40.4 Photons and Electromagnetic waves

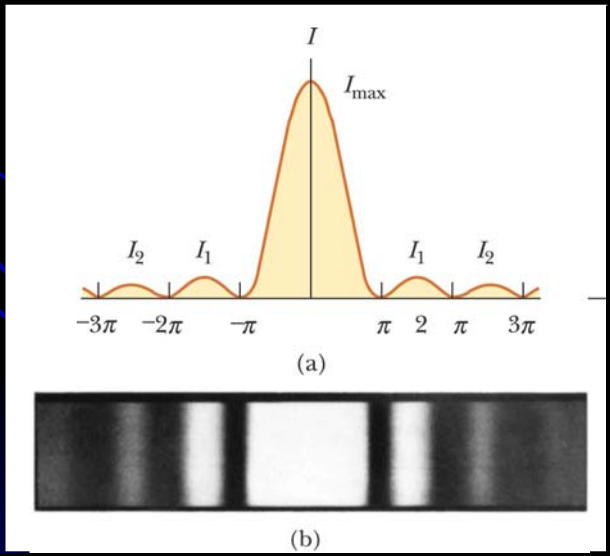
- Wave – Particle Duality :

  → Light has a dual nature: It exhibits both wave and particle characteristics.

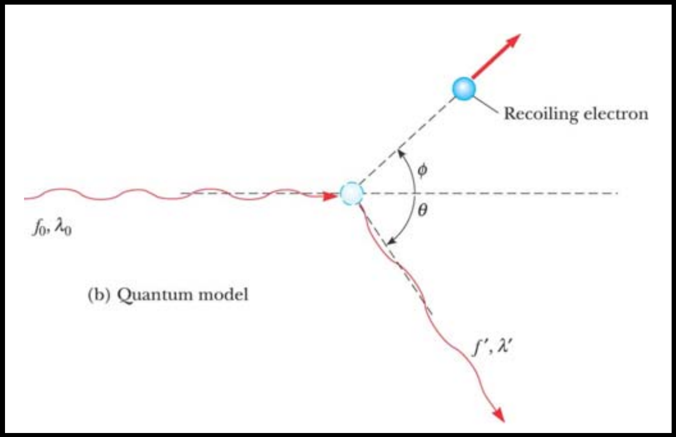
Einstein's light quantum : $\boxed{E = hf}$

- Principle of complementarity (Bohr) :

  → Use either the wave or the photon theory, not both simultaneously.



Single-slit diffraction pattern



Compton effect

40.5 The wave properties of particles

- de Broglie's matter wave (*inspired by the dual nature of light*) :

  → All forms of matter have dual wave – particle nature, and the wavelength of a particle is related to its momentum in the same way as for a photon.

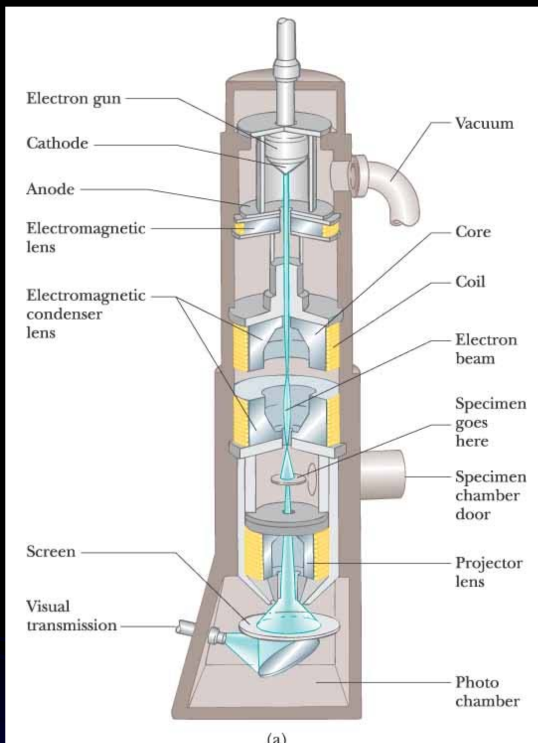
  → $\boxed{\lambda = h / p = h / mv}$ (de Broglie wavelength of a particle)

- Davisson – Germer experiment :

  → Experimental verification of ***matter waves***.
  (Diffraction of electrons)

