Observations that led to quantum wave theory of matter:

1. **Planetary atom**
   
   Classically, an electron orbiting an atom would radiate away all of its energy and crash into the nucleus.

2. **Atomic spectra**
   
   Atoms emit light at discrete wavelengths, e.g., hydrogen visible "Balmer" lines, which fit a simple empirical formula:
   
   \[
   \frac{1}{\lambda} = \frac{1}{91.127 \text{ nm}} \times \left( \frac{1}{z^2} - \frac{1}{n^2} \right)
   \]
   
   \[\lambda = 656.3 \text{ nm (red)}, \quad \lambda = 486.1 \text{ nm (cyan)}, \quad \lambda = 434.1 \text{ nm (blue)}\]
   
   "Balmer Series"

   Then in UV, Lyman observed a series:
   
   \[
   \frac{1}{\lambda} = \frac{1}{91.127 \text{ nm}} \times \left( \frac{1}{z^2} - \frac{1}{n^2} \right)
   \]
   
   \[\lambda = 121.6 \text{ nm (Ly-\alpha)}, \quad \lambda = 102.6 \text{ nm (Ly-\beta)}, \quad \lambda = 97.2 \text{ nm (Ly-\gamma)}\]
   
   "Lyman Series"

   Then in IR, Paschen observed a series:
   
   \[
   \frac{1}{\lambda} = \frac{1}{91.127 \text{ nm}} \times \left( \frac{1}{z^2} - \frac{1}{n^2} \right)
   \]
   
   \[\lambda = 1870 \text{ nm (Pa-\alpha)}, \quad \lambda = 1280 \text{ nm (Pa-\beta)}, \quad \lambda = 1090 \text{ nm (Pa-\delta)}\]
   
   "Paschen Series"
Explanation (Bohr, de Broglie):

Electron has wave nature in orbit around proton, and only multiples of a wavelength are allowed \(\Rightarrow\) quantum orbit:

\[2\pi r = n\lambda, \quad n = 1, 2, 3, \ldots\]

Two wavelengths in this example:

\[2\pi r = 2\lambda, \quad "\text{n}=2\ " \text{excited state} \]

Where \(\lambda = \frac{h}{p}\) is "de Broglie wavelength.

Ground state of H: \(2\pi r = \lambda = \frac{h}{p} = \frac{h}{m_0 v} \)

Also centrifugal force balance:

\[\frac{m_0 v^2}{r} = \frac{ke^2}{v^2} \]

\[\Rightarrow r = \frac{ke^2}{m_0 v^2} \]

\[2\pi \frac{ke^2}{m_0 v^2} = \lambda = \frac{h}{m_0 v} \]

\[\Rightarrow v = \frac{ke^2}{m_0 v} \]

\[\frac{v}{c} = \frac{ke^2}{\hbar c} = \alpha \] "Fine Structure Constant"

\[n = \frac{\lambda}{2\pi r} = \frac{h}{2\pi r} = \frac{h}{m_0 v} = \frac{\hbar c}{m_0 c^2} \]

\[\hbar c = 197.3 \text{ eV mm} \]

\[\frac{v}{c} = \frac{1}{137} \]

\[mc^2 = 54,900 \text{ eV} \]

\[n = 3 \]

\[\frac{1}{n} = 0.0529 \text{ nm} \]

\[n = 2 \]

\[n = 1 \]

Emission lines are photons emitted by transition from one state to another.
Applications of electron waves

- electron crystallography (diffraction)
- electron microscopy

Later, Schrödinger came up with a wave equation for matter waves

⇒ wave interpreted as probability amplitude or "matter field"

Can solve complex problems to get detailed solutions for big atoms

ANIM: "What does an atom look like?"

Important transition from classical determinism (planet orbits, etc.) to quantum uncertainty (probability waves)