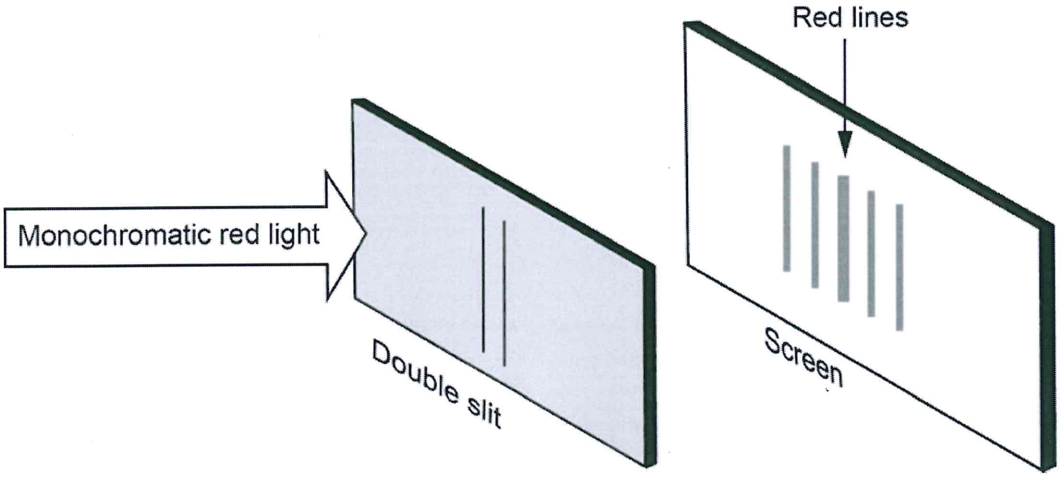
EXAM SOLUTIONS
Chapter 7.3 - Light as a Photon
Answer 1 2011:1:14

(3 marks)

The pattern observed when monochromatic light passes through a piece of cardboard with twin slits close together is often considered evidence for the wave theory of light. A diagram of an experiment set up in a classroom is provided below.



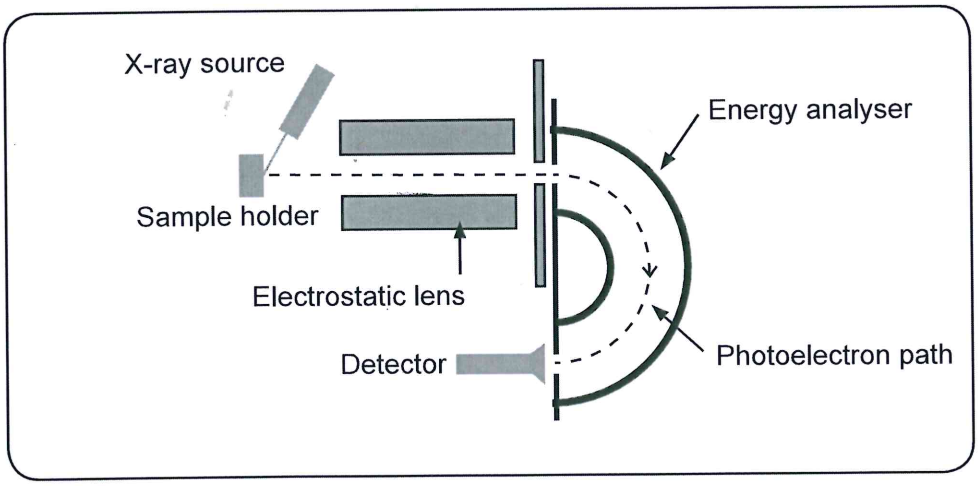
Explain how the pattern of red lines is formed on the screen and why this is considered to be evidence for the wave theory of light.

Description	Marks
diffraction spreads the light sideways	1
Interference: dark where destructive, light where constructive	1
only wave theory explains interference pattern formed	1
	Total 3

Answer 2 2014:3:22

(18 marks)

An X-ray photoelectron spectroscope (XPS) measures the energy distribution of electrons emitted from a sample material. The essential components of an XPS are an X-ray source, a sample holder, an electrostatic lens, an energy analyser and a detector, all in an ultra-high vacuum. This is shown in the diagram below.



Schematic diagram of an X-ray photoelectron spectroscopy unit (vacuum system and cooling system are not shown for clarity)

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In the X-ray source, electrons are accelerated through a large potential difference, then stopped suddenly. The change in kinetic energy of these electrons creates a range of very high-energy X-ray photons, which are directed at the sample to be analysed in the XPS. In the sample, atoms absorb the incident photons and then emit electrons ('photoelectrons'). By using a wide range of incident photon energies, an XPS can measure with great accuracy the kinetic energies of photoelectrons emitted from the outermost to the deepest energy levels of the atoms in a sample.

The minimum energy needed to release a photoelectron from the outermost energy level of a sample is called the work function, W. The maximum kinetic energy E_k of a photoelectron emitted from the outermost energy level is related to the work function by the equation:

