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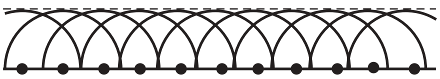
Unit 4 Area of study 1: Interactions of light and matter

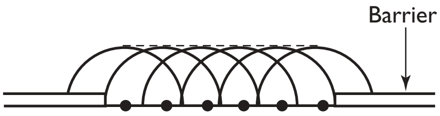
Chapter 10

Light – waves and particles

1. (a)

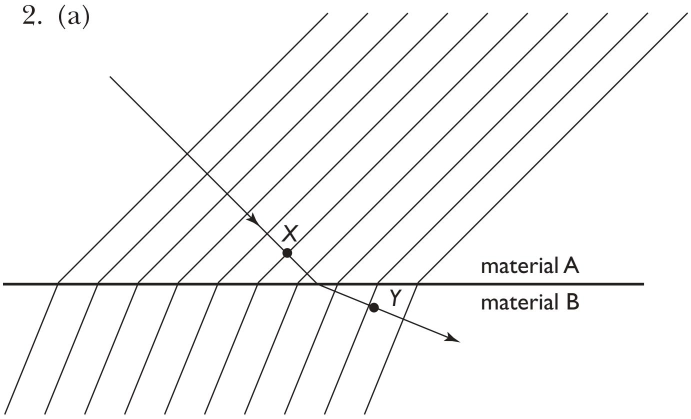


(b)



The wavelets at the edge of the slits form a wavefront which represents the bending of diffracting waves around the edge of the slit.

2. (a)



(b) The same number of wavefronts pass X and Y each minute, since wavefronts cannot disappear nor appear between those points. The wave frequency is the same in both materials.

(c) Wave speed is greater in material B. Since the wave frequency is the same in materials A and B, the greater speed will be seen as a greater wavelength. This occurs in material B.

3. *Superposition* means the adding together of the effects of waves coinciding at a particular location. For example, the bright and dark bands in the pattern produced when light passes through two slits to a screen are caused by the addition of the effects of waves travelling from each of the two slits to each point on the screen.

4. (a) Two waves are *in phase* when corresponding points on the waves are synchronised; for example, wave crests leaving two slits at the same time, or wave troughs arriving at a certain place at the same time. Waves experience *constructive interference* when they are in phase at a point in space, and continue to be in phase as the waves pass through that point. The crests arrive together and the troughs arrive together. This point is said to be on an *antinode*, which is a point, or a line, where maximum wave disturbance occurs.

(b) Two waves are *exactly out of phase* when one wave is exactly half a cycle ahead of another; for example, a wave crest from one source coincides with a wave trough from another source. *Destructive interference* happens when the addition of waves results in zero disturbance, commonly as a result of two waves arriving at a point in space exactly out of phase, with crests meeting troughs. A *node* is a point, or a line, where destructive interference occurs, that is, where there is no wave disturbance.

5. (a) A: antinode, B: node, C: neither

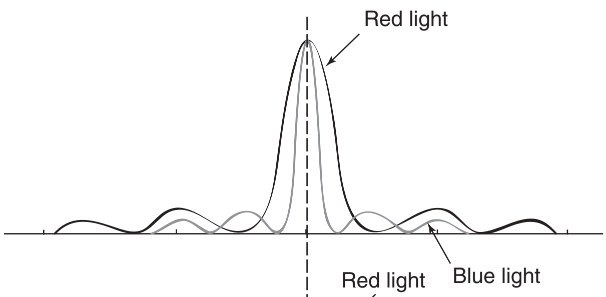
(b) A: bobbing up and down, with greatest possible amplitude
B: stationary
C: bobbing up and down, but with amplitude less than at A

(c) A: 0, A is on central antinode at an equal distance from both sources
B: $\frac{3\lambda}{2}$, B is on second node
C: between $\frac{\lambda}{2}$ and λ, C is between first node and first antinode away from central maximum.

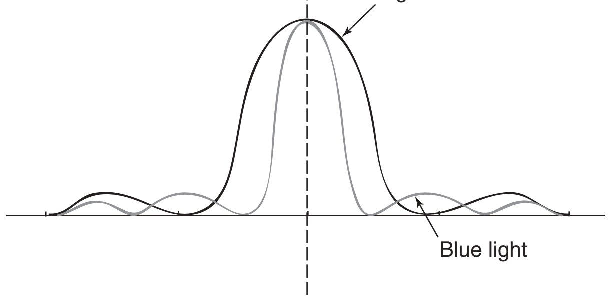
(d) A: bright, B: dark, C: in-between

6. (a) The first minima occur where the path difference for light rays travelling from different places on the opening reaches $\frac{\lambda}{2}$. This will be a region where the intensity of the light will be diminished due to destructive interference.

