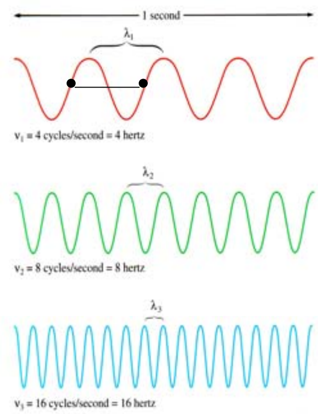
Zumdahl *Chapter 7*

Atomic Structure and Periodicity

1. The nature and properties of waves:



- **Wavelength ≡ distance between two peaks or troughs. (λ)**
- **Frequency ≡ number of cycles that pass through a given point in space per unit time. (ν)**

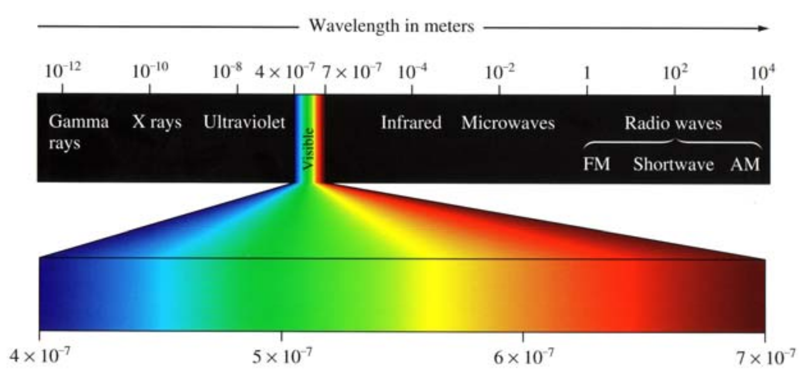
$$\nu = \frac{\text{distance travelled/second}}{\text{distance/cycle}}$$

$$= \frac{\text{speed}}{\text{wavelength}} = \frac{v}{\lambda} \qquad \frac{(m/s)}{m} \equiv s^{-1} \; or \; \text{Hz}$$

- **Light ≡ electromagnetic radiation (how energy "travels" through space)**
- **Radiation ≡ emission and transmission of energy in the form of waves**

[Magnetic and Electric fields]

- **For all electromagnetic radiation, speed $c = 2.998 \times 10^8$ m/s**



- **For an electromagnetic wave:**

$$\nu = \frac{c}{\lambda}$$

WHY? **Interaction between matter and electromagnetic radiation ≡ SPECTROSCOPY ⟶ information about atoms, molecules and structure.**

2. The nature of matter

- **Before 1900**:
  - matter ≡ particles
  - light ≡ electromagnetic radiation (waves)

- **Beginning of the 20th century:** discovery of ***phenomena*** that could not be explained by classical physics:

  Blackbody radiation, photoelectric effect, Compton effect, atomic and molecular spectra, etc.. could be explained only by a modern view: development of ***QUANTUM THEORY***

- **Planck (1900): energy can be gained or lost only in whole numbers of the quantity $h\nu$, where**

  ν ≡ frequency of the electromagnetic radiation absorbed or emitted.

$$\Delta E = n\,h\nu$$

$$n = 1,\ 2,\ 3, ...$$

h **= 6.626 × 10^{-34} J s**
Planck's constant

$h\nu$ ≡ **a discrete package of energy or *quantum* ⇒ energy is quantized.**

- **Einstein (1905): "special theory of relativity"**

  E = mc^2 ⇒ m = E/c^2 … energy has mass!

Einstein (1905): "The photoelectric effect"

When a metal is irradiated with light, electrons are ejected from its surface → generation of a **photocurrent**.

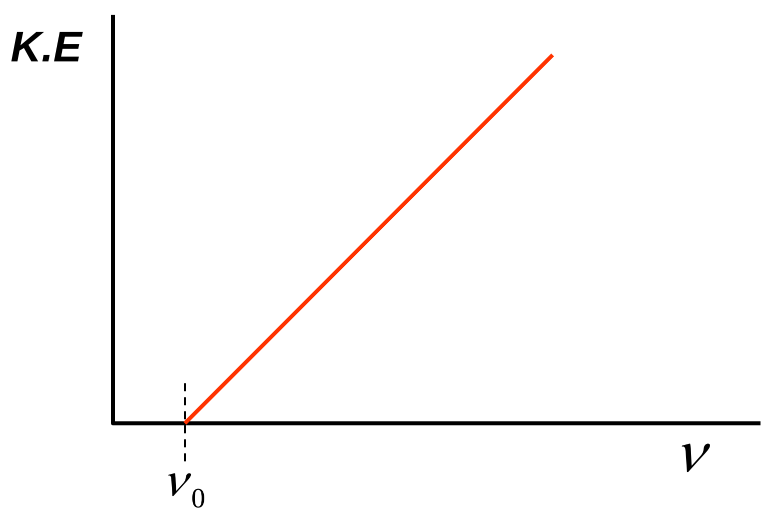
1. No electrons are emitted unless the frequency of the incident light exceeds a minimum frequency (threshold): $\nu > \nu_0$.
2. For light with frequency less than the threshold, no electrons are emitted, regardless of the intensity of the light.
3. If $\nu > \nu_0$, the number of electrons emitted increases with the intensity of the light.
4. If $\nu > \nu_0$, the kinetic energy (K.E) of the emitted electrons increases linearly with the frequency of the light.

