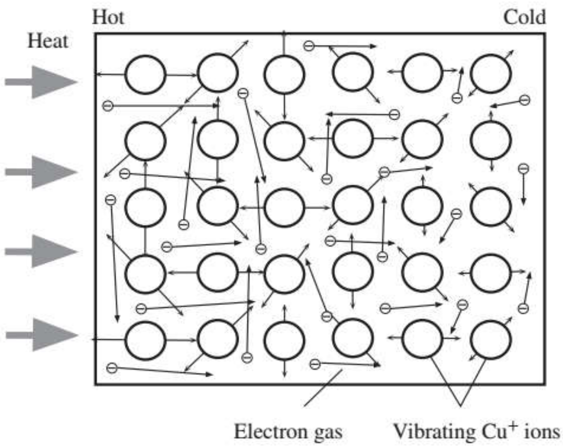
THERMAL CONDUCTION

1

Thermal Conduction

- The transport of heat in a metal is accomplished by the electron gas (conduction electrons), whereas in nonmetals, the conduction is due to lattice vibrations.

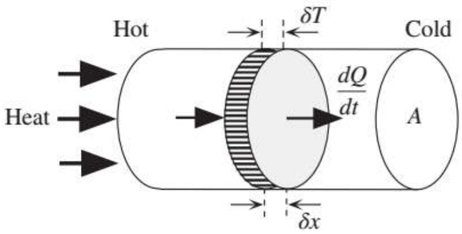


2

Thermal Conductivity

- The thermal conductivity measures the ease with which heat, that is, thermal energy, can be transported through the medium.

$$\frac{dQ}{dt} = -A\kappa \frac{\delta T}{\delta x}$$



- κ is a material-dependent constant of proportionality that we call the thermal conductivity.
- Negative sign → heat flow direction is that of decreasing temperature.

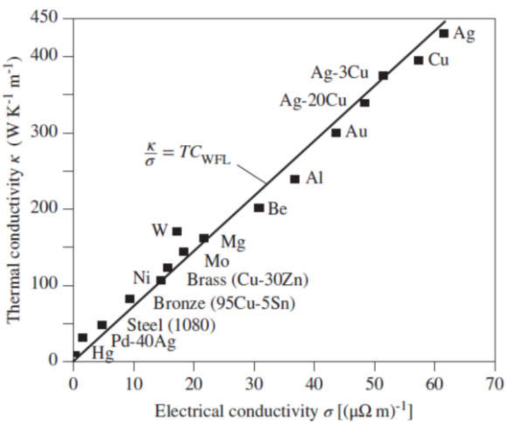
κ Versus σ

$$\frac{dQ}{dt} = -A\kappa \frac{\delta T}{\delta x}$$

$$I = -A\sigma \frac{\delta V}{\delta x}$$

- In metals, electrons participate in the processes of charge and heat transport → σ, κ.
- σ and κ are related by the Wiedemann–Franz–Lorenz law, which is

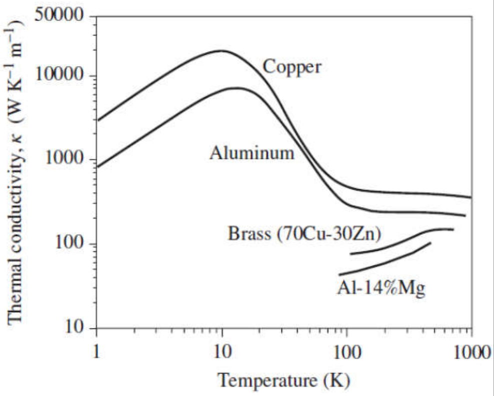
$$\frac{\kappa}{\sigma T} = C_{\mathrm{WFL}}$$



$C_{\mathrm{WFL}} = \pi^2 k^2/3e^2 = 2.44 \times 10^{-8}$ W Ω K^{-2} is a constant called the **Lorenz number** (or the Wiedemann–Franz–Lorenz coefficient).

Temperature Dependence of κ

- **$T \gtrsim 100$ K:** κ is constant, because heat conduction depends essentially on the rate at which the electron transfers energy from one atomic vibration to another as it collides with them.
- This rate of energy transfer depends on the mean speed of the electron u, which increases only fractionally with the temperature.