(b)



(c)



7. (a) Diffraction depends on wavelength or colour of light. White light is a mixture of the different colours in the spectrum, so when it diffracts when passing through a small slit, the colours that make up the white light form slightly different diffraction patterns.

(b) The positions of the minima are given by $\sin\theta = \dfrac{m\lambda}{d}$. The red end of the spectrum has the longest wavelengths, therefore θ for any particular minimum occurs at a greater angle than for blue light and other parts of the visible spectrum. This means that the bright fringes in an interference pattern will be reddened on their outer edges.

8. See table at bottom of page.

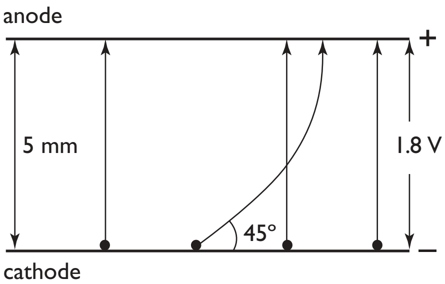
9. (a) $E_k = \frac{1}{2}mv^2$

$$\Rightarrow v = \sqrt{\frac{2E_k}{m}}$$

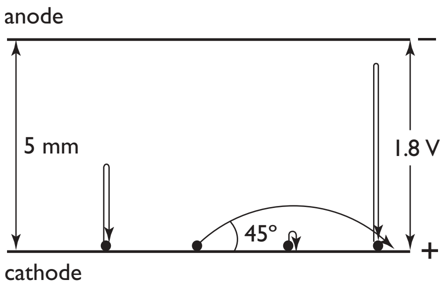
$$= \sqrt{\frac{2 \times 0.8 \times 1.60 \times 10^{-19}\ \text{J eV}^{-1}}{9.1 \times 10^{-31}\ \text{kg}}}$$

$$= 5.3 \times 10^5\ \text{m s}^{-1}$$

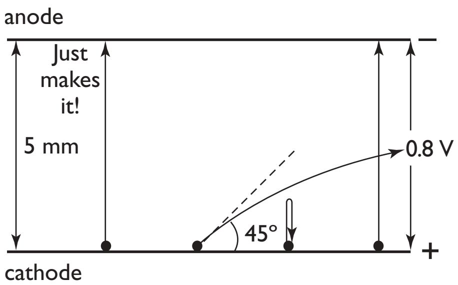
(b)



(c)



(d)



10. $E_{photon} = \dfrac{hc}{\lambda}$

$$= \frac{6.6262 \times 10^{-34}\ \text{J s} \times 2.9979 \times 10^8\ \text{m s}^{-1}}{200 \times 10^{-9}\ \text{m}}$$

$$= 9.932 \times 10^{-19}\ \text{J}$$

$$= \frac{9.932 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}}$$

$$= 6.21\ \text{eV}$$

Maximum $E_{k,\ photoelectron} = E_{photon} - W$
$= 6.21\ \text{eV} - 5.1\ \text{eV}$
$= 1.11\ \text{eV}$

To stop an electron with 1.11 eV of kinetic energy requires a stopping voltage of 1.11 V.

11. (a) Minimum energy required to raise the electron energy to zero is 4.5 eV.

(b) In each case E_k of electron is given by E_{photon} + initial electron energy

(i) E_k = 5.9 eV – 4.7 eV = 1.2 eV
Electron is ejected with kinetic energy of 1.2 eV.

(ii) E_k = 5.9 eV – 5.3 eV = 0.6 eV
Electron is ejected with kinetic energy of 0.6 eV.

(iii) E_k = 5.9 eV – 5.9 eV = 0.0 eV
Electron is ejected with zero kinetic energy.

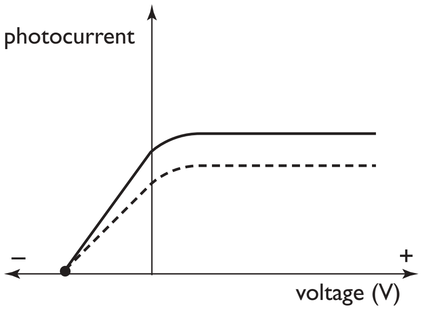
(iv) Energy of photon not sufficient to raise electron energy to zero, so electron is not ejected.

12. (a) The maximum current occurs when the accelerating voltage causes all ejected electrons to be collected at the anode. The voltage required for this is greater than zero because some electrons leave at an angle and their parabolic path may miss the anode at lower voltages. When the voltage opposes the motion towards the cathode, electrons travelling towards the anode slow down. When the magnitude of the voltage is large enough, the electrons reverse direction and so do not contribute to the current. At a high enough retarding voltage, *all* electrons turn around before reaching the anode so the current is zero.

