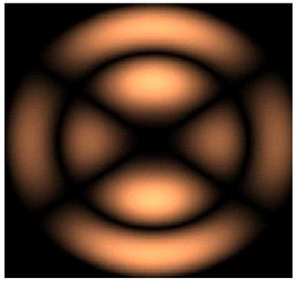
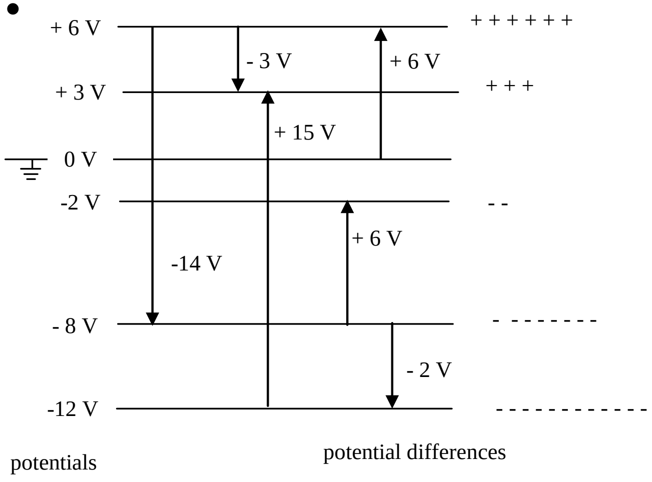


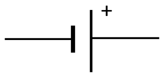
DO PHYSICS ONLINE

9.4 ROM IDEAS TO IMPLEMENTATION

MINDMAP SUMMARIES

ELECTRIC POTENTIAL *V* [V]

- Measure of charge imbalance
- 

- Battery voltage – *emf* 

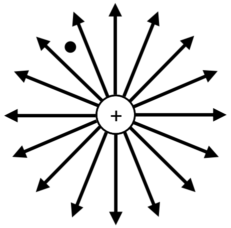
- Induced *emf* equals time rate of change of magnetic flux $emf = -\dfrac{\Delta \phi_B}{\Delta t}$ (eg conductor moving in a B-field)

ELECTRIC FIELD *E* [V.m^{-1} N.C^{-1}]

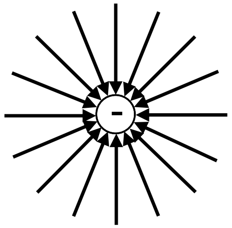
- Electric field $\vec{E}$ - region surrounding charge distribution
- A charge *q* of mass *m* in an electric field *E*, accelerated by a voltage *V* increases its kinetic energy E_K by

$q\,V = ½\,m\,v^2$

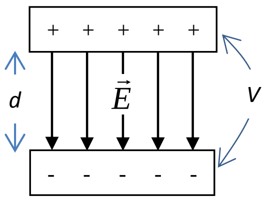
- $F = E\,q$ or $\vec{F} = q\,\vec{E}$ $\qquad \vec{E} = -\dfrac{\Delta V}{\Delta x}$
-



Electric field
POSTIVE charge

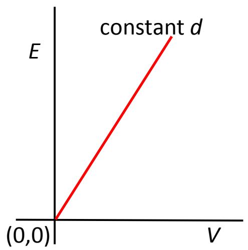


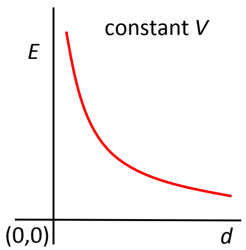
Electric field
NEGATIVE charge



Uniform electric field

$$E = \frac{V}{d}$$

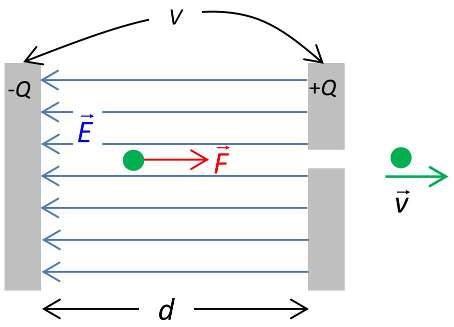


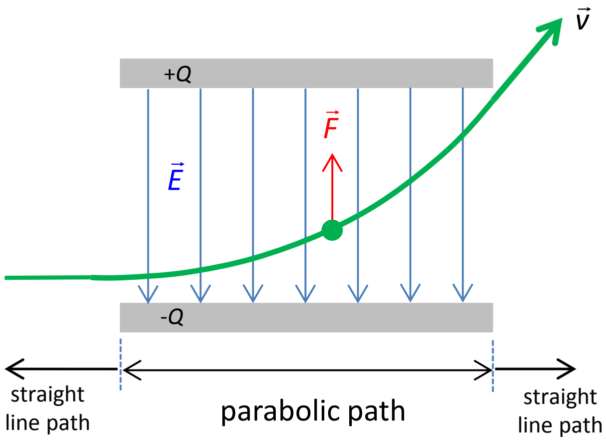


Motion of charged particle in an electric field

Motion of an electron in an electric field

$F = E\,q \qquad a = \dfrac{qE}{m} \qquad E = \dfrac{V}{d} = \text{constant}$





If an electron is initially at rest and moves in the direction of the electric field lines from the negative plate to the positive plate through the distance *d* then work *W* is done on the electron to increase in its kinetic energy

