Physics (A-level)

<mark>Electromagnetic induction (Chapter 23):</mark>

- For a straight wire, the induced current or e.m.f. depends on:
    - ➢ The magnitude of the magnetic flux density
    - ➢ The length of the wire in the field
    - ➢ The speed of movement of the wire
- For a coil of wire, the induced current or e.m.f. depends on:
    - ➢ The magnitude of the magnetic flux density
    - ➢ The cross-sectional area of the coil
    - ➢ The number of turns of wire
    - ➢ The rate at which the coil turns in the field
- In electromagnetic induction, Fleming's right-hand (generator) rule is used:
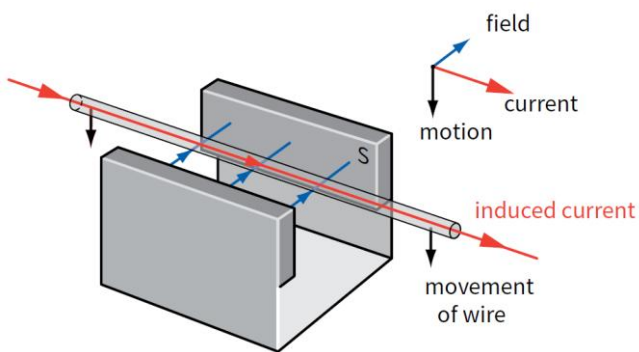

Figure 28.9 Deducing the direction of the induced current using Fleming's right-hand rule.

   - ➢ By pushing the wire through the magnetic field, work is done and transformed into electrical energy (e.m.f.)
- We can picture the **magnetic flux density** as the number of magnetic field lines passing through a region **per unit area**; we can picture **magnetic flux** as the total number of magnetic field lines passing through an area A; therefore the **magnetic flux** Φ is defined as the product of magnetic flux density and the cross-sectional area A (normal to the field):
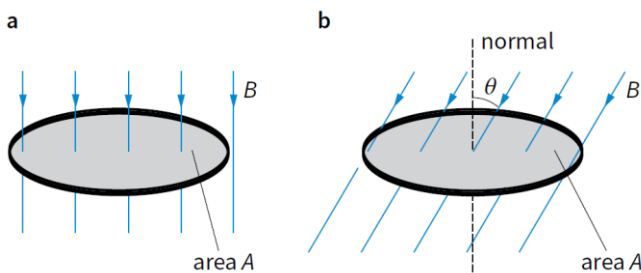
$\Phi = BA$

Figure 28.12 a The magnetic flux is equal to BA when the field is normal to the area. b The magnetic flux becomes $BA\cos\theta$ when the field is at an angle θ to the normal of the area.

- For an coil with N turns, the **magnetic flux linkage** is defined as the product of the magnetic flux and the number of turns:

magnetic flux linkage $= N\Phi$ or   magnetic flux linkage $= BAN\cos\theta$

- The unit for magnetix flux or flux linkage is the **Weber** (Wb)
- **One Weber** (1 Wb) is the flux that passes through an area of $1m^2$ when the magnetic flux density is 1 T. ($1Wb = 1\ Tm^2$)
- e.m.f. is induced whenever there is a **change** in magnetic flux linking the circuit; this can be done by:
  - ➢ Changing the magnetic flux density B
  - ➢ Changing the area A of the circuit
  - ➢ Changing the angle θ
- Electromagnetic induction occurs whenever a conductor cuts across lines of magnetic flux
- **Faraday's law of electromagnetic induction** (to determine the magnitude of the induced e.m.f. in a circuit): the magnitude of the induced e.m.f. is proportional to the rate of change of magnetic flux linkage

$$E = \frac{\Delta(N\Phi)}{\Delta t}$$

- **Lenz's law**: any induced current or e.m.f. will be established in a direction so as to produce effects which oppose the change that is producing it
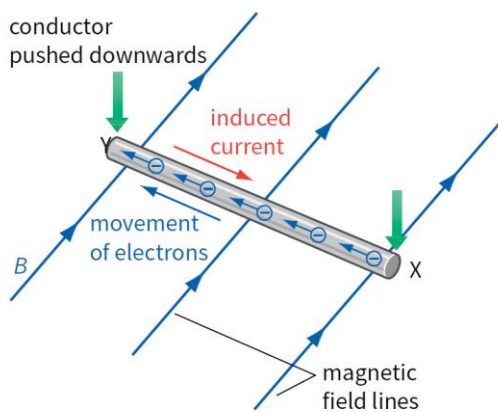

