AS Level Physics

Chapter 2 – Particles and radiation

2.1.1 Photons

Notes

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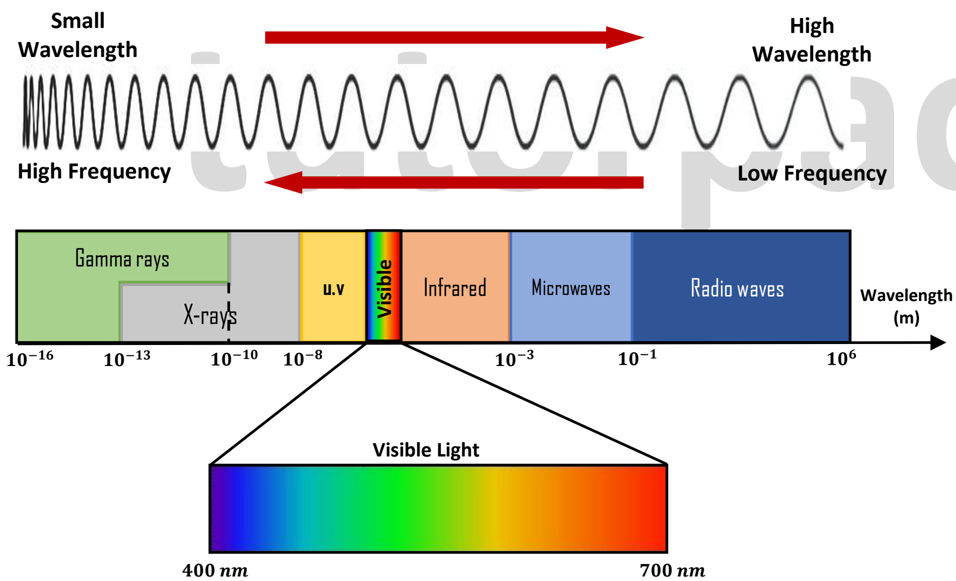
Electromagnetic Wave Spectrum

Visible light is just one type of electromagnetic (EM) radiation.

The EM spectrum is a continuous spectrum of all the possible frequencies of the EM radiation.

- The frequency of a wave is the number of complete waves passing a point per second.
- The wavelength of a wave is the distance between two adjacent cresets of a wave.

Electromagnetic radiation is split up into seven different types based on the frequency of the radiation and its properties.



Electromagnetic Wave Spectrum

The wave properties become more obvious as the wavelength increases - for example, long radio waves can diffract around hills whereas visible light can only diffract through a very narrow slit.

Energy is directly proportional to frequency. Gamma rays have the highest energy; while radio waves the lowest. In general, the more energy (or frequency) a wave has, the more harmful it is.

For your exam you need to remember:

- The names of all the 7 regions.
- The order they appear in.
- Their approx. wavelength ranges.

Photons

When Max Planck was researching black body* radiation, he proposed that electromagnetic waves can only be released in discrete packets known as Quanta. A quantum is a single packet of electromagnetic energy.

This simply means that electromagnetic radiation is emitted in short 'bursts' or 'packets' of energy.

The energy carried by one of these wave-packets is proportional to the frequency, according to Max Planck:

$$\boldsymbol{E \propto f}$$

And because they're proportional, he needed a constant, which he named Planck's constant (h). As a result, the energy carried by one of these wave-packets had to be:

$$\boldsymbol{E = hf}$$

Where:

E = Energy emitted measured in Joules, J,

h = Planck's constant (= $6.63 \times 10^{-34} Js$),

f = Frequency of the radiation measured in hertz, Hz.

Therefore, the greater the EM radiation's frequency, the more energy its wave-packets carry.

The Planck's constant unit Js is equivalent to 'joules per hertz ($J\ Hz^{-1}$)'. Each wave packet carries more joules as the hertz (or frequency) increases.

Photons

We can take it a step further. We know, $f = \frac{v}{\lambda}$, and that all EM waves travel at the speed of light, c, we can substitute $f = \frac{c}{\lambda}$ into $E = hf$ to get:

$$\boldsymbol{E = \frac{hc}{\lambda}}$$

Where:

c = speed of light in a vacuum measured in ms^{-1} ($\approx 3 \times 10^8\ ms^{-1}$)

λ = Photon wavelength measured in metres, m.

Albert Einstein went even further a few years later, claiming that EM waves (and the energy they carry) can only exist in discrete packets. He called these wave-packets photons.

He believed that a photon acts as a particle, and when a photon interacts with another particle, like an electron, it transfers all or none of its energy.

* The Sun can be assumed to be a black body. It absorbs nearly all of the light that strikes it and releases the most powerful radiation in the visible range (i.e. yellow region) of the EM spectrum. No light reflects off a black body. In a later pack, we'll talk more about black bodies.

The Electronvolt (eV)

When dealing with photons, the energies involved are so little that it makes sense to use a unit other than the Joule, J. When dealing with photon energy, you can use the electronvolt (eV) as a more convenient unit.

1 electronvolt (eV) is the energy transferred by an electron when it moves between two points by a potential difference (p.d.) of 1 Volt.

The kinetic energy (E) gained by an electron (with charge, $Q = e = 1.6 \times 10^{-19} C$) moving through a p.d. of $1\ V$ is given by:

$$E = QV = (1.6 \times 10^{-19}\ C) \times (1\ V)$$

Hence,

$$1\ eV = 1.6 \times 10^{-19}\ J$$

To convert from J to eV: divide by $1.6 \times 10^{-19}\ J$

To convert from eV to J: multiply by $1.6 \times 10^{-19}\ J$

Kinetic Energy and eV

When an electron is accelerated between two electrodes, some electrical potential energy (eV) is converted into kinetic energy (KE).

Consider an electron with a charge (e) and mass (m) that is initially at rest before being accelerated through a p.d. (V) to a final speed (v).

Then:

The KE energy gained by an electron is equal to the work done on it by the accelerating p.d. so:

$$\frac{1}{2}mv^2 = eV$$

Where:

m = mass of electron measured in kg

v = speed of electron measured in ms^{-1}

e = electron charge measured in C

V = potential difference measured in volts, V

Rearranging the above formula, we get the following equation for electron speed (v):

$$v = \sqrt{\frac{2eV}{m}}$$

Note:

These equations apply to any charged particle.

When the accelerating p.d. is large, the equations are invalid. This is because the charged particles' speeds could approach the speed of light (c), requiring consideration of the relativistic effect of mass increase (i.e. mass is no longer constant).

Please see '2.1.2 Photons worked examples' pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.