Work = change in kinetic energy

$$W = F\,d = qE\,d = q\left(\frac{V}{d}\right)d = qV$$

$$\Delta E_K = \tfrac{1}{2}mv^2$$

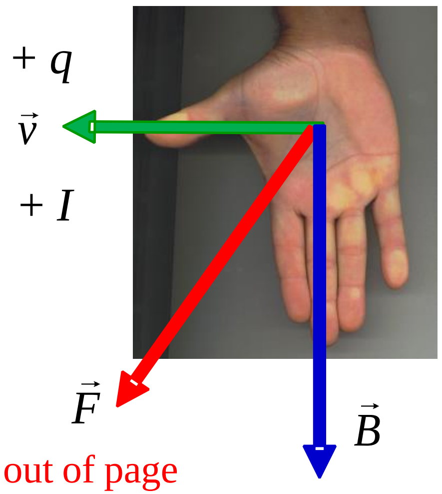
$$\tfrac{1}{2}mv^2 = qV$$

This is the principle of the **electron gun** in a cathode ray tube

Motion of charged particle in a magnetic field

$$F_B = qv_{\perp}B = q(v\sin\theta)B$$

$$F_B = qvB\sin\theta$$



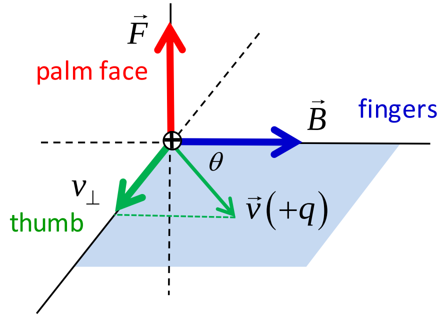
Right Hand Palm Rule

Fingers point along the direction of the B-field

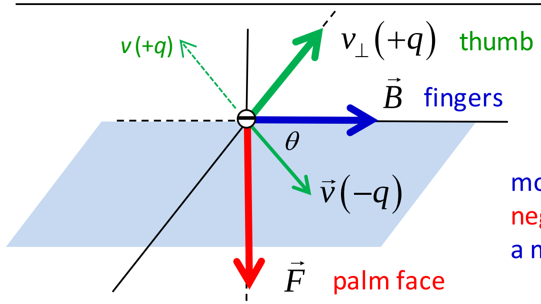
Thumb points in the direction in which ***positive*** charges would move

(negative is moving to the left, then the thumb points to the right)

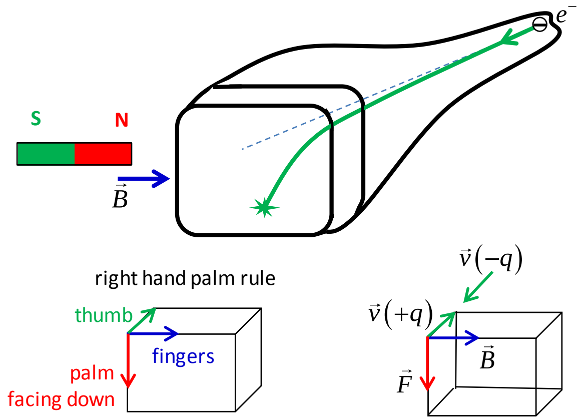
Palm gives the direction of the force on the charged particle



motion of a *positive* charge in a magnetic field



motion of a negative charge in a magnetic field



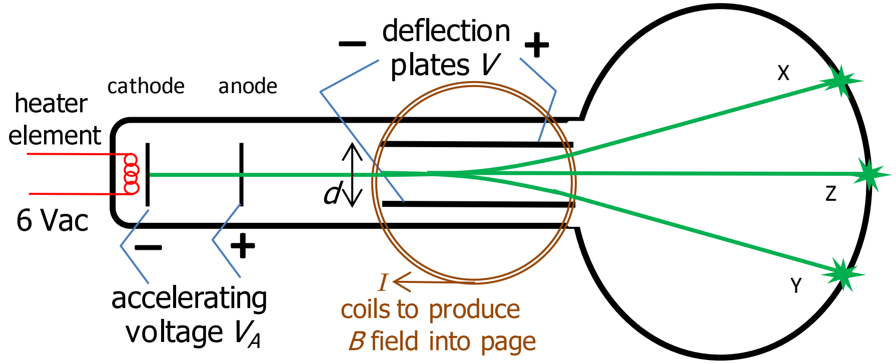
Motion of charged particle in a cross magnetic and electric fields

J. J. Thompson - measured q_e / m_e → conclusive evidence that cathode rays were a stream of **electrons**.

Electric field E → electrons deflected up

Magnetic field B → electrons deflected down

Electron gun → acceleration of electrons



$$eV_A = \tfrac{1}{2} m_e v^2 \quad \Rightarrow \quad v = \sqrt{\frac{2eV_A}{m_e}}$$

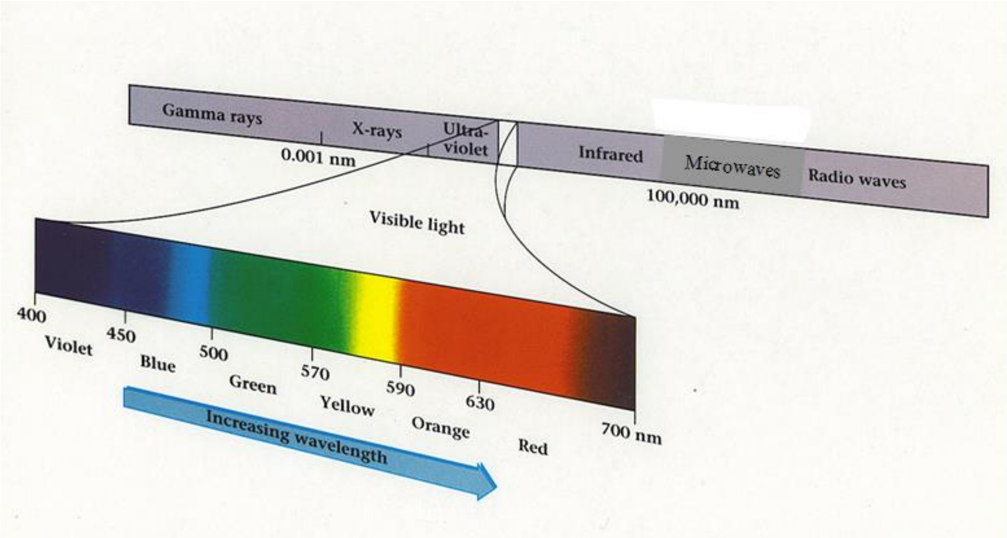
Electric force F_E = magnetic force F_B
→ zero deflection of electron beam

