# Phyx 320
# Modern Physics

March 1, 2021

Reading: 38.5 – 38.7

Homework #5 and Reading Reflection Tuesday 11:59 pm

# Matter Waves

Both light and matter are waves

De Broglie wavelength:

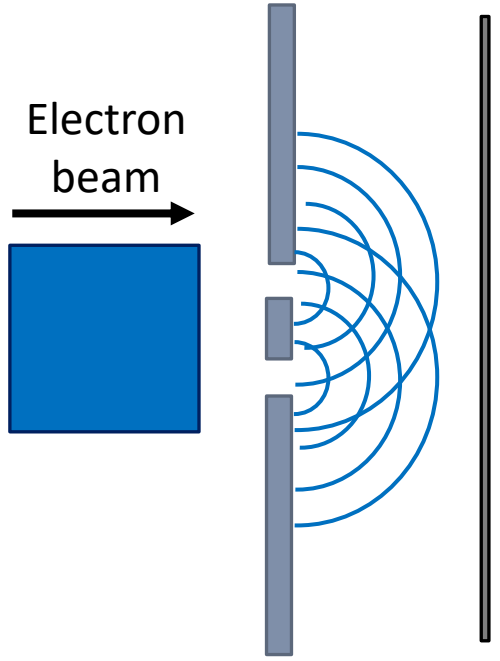
$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

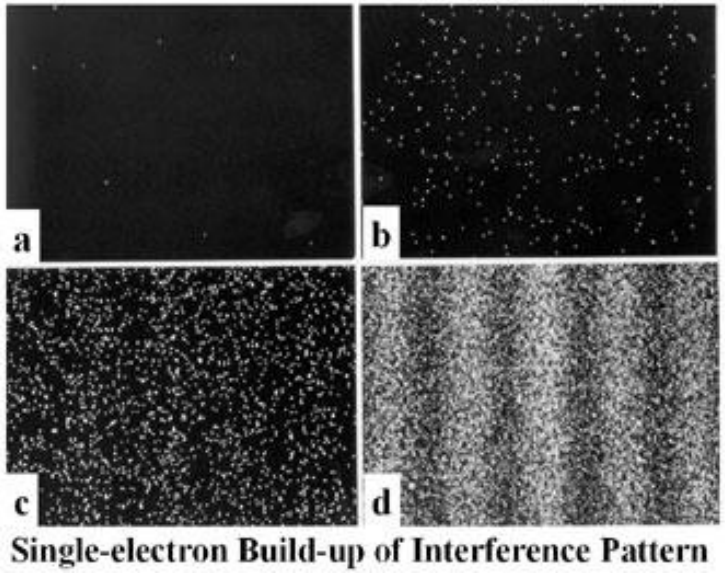
Wave nature of matter causes particle in box to have quantized energy

$$E = \frac{n^2 h^2}{8mL^2}$$

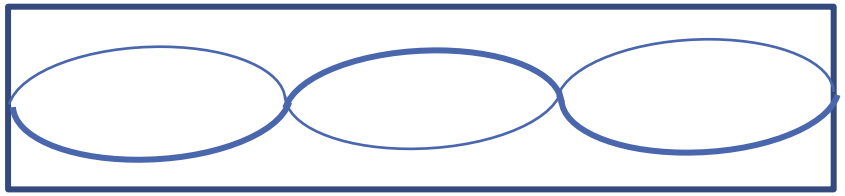
Quantum number:

