Topic 3 Waves and the Particle Nature of Light
3D Quantum physics

3D.1 Wave–particle duality

1 (a) Students' own answers, e.g. two-slit interference, diffraction grating, refraction, polarisation experiments

(b) Students' own answers, e.g. electron diffraction

2 9.95×10^{-19} J

3 Polarisation is a wave property.

4 Students' own answers, explaining wave–particle duality

5 Students should produce diagrams along the lines of fig B, but with only two secondary sources, one at each side of the rock. The multiple wavelets are then overdrawn with the sum (new) wavefront to show diffraction behind the rock.

3D.2 The photoelectric effect

1 2.3 eV

2 (a) Zinc will not do so, and iron has a higher work function than zinc

(b) There would be no change.

3 The stopping voltage is designed to stop and measure the energy of the electrons that are released with maximum kinetic energy.

4 5.07×10^{14} Hz

3D.3 Electron diffraction and interference

1 Electron diffraction: diffraction is a wave phenomenon

2 Resolution is roughly the same size as the wavelength. Higher energy electrons have a shorter wavelength.

3 6.14×10^{-11} m

4 Students' own answers, using $\lambda = \frac{h}{p}$:

e.g. estimated speed of the football is 20 m s^{-1}; estimated mass is 300 g

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{(0.3 \times 20)} = 1.1 \times 10^{-34}$ m

3D.4 Atomic electron energies

1 1.22×10^{-7} m

2 The photon's energy is not enough to lift the electron to any other energy level.

3 1.96 eV

4 Through energy absorbed by conducting electricity

5 The electrical energy will excite electrons in the mercury atoms to various levels. The electrons will then fall various numbers of levels. The variety of level drops equate to a variety of photon energies, and hence various wavelengths (colours).

6 Students' own answers, using photon energy $E = hf$, and intensity I:

e.g. estimated sunlight intensity is 1000 W m^{-2}; estimated width of face is 15 cm; estimated face height is 20 cm; estimated sunlight wavelength is 550 nm:

$A = w \times h = 0.15 \times 0.2 = 0.03$ m^2

$P = I \times A = 1000 \times 0.03 = 30$ J s^{-1}

photon energy, $E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \times 3 \times 10^{8})}{(550 \times 10^{-9})} = 3.6 \times 10^{-19}$ J

$N = \frac{P}{E} = \frac{30}{3.6 \times 10^{-19})} = 8.3 \times 10^{19}$ photons per second

3D Exam Practice

1 C

2 C

3 D

4 D

5 (a) LED 1 green

LED 2 orange

LED 3 red

(b) $E = 6.63 \times 10^{-34}$ Js $\times 4.41 \times 10^{14}$ Hz

$E = 2.92 \times 10^{-19}$ J

6 QWC (quality of written communication) – work must be clear and organised in a logical sequence and include four of the following points:

Particle theory

Reference to $E = hf$ or quanta of energy / packets of energy / photons

Increased f means more energy of photon

Release of electron requires minimum energy / work function

One photon releases one electron

Greater energy of photon means greater KE of electrons

More intense light means more photons, therefore more electrons

And, an additional two of the following points:

Wave theory

Wave energy depends on intensity

More intense light should give greater KE of electrons

Energy is spread over the whole wave

If exposed for long enough, photons eventually released – does not happen

7 (a) Photon energy is too small / less than work function

(b) Method 1: Use of intercept x-axis:

Use of $E = hf$ with $f = 10 \times 10^{14}$ Hz

Divide by 1.6×10^{-19} to convert to eV

$\Phi = 4.1$ (eV)

OR

Method 2: Use of photoelectric equation:

Use of $hf = \Phi + E_{max}$ with any pair of values

Divide by 1.6×10^{-19} to convert to eV

$\Phi = 4.1$ to 4.5 (eV)

(c) Planck's constant / e

(d) Line parallel to original line, cutting x-axis with a value less than 10

8 (a) (i) $f = \frac{3 \times 10^{8}\ \text{m s}^{-1}}{6.56 \times 10^{-7}\ \text{m}}$

$f = 4.57 \times 10^{14}$ Hz

(ii) $\frac{3.03 \times 10^{-19}}{1.6 \times 10^{-19}}$

Transition from (−)1.5 eV to (−)3.4 eV

(b) The light from the sun passes through a gas on the way to Earth. This gas has an electron transition for which the energy difference exactly matches the wavelength 656 nm.

That wavelength is absorbed in exciting the electrons of the gas. When the light is re-emitted, it travels in a random direction so most will not come to Earth.

9 (a) QWC (quality of written communication) – work must be clear and organised in a logical manner using technical wording where appropriate, including:

Reference to photons (may be descriptive, e.g. quantum of energy / light arrives in small packets / light particles, etc.)

Energy of photon greater than or equal to work function (of zinc) / $hf \geq \varphi$

Results in electrons being emitted

So electroscope loses charge / charge decreases and the leaf falls

(b) Photon energy for visible light is less than the work function

OR frequency of visible light less than threshold frequency

(c) $KE = \frac{(6.63 \times 10^{-34} \times 3 \times 10^{8})}{(200 \times 10^{-9} - 6.88 \times 10^{-19})}$

$KE = 3.07 \times 10^{-19}$ J

$v = \sqrt{\frac{(2 \times 3.07 \times 10^{-19})}{9.11 \times 10^{-31}}}$

$v = 8.20 \times 10^{5}$ m s^{-1}

(d) No change, as the photon energy does not change (with distance)

OR photon energy depends (only) on frequency / wavelength