations also possible

$\lambda = \frac{h}{\sqrt{2meV}} =$

(2)

Question 7 (8 marks)

When a clean metal surface in a vacuum is irradiated with ultraviolet radiation, electrons are emitted from the metal. The following equation relates the frequency of the incident radiation to the kinetic energy of the emitted electrons.

$$hf = \phi + E_k$$

(a) Briefly state what each of the following terms represents in the above equation.

(i) hf The energy of the photon

(ii) ϕ

Minimum energy to eject the electron from the surface of the metal

(½) only if min / max not stated

(iii) E_k

Maximum kinetic energy of a photo electron

(3)

(b) (i) State what would happen to the number of photoelectrons ejected per second if the ultraviolet source were replaced by a source of red light of the same intensity but of frequency less than ϕ/h.

No photo electrons are emitted

(1)

(ii) What would the **wave theory of light** predict about the effect of using the red light source instead of an ultraviolet source?

Wave theory predicts photo electrons are emitted with red light (or any frequency of light)

Wave theory predicts a time delay for low intensity red light

(1)

(iii) Use the **photon theory of light** to explain the effect of using the red light source instead of an ultraviolet source.

- One photon is absorbed by one electron
- Electron is emitted from metal if photon energy $(hf) > \phi$ but isn't emitted if photon energy $(hf) < \phi$
- Red light photon energy $< \phi$

(3)

Question 8 (12 marks)

$E = 0$	________________	ionisation level
$E_2 = -2.42 \times 10^{-19}$ J	________________	level 2
$E_1 = -5.48 \times 10^{-19}$ J	________________	level 1
$E_0 = -2.18 \times 10^{-18}$ J	________________	ground state

The diagram represents some of the energy levels of an isolated atom. An electron with a kinetic energy of 2.0×10^{-18} J makes an inelastic collision with an atom in the ground state.

(a) Calculate the speed of the electron just before the collision.

$$E_{KE} = \frac{1}{2} m v^2 \Rightarrow v = \sqrt{\frac{2E_{KE}}{m}} = \sqrt{\frac{2 \times (2.0 \times 10^{-18})}{9.11 \times 10^{-31}}}$$

$$= 2.1 \times 10^{6} \text{ m s}^{-1}$$

(2)

(b) (i) Show that the bombarding electron can excite the electron in the atom to excitation level 2.

$$E_2 - E_0 = -2.42 \times 10^{-19} - (-2.18 \times 10^{-18})$$

$$= 1.94 \times 10^{-18} \text{ J}$$

$2.0 \times 10^{-18} > 1.94 \times 10^{-18}$ $\Rightarrow$ can excite to 2nd excited state

(2)

(ii) Calculate the wavelength of the radiation that will result when an atom in level 2 falls to level 1 and state the region of the spectrum to which this radiation belongs.

$E_2 - E_1 = -2.42 \times 10^{-19} - (-5.48 \times 10^{-19}) = 3.06 \times 10^{-19}\ J$

$E = hf = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}\ \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{3.06 \times 10^{-19}}$

$= 6.5 \times 10^{-7}\ m$

Visible region / Red light

(3)

(c) Calculate the minimum potential difference through which an electron must be accelerated from rest in order to be able to ionise an atom in its ground state with the above energy level structure.

$E = 2.18 \times 10^{-18}\ J$

$q = 1.6 \times 10^{-19}\ C$

$V = ?$

Energy
Work = voltage × charge

$W = V \times q$

$V = \frac{2.18 \times 10^{-18}}{1.6 \times 10^{-19}} = 13.6\ V$

(2)

(d) An atom can be excited by bombardment by electrons or by bombardment by photons. Explain why, for a particular transition the photon must have an exact amount of energy whereas the free electron only needs a minimum amount of energy.

- For a transition / excitation / change of levels an exact amount of energy is needed
- All the photon's energy must be absorbed in a 1 to 1 interaction
- Electrons can transfer part of its energy to cause excitation and then continues moving with a lower kinetic energy / lower speed

(3)