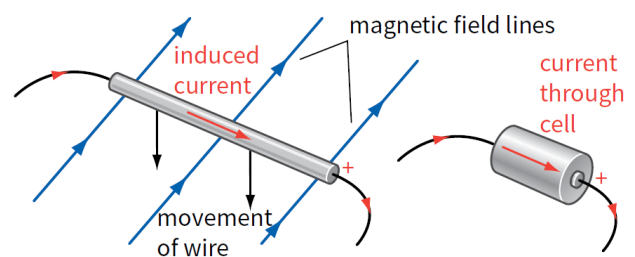Figure 28.20 Showing the direction of the induced current.

Figure 28.21 A moving conductor in a magnetic field is a source of e.m.f., equivalent to a cell.

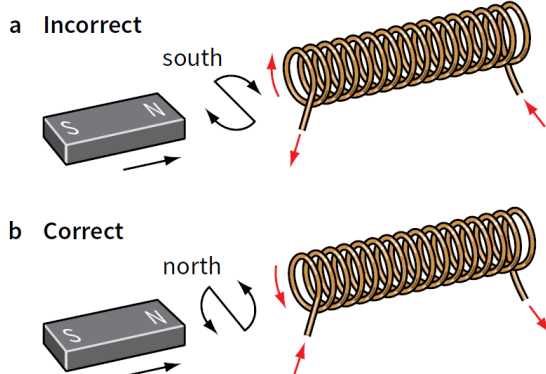- Conservation of energy in electromagnetic induction:

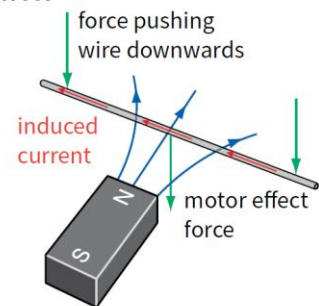

Figure 28.22 Moving a magnet towards a coil: the direction of the induced current is as shown in **b**, not **a**.
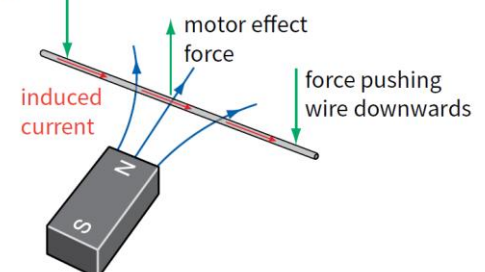

Figure 28.23 Moving a conductor through a magnetic field: the direction of the induced current is as shown in **b**, not **a**.
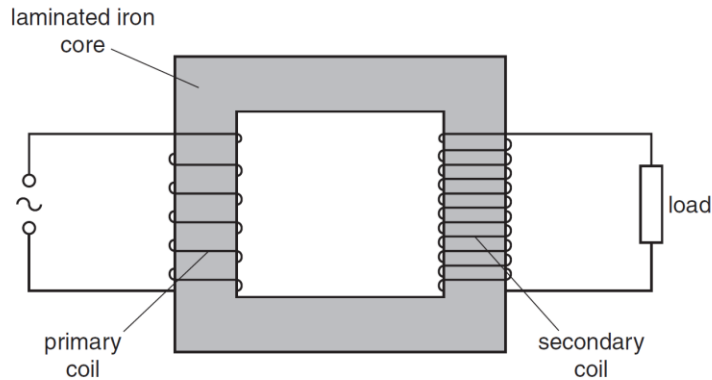
Fig. 6.1