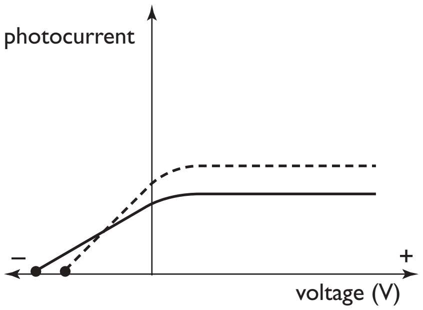
8.

Source	Wavelength	Frequency	Energy	Momentum
Infra-red from CO_2 laser	10.6 μm	2.83×10^{13} Hz	1.87×10^{-20} J, 0.117 eV	6.25×10^{-29} kg m s^{-1}
Red helium–neon laser	633 nm	4.74×10^{14} Hz	3.14×10^{-19} J, 1.96 eV	1.05×10^{-27} kg m s^{-1}
Yellow sodium lamp	589 nm	5.09×10^{14} Hz	3.37×10^{-19} J, 2.11 eV	1.125×10^{-27} kg m s^{-1}
UV from eximer laser	0.193 μm	1.55×10^{15} Hz	1.03×10^{-18} J, 6.42 eV	3.43×10^{-27} kg m s^{-1}
X-rays from aluminium	0.988 nm	3.03×10^{17} Hz	2.01×10^{-16} J, 1.25 keV	6.69×10^{-25} kg m s^{-1}

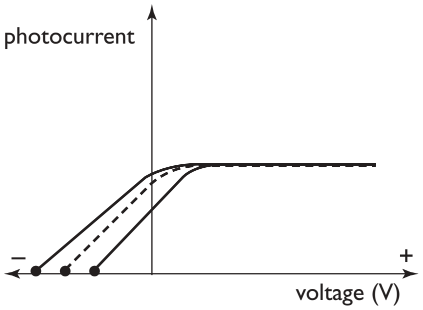
(b) Increasing the intensity without changing the frequency would increase the number of photons per second reaching the cathode but not change their energy. As a result, the photoelectrons will have the same energy spread, and therefore the same stopping voltage, but there will be more electrons ejected per second, resulting in a higher photocurrent.



(c) Increasing the frequency of the light would increase the energy of each photon, resulting in higher energy photoelectrons and a greater stopping voltage. If the intensity is unchanged, the energy per second reaching the cathode is not changed, but since each photon has a greater energy, this means that there are fewer photons per second reaching the cathode and the photocurrent will be reduced.



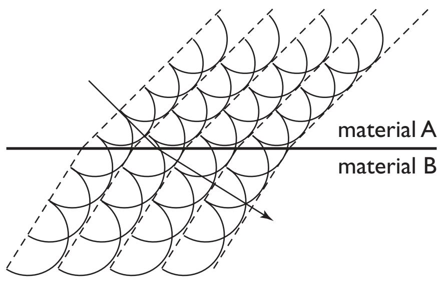
(d) There will be the same number of photons per second and they have the same energy but it requires a different energy to eject an electron. This will change the maximum E_k of the electrons and therefore the stopping voltage but since the same number of photons reach the cathode each second, the maximum photocurrent will be unchanged. Two answers are shown. One is for a material with a greater work function (lower maximum E_k and therefore lower stopping voltage) and the other is for a material with a smaller work function (higher maximum E_k and therefore higher stopping voltage).



13. The frequency of the light determines the photon energy, and so determines energy delivered to each electron and the maximum kinetic energy of the electrons. The maximum kinetic energy also depends on the surface because this determines the energy supplied to allow the electron to escape. The wave model predicts that electrons would be ejected below this threshold frequency. It would just take a longer time for the energy to accumulate for electrons to escape.
14. The individual points showing where a chemical reaction of the film emulsion has occurred, would be the sign of the effect of a single photon. The pattern of arrangement of these spots demonstrates the wave characteristics of the light.
15. Atoms and molecules in the outer part of the Sun absorb at characteristic wavelengths, reducing the intensity of those colours in the light which reaches us.
16. Neon atoms have well defined energy levels, and the wavelengths of light emitted by neon atoms correspond to atoms jumping from higher to lower energy levels. The sharpness of the wavelengths in the spectrum indicates the sharpness of the possible energies of the atoms.
17. The magnitude of the energy change of the electrons is equal to the photon energy, hf.

$$E_{photon} = 6.6262 \times 10^{-34} \text{ J s} \times 4.59 \times 10^{14} \text{ Hz}$$
$$= 3.04 \times 10^{-19} \text{ J}$$
$$= \frac{3.04 \times 10^{-19} \text{ J}}{1.60 \times 10^{-19} \text{ J eV}^{-1}}$$
$$= 1.90 \text{ eV}$$
$$\Delta E_{electron} = -3.04 \times 10^{-19} \text{ J}$$
$$= -1.90 \text{ eV}$$

18.