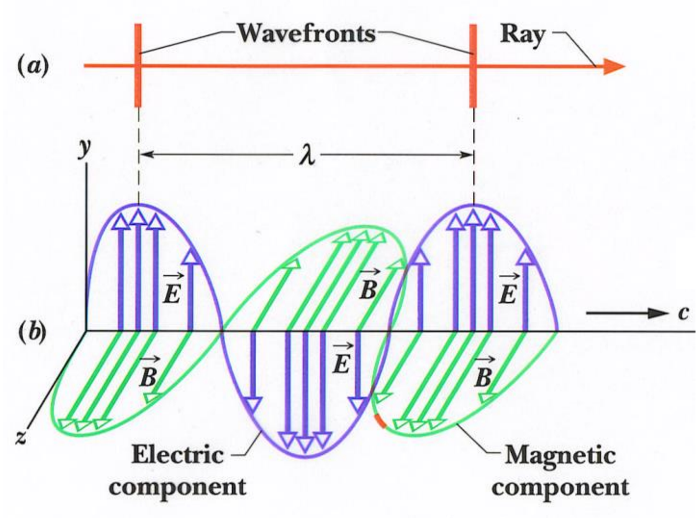
$$F_E = eE = \frac{eV}{d} \qquad F_B = evB = eB\sqrt{\frac{2eV_A}{m_e}} \quad \rightarrow \quad \boxed{\frac{e}{m_e} = \frac{V^2}{2d^2 V_A B}}$$

Motion of electron in uniform magnetic field → circular motion of electron as magnetic force also directed perpendicular to the motion → magnetic force FB = centripetal force FC

$$F_B = F_C \qquad evB = m\frac{v^2}{R} \qquad v = \sqrt{\frac{2eV_A}{m_e}} \qquad F_E = F_B \;\Rightarrow\; eE = evB \qquad v = \frac{E}{B} \;\rightarrow\; \boxed{\frac{e}{m_e} = \frac{E}{RB^2} = \frac{V}{dRB^2}}$$

ELECTROMAGNETIC RADIATION speed of light $c = 3 \times 10^{8}$ m.s^{-1}

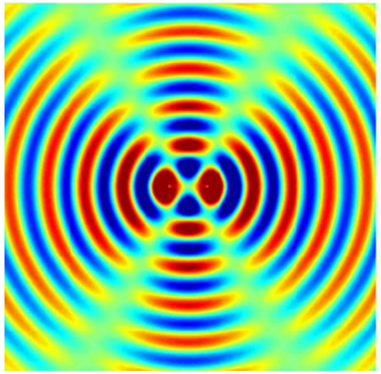




← **particle-like** **wave-like** →

Wave Model

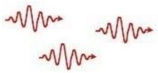
wavelength λ [m] frequency f [hertz Hz] $c = f\lambda \quad f = \dfrac{c}{\lambda} \quad \lambda = \dfrac{c}{f}$



Interference and diffraction (constructive destructive)

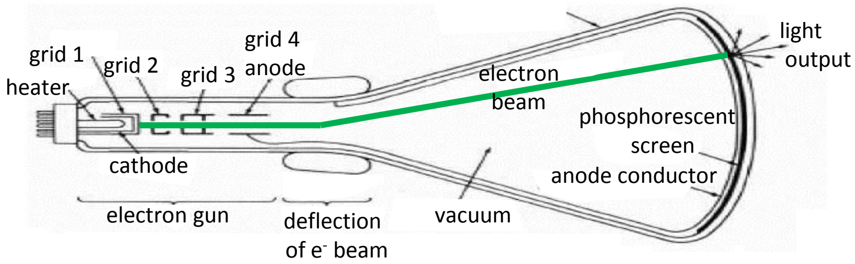
Particle Model

stream of particles **photons**



$$E_{photon} = hf = \frac{hc}{\lambda}$$

CATHODE RAY TUBE



charged parallel plates → electric field
$F_E = q\,E$

current carrying coil → magnetic field
$F_B = q\,v\,B$

CATHODE RAYS

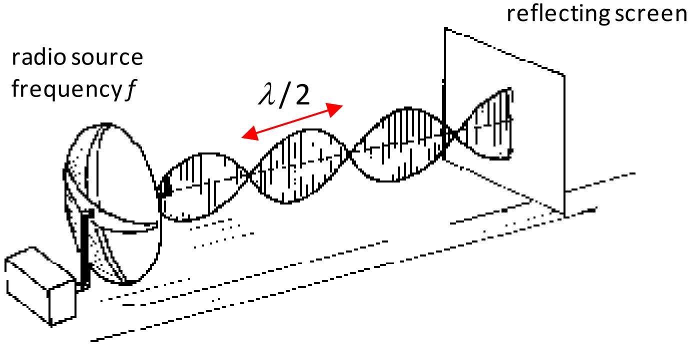
High voltage connected to terminals of evacuated tube.

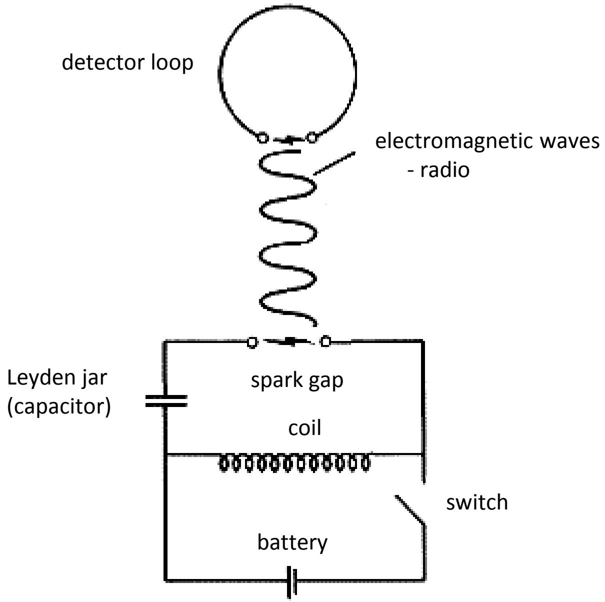
Cathode rays emerge from cathode and strike glass causing it to fluoresce. Metal cross blocks part of beam – sharp shadow indicates cathode rays travel in straight lines.