- The coils are wounded on a core made of iron to concentrate the magnetic flux, and reduce magnetic flux losses
- The core is laminated to reduce energy or heat losses caused by the eddy currents
- Thermal energy is generated in the core due to the change in magnetic flux in the core, inducing current in it, which in turn gives rise to a heating effect, due to the induction of different e.m.f in different parts of the core, forming eddy currents in the core
- An e.m.f is induced in the secondary coil, a current in the primary coil gives rise to this induced e.m.f explanation: alternating current gives rise to changing magnetic flux in the core, which links to the secondary coil; by Faraday's law, changing of magnetic flux induces e.m.f in the secondary coil
- Using Faraday's law, the difference in phase of the p.d. across the load and e.m.f can be explained: the magnetic flux is in phase with the e.m.f or current in the primary coil; e.m.f or p.d. across the secondary coil is proportional to the rate of change of magnetic flux; hence e.m.f of the supply is not in phase with p.d. across secondary
- Alternating current is used in transmitting electrical energy as voltage can be easily and efficiently changed
- High voltages are used in transmitting electrical energy as for the same power transmission, high voltages means low currents, hence less energy will be lost in the transmission of the cables

Quantum physics (Chapter 25):

- Phenomena such as interference and diffraction provide evidence for a wave nature
- The photoelectric effect provides evidence for a particulate nature of electromagnetic radiation – all consists of photons
- **Photon**: packet of discrete amount of energy of electromagnetic radiation; energy (E, in joules (J)) = Planck constant (value: 6.63×10^{-34}) × frequency
  - ➤ Photon's energy is directly proportional to the frequency of the electromagnetic wave, hence high-frequency radiation means high-frequency photons

$E = hf$, and substituting the wave equation c = $f \lambda$: $E = \dfrac{hc}{\lambda}$

- **Gamma radiation** (γ-radiation): photons of electromagnetic radiation emitted from the nuclei
- **One electronvolt** (1 eV) is the energy transferred when an electron travels through a potential difference of one volt, therefore 1eV = 1.60×10^{-19} J

- ■ To convert from eV to J, multiply by 1.60×10^{-19}.
- ■ To convert from J to eV, divide by 1.60×10^{-19}.

- When an electron is accelerated through a p.d., V, its K.E. increases given by:

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

➢ Rearranging the equation gives the electron's speed:

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

➢ Equation applies to all charged particle: photons (+ e) and ions
- The **threshold frequency** is defined as the minimum frequency for electrons to be emitted from the surface of a metal
- The **work function energy**, Φ, of a metal is the minimum amount of energy required by an electron to escape its surface
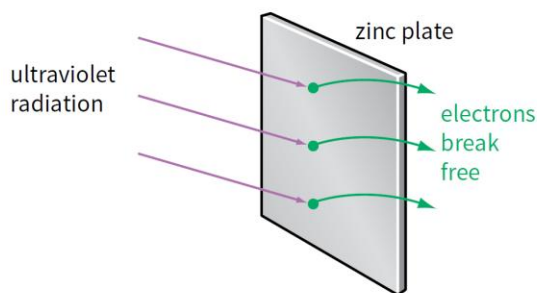

Figure 30.8 The photoelectric effect. When a photon of ultraviolet radiation strikes the metal plate, its energy may be sufficient to release an electron.
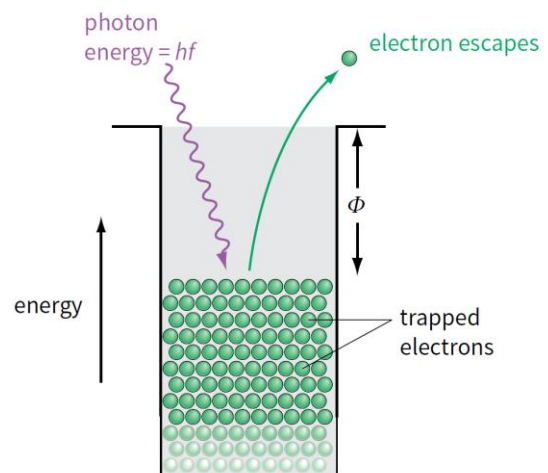
Figure 30.9 A single photon may interact with a single electron to release it.

