Page 42 Test yourself on prior knowledge

1 a) Energy = potential difference × charge

= 6 V × 2 C

= 12 J

2 a) 11 electrons

b) Positive (there are fewer electrons than protons)

3 A sodium atom has no charge (equal numbers of protons and electrons) but a sodium ion is charged (more protons than electrons)

4 Microwaves, infrared, visible light, gamma rays

5 Red

Page 45–46 Test yourself

1 $E = hf$, Energy (J) = Planck's constant (6.63×10^{-34} J s) × frequency (Hz)

a) 6.63×10^{-34} J s × 2 × 10^{13} Hz =1.33×10^{-20} J

b) 6.63×10^{-34} J s × 6 × 10^{14} Hz = 3.98×10^{-19} J

c) 6.63×10^{-34} J s × 9 × 10^{15} Hz = 5.97×10^{-18} J

2 To convert joules into electron volts, divide by 1.6×10^{-19}

a) $\frac{1.33 \times 10^{-20}\text{ J}}{1.6 \times 10^{-19}} = 8.31 \times 10^{-2}$ eV

b) $\frac{3.98 \times 10^{-19}\text{ J}}{1.6 \times 10^{-19}} = 2.49$ eV

c) $\frac{5.97 \times 10^{-18}\text{ J}}{1.6 \times 10^{-19}} = 37.3$ eV

3 $\text{Frequency (Hz)} = \frac{\text{Energy (J)}}{\text{Planck's constant, h (J s)}}$

a) $\frac{5.0 \times 10^{-19}\text{ J}}{6.63 \times 10^{-34}\text{ J s}} = 7.5 \times 10^{14}\text{ Hz}$

b) $\frac{(2.5 \times 1.6 \times 10^{-19})\text{J}}{6.63 \times 10^{-34}\text{ J s}} = 6.0 \times 10^{14}\text{ Hz}$

c) $\frac{(1975 \times 1.6 \times 10^{-19})\text{J}}{6.63 \times 10^{-34}\text{ J s}} = 4.77 \times 10^{17}\text{ Hz}$

4 $\lambda = \frac{hc}{E}$, $\text{Wavelength of a photon} = \frac{\text{Planck's constant, h} \times \text{speed of light, c}}{\text{energy in J}}$

a) $\frac{6.63 \times 10^{-34}\text{ J s} \times 3 \times 10^{8}\text{ m s -1}}{8 \times 10^{-19}\text{ J}} = 2.49 \times 10^{-7}\text{ m}$

b) $\frac{6.63 \times 10^{-34}\text{ J s} \times 3 \times 10^{8}\text{ m s -1}}{(16 \times 1.6 \times 10^{-19})\text{J}} = 7.77 \times 10^{-8}\text{ m}$

c) $\frac{6.63 \times 10^{-34}\ \text{J s} \times 3 \times 10^{8}\ \text{m s}^{-1}}{(254 \times 1.6 \times 10^{-19})\ \text{J}} = 4.89 \times 10^{-9}\ \text{m}$

5 a) An electron volt is the energy needed to move an electron through a potential difference of 1 Volt; to convert electron volts to joules, multiply by 1.6×10^{-19}. To convert joules to electron volts, divide by 1.6×10^{-19}.

b) i) $600\ \text{V} \times e = 600\ \text{eV}$
$600\ \text{eV} = 600 \times 1.6 \times 10^{-19} = 9.6 \times 10^{-17}\ \text{J}$

ii) Since the charge of the helium nucleus is double the electron charge, energy required is
$600\ \text{V} \times 2e = 1200\ \text{eV}$
$1200\ \text{eV} = 1200 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-16}\ \text{J}$

Page 47 Test yourself

6 Electrons gain energy by absorbing a photon.
Electrons lose energy by emitting a photon.

7 The ground state is when electrons in an atom are in their lowest possible energy state.
An excited state is when one or more electrons in an atom have moved to a higher energy level.