$n$ = (number of nodes)-1



Single-electron Build-up of Interference Pattern



# Bohr's Atomic Model

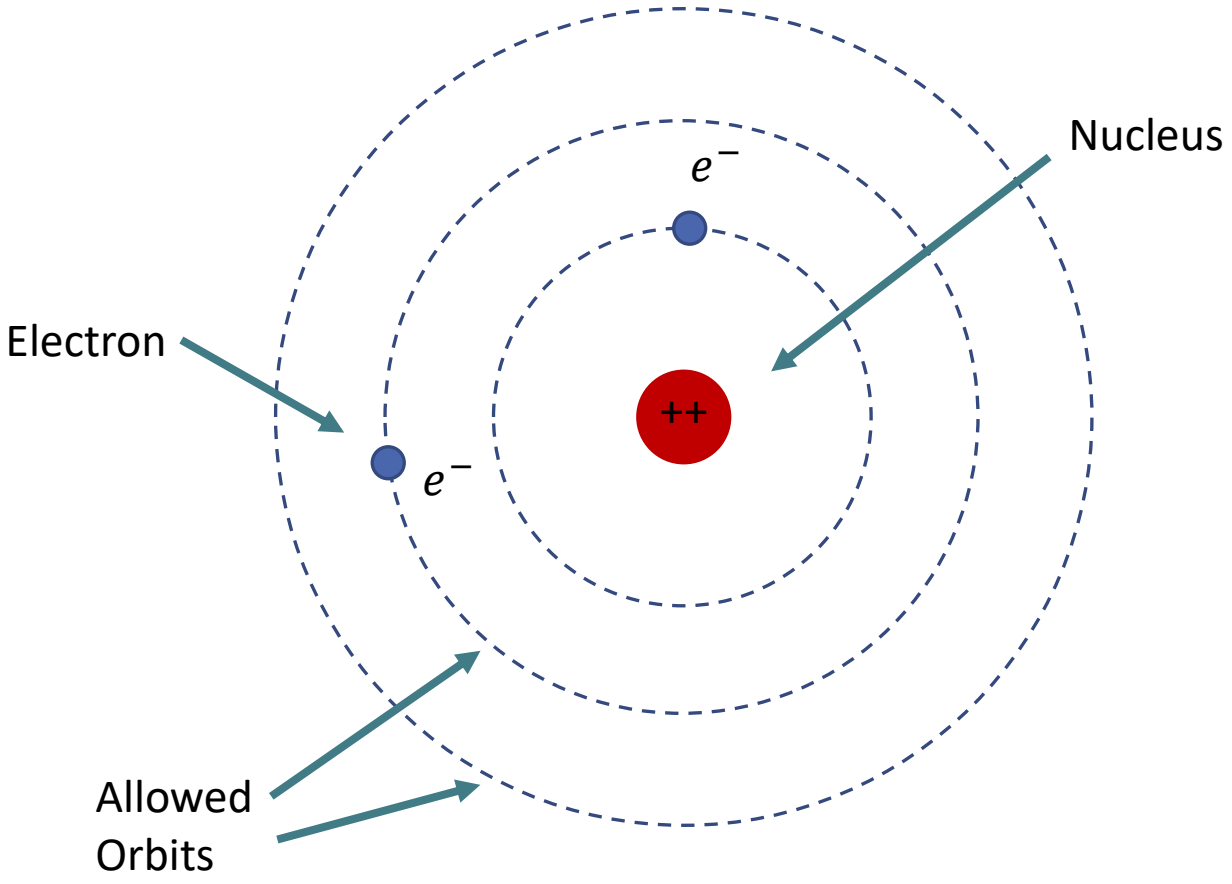
It was understood that atoms were made of a positively charge nucleus surrounded by negatively charged electrons

But why didn't the electrons fall into the nucleus? Why is matter stable?

Bohr solved this by introducing a new model of the atom

Electrons only allowed at specific orbits

The arrangement of orbits is called a stationary state



# Bohr's Atomic Model

Each stationary state has a distinct, quantized energy

Energy determined with quantum number: $n$

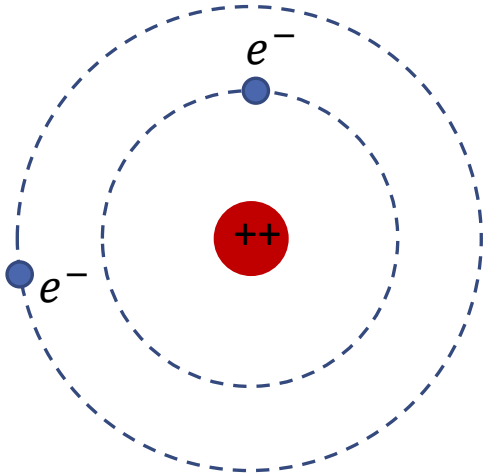
Lowest energy state ($n = 1$) called the ground state

All other higher energy states called excited states

Ground state is stable (persists indefinitely)