- Some of the energy from the photons is needed for the electrons to escape from the energy well; the rest is the electron's K.e.
- Electrons from the surface of the metal is removed
- A single photon can only interact (exchange energy) with a single electron

- A surface electron is removed **instantaneously** from the metal surface when the energy of the incident photon is greater than, or equal to, the work function Φ of the metal
- Energy of photon = work function energy + maximum K.e. of the electron

$$hf = \Phi + \text{k.e.}_{\text{max}} \quad \text{or} \quad hf = \Phi + \tfrac{1}{2}mv_{\text{max}}{}^2$$

  ➢ If the photon is absorbed by an electron that is lower in the energy well, the electron will have less K.e. than K.e.$_{\text{max}}$

- If the incident radiation has a frequency equal to the threshold frequency, f_0, then the K.e. of the electrons is zero:
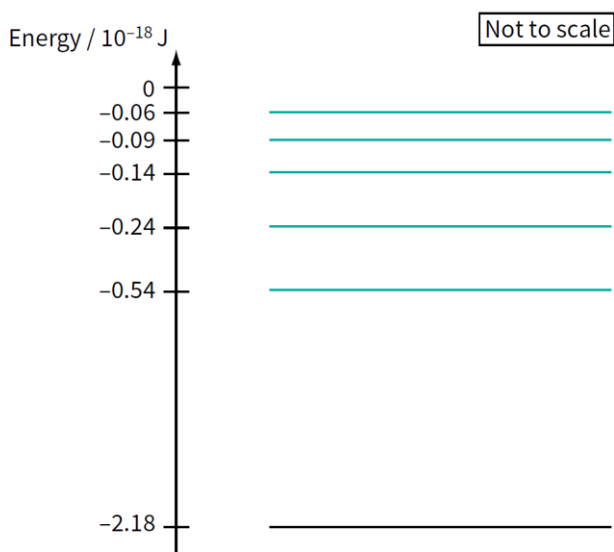
$$hf_0 = \Phi$$

Figure 30.15 Some of the energy levels of the hydrogen atom.

- An electron in a hydrogen atom can only have one of these values of energy, no in betweens
- The energy levels have negative values due to the attractive forces within the atom by the atomic nucleus, hence external energy needs to be supplied to emit an electron from the atom; zero energy results in 'free' electrons
- Atoms of different elements have different line spectra as they have different spacings between their energy levels
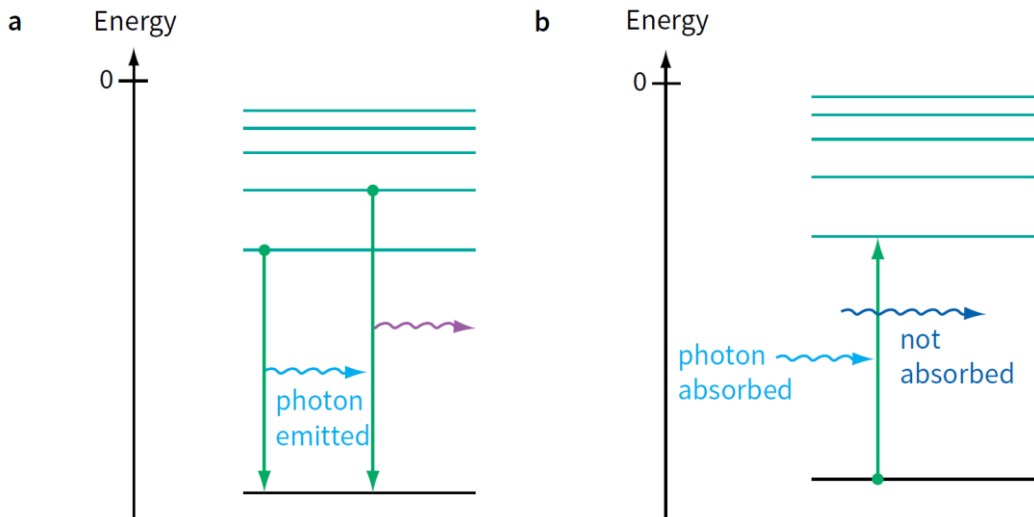
Figure 30.16 a When an electron drops to a lower energy level, it emits a single photon. **b** A photon must have just the right energy if it is to be absorbed by an electron.