Each wavefront forms a set of centres for circular wavelets. The wavelets closest to the boundary will reach the material where they will travel at higher speed first. These wavelets will form the new wavefront in this material as shown in the diagram, at a different direction to the incoming wavefront.

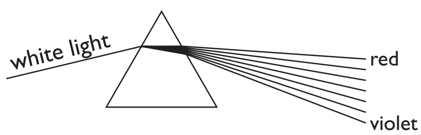
19. (a) $\lambda = \frac{c}{f}$

$$= \frac{3.00 \times 10^{8} \text{ m s}^{-1}}{4.59 \times 10^{14} \text{ Hz}}$$
$$= 6.53 \times 10^{-7} \text{ m}$$

(b) $\lambda_{glass} = \frac{\lambda_{air}}{n}$

$$= \frac{6.53 \times 10^{-7} \text{ m}}{1.50}$$
$$= 4.35 \times 10^{-7} \text{ m}$$

20.



Since violet light experiences the greater change in direction, its change in speed must also be greater. The refractive index is equal to the ratio $\frac{\text{speed in air}}{\text{speed in flint}}$. Since this ratio is greater for violet light, violet light travels more slowly than red light in flint.

21. Constructive: $n\lambda$, $n = 0, 1, 2, \ldots$, 0, 1.06 μm, 2.12 μm, 3.18 μm . . .

    Destructive: $(n + \frac{1}{2})\lambda$, $n = 0, 1, 2, \ldots$, 0.53 μm, 1.59 μm, 2.65 μm . . .

22. (a) (i) The bright band corresponds to constructive interference where crests from the two slits arrive together, and troughs in the light waves arrive together.
    (ii) The dark band is where destructive interference occurs. At all times, the sum of the waves from the two slits is zero, including crests from one slit coinciding with troughs from the other.

    (b) (i) 0
    (ii) $\frac{\lambda}{2} = 317$ nm
    (iii) $2\lambda = 1266$ nm

    (c) The wavelength is smaller so the bright fringes in the interference pattern would be closer together. As path difference for the bright fringes equal $n\lambda$, a smaller wavelength means that each bright fringe would be moved closer to the central bright band.

    (d) The increase in distance between the slits would result in the bright bands being closer together.

    (e) Moving the screen away would result in the interference pattern spreading out, increasing the distance between the bright bands.

23. Circular wavefronts can be used when the slit width is extremely narrow in comparison with the wavelength of the light. Then diffraction produces effectively circular wavefronts.

24. Each stripe on the soap film corresponds to a certain path difference for light reflected from the front and back of the film, resulting in destructive interference for a particular set of wavelengths. The stripes are approximately horizontal because the part of the film that has a certain thickness is a horizontal slice through the film. As the soap film drains, the part of the film with this thickness moves downwards, so each stripe does too.

25. The positions of the minima are given by $\sin\theta = \frac{m\lambda}{d}$.

    For the first minimum, $m = 1$ so

$$\sin\theta = \frac{\lambda}{d} = \frac{633 \times 10^{-9}}{2 \times 10^{-6}} = 0.3165$$
$$\Rightarrow \theta = \sin^{-1} 0.3165 = 18°$$

26. $\sin\theta = \frac{m\lambda}{d}$, $m = 1$, $\theta = 3.7°$, $\lambda = 415 \times 10^{-9}$ m

$$\sin 3.7 = 1 \times 415 \times \frac{10^{-9}}{d}$$
$$\Rightarrow d = 6.4 \times 10^{-6} \text{ m} = 6.4\ \mu\text{m}$$

27. $\lambda_{red} = 650 \times 10^{-9}$ m, $\lambda_{blue} = 360 \times 10^{-9}$ m, $d = 0.70 \times 10^{-6}$ m, $L = 3.0$ m

    (a) Red light:

$$\sin\theta = \frac{\lambda}{d} = \frac{650 \times 10^{-9}}{0.7 \times 10^{-6}} = 0.929$$
$$\Rightarrow \theta = \sin^{-1} 0.929 = 68.2° = 68°$$

    Blue light:

$$\sin\theta = \frac{\lambda}{d} = \frac{360 \times 10^{-9}}{0.7 \times 10^{-6}} = 0.514$$
$$\Rightarrow \theta = \sin^{-1} 0.514 = 30.9° = 31°$$

    (b) Distance from central maximum to first red minimum = x. Forming a right angle triangle and using trigonometry,

$$\tan 68.2 = \frac{x}{3}$$
$$\Rightarrow \quad x = 7.5 \text{ m}$$

    Similarly, distance from central maximum to first blue minimum = y;

$$\tan 30.9 = \frac{y}{3}$$
$$\Rightarrow \quad y = 1.8 \text{ m}$$

    The distance between the first red minimum and the first blue minimum on the screen is 7.5 − 1.8 = 5.7 m.

