late 1800's - several failures of classical (Newtonian) physics discovered.

1905 - 1925 } - development of QM - resolved discrepencies between expt. and cl. theory

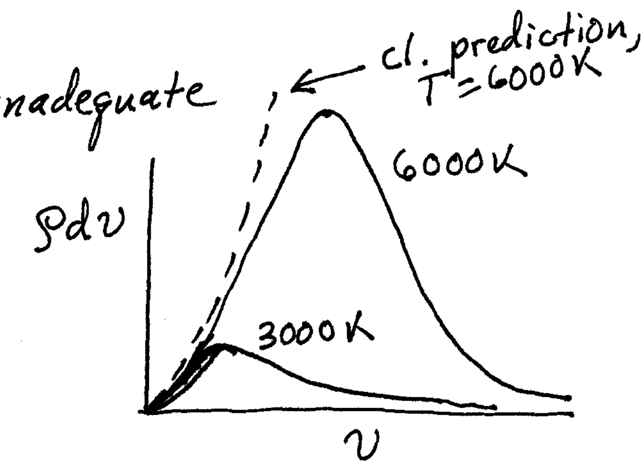
QM - essential for understanding many phenomena in Chemistry, Biology, Physics

- photosynthesis + vision
- magnetic resonance imaging
- radioactivity
- operation of transistors
- lasers (CD + DVD players)
- van der Waals interactions

Examples where cl. physics inadequate

1. blackbody radiation

heated objects → light



cl. theory

$$\rho d\nu = \frac{8\pi\nu^2}{c^3}\bar{E}_{osc}\, d\nu = \frac{8\pi\nu^2}{c^3} kT\, d\nu$$

} ⇒ emits ∞ energy at all T

Planck (1900): $\rho d\nu = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/kT}-1}d\nu$

originally by fitting expt.

Planck later showed this is consistent with the energies of the oscillators (atoms) making up the black body object taking on discrete values

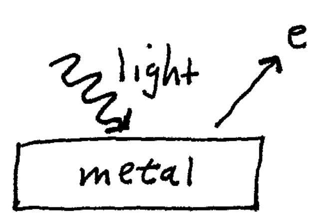
$$E = nh\nu \quad , \quad n = 0, 1, 2, \ldots$$

$$\Rightarrow \bar{E} = \frac{h\nu}{e^{h\nu/kT} - 1} \xrightarrow{T \to 0} 0$$

$$\xrightarrow{T \to \infty} kT \quad \Big\} \text{ classical result}$$

$$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$$

2. photoelectric effect



expected behavior

- light is a wave, so each e^- absorbs small fraction of the energy
- e^- emitted at all ν, if I great enough
- KE > with I

observed

- \# e^- emitted $\propto I$
- critical frequency ν_0. e^- emitted if $\nu > \nu_0$
- KE > with ν
- KE independent of I

Explained by Einstein in 2005.

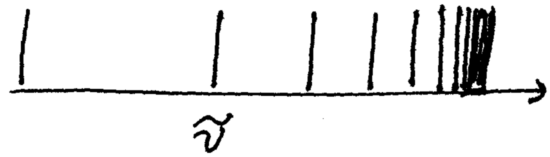
light has energy $h\nu$ and acts particle-like enabling its energy to be focused on one e^-

$$E_{el} = h\nu - \phi \quad , \quad \phi = \text{workfunction of metal}$$

3. heat capacity of solids

4. spectra of atoms + molecules – discrete lines

→ spectrum H atom



$$\tilde{\nu} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n^2} \right)$$

n_1, n integers, $n = n_1+1, n_1+2, n_1+3, \ldots$

$R_H = 109{,}677.581\ cm^{-1}$

} we will return to this.

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photoelectric effect ⇒ light can behave as a particle

diffraction of light ⇒ light can behave as a wave

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de Broglie: (1924) particles have a wavelength: $\lambda = \frac{h}{p}$

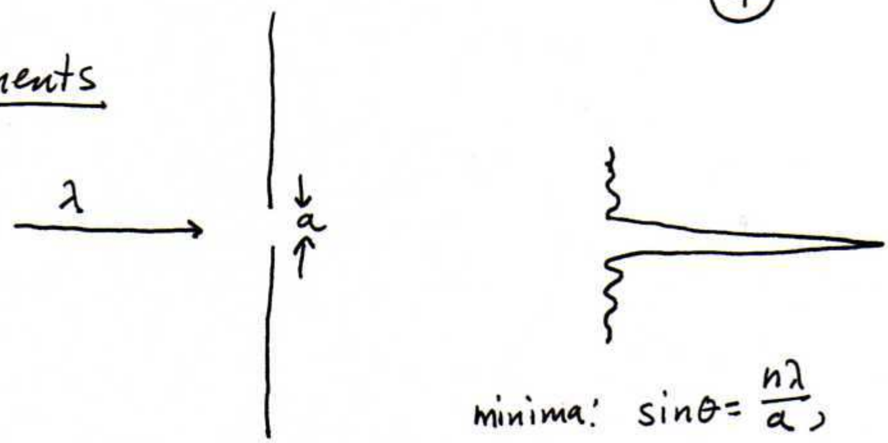
subsequently diffraction of e^-, He, H_2 from crystalline surfaces demonstrated.

e^- with KE = 17 eV has $\lambda = 3\ \text{Å}$, a typical lattice spacing in a xtal ⟶ interference (diffraction)

large objects – baseballs, cars, etc., have de Broglie wavelengths too small to be detected.

Diffraction experiments

light incident on a <u>single</u> slit.



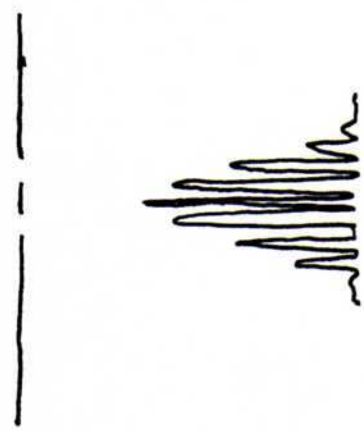
minima: $\sin\theta = \frac{n\lambda}{a}$, $n = \pm 1, \pm 2, \pm 3, \ldots$

well separated peaks when $\lambda \approx a$.

$\lambda >> a$ - can't see diffr.

double-slit expt. with e^-

the e^- goes through both slits !!



in 1997 the expt. was done with He atoms ⇒ Each atom goes through both slits !!

Summary:

- energy + oscillators are quantized
- wave-particle duality
- these ideas paved the way for QM

Note: guitar string freq. is "quantized"

Fourier transforms:
(frequency + time)
(position, momentum)
are conjugate variables

We will come back to these considerations.