- When an electron changes its energy from one level E_1 to another E_2, it either emits or absorbs a single photon; the energy equals to the difference in energies between the two levels:

$$\text{photon energy} = \Delta E, \quad hf = E_1 - E_2 \quad \text{or} \quad \frac{hc}{\lambda} = E_1 - E_2$$

➤ E.g. figure 30.15, falling from second level to the lowest energy level (ground state):

$$\text{photon energy} = \Delta E$$
$$hf = [(-0.54) - (-2.18)] \times 10^{-18}\,\text{J}$$
$$hf = 1.64 \times 10^{-18}\,\text{J}$$

➤ Wavelength and frequency can then be calculated:

The frequency is:
$$f = \frac{E}{h} = \frac{1.64 \times 10^{-18}}{6.63 \times 10^{-34}}$$
$$f = 2.47 \times 10^{15}\,\text{Hz}$$

The wavelength is:
$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8}{2.47 \times 10^{15}}$$
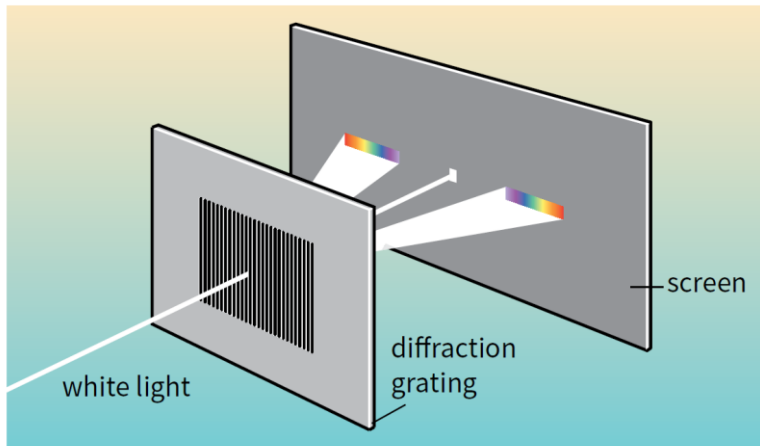$$\lambda = 1.21 \times 10^{-7}\,\text{m} = 121\,\text{nm}$$

Figure 30.11 White light is split up into a continuous spectrum when it passes through a diffraction grating.

➢ Line spectrum can be seen
➢ The line spectra that show the composition of light emitted by hot gases are called **emission line spectra**
➢ The line spectra observable when white light passed through cool gases are called **absorption line spectra**
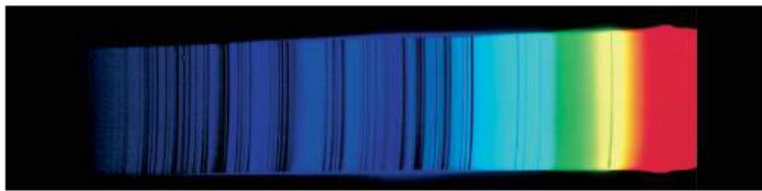

Figure 30.14 The Sun's spectrum shows dark lines. These dark lines arise when light of specific wavelengths coming from the Sun's hot interior is absorbed by its cooler atmosphere.

