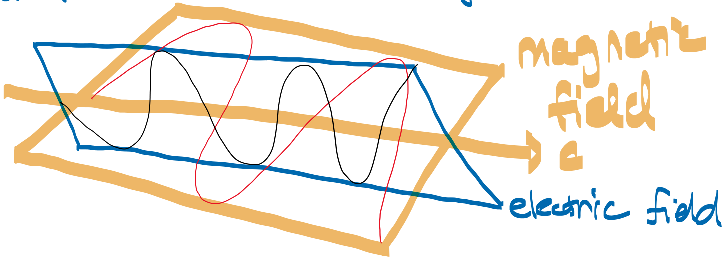
Lecture 1

Monday, September 11, 2023 1:38 PM

Topic 7A : The Origins of Quantum Mechanics (from Atkins)

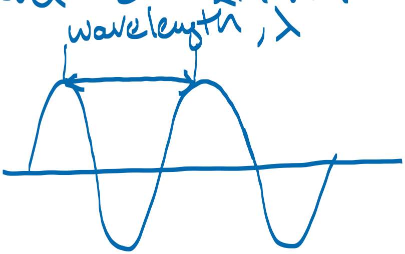
Electromagnetic radiation

- oscillating electric and magnetic disturbances that propagate as waves



- two components ; mutually perpendicular

- in vacuum : constant speed of travel $c = 2.99792458 \times 10^{8}\ \mathrm{m\,s^{-1}}$.



$c = \lambda \nu$

↑

frequency

in spectroscopy, typically use wave-number $\tilde{\nu}$

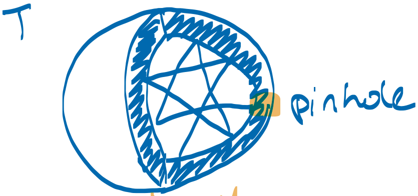
$$\tilde{\nu} = \frac{1}{\lambda} \quad \text{or} \quad \tilde{\nu} = \frac{\nu}{c}$$

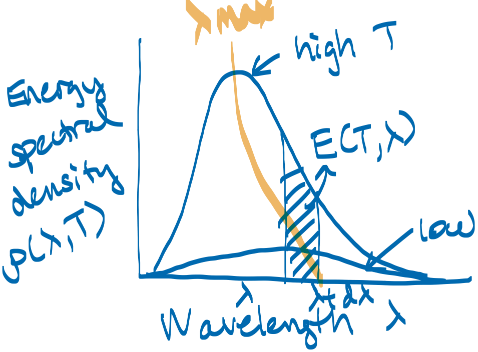
radio	m
	dm
microwave	cm
	mm
~~for~~ infrared	10^{-4}
	10^{-5}
near infrared	μm / 10^{-6}
visible	

ultraviolet	10^{-7}
Vacuum ultraviolet	10^{-8}
X-ray	10^{-9} to 10^{-12}
γ-ray	10^{-13}
cosmic ray	10^{-14}

Energy quantization

- blackbody radiation : emits and absorbs electromagnetic radiation without favouring any wavelengths





Wien's law

$\lambda_{max} T = 2.9 \times 10^{-3}$

m · K

Energy density E(T): total energy inside the container divided by its volume

Energy spectral density ρ(λ,T): defined such that $\rho(\lambda,T)\,d\lambda$ is the energy density at temperature T with wavelengths between λ and $\lambda + d\lambda$.

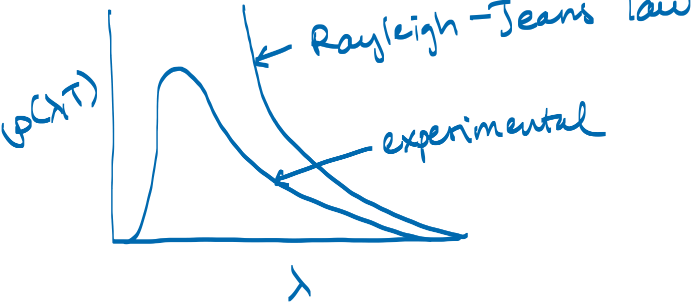
$$\mathcal{E}(T) = \int_0^\infty \rho(\lambda,T)\,d\lambda$$

Stefan-Boltzmann Law

$$\mathcal{E}(T) = \text{constant} \times T^4$$

Rayleigh-Jeans Law

$$\omega(\lambda, T) = \frac{8\pi k_B T}{\lambda^4}$$



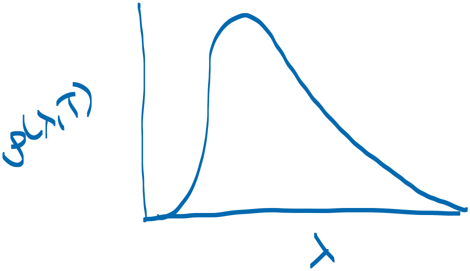
"ultraviolet catastrophe" : consequence of classical physics; arises from the assumption that every oscillator has the same energy ($k_B T$) regardless of its frequency (equipartition principle)

quantization (Max Planck) : the energy of each oscillator is limited to discrete values ; $E = nh\nu$, $n = 0, 1, 2, \ldots$

h : Planck's constant

$$\rho(\lambda,T) = \frac{8\pi hc}{\lambda^5\left(e^{hc/\lambda k_BT}-1\right)}$$