13/05

Hertz

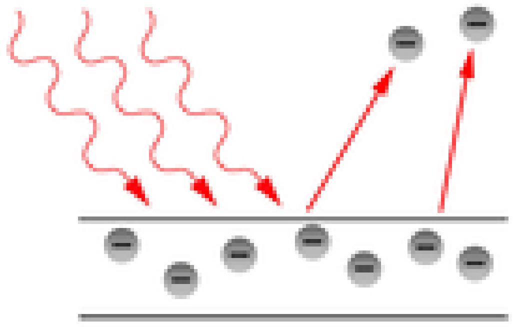
- Investigated the production, transmission and detection of **radio waves**
- His findings → experimental evidence to support Maxwell's mathematical theory on the propagation of electromagnetic waves
- Measured the **speed of light** c: frequency of oscillated, wavelength λ from standing wave pattern $c = f\lambda$





- Discovered the **photoelectric effect**:
  When light above a critical frequency hits a metal surface electrons are releases

- When he placed a glass sheet between the transmitter and receiver an observation he made which is consistent with the photoelectric effect is that the maximum spark length was shorter (weaker) when the glass was in place. The glass sheet will prevent most of the ultraviolet from reaching the receiver but has little impact of the reception of radio waves hence the weaker spark produced by the receiver.

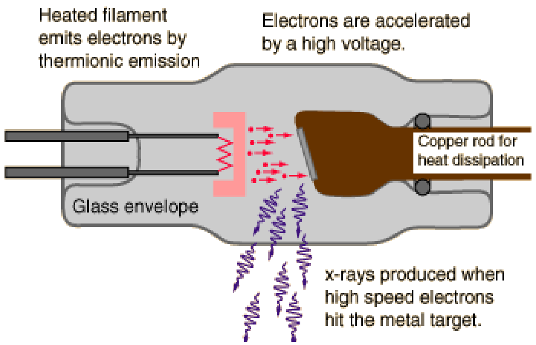


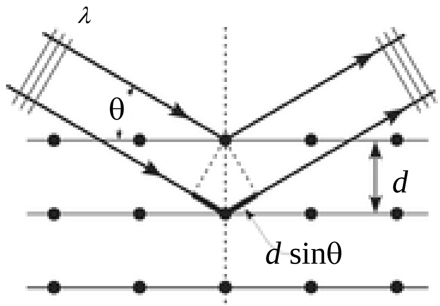
13/11

Bragg

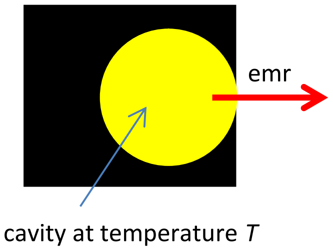
- Used X-ray diffraction to investigate the structure of crystals
- Used **X-rays** because short wavelengths – this distance similar to the spacing of parallel planes in crystals (~ 10^{-10} m)
- Constructive interference occurs from the interference of the waves (X-rays) reflected from the two adjacent planes
-

$n\lambda = 2d\sin\theta$ Bragg Equation $n = 1, 2, 3$

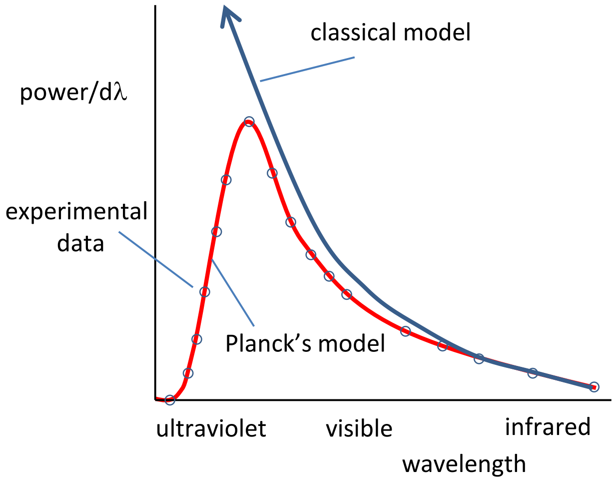


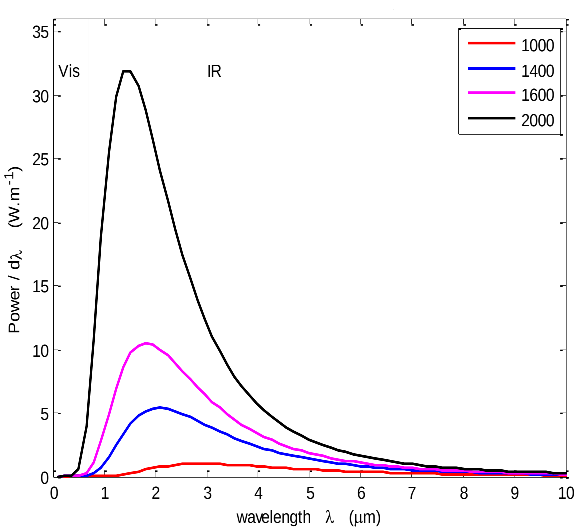


BLACKBODY



In 1900 Planck proposed a mathematical model that predicted an intensity / wavelength relationship for the emission of electromagnetic radiation emitted from a blackbody which was consistent with experimental data. His theory was based upon the hypothesis that light is quantized, with the energy of light quanta depending upon the frequency $E = h\,f$





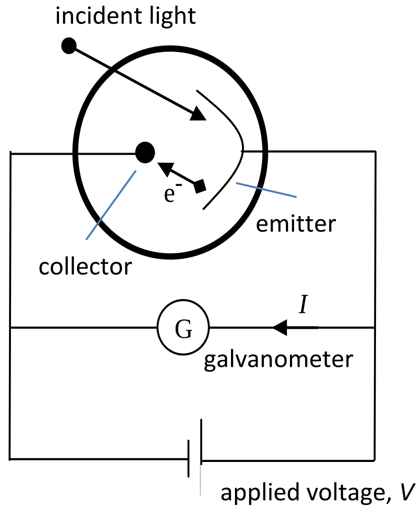
PHOTOELECTRIC EFFECT

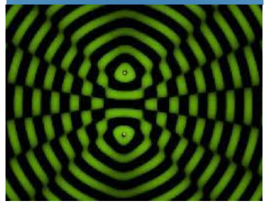
- Discovered by Hertz in 1887 as he confirmed Maxwell's electromagnetic wave theory of light.
- In the **photoelectric effect**, incident electromagnetic radiation (light) shining upon a material transfers energy to electrons so that they can escape from the surface of the material.
- Experimental findings could not be explained by classical physics concepts.
- Einstein 1905 – explanation: necessary to model the incident electromagnetic wave as a stream of particles called photons.
- Einstein took Planck's idea about quantization of energy for an oscillator a step further and suggested that the electromagnetic radiation field is itself quantized and that the energy of a beam of light spreading out from a source is not continuously distributed over an increasing space but consists of a finite number of energy quanta which are localized at points in space which move without dividing, and which can only be produced and absorbed as complete units.
- These quantized energy units of light are called **photons**. Each individual photon has an energy quantum