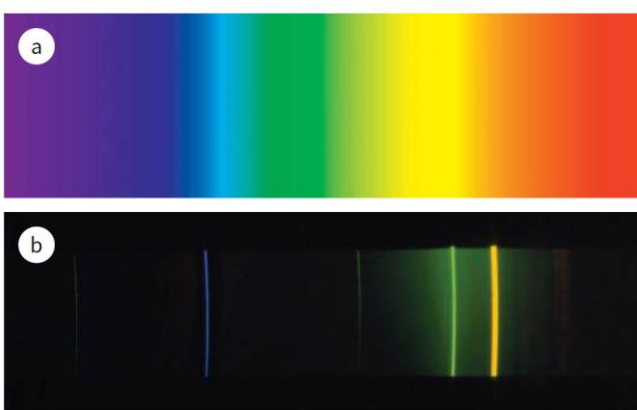**Figure 30.12** Spectra of **a** white light, and of light from **b** mercury, **c** helium and **d** cadmium vapour.

• Wave-particle duality of light:
➢ Light interacts with matter (e.g. electrons) as a particle – the photon (photoelectric effect)

➢ Light travels through space as a wave (diffraction and interference of light using slits)

• De Broglie wavelength given by:

$$\lambda = \frac{h}{p}$$ or $$\lambda = \frac{h}{mv}$$

➢ h is the Planck constant
➢ p is the momentum

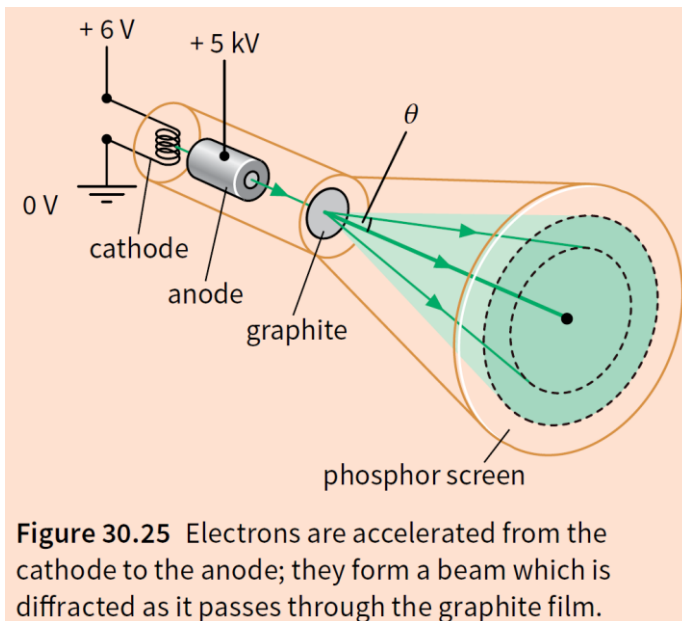• Investigating wave nature of electrons through electron diffraction:

Figure 30.25 Electrons are accelerated from the cathode to the anode; they form a beam which is diffracted as it passes through the graphite film.

➢ Electron beam in a vacuum
➢ Incident on thin metal target / carbon film (graphite)
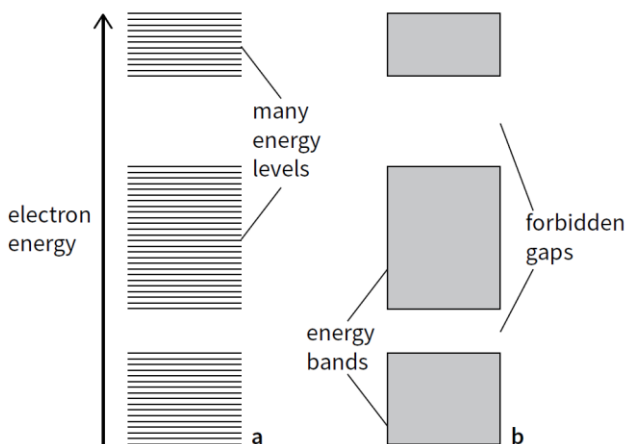➢ Fluorescent screen (phosphor screen)

Figure 30.19 a In a solid, the electron energy levels are very close together. **b** The energy levels form bands with forbidden gaps between them.