8 Excitation is when electrons gain energy and move to a higher energy level in the atom; ionisation is when electrons gain enough energy to leave the atom completely.

9 a) The difference between the two energy levels is

$13.6\ \text{eV} - 3.4\ \text{eV} = 10.2\ \text{eV}$ ($= 1.63 \times 10^{-18}$ J)

b) Wavelength $= \frac{hc}{E}$

$= \frac{(6.63 \times 10^{-34}\ \text{J s}) \times (3 \times 10^{8}\ \text{m s}^{-1})}{10.2 \times 1.6 \times 10^{-19})\text{J}}$

$= 1.22 \times 10^{-7}$ m

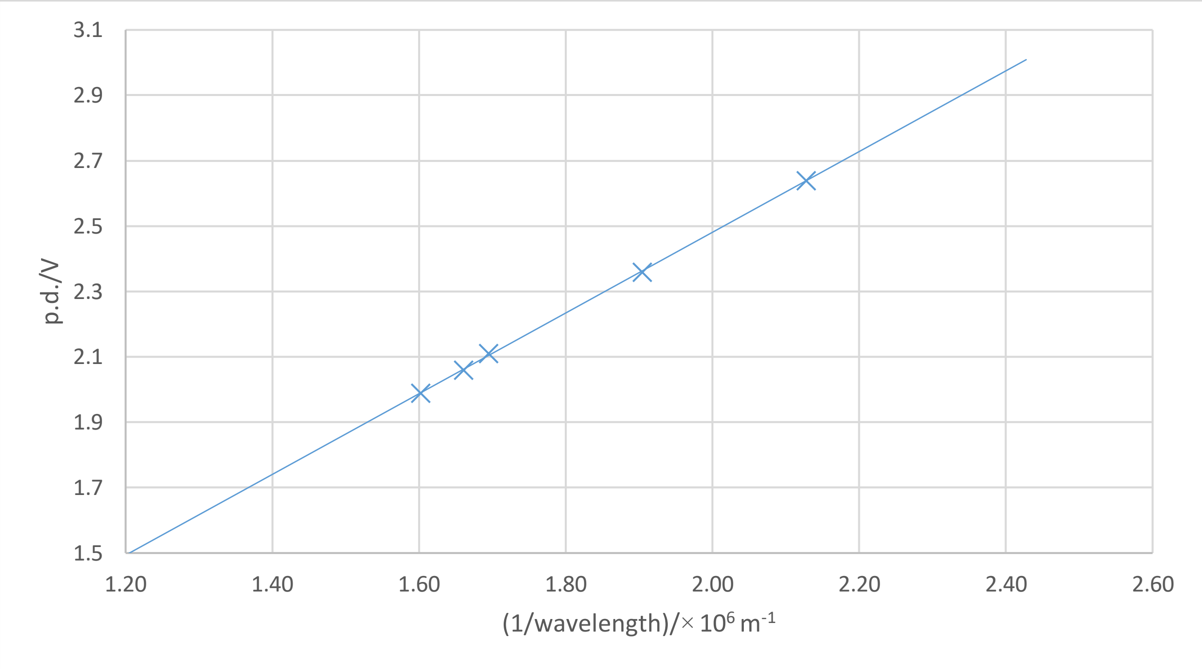
Page 47–48 Activity

Calculating the Plank constant using light-emitting diodes

1 The blue LED needs a higher voltage to light than the red LED as blue light has a shorter wavelength/higher frequency, and hence higher energy, than red light.

