29 Marking scheme: Worksheet (A2)

1 A ‘packet’, or quantum, of electromagnetic energy. [1]

2 The energy of a photon is proportional to the frequency of the radiation. [1]
Hence a γ-ray photon has greater energy than a photon of visible light (and therefore is more harmful). [1]

3 **a** Electromagnetic radiation travels through space as waves and, as such, shows **diffraction** and **interference** effects. [1]
b Electromagnetic radiation interacts with matter as ‘particles’. The photoelectric effect provides strong evidence for the particle-like (photon) behaviour of electromagnetic radiation. [1]

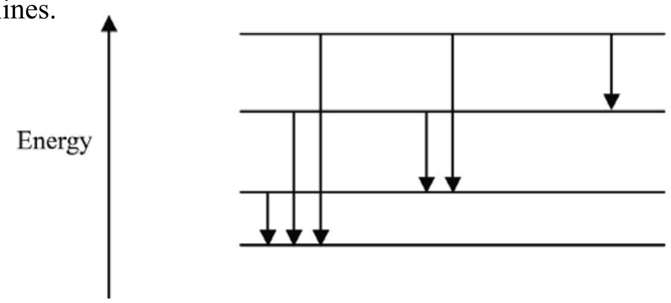
4 **a** $c = f\lambda$ so $f = \dfrac{c}{\lambda} = \dfrac{3.0\times10^{8}}{6.4\times10^{-7}}$ [1]
$f = 4.69 \times 10^{14}$ Hz $\approx 4.7 \times 10^{14}$ Hz [1]

b $E = hf$ [1]
$E = 6.63 \times 10^{-34} \times 4.69 \times 10^{14}$ [1]
$E = 3.1 \times 10^{-19}$ J [1]

5 For an electron to escape from the surface of the metal, it must absorb energy from the photon that is greater than the work function. [1]
The work function is the minimum energy required by the electron to escape from the surface of the metal. [1]
The photon of visible light has energy less than the work function of the metal, whereas the photon of ultraviolet radiation has energy greater than the work function. [1]

6 **a** The electron loses energy. [1]
This energy appears as a photon of electromagnetic radiation. [1]
b Energy of photon = $E_1 - E_2$ [1]
Therefore:
$hf = E_1 - E_2$ or $f = \dfrac{E_1 - E_2}{h}$ [1]
c The change in energy ΔE is greater. [1]
Hence the frequency of the radiation is greater ($f \propto \Delta E$). [1]
The spectral line will be the right side of the line shown on the spectrum diagram.

7 There are six spectral lines. [1]



Correct transitions shown on the energy level diagram. [1]

8 $\Delta E = hf = \dfrac{hc}{\lambda}$ [1]

$\Delta E = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{670\times10^{-9}}$ [1]

$\Delta E = 2.97 \times 10^{-19}$ J $\approx 3.0 \times 10^{-19}$ J [1]

9 **a** Continuous spectrum [1]
b Emission spectrum [1]
c Absorption spectrum [1]

10 Electrons travel through space as waves. Evidence for this is provided by the diffraction of electrons by matter (e.g. graphite). [1]

11 The electronvolt is the energy gained by an electron travelling through a potential difference of one volt. [1]

12 The kinetic energy E_e of the electron is:
$E_e = VQ = 6.0 \times 1.6 \times 10^{-19}$ [1]
$E_e = 9.6 \times 10^{-19}$ J [1]
The energy E_{UV} of the ultraviolet photon is:

$E_{UV} = hf = \dfrac{hc}{\lambda}$ [1]

$E_{UV} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{2.5\times10^{-7}}$ [1]

$E_{UV} = 7.96 \times 10^{-19}$ J $\approx 8.0 \times 10^{-19}$ J [1]
The energy of the ultraviolet photon is less than the kinetic energy of the electron.
(The student is correct.)

13 **a** The threshold frequency is the **minimum** frequency of electromagnetic radiation that just removes electrons from the surface of the metal. [1]
b At the threshold frequency, the energy of the photon is equal to the work function ϕ of the metal. Hence:
$\phi = hf_0$ (f_0 = threshold frequency) [1]

$f_0 = \dfrac{1.9\times1.6\times10^{-19}}{6.63\times10^{-34}}$ [1]

$f_0 = 4.6 \times 10^{14}$ Hz [1]

14 **a** $E = hf = \dfrac{hc}{\lambda}$ [1]

$E = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{550\times10^{-9}}$ [1]

$E = 3.62 \times 10^{-19}$ J $\approx 3.6 \times 10^{-19}$ J [1]
b Power emitted as light = 0.05 × 60 = 3.0 W [1]

Number of photons emitted per second = $\dfrac{3.0}{3.62\times10^{-19}}$ [1]

$= 8.3 \times 10^{18}$ [1]

15 $\phi = 4.3 \times 1.6 \times 10^{-19} = 6.88 \times 10^{-19}$ J [1]

Energy of photon = $\dfrac{hc}{\lambda} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{2.1\times10^{-7}} = 9.47 \times 10^{-19}$ J [1]

energy of photon = work function + maximum kinetic energy of electron [1]
maximum kinetic energy of electron = $(9.47 - 6.88) \times 10^{-19} \approx 2.6 \times 10^{-19}$ J [1]