• **Forbidden gap**: a range of energy values which an electron in a solid cannot have
• **Conduction band**: a range of electron energies in a solid, which are free to move throughout the material

- **Valence band**: a range of electron energies in a solid, which electrons are bound to individual atoms
- In isolated atoms (gases), electron energy levels have discrete values, while in a solid, there are energy bands; this is because in a solid electrons in neighbouring atoms are very close together and influence / interact with each other; this changes their electron energy levels; many atoms in lattice cause spread of energy levels into a band
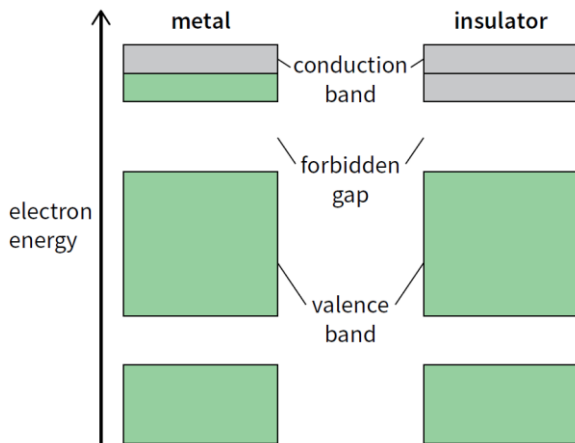

Figure 30.20 How the energy bands are filled in a metal and in an insulator.

  ➢ Conduction band is partially filled in metals, hence it can conduct electricity (free electrons)
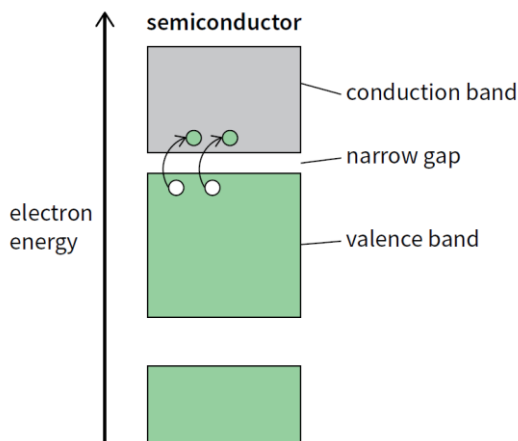- An intrinsic semiconductor (pure material) conducts electric current, but only very slightly:

Figure 30.21 Electron energy bands in a semiconductor.

  ➢ It is similar to an insulator (full valence electrons and empty conduction band), difference is its small gap between the bands
  ➢ With heating, more electrons will gain the energy to jump up into the conduction band; leaving holes in the valence band; these electrons and holes are charge carriers; increase in current, hence reduced resistance
  ➢ Unlike metal when heated, as its resistance will increase due to the decrease in free electron density, as its atoms vibrate more, the electrons collide more frequently with the vibrating atoms
- In LDR (consisting of intrinsic semiconductor) at constant temperature, it will be dependent on light intensity, as photons of light give energy to electrons in the valence band;

electrons move up into the conduction band; leaving holes in the valence band; these electrons and holes are charge carriers; increase in current, hence reduced resistance

- **De Broglie wavelength**: the wavelength associated with a moving particle dependent on its momentum
- Observations of photoelectric effect has proven that either electrons are emitted immediately or they are not emitted at all with exposure of light on a metal surface, suggest why this observation does not support a wave theory of light:
  - ➢ For a wave, electron can 'collect' energy continuously, electron will be emitted at all frequencies of electromagnetic radiation after a sufficiently long delay
- Explain how the line spectrum of hydrogen provides evidence for the existence of discrete electron energy levels in atoms:
  - ➢ Each line represents photon of specific energy
  - ➢ Photon emitted as a result of energy change of an electron
  - ➢ There are specific energy changes, hence discrete levels