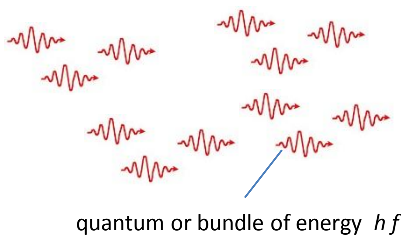
(1) $$E = h\,f \qquad\qquad c = f\,\lambda$$

Energy of photon, E [joule J]
Frequency of electromagnetic radiation, f [hertz Hz $\equiv$ s^{-1}]
Planck's constant, h = 6.6261x10^{-34} J.s

- Einstein's proposal meant that as well as light behaving as a **wave** as shown by its interference effects, light must also have a **particle-like** aspect.







PHOTOELECTRIC EFFECT

Each photon delivers its entire energy hf to a single electron in the material. For an electron to be ejected from the material, the photon's energy must be greater than the energy binding the electron to the material. If the photons energies are less than the binding energies, zero electrons can be emitted from the material, irrespective of how intense the incident light beam. Hence, using the principle of conservation of energy

Energy before (photon) E
= Energy after (ejection of electron from material W + K.E. of ejected electron E_K)

(2) $$E = hf = W + E_K$$

When the energy required to remove an electron from the material is a minimum W_{min}, (W_{min} is the **work function** of the material), the kinetic energy of the ejected electron will be a maximum E_{Kmax}, hence,

(3a) $$hf = W_{\min} + E_{K\max}$$

(3b) $$hf = W_{\min} + \tfrac{1}{2} m_e v_{\max}{}^2$$

The applied potential can be used to retard the electrons from reaching the collector. The retarding voltage, when the photocurrent I becomes zero, is called the **stopping voltage** and its value can be used to measure the maximum kinetic energy of the photoelectrons

(4) $$eV_S = \tfrac{1}{2} m_e v_{\max}{}^2$$

Einstein's quantum interpretation can explain all the details of photoelectric effect experiments.

Measurements of E_{Kmax} and f can be used to measure Planck's constant h by plotting E_{Kmax} vs f. This gives a straight line with intercept W_{min} and slope h since $E_{Kmax} = hf - W_{min}$

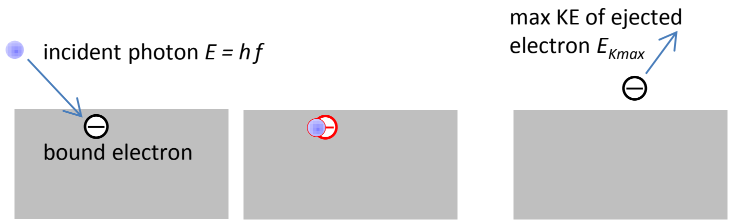
Electrons emitted **only** when incident frequency f greater or equal to **critical frequency** f_C

photoelectrons when $f \geq f_C$ $f_C = W_{min} / h$

If $f \geq f_C$ doubling incident light intensity

→ doubles the photocurrent but does not increase the kinetic energy of the emitted electrons

PHOTOELECTRIC EFFECT

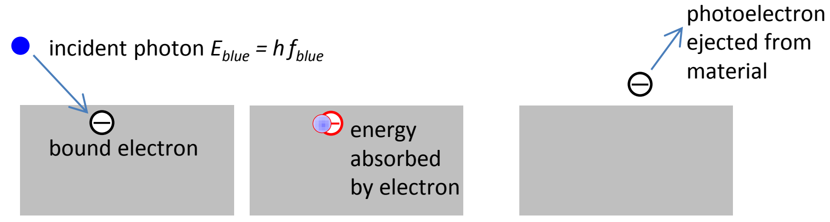


all photon energy acquired by electron: min energy required to remove electron from material W_{min} (work function)

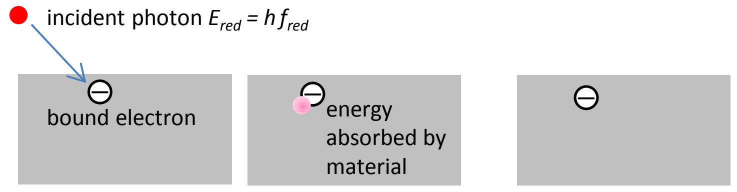
Conservation of energy:

$$hf = W_{\min} + \tfrac{1}{2} m_e v_{\max}{}^2$$

Electron ejected from surface without delay ("kicked-out")