28. For green light at, say, 515 nm:

$$E_{photon} = \frac{hc}{\lambda} = \frac{6.6262 \times 10^{-34} \text{ J s} \times 2.9979 \times 10^{8} \text{ m s}^{-1}}{515 \times 10^{-9} \text{ m}} = 3.86 \times 10^{-19} \text{ J}$$

    So the detection limit of 2×10^{-17} J is equivalent to:

$$\frac{2 \times 10^{-17} \text{ J}}{3.86 \times 10^{-19} \text{ J}} = 52 \text{ photons.}$$

29. P = energy per second
    = rate of photon emission × energy of one photon

    $P_{blue} = P_{red}$

    ⇒ rate of emission of blue photons × $E_{blue\ photon}$ = rate of emission of red photons × $E_{red\ photon}$

$$\Rightarrow \frac{\text{rate of emission of red photons}}{\text{rate of emission of blue photons}} = \frac{E_{\text{blue photon}}}{E_{\text{red photon}}}$$
$$= \frac{\lambda_{\text{red photon}}}{\lambda_{\text{blue photon}}}$$
$$= 1.33$$

30. Electron energy $= 4.0 \times 10^{-19}$ J

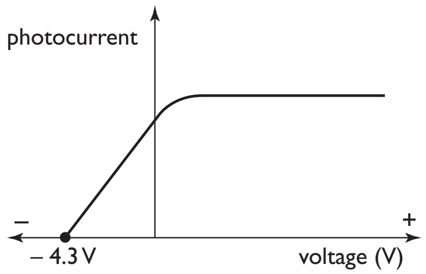
$$= \frac{4.0 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}}$$
$$= 2.5\ \text{eV}$$

(a) A retarding voltage of 1.0 V would reduce the kinetic energy by 1.0 eV to 1.5 eV, or 2.4×10^{-19} J.

(b) A retarding voltage of 2.5 V is required to completely transform the 2.5 eV of kinetic energy into electric potential energy, that is, to stop the electron.

(c) A stopping voltage of 4.3 V means that the highest kinetic energy of electrons is 4.3 eV, or 6.9×10^{-19} J.

(d)



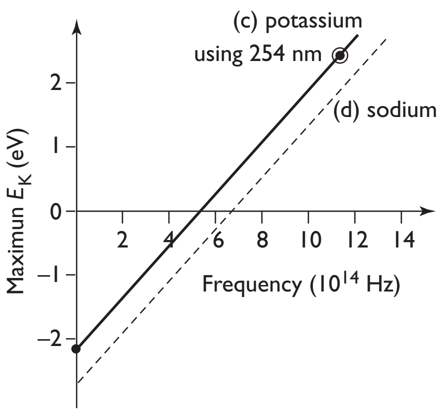
31. (a) Maximum $E_k = E_{\text{photon}} - W$

$$E_{\text{photon}} = \frac{hc}{\lambda}$$
$$= \frac{6.6262 \times 10^{-34}\ \text{J s} \times 2.9979 \times 10^{8}\ \text{m s}^{-1}}{254 \times 10^{-9}\ \text{nm}}$$
$$= 7.82 \times 10^{-19}\ \text{J}$$
$$= 4.88\ \text{eV}$$

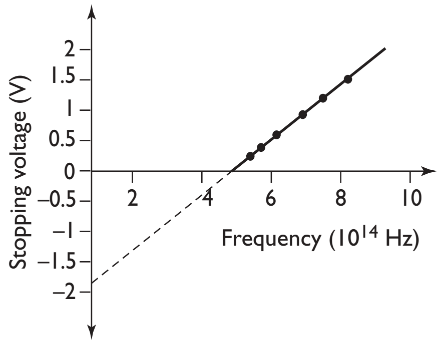
Maximum $E_k = 4.89\ \text{eV} - 2.30\ \text{eV}$
$= 2.59$ eV, or 4.14×10^{-19} J

(b) To transform this kinetic energy into electric potential energy would require 2.59 V.

(c) and (d)



32.



(a) Threshold frequency is where the graph crosses the frequency axis, that is, where the maximum E_k of the electrons, and the stopping voltage, is zero:
$f_0 = 4.6 \times 10^{14}$ Hz

(b) $\lambda = \frac{c}{f}$
$$= \frac{2.9979 \times 10^{8}\ \text{m s}^{-1}}{4.6 \times 10^{14}\ \text{Hz}}$$
$$= 6.5 \times 10^{-7}\ \text{m}$$

(c) $W = hf_0$
$= 6.6262 \times 10^{-34}$ J s $\times 4.6 \times 10^{14}$ Hz
$= 3.0 \times 10^{-19}$ J $= 1.9$ eV
or, use the intercept with the stopping voltage graph.

(d) Planck's constant is the gradient of the graph:
6.6×10^{-34} J s, or 4.1×10^{-15} eV s

33. (a) Red light is diffracted more as it passes through a narrow slit because it has a longer wavelength. As a result its diffraction pattern will be broader.