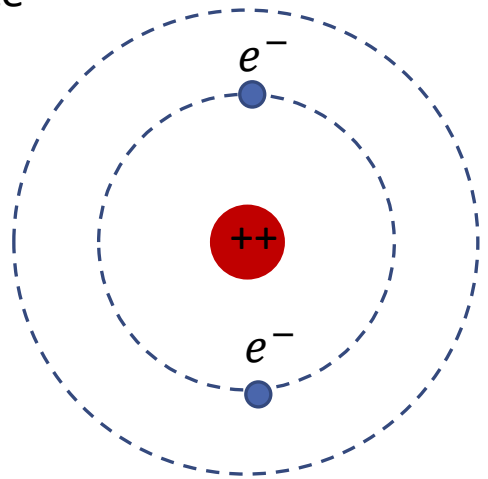
Excited State

$E_2 > E_1$




Ground State

$E_1$



# Bohr's Atomic Model

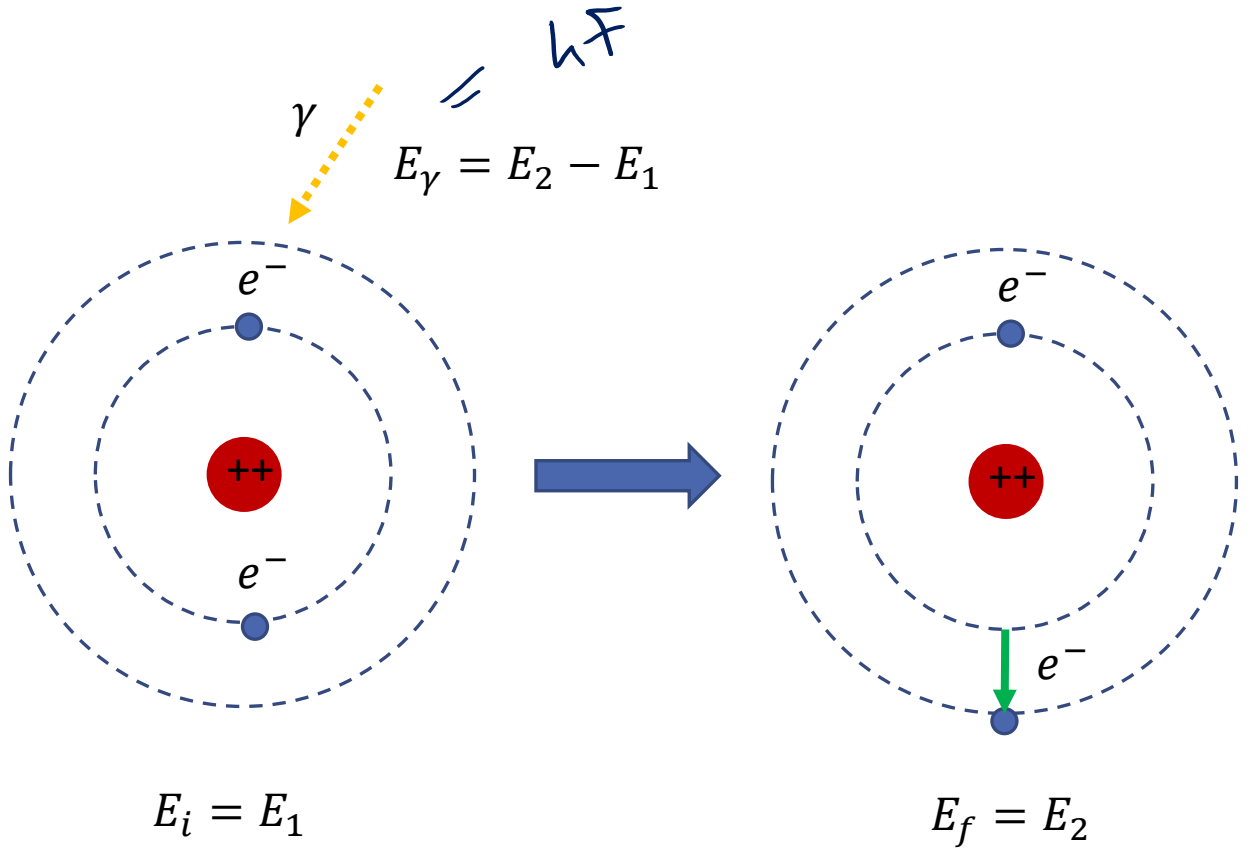
Atoms can transition between states by interacting with a photon

Absorbing a photon moves the atom to higher energy state (excites)

Emitting a photon moves the atom to a lower energy state (decays)

