A Level H2 Physics Tutorial 19: Quantum Physics

Syllabus :
(a) show an appreciation of the particulate nature of electromagnetic radiation .

(b) recall and use the equation E = hf for the energy of a photon

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1. (a) What is a photon?

(b) Green light has a wavelength of about 530 nm. Find the energy of a photon of green light with this wavelength.

(c) show an understanding that the photoelectric effect provides evidence for the particulate nature of electromagnetic radiation while phenomena such as interference and diffraction provide evidence for the wave nature

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2. (a) What experimental evidence shows that light is a wave?

(b) What experimental evidence shows that light is a particle?

(d) recall the significance of threshold frequency

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3. Light of certain frequencies falling on a metal can cause electrons to be emitted by the metal.

State the meaning of threshold frequency of a metal.

(e) recall and use the equation $\frac{1}{2}mv_{max}^2 = eV_s$, where V_s is the stopping potential

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4. When light of a certain frequency falls on a particular metal surface, the maximum velocity of electrons emitted is 6×10^5 m/s.

(i) What voltage is needed to stop these electrons?

(ii) What is this voltage called?

(f) explain photoelectric phenomena in terms of photon energy and work function energy

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5. Explain photoelectric effect in terms of photon energy and work function.

(g) explain why the stopping potential is independent of intensity whereas the photoelectric current is proportional to intensity at constant frequency

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6.

(a) Why is stopping potential independent of intensity?

(b) Why is the photoelectric current proportional to intensity at constant frequency?

(h) recall, use and explain the significance of the equation $hf = \Phi + \frac{1}{2}mv_{max}^2$

7.

(a) Explain the meanings of hf, Φ and $\frac{1}{2}mv_{max}^2$ in photoelectric effect.

(b) Explain why $hf = \Phi + \frac{1}{2}mv_{max}^2$.

(i) describe and interpret qualitatively the evidence provided by electron diffraction for the wave nature of particles

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8. In 1987, the Hitachi company set up an experiment which demonstrated that electrons can produce interference fringes.

As the expected wavelength is about 1 million times smaller than the wavelength of light, they used a 1 μm diameter wire to separate the electron beam into two. So 1 μm became the spacing between the 2 slits.

The screen is 1 m away and the electron beam is 50 kV. They turned on the beam, looked at the screen and saw … interference fringes!

So particles of electrons can also behave as a wave. The fringe spacing is 5.5×10^{-6} m. Find the wavelength of the electrons.

(j) recall and use the relation for the de Broglie wavelength $\lambda = h/p$

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9. An electron has a speed of 10^7 m/s. Find its de Broglie wavelength.

(k) show an understanding of the existence of discrete electronic energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to the observation of spectral lines

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10.

A hydrogen atom has a positively charged proton as nucleus and a much lighter, negatively charged electron around it. The wave nature of electron makes it possible to have specific energy values only.

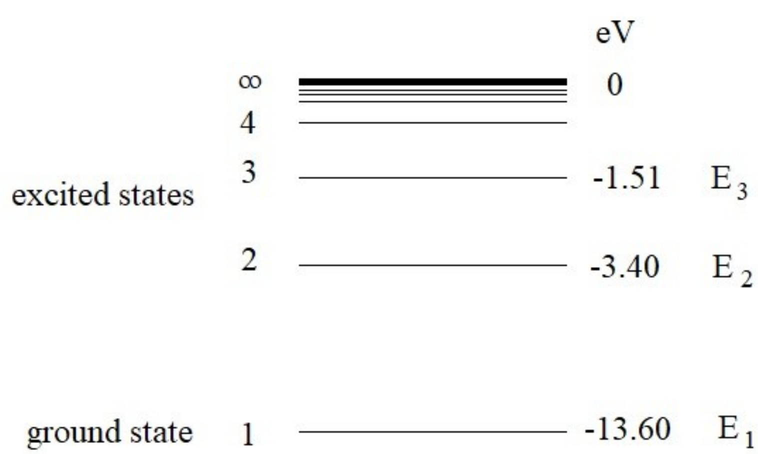

Figure 19-1

(a) What do these energies mean?

(b) What do ground state and excited state mean?

(c) For the atom at the ground state, what are two possible ways to raise its electron to an excited state?

(d) (i) If the electron falls from state 3 to state 2, find the energy of the photon emitted? (Note: such a change from from one state to another is called a "transition".)

(ii) Find the wavelength of this photon. What is its colour?

(l) distinguish between emission and absorption line spectra

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11. Referring to the previous question, a hydrogen gas is heated by burning it slowly, like on a gas cooker. The resulting heat cause electron in the hydrogen atom to gain energy and move to higher energy levels. When an electron fall from higher to a lower level, the photon energy depend on the energy difference between the two levels.

(i) Explain why the light emitted by a hot hydrogen gas, when passed through a slit and a prism, produces a spectrum of coloured lines instead of a continuous rainbow.