(b) The edge of the pattern will be reached by white light, but minus the colour which experiences destructive interference there. The violet light has the narrower interference pattern, so its first node occurs closest to the centre of the pattern. The remaining light will therefore have a yellow tinge.

Chapter 11

Matter – particles and waves

1. The cathode rays are deflected by both magnetic and electric fields, and have mass and charge, unlike electromagnetic radiation.
2. There is an electric field between the plates. When a negative particle enters the electric field, it is attracted to the positive plate and repelled from the negative plate.
3. A fire glows with a continuous range of wavelengths, and in a red fire, the red wavelengths have the greatest intensity. Neon in a discharge tube glows red because the electrons in the neon atoms are excited to particular energies. When the electrons return to the ground state they produce light of a few fixed wavelengths, mainly in the red part of the spectrum.
4. Atoms and molecules in the outer part of the Sun absorb at characteristic wavelengths, reducing the intensity of those colours in the light which reaches us.

5. Emission lines are produced when electrons return from an excited state to a lower energy state. The energy is released in the form of photons of particular frequencies. Absorption lines are produced when light from a continuous spectrum passes through a gas. This light excites some of the electrons in the atoms making up the gas, so photons with the energies allowed by the atoms will be removed from the continuous spectrum. As the energy required to raise an electron to a more excited state is equal to the energy released when the electrons drop back to the lower state, the emission lines and absorption lines for a particular element will be the same.
6. Possible answers include refracting the light through a prism. Spectral yellow will remain yellow whereas a mixture of green and red light will separate into two beams.
7. The magnitude of the energy change of the electrons is equal to the photon energy, h*f*.

$$E_{photon} = 6.6262 \times 10^{-34}\ \text{J s} \times 4.59 \times 10^{14}\ \text{Hz}$$
$$= 3.04 \times 10^{-19}\ \text{J}$$
$$= \frac{3.04 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{J eV}^{-1}}$$
$$= 1.90\ \text{eV}$$
$$\Delta E_{electron} = -3.04 \times 10^{-19}\ \text{J}$$
$$= -1.90\ \text{eV}$$

8. (a) Light of this wavelength corresponds to a photon energy of

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{420 \times 10^{-9}} = 4.7 \times 10^{-19}\ \text{J}$$

Electrons in helium absorb these photons indicating that there is an energy level within the helium atom 4.7×10^{-19} J above the ground state of the atom.

(b) The increase in energy of the electron is equal to the energy of the absorbed photon:
$\Delta E = 4.7 \times 10^{-19}\ \text{J} = 2.94\ \text{eV}$

9. (a)

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 3.0 \times 10^{7}} = 1.3 \times 10^{-14}\ \text{m}$$

(b)

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 54}} = 1.7 \times 10^{-10}\ \text{m}$$

(c)

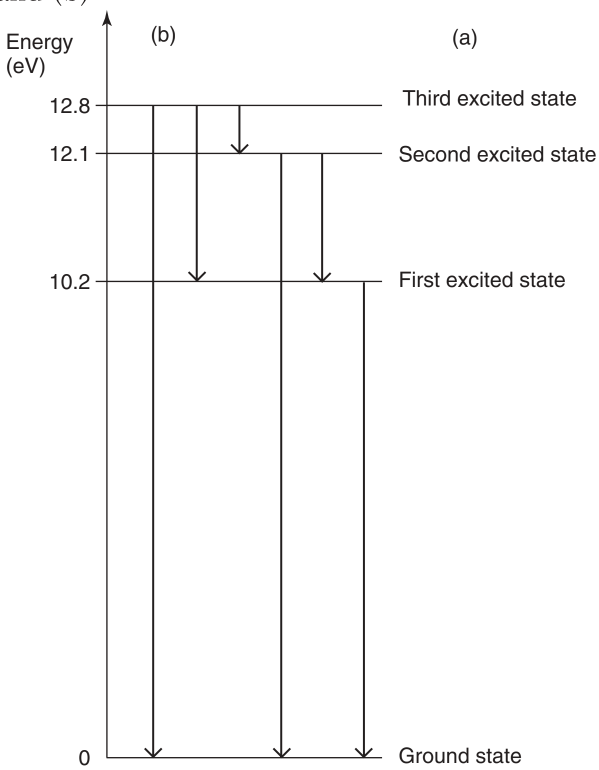
$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{0.2 \times 50} = 6.6 \times 10^{-35}\ \text{m}$$

10. See table at bottom of page.

For red light:
Convert E (eV) to E (J) by multiplying by 1.60×10^{-19}.
Calculate $p = \frac{E\ (J)}{c}$.
Calculate $f = \frac{E\ (J)}{h}$.
Calculate $\lambda = \frac{c}{f}$.

