Particles, Waves and Quanta: Set 12

Set	Problem	Solution
12	1a	An atom in its ground state has all its electrons in their lowest possible energy levels.
	1b	An atom in an excited state has one or more electrons in higher energy levels, ealving gaps in lower energy levels. Atoms become excited by gaining energy, from light, bombardment by electrons or by being heated.
	2	At 200°C, the iron bar appears grey because it is only seen by the light it reflects. At 800°C, the bar is hot enough to emit visible photons, these are only the low-energy I.R. photons, the bar appears red. At 1400°C the bar is hot enough to emit all frequencies of visible light and so it appears to be emitting white light.
	3	In each case $E_n = -\frac{13.6}{n^2}$ $E_1 = -13.6$ eV $E_2 = -3.4$ eV $E_3 = -1.5$ eV $E_4 = -0.85$ eV $E_5 = -0.54$ eV
	4a(i)	$E_2 \rightarrow E_1$ $E_1 = -21.8 \times 10^{-19}$ J $E_2 = -5.43 \times 10^{-19}$ J $hf = \Delta E = \lvert E_1 - E_2 \rvert = \lvert -21.8 \times 10^{-19} J - (-5.43 \times 10^{-19} J) \rvert$ photon energy $= 1.6 \times 10^{-18}$ J $f = \frac{E}{h} = \frac{1.6 \times 10^{-18} J}{6.63 \times 10^{-34} J\,s}$ $f = 2.4 \times 10^{15}$ Hz; UV Follow the same method for parts ii, iii and iv
	4a(ii)	4.07×10^{-19} J ,6.14×10^{14} Hz; visible
	4a(iii)	3.02×10^{-19} J, 4.56×10^{14} Hz; visible
	4a(iv)	1.54×10^{-19}J, 2.32×10^{14} Hz; IR
	4b	434 nm = 434×10^{-9} m $E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} m\,s^{-1}}{434 \times 10^{-9} m}$ $E = 4.58 \times 10^{-19}$ J; By process of elimination this corresponds to E_5 to E_2
	5a	The highest energy X-ray would be 45 keV which would correspond to the electron losing all of its energy in a single interaction.
	5c	45 keV – 15 keV = 30 keV 45 keV – 5 keV = 40 keV
	5d	These are both hard x-rays as they fall in the range 12 to 120 keV.
	5e	$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} m\,s^{-1}}{1 \times 10^{-9} m}$ Energy difference = 2.0×10^{-16} J
	6	Fluoresence occurs when atoms absorb UV photons, become excited and then return to the ground state by releasing the absorbed energy as two or more photons of lower energy; at least one of them visible.
	7a	5.13 eV
	7b	$\Delta E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} m\,s^{-1}}{589 \times 10^{-9} m}$ $\Delta E = 3.38 \times 10^{-19}$ J. 3.38×10^{-19} J/ 1.6×10^{-19} C = 2.11 eV; The energy difference between E_2 and E_1 is 2.10 eV so the electron falls between these two lower levels.

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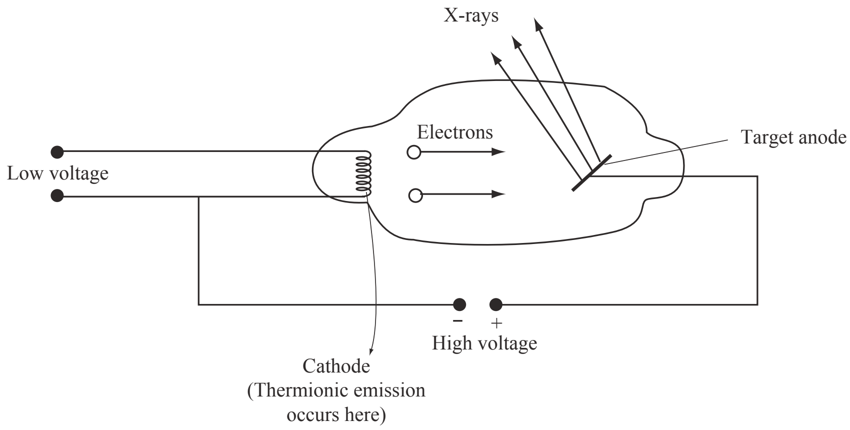
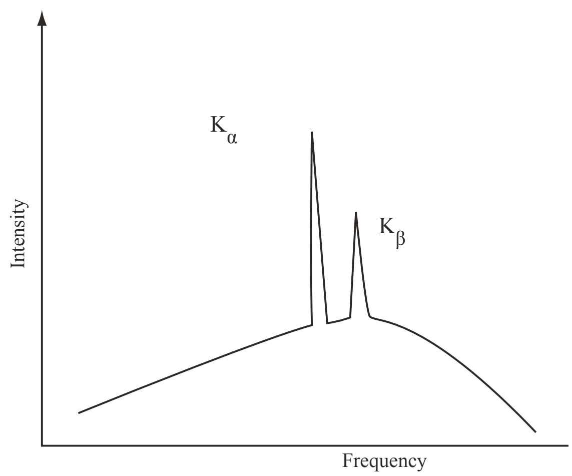
12	7c	$\Delta E_1 = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} J\ s \times 3\times10^{8} m\ s^{-1}}{589\times10^{-9} m} = 3.37\times10^{-19}$ J $\Delta E_2 = \frac{hc}{\lambda} = \frac{6.63\times10^{-34} J\ s \times 3\times10^{8} m\ s^{-1}}{589.6\times10^{-9} m} = 3.369\times10^{-19}$ J Difference between levels = 4×10^{-22} J ~ 2e 0.002 eV
	7d	The following transitions will produce UV light $E_{3,4,5 \text{ or } 6} \rightarrow E_1$. The following transitions will produce IR light $E_{3 \text{ or } 4} \rightarrow E_2$, $E_{4 \text{ or } 5} \rightarrow E_3$
	8a	
	8b	The thermionic effect is the release if electrons from a solid as a result of its temperature. It is caused when electrons gain enough energy to overcome the potential barrier (work function) at the surface. In a X-ray tube a cathode is heated by the current and electrons are emitted from its surface.
	8c	The anode rotates so that the electrons do not continuously heat and therefore melt the same section of the metal.
	8d	High melting points, large conductivity.
	8e	