Photon **must** be exact energy of the difference between the two states

Ground state can't emit photon because there are no lower energy states allowed

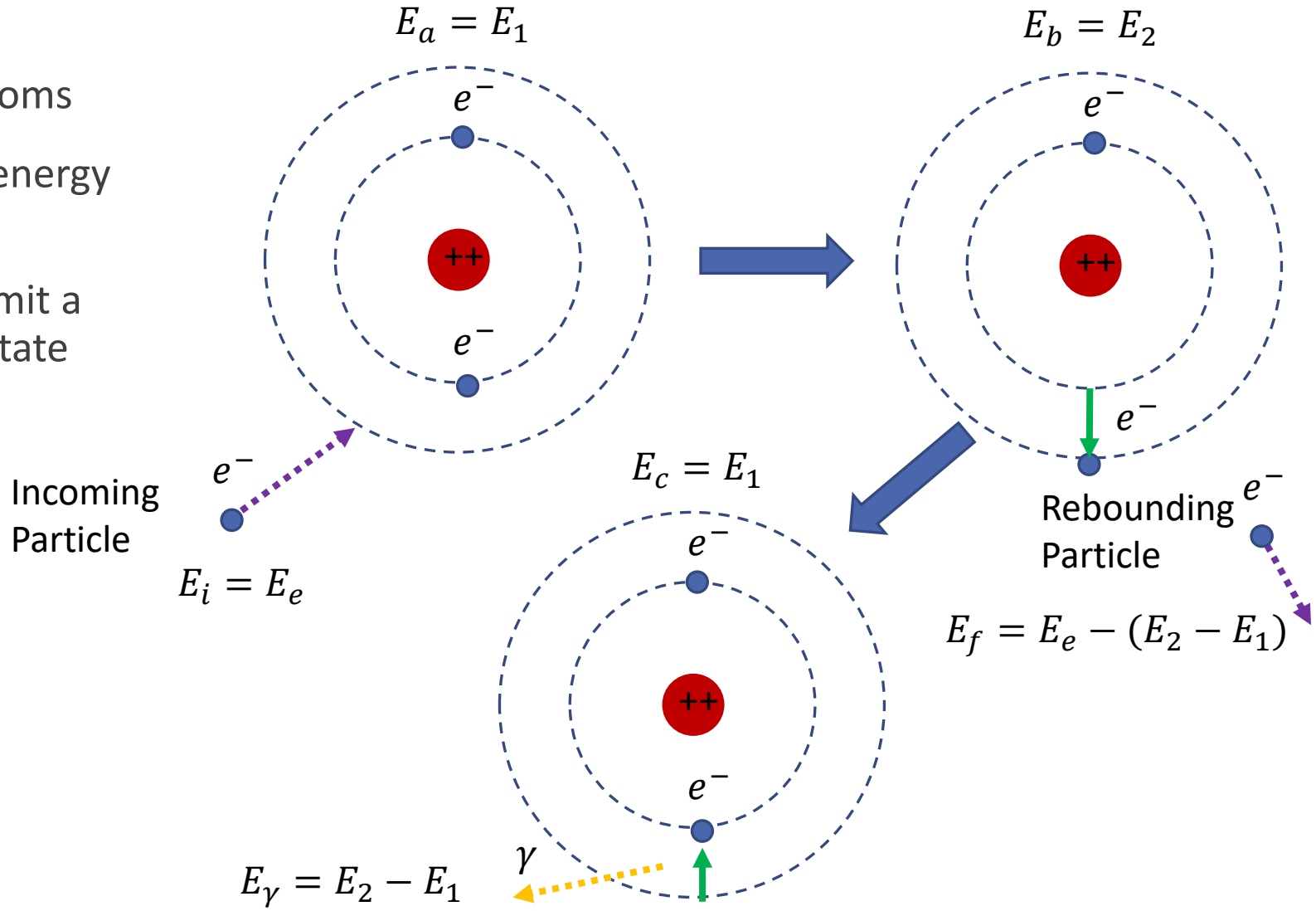


# Bohr's Atomic Model

Other particles can also excite atoms

Some of the incoming particle's energy gets transferred to an electron

At a later time, this could then emit a photon to get back into ground state



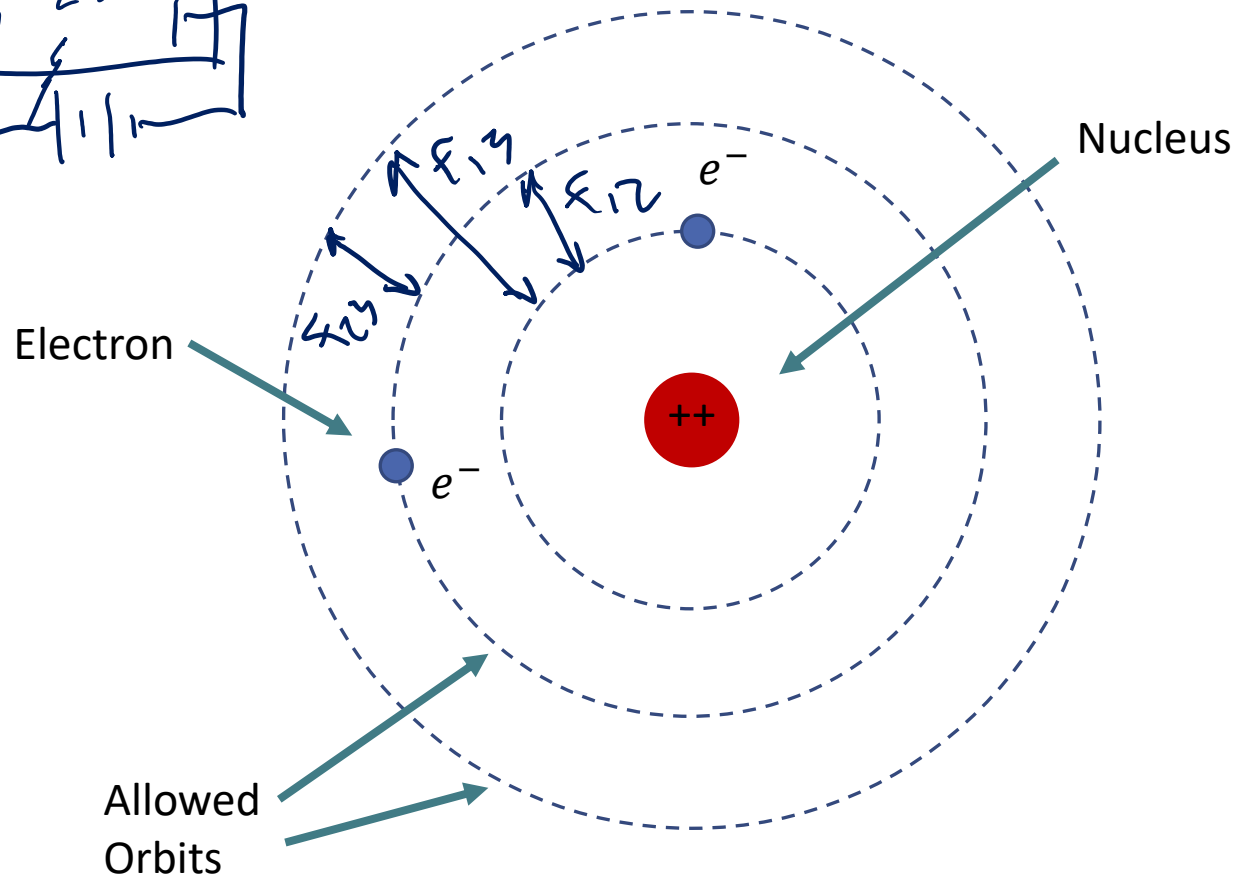
# Bohr's Atomic Model

Implications:

- Matter is stable since ground state is lowest energy so can't decay
- Atoms absorb and emit discrete spectra