2

Colour of LED	Wavelength/nm	p.d. when LED is just lit /V	(1/wavelength) /x 10^6 m^{-1}
Red	624	1.99	1.60
Orange	602	2.06	1.66
Yellow	590	2.11	1.69
Green	525	2.36	1.90
Blue	470	2.64	2.13



The gradient is the change in potential difference / change in (1/wavelength), $\Delta V/\Delta\,(1/\lambda)$

Since $eV = hc\left(\frac{1}{\lambda}\right)$, the gradient, $\frac{\Delta V}{\Delta\left(\frac{1}{\lambda}\right)} = \frac{hc}{e}$

and $h = \frac{e}{c} \times \frac{\Delta V}{\Delta\left(\frac{1}{\lambda}\right)}$

You can use known values of *e* and *c* to calculate *h* from the gradient $\approx 1.23 \times 10^{-6}$ Vm

$h = \frac{1.6\times10^{-19}}{3\times10^{8}} \times 1.23 \times 10^{-6}$

$= 6.56 \times 10^{-34}$Js

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10 The photons produced within the sun have a continuous range of energies (as sunlight forms a continuous spectrum). Atoms in the sun's atmosphere absorb only those photons which have energy corresponding to the differences between their discrete energy levels. They re-emit these in all directions (including back towards the centre of the sun) so reducing the intensity of light of certain wavelengths leaving the sun.

11 An emission spectrum is a set of coloured lines produced by photons of discrete energies released when excited electrons in an atom return to the ground state (or lower energy levels).
An absorption spectrum is a set of dark lines on a continuous spectrum produced when electrons in lower energy states absorb photons of the correct energy to move them to an excited state.

12 An emission spectrum is due to atoms in an excited state falling to a lower energy state (which may be the ground state).

Page 50 Test yourself

13 The ionisation energy is the difference between the ground state energy level (n = 1) and the energy level for n = infinity. For this atom, E_i = 13.6 eV.

14 The arrows would point upwards because the electrons gain energy and move to a higher energy level.

15 a) The electron moves between levels 5 and 4 because the energy difference between these levels is −0.54 eV − (−0.85 eV) = 0.31 eV.

b) The electron moves between levels 3 and 2 because the energy difference between these levels is −1.51 eV − (−3.41 eV) = 1.9 eV.

c) The electron moves between levels 6 and 3 because the energy difference between these levels is −0.38 eV − (−1.51 eV) = 1.13 eV.

16 a) The energy difference is 3.41 eV − 0.54 eV = 2.87 eV, which corresponds to a photon of frequency 6.93×10^{-14} Hz.

This is because frequency $= \dfrac{\text{energy (in J)}}{\text{Planck's constant, h}}$

$$= \frac{(2.87 \times 1.6 \times 10^{-19})\,\text{J}}{6.63 \times 10^{-34}\ \text{J s}}$$

b) The energy difference is 0.54 eV − 0.38 eV = 0.16 eV, which corresponds to a photon of frequency 3.86×10^{13} Hz.

This is because frequency $= \dfrac{\text{energy (in J)}}{\text{Planck's constant, h}}$

$$= \frac{(0.16 \times 1.6 \times 10^{-19})\,\text{J}}{6.63 \times 10^{-34}\ \text{J s}}$$

17 The photons with energies of 10.1 eV and 1.20 eV cannot be absorbed as these energies do not match the difference between any pairs of energy levels in the atom.
The photons with energies of 0.47 eV and 0.16 eV will be absorbed as their energies correspond to the difference in energy between levels 6 and 4 and levels 6 and 5, respectively.

Page 51 Test yourself

18 The electrodes provide a potential difference between the ends of the tube, which accelerates electrons emitted by the cathode; atoms in the mercury vapour release UV photons when struck by fast-moving electrons; the phosphor coating absorbs UV photons and re-emits them as visible photons.

19 A fluorescent tube only emits certain frequencies of light because the atoms in the phosphor coating have discrete energy levels. All photons that are emitted are produced when electrons move between these allowed energy levels and so they can only have certain energy values.

20 The spectrum from a fluorescent lamp consists of discrete lines corresponding to allowed transitions between discrete energy levels because the light is produced when excited atoms in the coating return to a ground (or lower) state.
An incandescent bulb has a solid filament which is heated and produces photons with a continuous range of energies, producing a continuous spectrum.

