Spec reference	Spec point	Additional guidance
4.5.1 Photons	(a) the particulate nature (photon model) of electromagnetic radiation (b) photon as a quantum of energy of electromagnetic radiation (c) energy of a photon; $E = hf$ and $E = \frac{hc}{\lambda}$ (d) the electron-volt (eV) as a unit of energy (e) (i) using LEDs and the equation: $eV = \frac{hc}{\lambda}$ to estimate the value of Planck constant h.	Determine the Planck constant using different coloured LEDs. Quantised packet of electromagnetic energy Photon energy E α f The work done on an electron when it moves through a potential difference of 1V. 1 eV = 1.6 x 10^{-19}J (W = eV from p.d. equation). V = hc/e . 1/λ Plot V against 1/λ Gradient = hc/e Re-arrange to find h.
4.5.2 The photoelectric effect	(a) (i) photoelectric effect, including a simple experiment to demonstrate this effect (ii) demonstration of the photoelectric effect using, e.g. gold-leaf electroscope and zinc plate	The photoelectric effect provides evidence for particulate nature of EM radiation. Light travels as wave but interacts with matter like a particle. Negatively charged zinc plate exposed to photons loses its charge when exposed to e.g. UV photons.

	(b) a one-to-one interaction between a photon and a surface electron. (c) Einstein's photoelectric equation $$hf = \phi + KE_{max}$$ (d) work function; threshold frequency (e) the idea that the maximum kinetic energy of the photoelectrons is independent of the intensity of the incident radiation (f) the idea that rate of emission of photoelectrons above the threshold frequency is directly proportional to the intensity of the incident radiation.	One photon interacts with one electron transferring all its energy to the electron. Conservation of energy. Minimum energy required to liberate a surface electron. No surface electron can be liberated unless the photon energy exceeds the work function. No electron can be liberated unless the photon's frequency exceeds the threshold frequency. $\Phi = hf_{threshold}$ Effect occurs even at low intensity with UV photons, but not when exposed to red light, even at very high intensity. Intensity = Power/Area For photon exposure: Power = number of photons/second x photon energy.
4.5.3 Wave–particle duality	(a) electron diffraction, including experimental evidence of this effect.	Electron diffraction provides evidence for wave-like behaviour of particles.

	(b) diffraction of electrons travelling through a thin slice of polycrystalline graphite by the atoms of graphite and the spacing between the atoms (c) the de Broglie equation $$\lambda = \frac{h}{p}$$	Electrons travel as waves but interact with matter as particles. The De Broglie wavelength of an electron with a momentum p. Electron diffraction occurs if λ_{DB} ≈ Gap size between atoms in crystal ≈ 10^{-10}m. Interference pattern a series of bright rings – gaps between maxima dependent on path difference and therefore λ_{DB}