Planck distribution



quantization gives a model that matches experiment

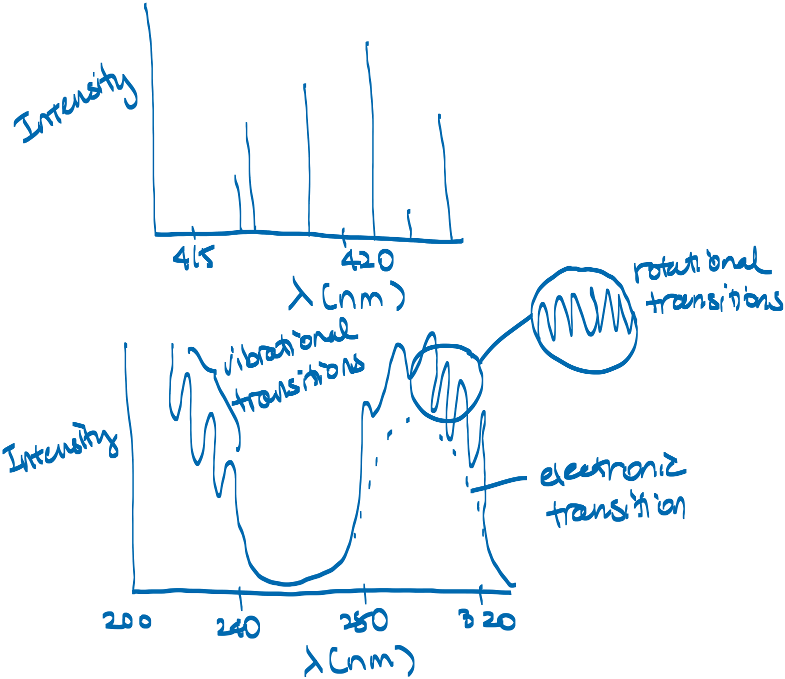
Atomic and molecular spectra

- spectroscopy gives the most direct and compelling evidence for the quantization of energy ; detecting absorbed, emitted, or scattered electromagnetic radiation by a substance

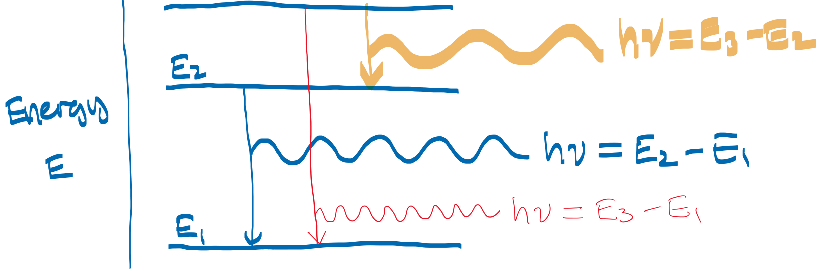
$\Delta E = h\nu$ Bohr frequency condition

Spectroscopic transitions result in e.g.

atomic emission spectra



| E_3

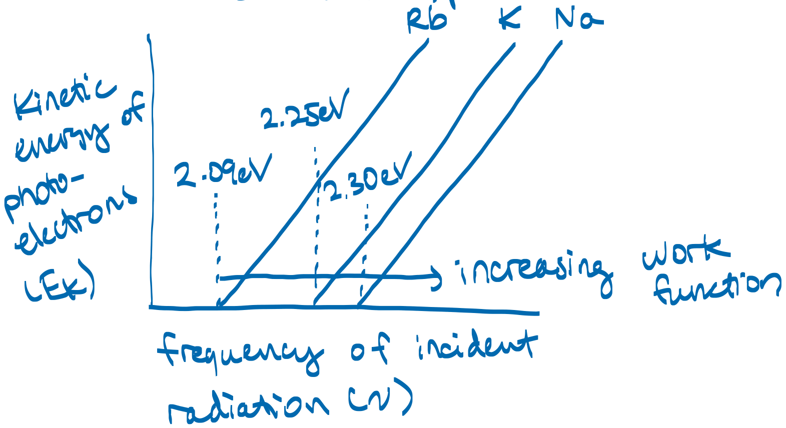


Wave-particle duality

- electromagnetic radiation is treated as wave-like by classical physics
- however, later experiments demonstrate that it also has particle characteristics
- as well, electrons were demonstrated to have wave-like properties

photons : particles of electromagnetic radiation; suggested first, proven later

photoelectric effect : ejection of electrons from metals when exposed to UV radiation

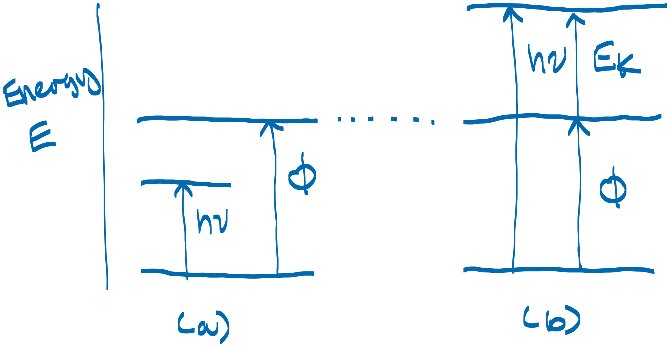


- frequency needs to exceed a threshold
- kinetic energy increases linearly with ν
- not related to intensity

work function (ϕ): minimum energy required to remove an electron from the metal

$$\boxed{h\nu = E_k + \phi \quad \text{or} \quad E_k = \underline{h\nu - \phi}}$$

photoelectric effect



(a) nothing happens

(b) ejection of electron with kinetic energy E_k.

the wave character of particles

- double-slit experiment : electrons moving through two openings one at a time still resulted in an interference pattern

de Broglie relation : $\lambda = \frac{h}{p}$

↑ linear momentum
$p = mv$

- any particle should have wave-like characteristics