**Worksheet 2 – Module 7 – The Nature of Light**

**Light: Quantum Model**

1. Calculate the energy of a photon of red light of wavelength 600 nm.
2. What potential difference must be applied to stop the fastest photoelectrons emitted by a nickel surface under the action of ultraviolet light of wavelength of 2.0 x 10-7 m? The work function of nickel is 5.01 eV.
3. The maximum kinetic energy of electrons ejected from a metal surface by monochromatic light of frequency, **n**, is measured for several different values of **n**. The straight line in the graph below is the line of best fit to the experimental points.

 

	1. Calculate the value of Planck’s constant (in eV s) from the graph.
	2. Using the value of Planck’s constant calculated above, determine the minimum energy (in eV) required to extract an electron from this metal surface.
	3. How could you use this graph or a modified form of it to calculate the work function of the metal?
4. Explain how experimental evidence gathered about black body radiation, including Wien’s Law led to a changed model of light.
5. Explain how photoelectric effect investigations provided evidence that demonstrated inconsistency with the wave model for light.
6.

 

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1. Identify the physical phenomenon depicted in the diagram above.
2. Describe Einstein’s explanation of this phenomenon.
3. Derive a formula relating the maximum kinetic energy of the emitted electrons to the frequency of the incident light.

**Solutions**

1. 
2. 
3. (a) The graph shows **KEmax** v’s **n**. Since, **KEmax** = **hn - f,** where **f** is a constant, the slope of this graph is Planck’s constant, **h**.

 

(b) Minimum energy will be the energy of the photon at the threshold frequency.

 

(c) Extend the vertical axis below zero and extrapolate the line of best fit backwards until it cuts the vertical axis. The value of **KEmax** where this occurs, is the value of the work function of the metal in eV. This is clear from the equation of the line of best fit:
**KEmax** = **hn - f**, **- f** is the y-intercept of this equation.

1. Wilhelm Wien, in 1896, proposed what became known as Wien’s approximation (also sometimes called Wien's law or the Wien distribution law – not to be confused with Wien’s Displacement Law) to describe the complete spectrum of thermal radiation. Unfortunately, it failed to accurately fit the experimental data for long wavelengths (low frequency) emission. The shape of blackbody radiation curves was determined experimentally as early as 1899. The shape of the curves posed a problem. Physicists could not satisfactorily explain the shape of these curves using classical electromagnetic theory. The wave theory of light predicted, that as the wavelength of emitted radiation becomes shorter (higher frequency), the radiation intensity would increase without limit. Based on the wave model of light, Rayleigh and Jeans derived an equation for black body radiation that suggested that at high frequencies the energy density approaches infinity (the ultraviolet catastrophe). Clearly, a new approach was needed. This came in 1900 when the German physicist, Max Planck, suggested that radiation was emitted or absorbed by a black body in discrete quanta (packets of energy) rather than continuously, as suggested by classical physics. This hypothesis led to the successful explanation of the shape of the energy density curves for black body radiation. Inspired by the work of Planck, Albert Einstein proposed the radical idea that light energy is transmitted in discrete packets of energy rather than as a spreading wave – the particle model of light.
2. Philipp Lenard in a series of experiments investigating the photoelectric effect found that:
* The number of electrons released (the photocurrent) is proportional to the light intensity.
* The emission of photoelectrons was virtually instantaneous (if it occurred).
* Emission was frequency dependent. There is a certain threshold frequency below which no photoelectrons were emitted.
* As the intensity of the light increased, the maximum kinetic energy of emitted electrons remained constant. The maximum kinetic energy of emitted electrons was found to depend on the frequency of the light used and the type of surface.

The last three of these experimental results could not be explained by the classical wave theory of light. Classical theory for instance predicted that electrons in a surface absorbing low intensity radiation of any frequency should accumulate energy for several seconds and then have sufficient energy to be ejected. Electrons absorbing higher intensity radiation should be ejected more quickly. Experimental results showed, however, that emission was almost immediate for all frequencies above the threshold frequency and was independent of intensity.

1. (a) The photoelectric effect.

(b) Einstein used his particle model of light to explain the photoelectric effect in the
 following way: Light striking a surface consists of photons. Each photon carries an
 energy hf into the surface. When a photon collides with an electron in the surface, it
 gives up all its energy to this electron, in accordance with the law of conservation of
 energy. Part of that energy () is used in causing the electron to pass through the
 metal surface. The rest of the energy (hf - ) is given to the electron as kinetic
 energy. This is the kinetic energy the electron will have outside the surface if it does
 not suffer any internal collisions on the way out. In other words, **(hf - )** is the
 maximum kinetic energy, **Kmax**, of the photoelectron.

 This is summarised in Einstein’s photoelectric equation: **(hf - ) = Kmax**

1. Just follow Einstein’s explanation.

 