21 The diagram shows three transitions from excited states to the ground state: from n = 6, n = 5 and n = 3. In all cases the energy difference corresponds to the energy of the level as the electrons are returning to the ground state, n = 1, where it has an energy of 0 eV.

a) The energy difference for n = 6 to n = 1 transition = 7.73 eV = 1.24×10^{-18} J

The energy difference for n = 5 to n = 1 transition = 6.70 eV = 1.07×10^{-18} J

The energy difference for n = 3 to n = 1 transition = 4.89 eV = 7.82×10^{-19} J

b) The wavelength for n = 6 to n = 1 transition $= \frac{\text{Planck's constant} \times \text{speed of light}}{\text{energy}}$

$$= \frac{6.63\times10^{-34}\,\text{J s} \times 3\times10^{8}\,\text{m s}^{-1}}{1.24\times10^{-18}\,\text{J}}$$

$$= 1.61 \times 10^{-7}\,\text{m}$$

The wavelength for n = 5 to n = 1 transition $= \frac{6.63\times10^{-34}\,\text{J s} \times 3\times10^{8}\,\text{m s}^{-1}}{1.07\times10^{-18}\,\text{J}}$

$$= 1.86 \times 10^{-7}\,\text{m}$$

The wavelength for n = 3 to n = 1 transition $= \frac{6.63\times10^{-34}\,\text{J s} \times 3\times10^{8}\,\text{m s}^{-1}}{7.82\times10^{-19}\,\text{J}}$

$$= 2.54 \times 10^{-7}\,\text{m}$$

Page 52–56 Practice questions

1 C

2 B

3 D

4 C

5 B

6 C

7 D

8 C

9 D

10 A

11 a) The electron must absorb energy from a colliding electron or photon [1]
to move to energy level $n = 2$, this must be exactly 13.6 eV – 3.4 eV = 10.2 eV [1]

b) The frequency is calculated using:

$f = E/h = (10.2 \times 1.6 \times 10^{-19})\text{J}/6.63 \times 10^{-34}\text{ Js}$ [1]

$= 2.46 \times 10^{15}\text{ Hz}$ [1]

A photon of this frequency is in the UV part of the spectrum. [1]

12 a) The ground state is when all electrons are in the lowest possible energy level [1]

b) The atoms collide with free electrons [1]

electrons in the atom absorb exactly the right amount of energy [1]
to move between quantised energy levels in the atom [1]

c) The cathode produces free electrons [1]

by thermionic emission [1]

d) Electrons fall back to the ground state/lower levels from an excited state releasing photons [1] of frequencies corresponding to differences between allowed energy levels in the mercury atom [1]

13 a) Energy difference = 11.4 keV – 1.8 keV = 9.6 keV [1]

$9.6\text{ keV} = 9.6 \times 10^3 \times 1.6 \times 10^{-19} = 1.536 \times 10^{-15}\text{ J}$ [1]

$\lambda = hc/E = 6.63 \times 10^{-34}\text{ Js} \times 3 \times 10^8\text{ ms}^{-1}/1.536 \times 10^{-15}\text{ J} = 1.3 \times 10^{-10}\text{ m}$ [1]

b) Ionisation energy = energy required to remove electron from atom = 69.6 keV [1]

$69.6\text{ keV} = 69.6 \times 10^3 \times 1.6 \times 10^{-19} = 1.11 \times 10^{-14}\text{ J}$ [1]

ionisation frequency, f = ionisation energy/h
$= (69.6 \times 10^3 \times 1.6 \times 10^{-19})\text{ J}/6.63 \times 10^{-34}\text{ J s} = 1.7 \times 10^{19}\text{ Hz}$ [1]

c) Any transition with an energy difference greater than 3.0 keV – 1.8 keV = 1.2 keV [1]

e.g. between energy levels 4 and 2; 4 and 1; 3 and 1; 3 and 2 [1]

d) **i)** Energy transferred to atom to excite electron from ground state to 11.4 keV
$= 69.6\text{ keV} - 11.4\text{ keV} = 58.2\text{ keV} = 9.3 \times 10^{-15}\text{ J}$ [1]

KE of electron after the collision = original KE – energy transferred during collision