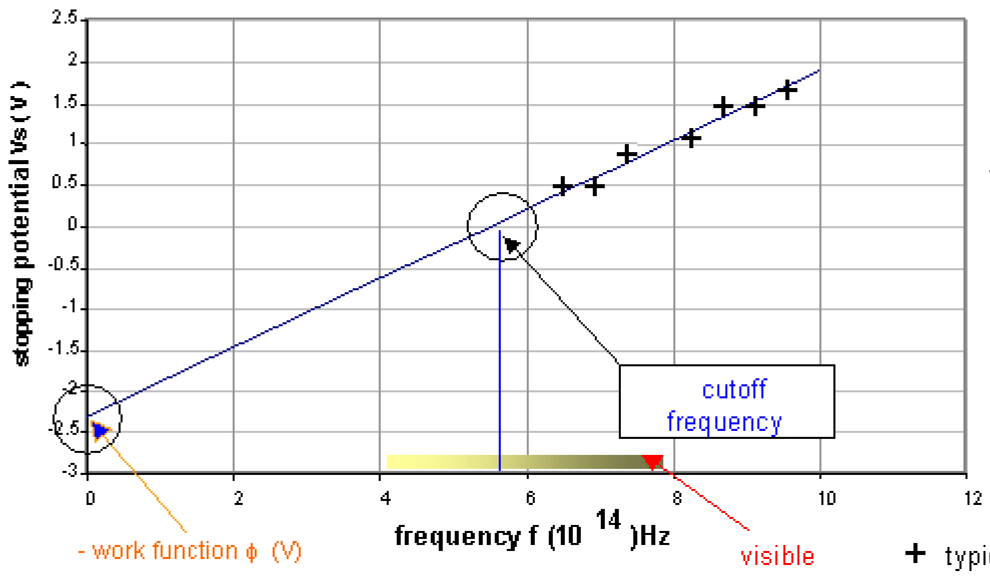


$f_{blue} > f_{red}$ $\quad hf_{blue} > W_{min}$ $\quad hf_{red} < W_{min}$



insufficient energy acquired to eject electron

Photoelectric Effect - sodium target



$V_s = (h / e) f - \Phi / e$

$\Phi = 2.3$ eV

$f_c = 5.5 \times 10^{14}$ Hz

V_s, f variables

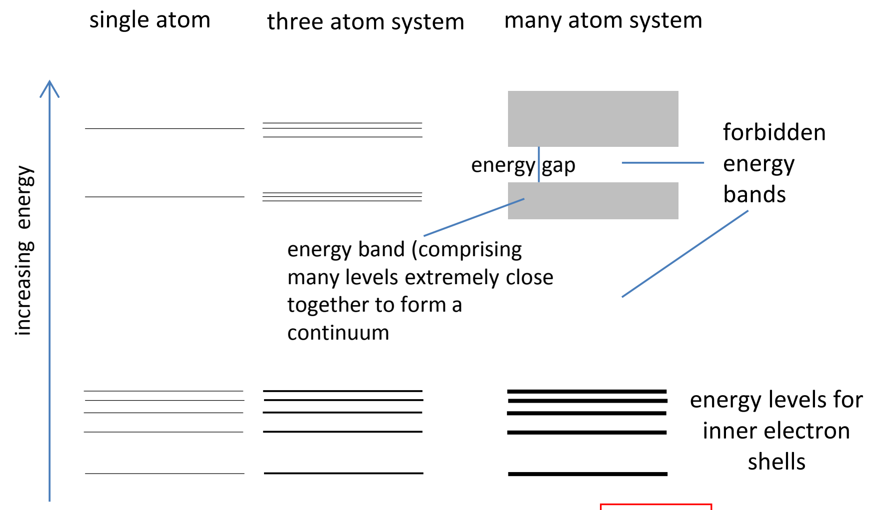
e, h, f constants

+ typical measurements

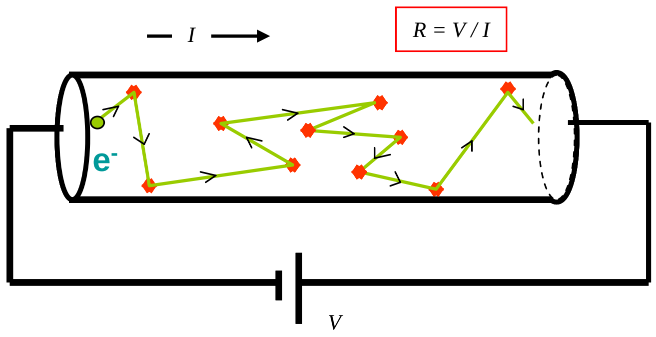
ELECTRICAL CONDUCTION IN SOLIDS – ENERGY BAND MODEL

$$I = \frac{\Delta q}{\Delta t} \qquad I = nqAv_{drift} \qquad I = \frac{V}{R} \qquad R = \rho\frac{L}{A} = \frac{1}{\sigma}\frac{L}{A}$$

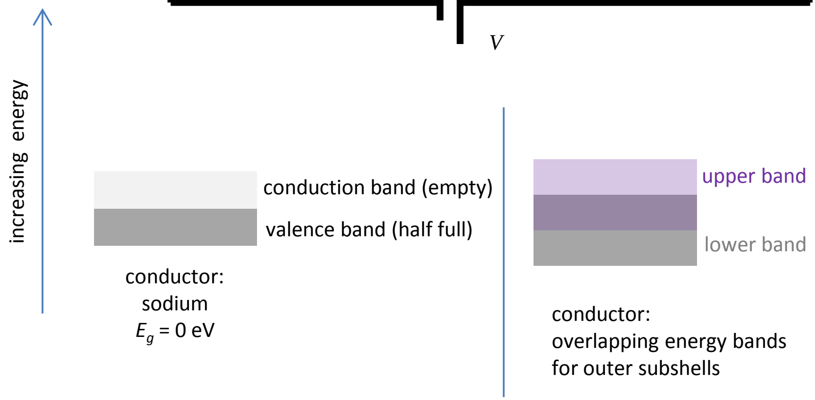
Schematic diagram: energy bands replace energy levels for outer electrons in an assembly of atoms close together.



Conduction in a metal is due to the movement of free electrons through the crystal lattice. The conduction electrons are in the partially filled outer energy band. Resistance of a metal is due to collisions between the lattice atoms and the moving electrons: electrons are scattered by (1) Imperfection (impurities & defects) in crystal lattice - resistance increases with the great the number of imperfections in the lattice structure and the greater number of impurity atoms. Lattice ion vibrations - resistance increases with increasing temperature because of greater lattice vibrations.

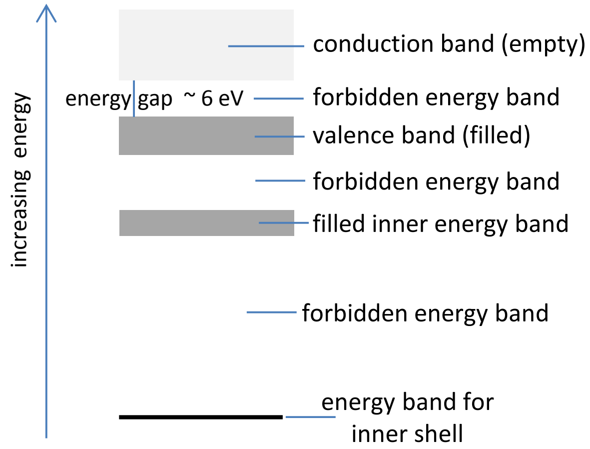


Conductors - currents can flow easily (low resistance) - metals are good conductors of electric current due to the metallic bonding where the number density n is large because about one electron per atom is not tightly bound to any one atom.