$$f_{photon} = \frac{\Delta E_{atom}}{h}$$

- Emission spectra can be produced by collisions
  Gas discharge tube = electrons from cathode strike gas atoms and excite them
- Absorption spectra don't include all emission wavelengths
  Emission: $3 \rightarrow 2,\ 3 \rightarrow 1$
  Absorption: $1 \rightarrow 2,\ 1 \rightarrow 3$
- Each element has a unique spectrum
  Different elements have different number of protons = different energies



# Energy Level Diagrams

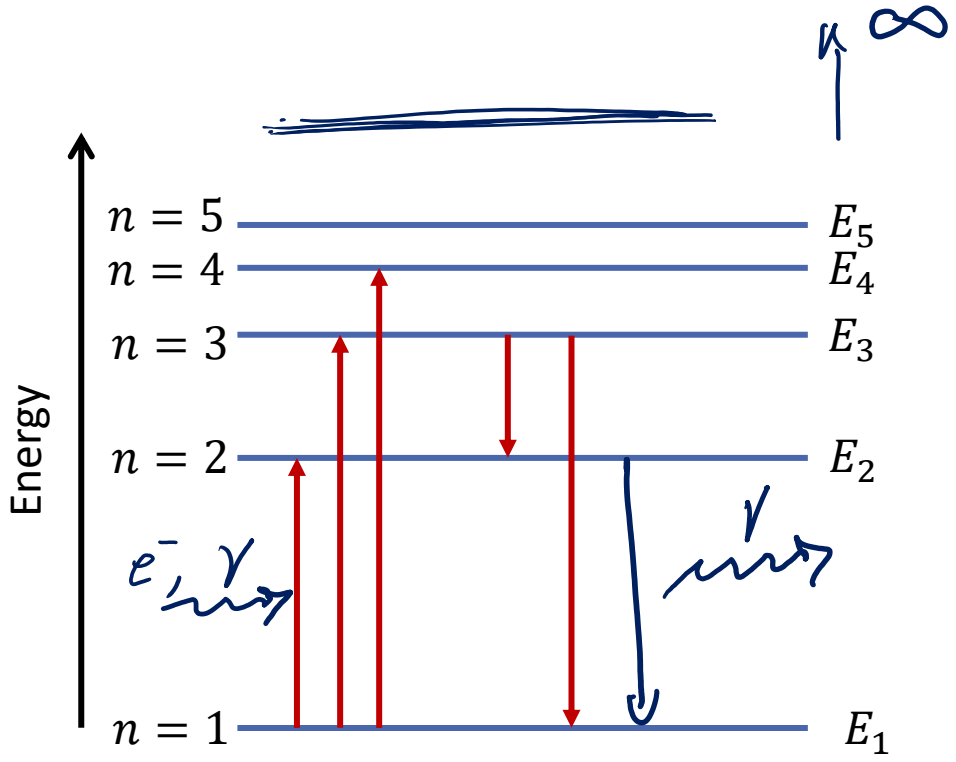
Transitions can be described using energy-level diagram