16 $\lambda = \dfrac{h}{mv}$ [1]

$v = \dfrac{h}{m\lambda} = \dfrac{6.63\times10^{-34}}{1.7\times10^{-27}\times2.0\times10^{-11}}$ [1]

$v = 1.95 \times 10^4$ m s^{-1} (20 km s^{-1}) [1]

17 Energy lost by a single electron = energy of photon [1]
(The energy lost by a single electron travelling through the LED reappears as the energy of a single photon.)
Therefore:

$eV = \dfrac{hc}{\lambda}$ [1]

$V = \dfrac{hc}{\lambda e} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{5.8\times10^{-7}\times1.6\times10^{-19}}$ [1]

$V = 2.14$ V ≈ 2.1 V [1]

18 a Kinetic energy of electron = $VQ = Ve$

$\dfrac{1}{2}m_e v^2 = Ve$ or $\dfrac{p^2}{2m_e} = Ve$ (where $p = m_e v$) [1]

$p = \sqrt{2m_e Ve}$ [1]

$\lambda = \dfrac{h}{m_e v} = \dfrac{h}{p}$ (de Broglie equation) [1]

Therefore, $\lambda = \dfrac{h}{\sqrt{2m_e Ve}}$

b $\lambda = \dfrac{h}{\sqrt{2m_e Ve}}$ or $V = \dfrac{h^2}{2m_e\lambda^2 e}$ [1]

$V = \dfrac{(6.63\times10^{-34})^2}{2\times9.1\times10^{-31}\times(4.0\times10^{-11})^2\times1.6\times10^{-19}}$ [1]

$V \approx 940$ V [1]

19 Using $f = \dfrac{c}{\lambda}$ and Einstein's photoelectric equation ($hf = \phi + \dfrac{1}{2}mv^2_{max}$) : [1]

Red light $\Rightarrow$ $\dfrac{h\times3.0\times10^{8}}{640\times10^{-9}} = \phi + (0.9 \times 1.6 \times 10^{-19})$

$\Rightarrow$ $4.688 \times 10^{14}\,h = \phi + 1.440 \times 10^{-19}$ (equation **1**) [1]

Blue light $\Rightarrow$ $\dfrac{h\times3.0\times10^{8}}{420\times10^{-9}} = \phi + (1.9 \times 1.6 \times 10^{-19})$

$\Rightarrow$ $7.143 \times 10^{14}\,h = \phi + 3.040 \times 10^{-19}$ (equation **2**) [1]

Equations **1** and **2** are two simultaneous equations.
$(7.143 - 4.688) \times 10^{14}\,h = (3.040 - 1.440) \times 10^{-19}$ [1]

$h = \dfrac{(3.040-1.440)\times10^{-19}}{(7.143-4.688)\times10^{14}} \approx 6.5 \times 10^{-34}$ J s [1]

20 a External energy has to be supplied to excite or free an electron. [1]
(**Allow**: The electrons are trapped in an energy well.)

b An energy level of 0 eV means the electron is free from the atom.
The minimum energy is equal to 3.00 eV. [1]
Energy needed to free electron = $3.00 \times 1.6 \times 10^{-19}$ [1]
Energy needed to free electron = 4.80×10^{-19} J [1]

c **i** The difference between the energy levels −3.00 eV and −1.59 eV is equal to 1.41 eV. [1]
Hence, an electron jumps from −3.00 eV energy level to −1.59 eV energy level. [1]

ii $\Delta E = hf = \dfrac{hc}{\lambda}$ [1]

$\lambda = \dfrac{hc}{\Delta E} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{1.41\times1.6\times10^{-19}}$ [1]

$\lambda = 8.82 \times 10^{-7}$ m [1]

21 a This is the lowest energy level occupied by an electron in an atom. [1]

b The shortest wavelength corresponds to the change in energy between the two most widely separated energy levels.
Hence, $\Delta E = 10.43$ eV [1]

$\Delta E = hf = \dfrac{hc}{\lambda}$ [1]

$\lambda = \dfrac{hc}{\Delta E} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{10.43\times1.6\times10^{-19}}$ [1]

$\lambda = 1.19 \times 10^{-7}$ m [1]

22 a $E_1 = -\dfrac{2.18\times10^{-18}}{1^2} = -2.18 \times 10^{-18}$ J [1]

$E_2 = -\dfrac{2.18\times10^{-18}}{2^2} = -5.45 \times 10^{-19}$ J [1]

b $E_2 - E_1 = \Delta E = \dfrac{hc}{\lambda}$ [1]

$\lambda = \dfrac{hc}{\Delta E} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{(21.8-5.45)\times10^{-19}}$ [1]

$\lambda = 1.22 \times 10^{-7}$ m [1]
This spectral line lies in the ultraviolet region of the spectrum. [1]

c $\Delta E = 2.18 \times 10^{-18}\left(\dfrac{1}{6^2}-\dfrac{1}{7^2}\right) = 1.607 \times 10^{-20}$ J [1]

$\lambda = \dfrac{hc}{\Delta E} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{1.607\times10^{-20}} = 1.238 \times 10^{-5}$ m [1]

$\lambda \approx 1.24 \times 10^{-5}$ m (12.4 μm) [1]
This spectral line lies in the infrared region of the electromagnetic spectrum. [1]