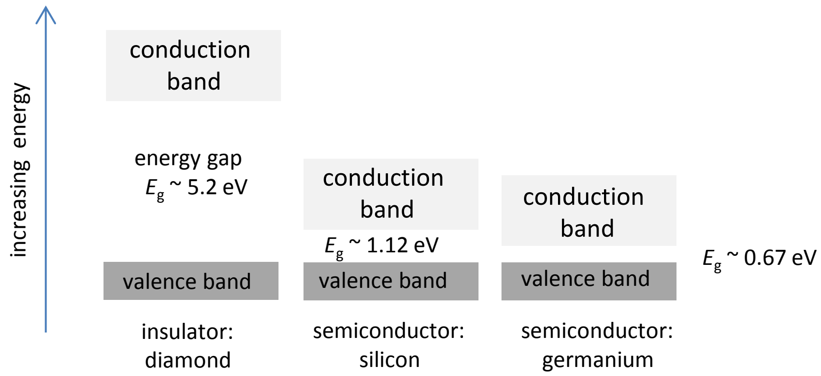


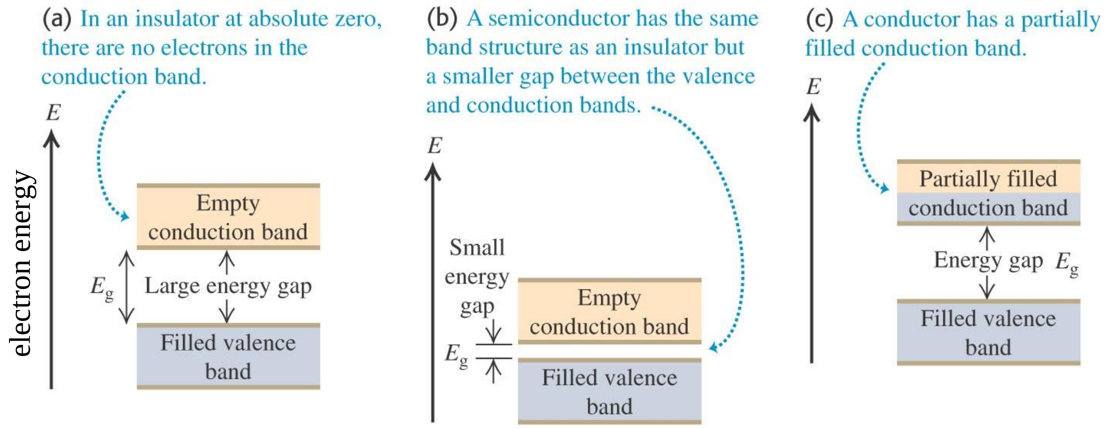
Insulators - through which currents have great difficulty in flowing (high resistance) - the number density is low since most electrons are shared between atoms in covalent bonds.

Energy bands in diamond, an insulator



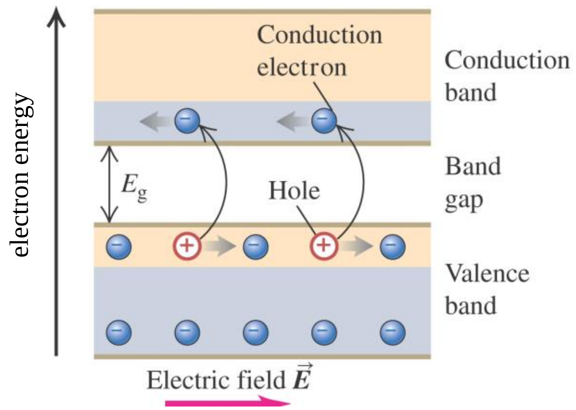
Semiconductors – eg germanium silicon - ability to conductor a current lies between that of conductors and insulators – charge carriers are electrons and **holes** ("missing electron" that acts like a positive charge with the mass of an electron). doped semiconductors – improved conductivity (less resistance): p-type charge carriers – holes in valency band n-type charge carriers – electrons in conduction band.





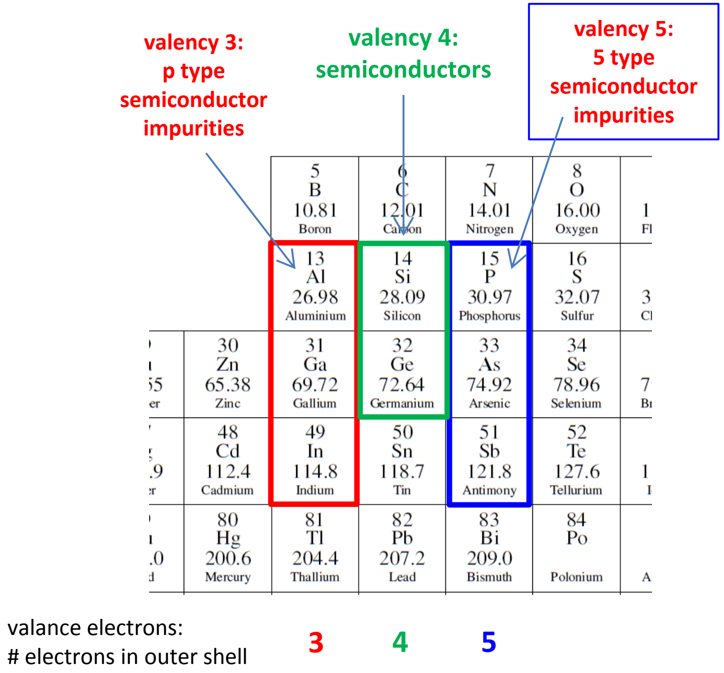
insulator semiconductor conductor

Semiconductor energy band structure showing the movement of the positive holes and negative electrons as the charge carriers for an electric current.