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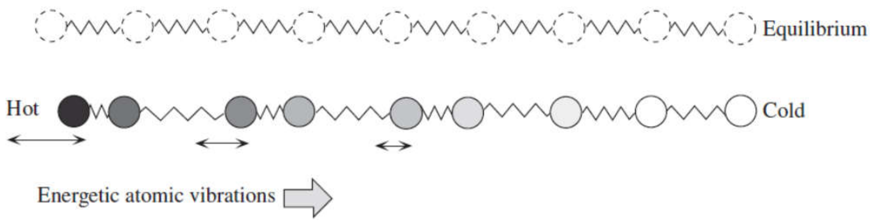
Heat Conduction in Non-metals

- Nonmetals do not have free conduction electrons → the energy transfer involves atomic vibrations of the crystal.
- The efficiency of heat transfer depends not only on the nature of interatomic bonding, but also on how the vibrational waves propagate and are scattered.
- The stronger the bonding, the greater will be the thermal conductivity.
- Diamond has an exceptionally strong covalent bond → $\kappa \approx 1000$ W m^{-1} K^{-1}.
- Polymers have weak secondary bonding → $\kappa < 1$ W m^{-1} K^{-1}.



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Thermal Resistance

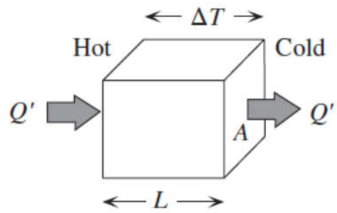
- The rate of heat flow:

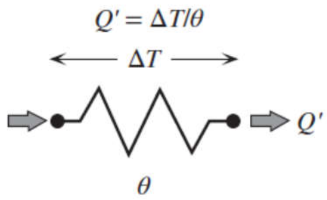
$$Q' = A\kappa\frac{\Delta T}{L} = \frac{\Delta T}{\frac{L}{\kappa A}}$$

- Ohm's law:

$$I = \frac{\Delta V}{R} = \frac{\Delta V}{\frac{L}{\sigma A}}$$

- In analogy with electrical circuits: $Q' = \dfrac{\Delta T}{\theta}$
- Thermal resistance: $\theta = \dfrac{L}{\kappa A}$





INTRODUCTION TO QUANTUM MECHANICS

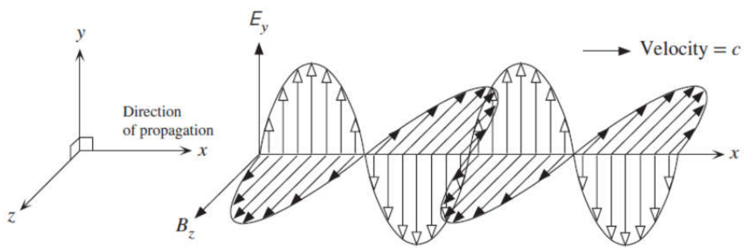
Wave-Particle Duality

- **Light:** Interference and diffraction phenomena displayed by light can only be explained by treating light as an electromagnetic wave. But light can also exhibit particle-like properties in which it behaves as if it were a stream of discrete entities (**Photons**), each carrying a linear momentum and each interacting discretely with electrons in matter (just like a particle colliding with another particle).
- **Electron:** Classically, electrons are considered to be a particle, and hence, they obey Newton's second law ($F = ma$). However, they can also exhibit wave-like properties quite contrary to our intuition. An electron beam can give rise to diffraction patterns and interference fringes, just like a light wave.

Light as a Wave

- A ray of light is considered to be an electromagnetic (EM) wave with a given frequency.
- The electric and magnetic fields (E_y and B_z) of this wave are perpendicular to each other and to the direction of propagation x.

$$E_y(x,t) = E_0 \sin(kx - \omega t)$$



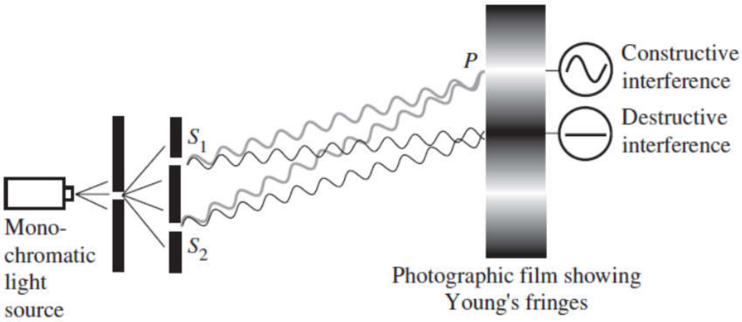
Young's Double-Slit Experiment

- For constructive interference at point *P*, the path difference between the two rays is an integer multiple of the wavelength λ