(b) Some electron energy levels in atomic hydrogen are illustrated in Fig. 7.1.
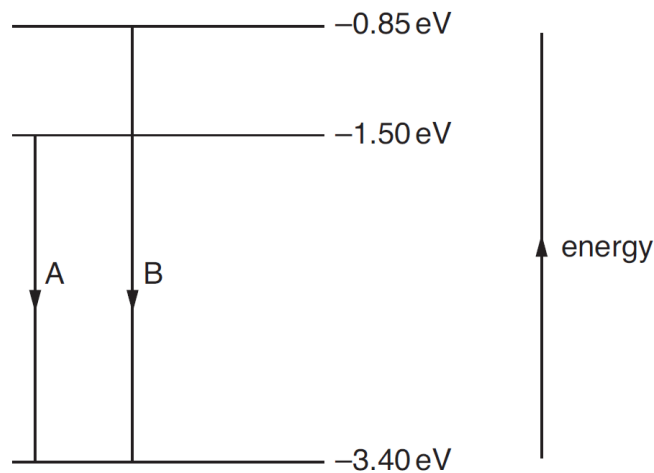

Fig. 7.1

Two possible electron transitions A and B giving rise to an emission spectrum are shown.
These electron transitions cause light of wavelengths 654 nm and 488 nm to be emitted.

(i) On Fig. 7.1, draw an arrow to show a third possible transition. [1]

(ii) Calculate the wavelength of the emitted light for the transition in **(i)**.

(b) (i) arrow from –0.85 eV level to –1.5 eV level   B1   [1]

(ii) $\Delta E = hc/\lambda$ C1
$= (1.5 - 0.85) \times 1.6 \times 10^{-19}$ C1
$= 1.04 \times 10^{-19}$ J
$\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(1.04 \times 10^{-19})$
$= 1.9 \times 10^{-6}$ m   A1   [3]

(c) The light in a beam has a continuous spectrum of wavelengths from 400 nm to 700 nm. The light is incident on some cool hydrogen gas, as illustrated in Fig. 7.2.
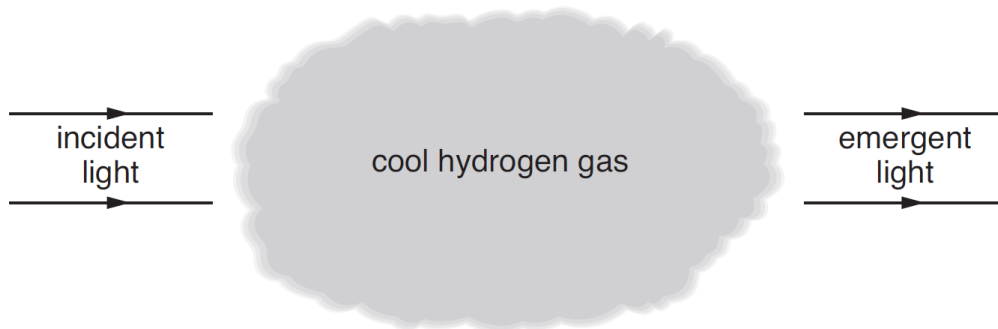

incident light → cool hydrogen gas → emergent light

Fig. 7.2

Using the values of wavelength in **(b)**, state and explain the appearance of the spectrum of the emergent light.

....

(c) spectrum appears as continuous spectrum crossed by dark lines   B1
two dark lines   B1
electrons in gas absorb photons with energies equal to the excitation energies   M1
light photons re-emitted in all directions   A1   [4]

- Light of a particular wavelength is incident on a metal surface and gives rise to a photoelectric current and the wavelength is reduced, and the intensity is kept constant, hence state and explain the effect on the photoelectric current:
  ➢ Each photon has more energy
  ➢ Fewer photons per unit time
  ➢ Fewer electrons per unit time, hence less current