(ii) If we now pass a brighter white light through through the same hot gas, slit and prism, we would to see a continuous rainbow spectrum as expected. But if we look more closely, we would find dark lines – at exactly where the coloured lines were in (i) ! Explain why.

(m) recall and solve problems using the relation $hf = E_2 – E_1$

(n) explain the origins of the features of a typical X-ray spectrum

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12.

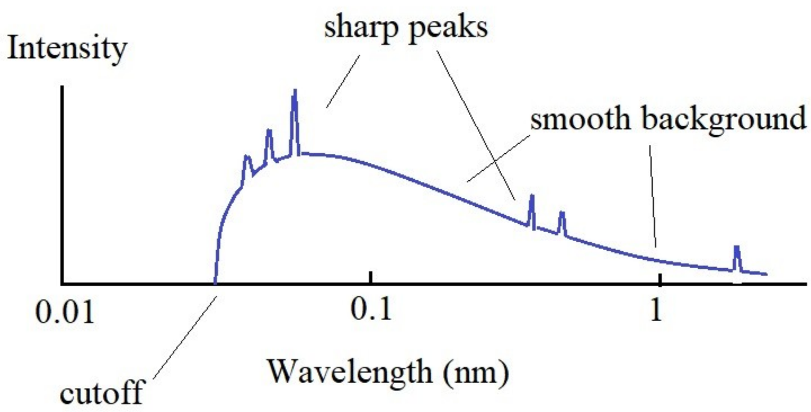

Figure 19-2

(a) The above graph shows a typical X ray spectrum. Briefly explain the origin of the following features :

(i) cutoff wavelength
(ii) sharp peaks
(iii) smooth background.

(b) If the spectrum is produced by a 5 MeV electron beam, find the cutoff wavelength.

(o) show an understanding of and apply $\Delta p \Delta x \gtrsim h$ as a form of the Heisenberg position-momentum uncertainty principle to new situations or to solve related problems.

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13. The idea of Heisenberg's uncertainty principle is that the position and momentum of a particle cannot be both measured perfectly accurately with zero uncertainties, even if we have perfect measuring instruments. It states that

$$\Delta p \, \Delta x \gtrsim h$$

where Δp is uncertainty in momentum p, and Δx is uncertainty in position x.

To help us get a better understanding, consider an experiment in which an electron beam falls on a narrow slit. We know from the wave nature of particles (proven e.g. by the Hitachi experiment in question 8) that the electron beam would behave like a wave with wavelength $\lambda = h/p$

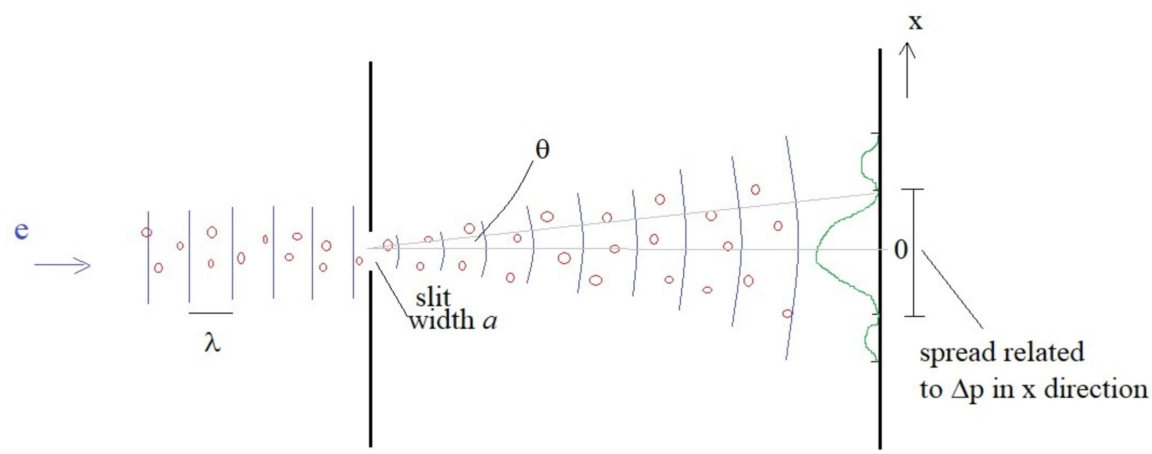

Figure 19-3

By extension, we can deduce that the single slit experiment should also work for electrons. Consider the position and momentum component of an electron in the vertical direction (x in above figure) just after it passes through the slit.

The uncertainty Δx would then be slit width *a*.

Δp, the uncertainty in vertical x direction of momentum p, can be obtained from the width of the central fringe - because Δp causes electrons to drift sideways (vertically). So $\Delta p/p = \theta$, which is the angle for the first dark fringe.

Show that this leads to the uncertainty principle, $\Delta p \, \Delta x = h$.

[The common expression uses $\Delta p \, \Delta x \gtrsim h$ to allow for possibility of measurement error.]