OCR

A Level

A Level Physics

Quantum Physics (Answers)

Name:

Total Marks: /30

1. Numerous models have now been developed to explain electromagnetic radiation and its interaction with matter and space. For example, the photon model accurately explains what happens when electromagnetic radiation reaches the surface of a solid but to explain its propagation through a vacuum, the wave model is used.

Total for Question 1: 10

(a) State three key observations from the photoelectric effect. [3]

Solution:
1/ Electrons emitted only if frequency of incident radiation is above a critical threshold frequency.
2/ If $f > f_0$ then emission is instantaneous.
3/ If $f > f_0$ then increasing intensity does not increase maximum KE, but does increase the number of electrons emitted (direct proportionality).

(b) Reconcile these observations in the context of the photon model and explain why the wave model is insufficient. [4]

Solution:
1/ E=hf - the energy of an incident photon is proportional to its frequency. Since interactions are one-to-one, there will be no emission if the frequency of the radiation is lower than that corresponding to the energy required to free an electron from the adjacent positive ions.
2/ One-to-one interactions - no accumulation by electrons of multiple photons' energy - either instant emission or no emission.
3/ Increasing the intensity increases the number of incident photons, since individual photon energies are quantised. This increases the number of one-to-one interactions and so causes more emissions. KE depends on energy of each photon, which doesn't change with intensity.
Wave model: the more intense the radiation the greater the rate of energy transfer.

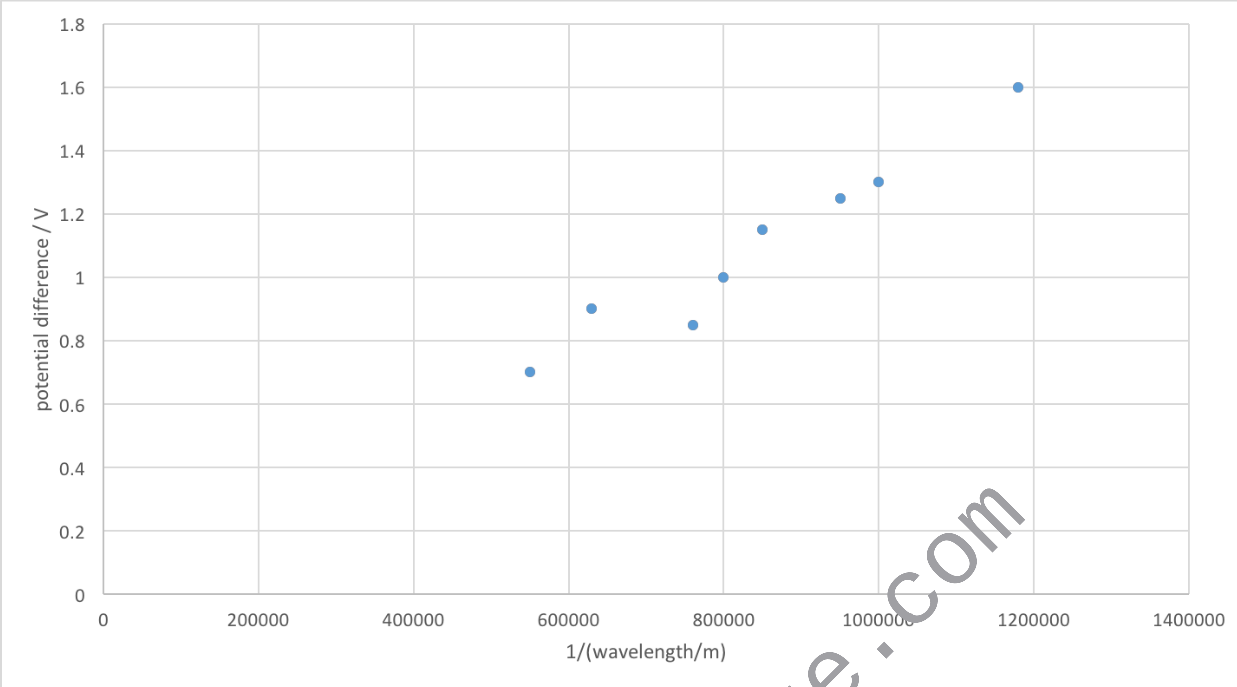

Figure 1: A graph of the potential difference of eight LEDs against the inverse of the wavelength of the light that they produce.

(c) Use the graph above to calculate an experimental value for the Planck constant. [3]

Solution: About 7×10^{-34} Js

2. In 1905 Einstein provided an explanation for the photoelectric effect first observed by Hertz in 1887. This question uses his equations to explore how electromagnetic radiation interacts with different metals.

Total for Question 2: 11

(a) This is Einstein's photoelectric equation: [3]

$$hf = \phi + \frac{1}{2}mv_{max}^2$$

Define each of the terms and explain why this is a statement of energy conservation.

Solution: h: Planck's constant
f: frequency of incident radiation
ϕ: minimum energy required to free an electron from the solid (work function)
m: electron mas
v_{max}: maximum speed of the electron emitted
Energy of each photon must be conserved; initially it frees a single electron from the surface; any remainder is transferred into kinetic energy of the photoelectron.

(b) The work function of a metal is 2.36 eV and the fastest electrons that Becky measures travel at a speed of 1.1×10^6 ms^{-1}. Calculate the maximum possible wavelength of the incident radiation. Why is this an upper bound? [4]

Solution: 2.1×10^{-7} m
Because there may have been faster travelling electrons, the KE-max calculated will be a lower bound. Thus, the frequency will also be a lower bound; the wavelength will be an upper bound.

(c) Becky doesn't know which metal she is using. The threshold frequencies of caesium, sodium and zinc are 5.16×10^{14} Hz, 5.70×10^{14} Hz and 1.04×10^{15} Hz, respectively. Which is it likely to be? [2]

Solution: Sodium.

(d) Next, she irradiates two samples of caesium with different radiation sources. Both sources have a radiant power of 10 mW. The frequencies of the radiation they emit are 5.00×10^{14} Hz and 5.50×10^{14} Hz. She then doubles the power of both lasers. Describe qualitatively the change she should expect to see in the number of electrons emitted in each case. [2]

Solution: For the lower frequency source: no change - no emissions will take place.
For the higher frequency source: the number of electrons emitted will double.

3. Experiments such as those of Young and Hertz show electromagnetic radiation to have characteristics of both waves and particles. In a similar way, electrons are now thought to exhibit wave-like and particle-like behaviour, depending on the circumstances.

Total for Question 3: 9

(a) State the principle requirement for a wave to be significant diffracted when it passes through a gap. [1]

Solution: The gap must be similar in width to the wavelength of the wave.

(b) How does an electron gun irradiating a polycrystalline graphite sample demonstrate wave-particle duality? [3]

Solution: When accelerated by the high PD, electrons are behaving as particles. When they diffract in the sample they behave in a wave-like fashion. They then hit the screen with discrete impacts, once again indicative of their particle nature.

(c) Define the de Broglie wavelength. [1]

Solution: $\lambda = \frac{h}{mv}$ where h is Planck's constant, m is the mass of an electron and v is its velocity.

(d) Electrons are accelerated through a potential difference of 300 V. What is their final de Broglie wavelength? [4]

Solution: 7.09×10^{-11} m