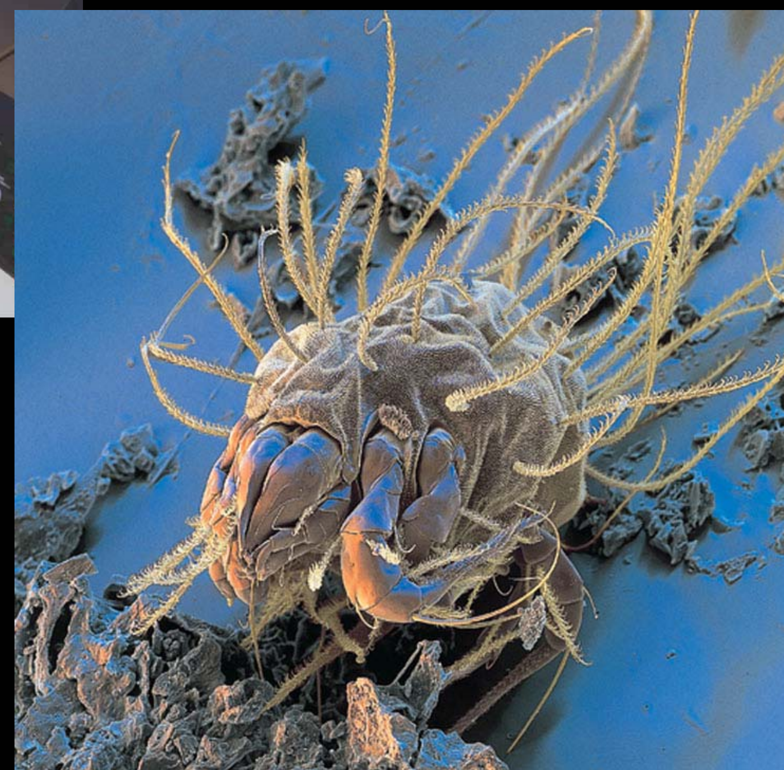
Application :

Wave nature of electron → The electron microscope



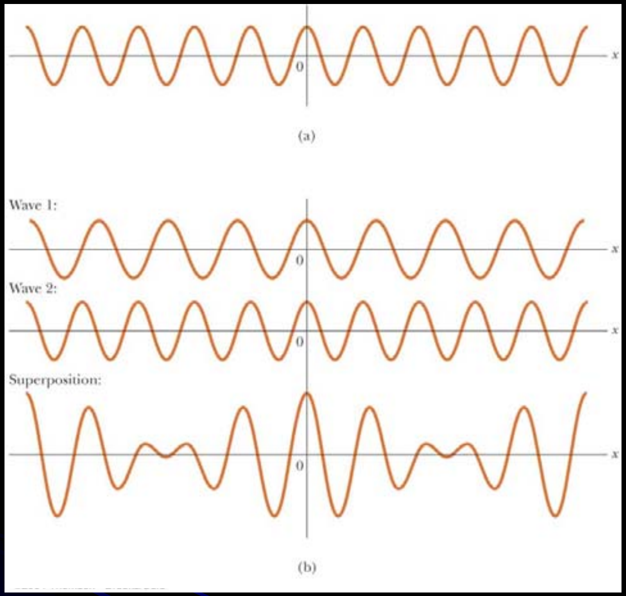
{ Resolution of ~1 nm
Magnification of ~ 10^6

An electron microscope photograph shows significant detail of a storage mite. The mite is so small, with a maximum length of 0.75 mm, that ordinary microscopes do not reveal minute anatomical details.



40.6 The Quantum Particle

⇒ **In quantum physics a localized particle is represented as a *wave packet* – a wave with a finite extent in space.**



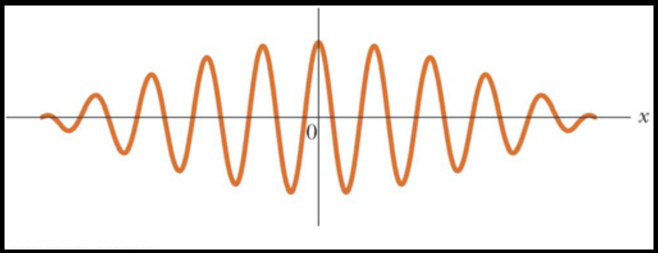
(a) An idealized wave of an exact single frequency is the same throughout space and time.

(b) If two ideal waves with slightly different frequencies are combined, ***beats*** result. The regions of space at which there is constructive interference are different from those at which there is destructive interference.

$\lambda = h/p = h/mv$ (de Broglie wavelength)

$p = \hbar k = \hbar(2\pi/\lambda)$ with $\hbar = h/2\pi$

If a large number of waves are combined, the result is a ***wave packet***, which represents a particle.



40.8 The Heisenberg Uncertainty Principle

- In quantum mechanics, there is a fundamental limit to the accuracy of certain measurements. (Measurement uncertainty inherent in nature.)

  $\Rightarrow$ Two factors :

  1) Interaction between the thing observed and the observing instrument.
  2) Wave–particle duality.

- Heisenberg's uncertainty in Momentum–Position :

$$\boxed{(\Delta x)(\Delta p) \geq \hbar/2} \qquad \text{with } \hbar = h / 2\pi$$

$\rightarrow$ *Measured values cannot be assigned to the position Δx and the momentum Δp of a particle simultaneously with unlimited precision. The product of a position uncertainty and a momentum uncertainty will be greater than $\hbar/2$; it can never be less.*

- Heisenberg's uncertainty in Energy–Time :

$$\boxed{(\Delta E)(\Delta t) \geq \hbar/2}$$

$\rightarrow$ *The energy of an object is uncertain by an amount ΔE for a time $\Delta t \approx \hbar / \Delta E$.*