Each line corresponds to different energy states

Labeled by quantum number: $n$

Arrow indicate changes in energy state

- Collision of another particle
- Emission of photon
- Absorption of photon



# Bohr Hydrogen

Let's apply the Bohr model to hydrogen

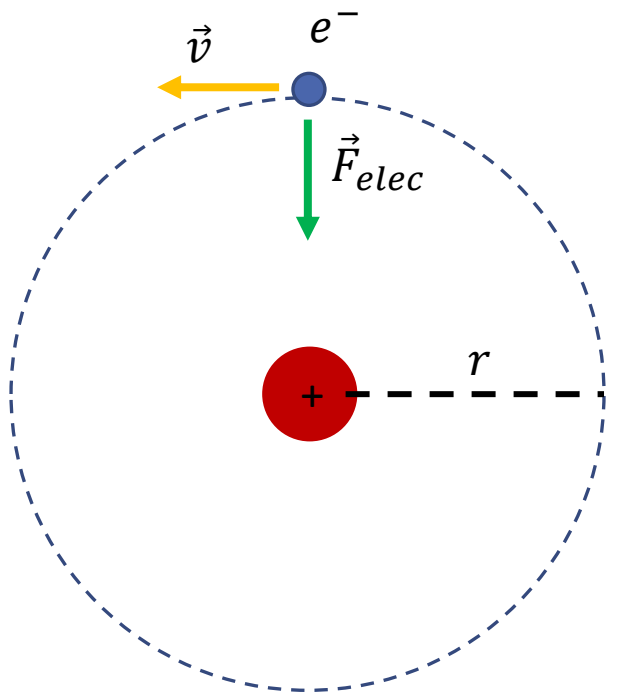
First what does it look like classically

$$E = K + U$$

$$K = \frac{1}{2} m v^2$$

$$U = \frac{q_e q_p}{4\pi\varepsilon_0 r} = \frac{-e^2}{4\pi\varepsilon_0 r}$$

$$E = \frac{1}{2} m v^2 - \frac{e^2}{4\pi\varepsilon_0 r}$$



# Bohr Hydrogen

Let's apply the Bohr model to hydrogen

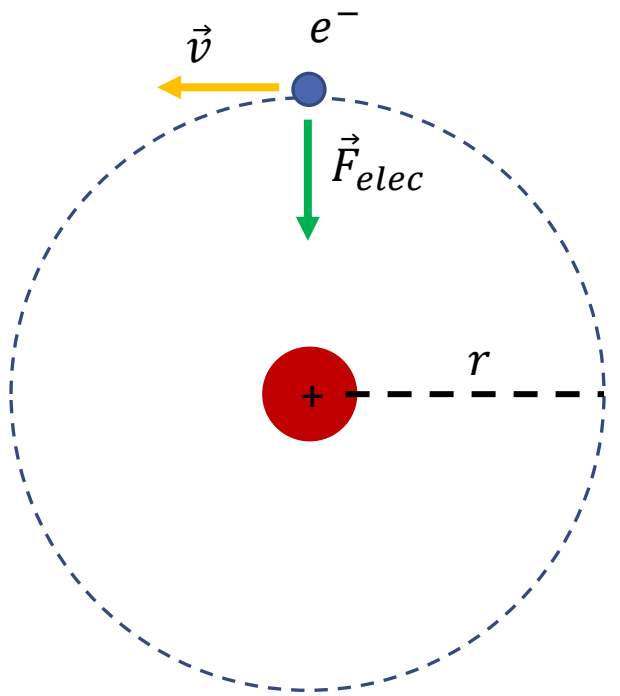
First what does it look like classically