$$h\nu = h\nu_0 + K.E$$

E_0 = ***Work function***

$$\equiv E_0 + \frac{1}{2}mv^2$$

Photoelectric effect

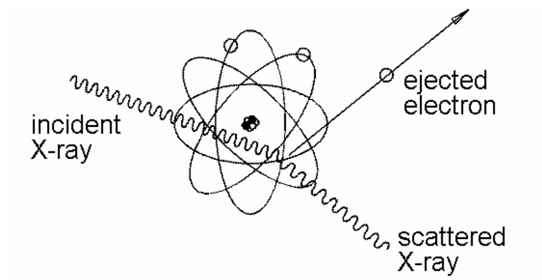


The kinetic energy of the electron increases linearly with ν.
Note that the kinetic energy ***cannot go negative***.

In the photoelectric effect: Einstein assumed the electromagnetic radiation itself to be quantized:

→ existence of **"particles of light"** or **photons**

- ***Does a photon have mass??***
- **Compton (1922): The collision of X-rays with electrons:**



photons exhibit the mass calculated from the equation:

$$m = \frac{h}{\lambda c}$$

Rationalization:

$$\begin{cases} E = mc^2 \\ \quad = h\dfrac{c}{\lambda} \end{cases} \Rightarrow m = \frac{h}{\lambda c}$$

***Dual nature of light*: light manifests itself as particles**

- **Conversely, *does matter possess wave properties??***
- **De Broglie (1923):** *Every particle is associated with a wave of wavelength:*

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

De Broglie's wavelength

Do sample exercises 7.1, 7.2, 7.3

Electron: $\begin{cases} m_e = 9.11 \times 10^{-31} \text{ kg} \\ v_e = 1.0 \times 10^{7} \text{ m/s} \end{cases} \Bigg| \Rightarrow \lambda_e = 7.3 \times 10^{-11} \text{ m}$

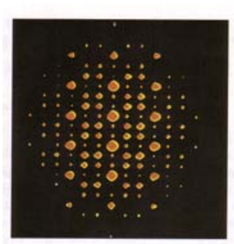
Ball: $\begin{cases} m_b = 0.10 \text{ kg} \\ v_b = 35 \text{ m/s} \end{cases} \Bigg| \Rightarrow \lambda_b = 1.9 \times 10^{-34} \text{ m}$ **!!**

- **DIFFRACTION**

Separation of the light into rays of different wavelengths, as it is scattered from a regular array of points or lines:

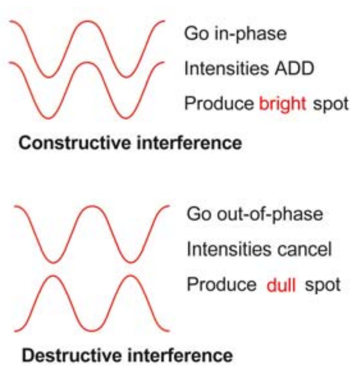
- spectrum of colors obtained as light is reflected from the grooves of a compact disk.
- shades of colors observed as light passes through a prism.

A crystal of NaCl (array of Na^+ Cl^- Na^+ Cl^- **...**) also produces a **DIFFRACTION PATTERN** upon interaction with X-rays.



Diffraction pattern of a Ti-Ni alloy

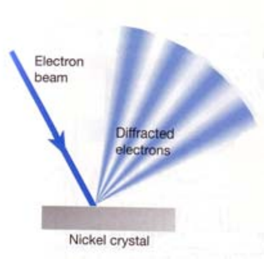
The diffraction pattern can only be explained in terms of interference of waves.



Recall: $\lambda_e \cong 10^{-10}$ m (1 Å) $\Rightarrow$ typically the distance between the ions in an NaCl crystal.

Hence, a crystal should be able to diffract electrons as well !

- Davisson and Germer (1927)



Electrons are diffracted from the Ni crystal, just like X-rays !

De Broglie's hypothesis is thus justified.

Wave and particle nature of matter melt together:

The ***WAVE PARTICLE DUALITY***