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	8f	Note: most textbook plot intensity vs wavelength ,so the graph of intensity vs frequency will be a reflection of the wavelength graph. There are 2 main features. The 'spikes' in the graph are characteristic of the target material. They are caused when an incoming electron strikes the atom with enough energy to remove an electron from an inner orbital. This will then cause an electron in a higher energy level to drop down to fill the gap. The α and β symbols indicate that the electrons have dropped from the L and M shell respectively into the K shell. The broad curve is a continuous X-ray spectrum and it can be called Bremsstrahlung radiation. It is caused by the bombarding electrons undergoing several collisions producing several photons all of different frequencies.
	8g	i) If a different material were used for the target the characteristic spikes would occur at different frequencies. ii) If the current through the heated filament was increased there would be more electrons to produce the x-rays but the shape would not change iii) with a greater accelerating potential the value for λ_{min} would decrease so the cut off frequency would increase.
	8h	For any given accelerating voltage the maximum energy of any bombarding electron is equal to e × V. The electron cannot give the target more energy than it has so the maximum energy of an x-ray is also e × V.
	9	It was realised that the risks associated with being exposed to X-rays outweighed the benefits of correctly fitted shoes.
	10	Emily is correct. Each electron can interact with the target differently. One electron can collide with an atom, give all of its energy to the atom and as a consequence cause a photon of 100 keV to be created. Other electrons may transfer much less energy.
	11a	E =60 keV or E = 60,000 V × 1.6×10^{-19} C = 9.6×10^{-15} J
	11b	$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 9.6 \times 10^{-15} J}{9.1 \times 10^{-31} kg}}$ 1.45×10^{8} m s^{-1}
	11c	$\lambda = \frac{hc}{eV} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} ms^{-1}}{1.6 \times 10^{-19} C \times 60 \times 10^{3} V}$ $\lambda = 2.07 \times 10^{-11}$ m
	12	$V = \frac{hc}{e\lambda} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} ms^{-1}}{1.6 \times 10^{-19} C \times 1 \times 10^{-10} m}$ V = 12.4 kV
	13	$\lambda = \frac{hc}{eV} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} ms^{-1}}{1.6 \times 10^{-19} C \times 33.5 \times 10^{3} V}$ 3.71×10^{-11} m We cannot calculate the longest wavelength because we do not know how much energy the bombarding electron will lose. We can only calculate the shortest wavelength created when all the energy of the electron is transferred to the atom. $E = e \times V$ $E = \frac{h\,c}{\lambda} = e\,V$, rearrange $\lambda = \frac{h\,c}{e\,V}$ $\lambda = \frac{hc}{eV} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} ms^{-1}}{1.6 \times 10^{-19} C \times 30 \times 10^{3} V}$ $\lambda = 4.14 \times 10^{-11}$ m; $f = \frac{c}{\lambda} = \frac{3 \times 10^{8} ms^{-1}}{.14 \times 10^{-11} m}$ 7.24×10^{18} Hz

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	14a	$E = e \times V$ $E = \frac{h\,c}{\lambda} = e\,V$, rearrange $\lambda = \frac{\mathrm{h}\,c}{e\,V}$
	14b	$\lambda = \frac{hc}{eV} = \frac{6.63 \times 10^{-34} J\,s \times 3 \times 10^{8} ms^{-1}}{1.6 \times 10^{-19} C \times 30 \times 10^{3} V}$ λ= 4.14 × 10^{-11} m; $f = \frac{c}{\lambda} = \frac{3 \times 10^{8} ms^{-1}}{4.14 \times 10^{-11} m}$ 7.24 × 10^{18} Hz
	15a	Proton: up up down
	15b	Neutron: up down down