$$\vec{F} = \frac{e^2}{4\pi\varepsilon_0 r^2}(-\hat{r})$$

Circular Motion

$$a = \frac{v^2}{r} = \frac{e^2}{4\pi\varepsilon_0 r^2}$$

$$v^2 = \frac{e^2}{4\pi\varepsilon_0 r}$$



# Bohr Hydrogen

But we know that electrons are also a matter wave

Circumference of orbit must be integer multiple of wavelength

$$2\pi r = n\lambda \qquad n = 1, 2, 3 \ldots$$

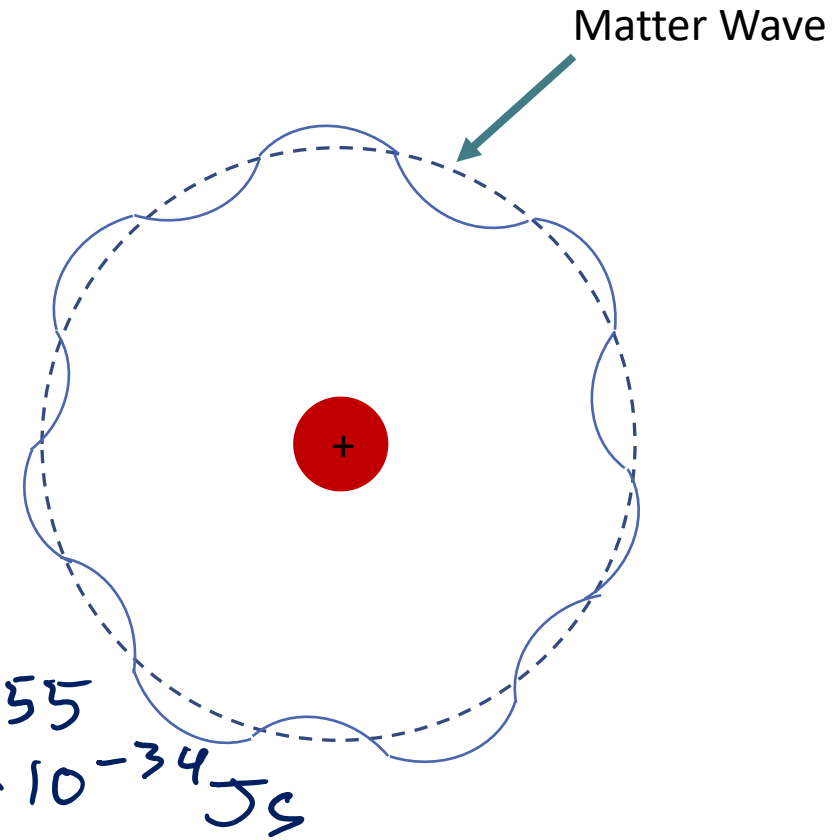
$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$2\pi r = \frac{nh}{mv}$$

$$v = \frac{nh}{2\pi mr} = \frac{n\hbar}{mr}$$

$\hbar$ - h-bar

$$\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34}\ \text{Js}$$



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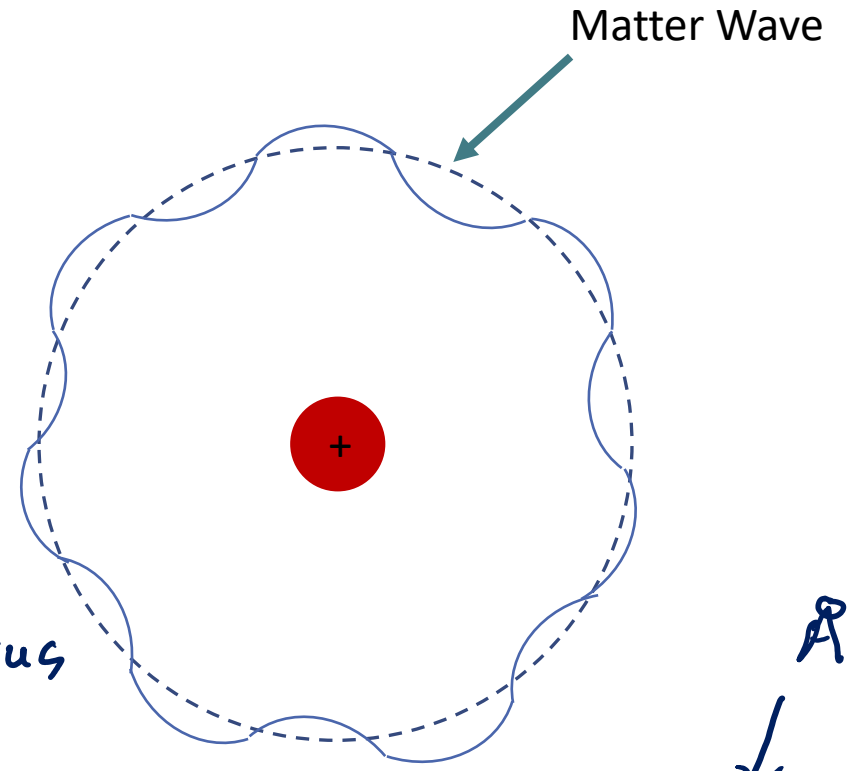