$= 9.9 \times 10^{-15}\text{ J} - 9.3 \times 10^{-15}\text{ J} = 0.6 \times 10^{-15}\text{ J}$ [1]

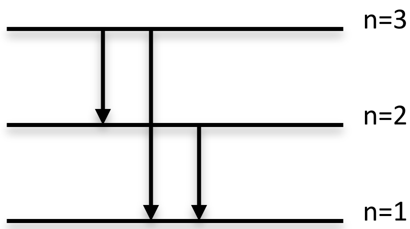
ii) The ionisation energy, 1.11×10^{-14} J, is greater than the energy of the incident electron [1] therefore the electron cannot ionise the atom [1]

e) Ionisation energy $= (69.6 \times 10^{3} \times 1.6 \times 10^{-19})\text{ J} = 1.11 \times 10^{-14}\text{ J}$

14 a) Photons are released when electrons move from one energy level to a lower level [1]

Diagram with arrows representing possible energy level transitions [1]

The photon frequency corresponds to the difference in energy between the two levels [1]



b) 3 frequencies are possible: $n = 3$ to $n = 2$, $n = 3$ to $n = 1$ and $n = 2$ to $n = 1$ [1]

possible transitions listed or clearly shown on diagram [1]

15 Any 5 from the following:

- A glass tube is filled with mercury vapour and coated inside with fluorescent materials. [1]
- A cathode releases free electrons with a range of kinetic energies. [1]
- Electrodes accelerate free electrons through the mercury vapour. [1]
- Collisions between free electrons and mercury atoms [1]
- leave mercury atoms ionised or excited. [1]
- When the electrons in the excited mercury atoms return to their ground state [1]
- photons of ultraviolet radiation are released [1].
- UV photons collide with the phosphors in the coating [1]
- and are reemitted as visible light [1]

QWC = 1 mark

16 a) 5.1 eV

b) Yellow – these lines are nearer the red end of the visible spectrum
(400 nm = violet; 700 nm = red)

c) 4s to 3p: transition energy is (approx.) 1.1ev;

wavelength = hc/E = (3 × 10^8 ms-^{1} ×6.63 × 10^{-34} J s)/(1.6 × 10^{-19} × 1.1)J = 1.1 × 10^{-6} m

3d to 3p: transition energy is (approx.) 1.6 eV;

wavelength = hc/E = (3 × 10^8 m s^{-1} × 6.63 × 10^{-34} J s)/(1.6 × 10^{-19} × 1.6)J = 7.8 × 10^{-7} m

3p to 3s: transition energy is (approx.) 2.1 eV;

wavelength = hc/E = (3 × 10^8 m s^{-1} × 6.63 × 10^{-34} J s)/(1.6 × 10^{-19} × 2.1)J = 5.9 × 10^{-7} m

d) $E = hc/\lambda$ = 3 × 10^8 m s^{-1} × 6.63 × 10^{-34} J s/620 × 10^{-9} m = 3.2 × 10^{-19} J or 2 eV

This energy corresponds to the lines produced by transitions from 5s to 3p.

Page 56 Stretch and challenge questions

17 Hard X-rays are used for diagnosis.

Soft X-rays will not pass through the body to produce an image of different types of tissue on a plate.

When soft X-rays are absorbed, they will ionise atoms in tissue and cause damage.

18 a) Energy = 24 keV = 24 × 10^3 × 1.6 × 10^{-19} = 3.84 × 10^{-15} J

$$\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.84\times10^{-15}}$$
$$= 5.18\times10^{-11}\text{m}$$

b) The difference in density between bone and surrounding tissue is greater than that between breast tissue and a tumour.

Therefore, the contrast produced by X-rays of a given energy will be greater for bone/tissue than for breast/tumour.

Harder X-rays, which would not give sufficient contrast for a mammogram, will work for investigating bone damage.

(These X-rays are also less likely to be absorbed and so will cause less damage to tissues.)

Harder X-rays have higher energy and, therefore, shorter wavelengths.