$$W = hf - E_k$$

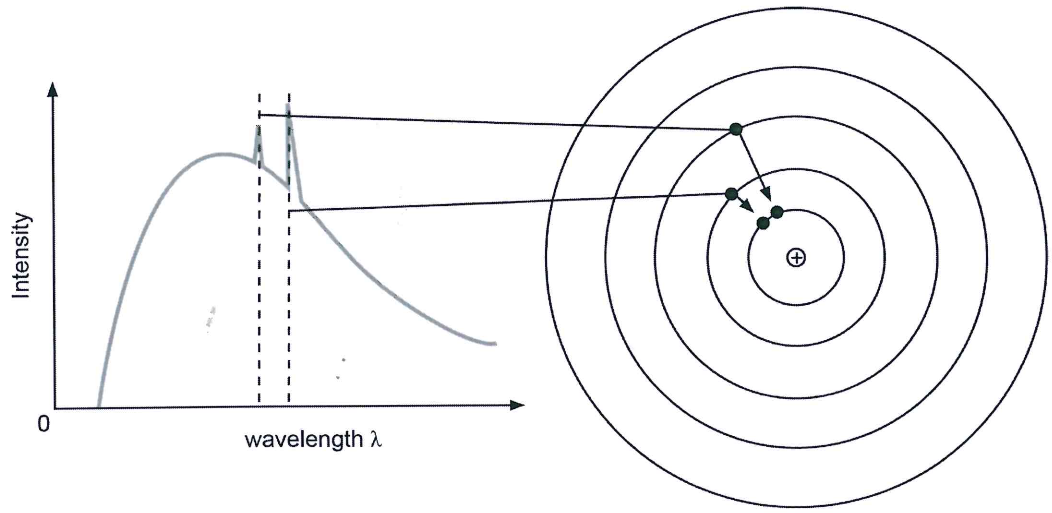
where h is Plank's constant and f is the frequency of the incident photon. W is usually quoted in electron volts. Using $h = 4.14 \times 10^{-15}$ eV s allows calculation in electron volts without the need for conversion to joules.

The binding energy (E_b) of an electron at any energy level in an atom is the energy needed to move the electron from its original level to the outermost level, as in the equation below:

$$E_k = hf - E_b - W.$$

An XPS that can scan a wide range of photoelectron kinetic energies, from a few to thousands of electron volts, can identify the chemical composition of a sample, since electron binding energies in each element are distinctive.

(a) The spectrum produced by an X-ray tube consists of two features. One is a smooth curve due to *bremsstrahlung* (the electron losing its energy as high energy photons). The second consists of peaks which are characteristic for the metal in the target of the tube. Explain what is meant by 'characteristic peaks', with reference to the diagram below. (3 marks)



Description	Marks
Extrapolates information from the text: '...changes in kinetic energy associated with changes in electron energy' and /or '...energy of electrons from a particular energy level ... is different ...' e.g. states that elements have different levels	1
Refers to the inner shell electrons in diagram above	1
States that 'characteristic' defines unique material/atom	1
Total	3

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(b) A 1486.6 eV X-ray is used for (i), (ii) and (iii) below, which relate to X-ray photoelectron spectrometry.

(i) Determine the minimum accelerating potential difference required to produce 1486.6 eV photons in the X-ray tube, rounding your answer to **two** significant figures. (2 marks)

Description	Marks
(i) 1486.6 V (Realises that eV=>V)	1
Rounds to 1.5×10^3 V	1
Total	**2**

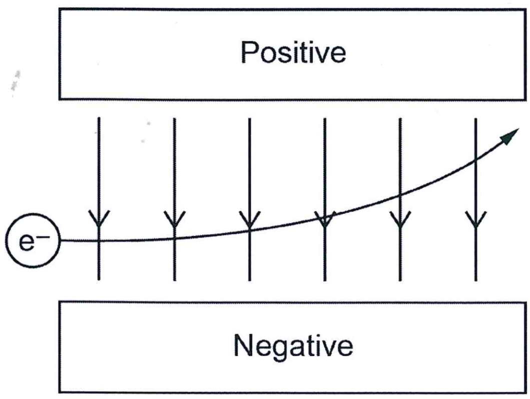
(ii) Calculate the wavelength of the 1486.6 eV X-rays. Show **all** workings. (2 marks)

Description	Marks
$hc/\lambda = 1486.6$ eV $\lambda = 4.14 \times 10^{-15} \times 3 \times 10^8 / 1486.6$	1
$\lambda = 4.14 \times 10^{-15} \times 3 \times 10^8 / 1486.6 = 8.35 \times 10^{-10}$ m	1
Total	**2**

(iii) The 1486.6 eV X-rays are directed onto a sample containing silicon, which has a work function of 4.50 eV. A photoelectron from a distinct energy level with binding energy of 99.7 eV is ejected from the sample. Calculate the kinetic energy and speed of this photoelectron. Show **all** workings. (5 marks)

Description	Marks
$E_k = hf - E_b - W$	1
$E_k = 1486.6 - 99.7 - 4.50 = 1382.4$ eV (rounding and units not required) 1382.4 eV	1
$E_k = ½ mv^2 = (1382.4 \times 1.6 \times 10^{-19})$ $v^2 = (1382.4 \times 2 \times 1.6 \times 10^{-19}) / (9.11 \times 10^{-31})$ $v^2 = 4.86 \times 10^{14}$	1–2
$v = 2.20 \times 10^7$ m s^{-1} (rounding and units not required)	1
Total	**5**

(c) Complete the simplified electrostatic lens diagram below. The electron shown is initially moving from left to right. Write the appropriate charge sign in each box to make the electron move along the path shown. Draw the field in the space between the boxes to aid your diagram. (3 marks)



Description	Marks
Labels top box as a positive plate and bottom negative	1
Field drawn showing field down (or appropriate for plates reversed or magnetic field moving into or out of page if drawn): parallel lines, evenly spread	1–2
Total	**3**

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(d) The energy analyser section of an XPS consists of parallel, curved plates that can be electrically charged. A photoelectron passing between these plates is affected by them. Explain how the voltage on the plates results in only photoelectrons having a specific energy reaching the detector. (3 marks)

Description	Marks
The voltage creates an electric field for the particle to move through	1
The electric field exerts a force on the electron	1
By varying the field strength (voltage across plates) only electrons of the desired velocity will curve with the correct radius and end up on the detector, therefore E_k (or v) can be determined.	1
Total	**3**