For electron:
Convert E (eV) to E (J) by multiplying by 1.60×10^{-19}.
Calculate $p = \sqrt{2mE}$.
Calculate $\lambda = \frac{h}{p}$.
Follow the above in reverse for the blue light and electron.

11. (a) and (b)



10.

	λ (nm)	*f* (Hz)	*E* (J)	*E* (eV)	*p* (Ns)
Red light	633	4.73×10^{14}	3.14×10^{-19}	1.96	1.05×10^{-27}
Electron	0.877	—	3.14×10^{-19}	1.96	7.56×10^{-25}
Blue light	405	7.41×10^{14}	4.91×10^{-19}	3.07	1.64×10^{-27}
Electron	405	—	1.47×10^{-24}	9.19×10^{-6}	1.64×10^{-27}

(c) $E_1 = 12.8 - 12.1 = 0.7$ eV
$E_2 = 12.8 - 10.2 = 2.6$ eV
$E_3 = 12.8$ eV
$E_4 = 12.1 - 10.2 = 1.9$ eV
$E_5 = 12.1$ eV
$E_6 = 10.2$ eV

(d) The least energy is 0.7 eV. The photon with this energy has a wavelength of

$$\lambda = \frac{hc}{E}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.60 \times 10^{-19} \times 0.7}$$
$$= 1.78 \times 10^{-6} \text{ m } (1.8 \times 10^{-6} \text{ m})$$

The greatest energy photon has energy 12.8 eV:

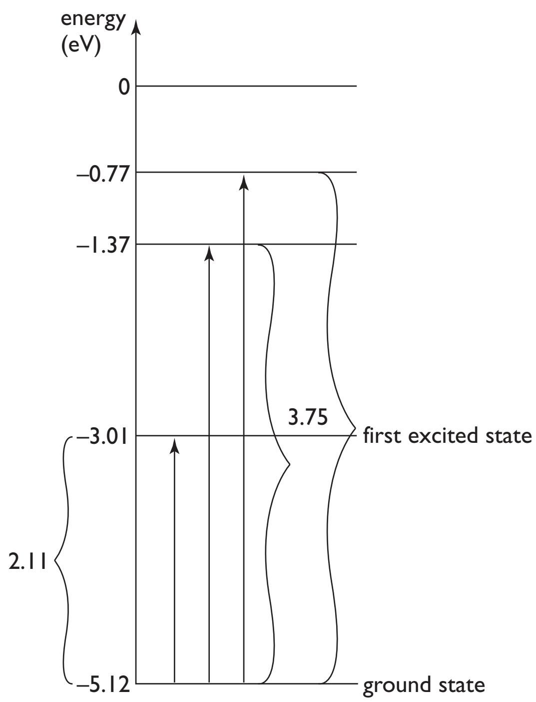
$$\lambda = \frac{hc}{E}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.60 \times 10^{-19} \times 12.8}$$
$$= 9.71 \times 10^{-8} \text{ m } (9.7 \times 10^{-8} \text{ m})$$

12. (a) $E_k = -\Delta E_p$
$= -Vq_{electron}$
$= -(5 \text{ kV} \times -1 \text{ e})$
$= 5$ keV
$= 5 \text{ keV} \times 1.60 \times 10^{-16} \text{ J keV}^{-1}$
$= 8.0 \times 10^{-16}$ J

(b) $E_{photon} = 8.0 \times 10^{-16}$ J
$$= \frac{hc}{\lambda}$$
$$\Rightarrow \quad \lambda = \frac{hc}{E_{photon}}$$
$$= \frac{6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1}}{8.0 \times 10^{-16} \text{ J}}$$
$$= 2.5 \times 10^{-10} \text{ m}$$

13. Light exhibits both wave and particle behaviour, depending on the experiment you are performing at the time. For further discussion of this issue argue with your friends and teacher!

14. (a) and (b)



(c) $E_{photon} = -\Delta E_{atom} = E_{atom\ initial} - E_{atom\ final}$

First excited state:

$E_{photon} = -\Delta E_{atom}$
$= -3.01 \text{ eV} - (-5.12 \text{ eV})$
$= 2.11$ eV
$= 3.38 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E_{photon}}$$
$$= \frac{6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1}}{3.38 \times 10^{-19} \text{ J}}$$
$$= 5.88 \times 10^{-7} \text{ m}$$

Second excited state:

$E_{photon} = -\Delta E_{atom}$
$= -1.37 \text{ eV} - (-5.12 \text{ eV})$
$= 3.75$ eV
$= 6.0 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E_{photon}}$$
$$= \frac{6.3 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1}}{6.0 \times 10^{-19} \text{ J}}$$
$$= 3.32 \times 10^{-7} \text{ m}$$

Third excited state:

$E_{photon} = -\Delta E_{atom}$
$= -0.77 \text{ eV} - (-5.12 \text{ eV})$
$= 4.35$ eV
$= 6.96 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E_{photon}}$$
$$= \frac{6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1}}{6.96 \times 10^{-19} \text{ J}}$$
$$= 2.86 \times 10^{-7} \text{ m}$$

The energy change from the first excited state is responsible for the yellow glow. A comparison with the answers to question 10 helps here. Yellow light is between red and blue light in the spectrum, that is between 405 nm and 633 nm. The first excited state is the only one that produces a wavelength in this range.