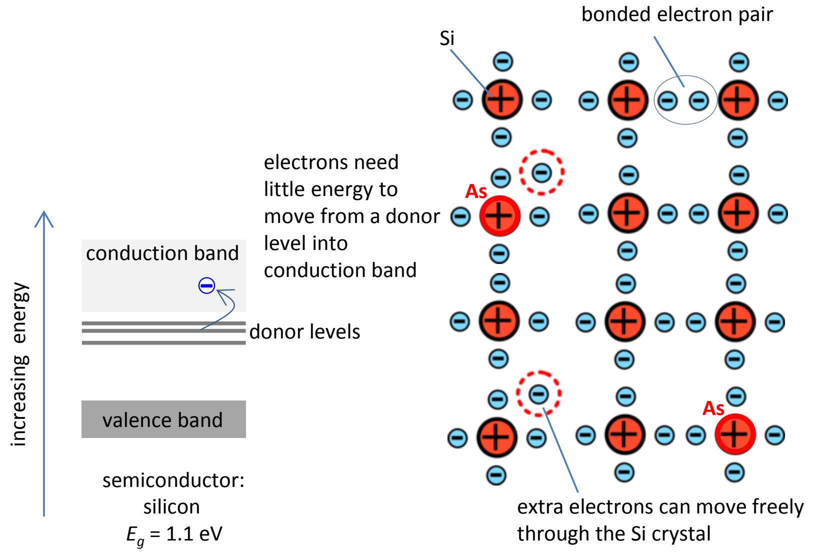


SEMICONDUCTORS

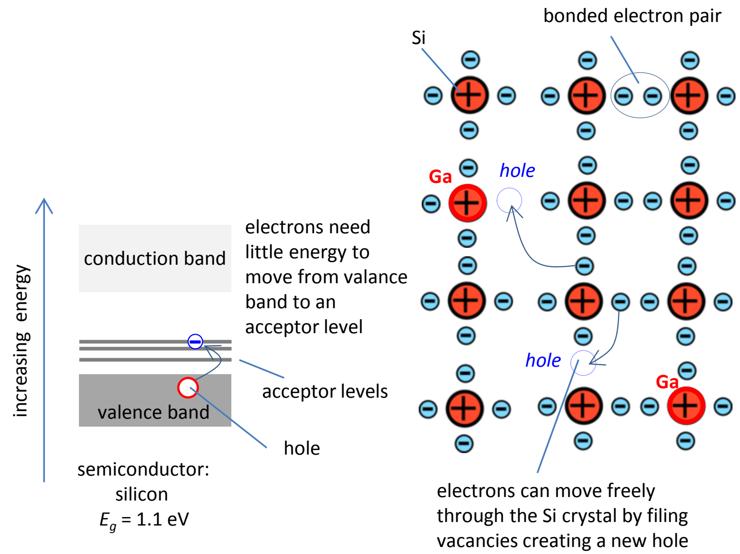
- Early semiconductors used germanium instead of silicon because at the time is was far easier to obtain a pure sample of germanium than silicon
- Silicon and germanium atoms have a valency of 4 (4 outmost electrons)
- n-type semiconductors are doped with atoms of valence 5 (phosphorus) to produce extra free in the conduction band which increases their conductivity
- p-type semiconductors are doped with atoms of valence 3 (arsenic) to give holes in the valance band which increases their conductivity



n-type semiconductor (**+5** valency impurity atoms).. Donor levels due to presence of arsenic atoms in silicon crystal. Conduction is by means of excess electrons.



p-type semiconductor (**+3** valency impurity atoms). Acceptor levels due to presence gallium atoms in silicon crystal. Conduction by means of holes (+) in the valance band.



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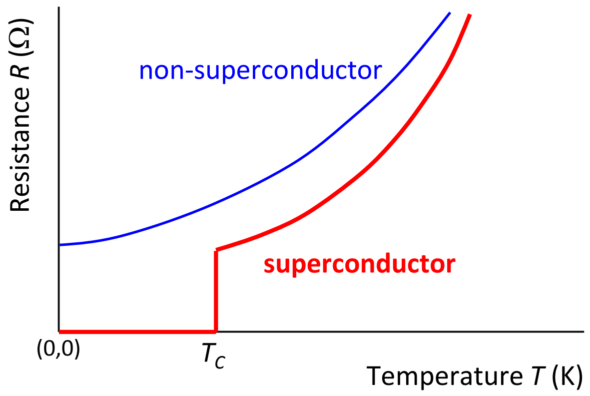
SUPERCONDUCTIVITY

Some materials become superconducting at very low temperatures because electrons pair up (**Cooper pairs**) so that they pass through the crystal lattice without losing energy in collisions with the lattice.



Critical Temperature T_C

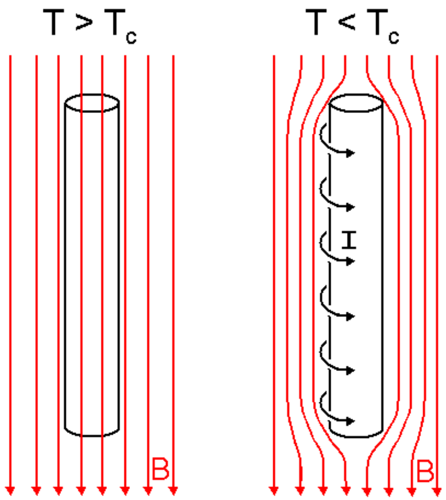
SUPERCONDUCTIVITY

Meissner Effect

A magnet will float on a superconductor as magnetic field lines can't penetrate a superconductor

When a superconductor is cooled below its transition temperature T_C in the presence of an external magnetic field, it expels the external magnetic field from its interior by eddy currents generated at its surface.

If a small magnet is brought near a superconductor, it will be repelled because induced super-currents around the surface will produce mirror images of each pole, that is, it can be levitated by this repulsive force.



- The superconductor in the external magnetic field due to magnet above it forms a small electric current on the surface of the superconductor.
- This surface current forms a magnetic field that cancels the external magnetic so that the net magnetic field within the superconductor is zero.
- The magnetic field lines are forced to bunch up near the magnet since the magnetic field lines can't pass through the superconductor.
- This creates a "cushion" of magnetic field lines which are all squeezed together, thereby pushing the magnet away from the superconductor, making it float.