$$S_1P - S_2P = n\lambda$$

- For destructive interference, the two rays have a path difference of $\lambda/2$

$$S_1P - S_2P = \left(n + \frac{1}{2}\right)\lambda$$



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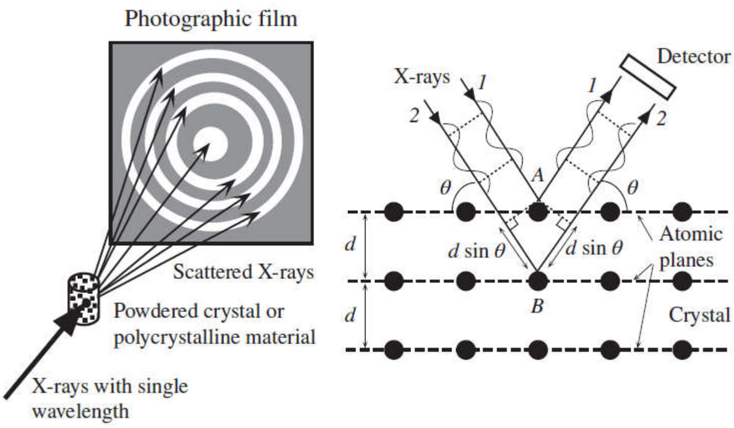
X-Ray Diffraction

- **Bragg's Law:** The condition for existence of a diffracted beam:

$$2d\ \sin\theta = n\lambda, \qquad n = 1, 2, 3, \ldots$$



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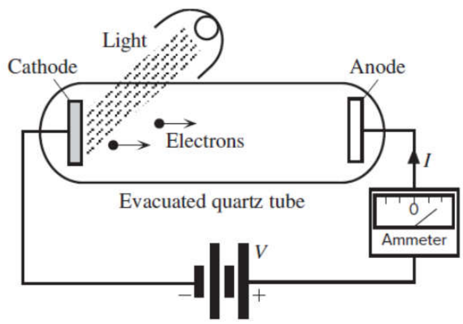
Photoelectric Effect

- When the cathode is illuminated with light, if the frequency f of the light is greater than a certain critical value f_0, the ammeter registers a current I.
- Applying a positive voltage to the anode helps to collect more of the electrons and thus increases the current, until it saturates because all the photoemitted electrons have been collected.



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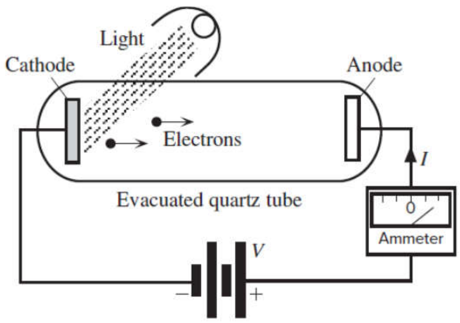
Photoelectric Current versus Voltage

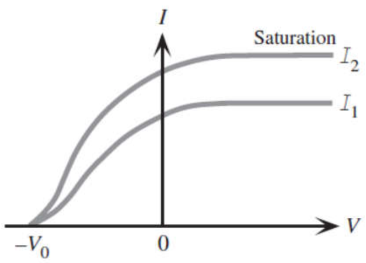
When $V = -V_0 \rightarrow$ just "extinguishes" $I \rightarrow$ potential energy "gained" by the electron is just the kinetic energy lost by the electron.

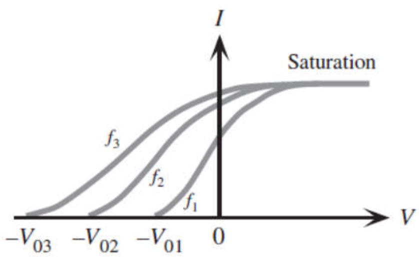
$$eV_0 = \frac{1}{2}m_e V^2 = \text{KE}_m$$

v : Velocity

KE_m : Kinetic energy of the electron just after photoemission.







Kinetic Energy versus Frequency

$KE_m = hf - hf_0$

- h : slope of the straight line and is independent of the type of metal; Planck's constant → 6.6×10^{-34} J s.
- f_0 : depends on the electrode material for the photocathode