$$v^2 = \frac{e^2}{4\pi\varepsilon_0 m r} = \frac{n^2\hbar^2}{m^2 r^2}$$

$$r = \frac{4\pi\varepsilon_0 n^2 \hbar^2}{m e^2}$$

$$r = a_B n^2$$

radius is discrete

$n = 1, 2, 3 \ldots$

Bohr radius

$$a_B = \frac{4\pi\varepsilon_0 \hbar^2}{m e^2} \simeq 5.29 \times 10^{-11}\ m$$

Å

# Bohr Hydrogen

Radii of electron orbit in hydrogen is quantized

$$r_n = a_B n^2 \qquad n = 1, 2, 3 \ldots$$

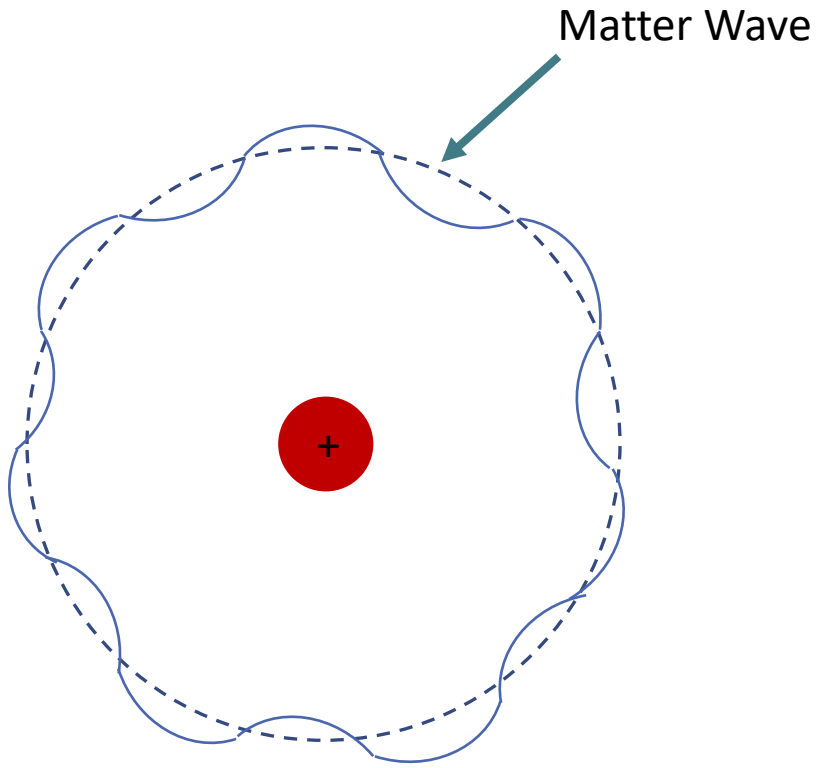
Defined Bohr radius

$$a_B = \frac{4\pi\epsilon_0\hbar^2}{me^2} = 0.0529\, nm$$

Examples of electron radius:

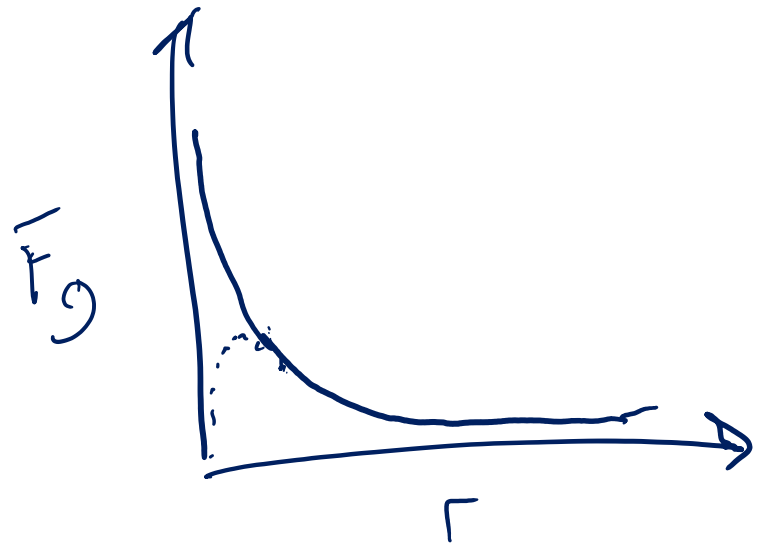
$$r_1 = 1a_B = 0.053\, nm$$
$$r_2 = 4a_B = 0.212\, nm$$
$$r_3 = 9a_B = 0.476\, nm$$

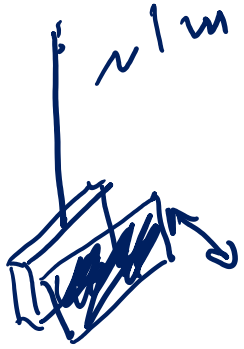
Hydrogen atoms at other radii **can not** exist



# Homework Questions

$$\bar{F}_g = \frac{G m_1 m_2}{r^2}$$



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