15. (a) $p = mv$
$= 9.11 \times 10^{-31} \times 2.5 \times 10^6$
$= 2.3 \times 10^{-24} \text{ kg m s}^{-1}$

$$\lambda = \frac{h}{p}$$
$$= \frac{6.63 \times 10^{-34}}{2.3 \times 10^{-24}}$$
$$= 2.9 \times 10^{-10} \text{ m}$$

(b) Significant diffraction occurs when $\frac{\lambda}{d} \approx 1$. As the wavelength is a little greater than the atomic spacing, diffraction will be significant.

16. (a) $$\lambda = \frac{h}{p}$$
$$= \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 1.6 \times 10^6}$$
$$= 4.55 \times 10^{-10} \text{ m}$$

$$\sin\theta = \frac{\lambda}{a}$$
$$= \frac{4.55\times10^{-10}}{8.0\times10^{-9}}$$
$$= 5.69\times10^{-2}$$
$$\Rightarrow \theta = \sin^{-1}(5.69\times10^{-2})$$
$$= 3.3^\circ$$

(b) A is at the position of the first minimum of the diffraction pattern produced by waves passing through the slit. The minimum is produced by waves passing through the slit and meeting at point A out of phase resulting in destructive interference. The diffraction pattern represents the probability that an electron would be found at the point. As the amplitude on the diffraction pattern is small at A, the probability of detecting an electron at A is very small.

17. $$c = f\lambda$$
$$\Rightarrow \lambda = \frac{c}{f}$$
$$= \frac{3.0\times10^{8}}{4.5\times10^{14}}$$
$$= 6.7\times10^{-7}\text{ m}$$
$$p = \frac{h}{\lambda}$$
$$\Rightarrow v = \frac{h}{\lambda m}$$
$$= \frac{6.63\times10^{-34}}{6.7\times10^{-7}\times9.1\times10^{-31}}$$
$$= 1.1\times10^{3}\text{ m s}^{-1}$$

18. (a) $$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$
Since E and h are constant, the larger the value of m, the smaller the wavelength. So the proton will have the shorter wavelength.

(b) $$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$
$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.11\times10^{-31}\times1000\times1.60\times10^{-19}}}$$
$$= 3.9\times10^{-11}\text{ m for the electron}$$
Using $m = 1.67\times10^{-27}$ kg for the proton,
$$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$
$$= \frac{6.63\times10^{-34}}{\sqrt{2\times1.67\times10^{-27}\times1000\times1.60\times10^{-19}}}$$
$$= 9.1\times10^{-13}\text{ m}$$

19. $$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$
$$= \frac{h}{\sqrt{2mqV}}$$
$$\Rightarrow V = \frac{h^2}{2mq\lambda^2}$$
$$= \frac{(6.63\times10^{-34})^2}{2\times9.1\times10^{-31}\times1.60\times10^{-19}\times(2.0\times10^{-10})^2}$$
$$= 38\text{ V}$$

20. At room temperature, virtually all hydrogen atoms are in their ground state. As a result, the absorption spectrum shows only lines corresponding to absorption by atoms in the ground state. The emission spectrum is formed when electrons which are in excited states due, for example, to the energy supplied by a flame or an electron in an electric discharge emit light as they drop to lower energy levels. Since there is no restriction on which levels they can fall to, series of spectra are seen which correspond to any final state of the atom, not just the ground state. The 0.0122 nm UV radiation corresponds to the transition between the ground and first excited state, so it will appear in both emission and absorption spectra. The 656 nm light corresponds to a transition between the first and second excited states of hydrogen. It will appear in the emission spectrum but not the absorption spectrum.

21. The wavelength depends on the mass, if the energy is equal, according to $\lambda = \frac{h}{\sqrt{2mE}}$.
The proton has the larger mass, therefore the smaller wavelength.

22. For a 10 eV electron:
$$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE}}$$
$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times10\times1.60\times10^{-19}}}$$
$$= 3.9\times10^{-10}\text{ m}$$
For a 10 eV photon:
$$E = \frac{hc}{\lambda}$$
$$\Rightarrow \lambda = \frac{hc}{E}$$
$$= \frac{6.63\times10^{-34}\times3.0\times10^{8}}{10\times1.60\times10^{-19}}$$
$$= 1.2\times10^{-7}\text{ m}$$
The electron has the smaller wavelength.