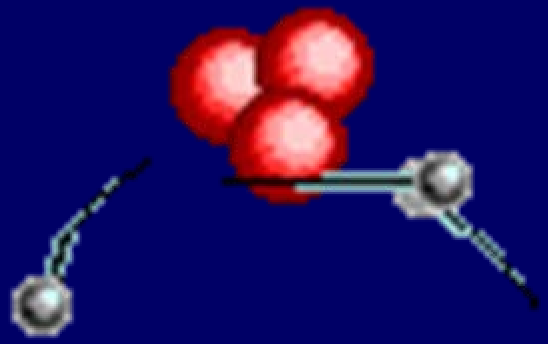
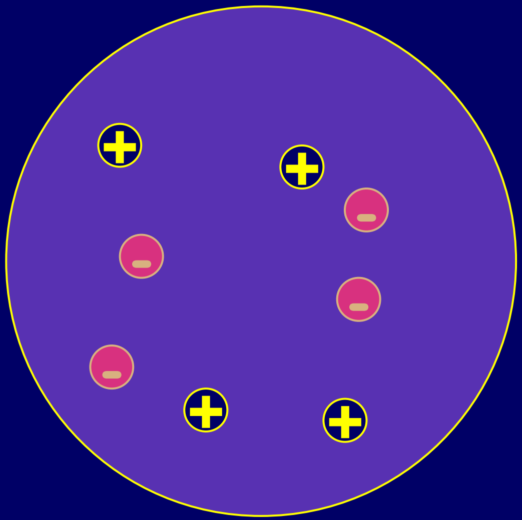
Physics 102: Lecture 24

Bohr vs. Correct Model of Atom



Early Model for Atom

- **Plum Pudding**
  - positive and negative charges uniformly distributed throughout the atom like plums in pudding

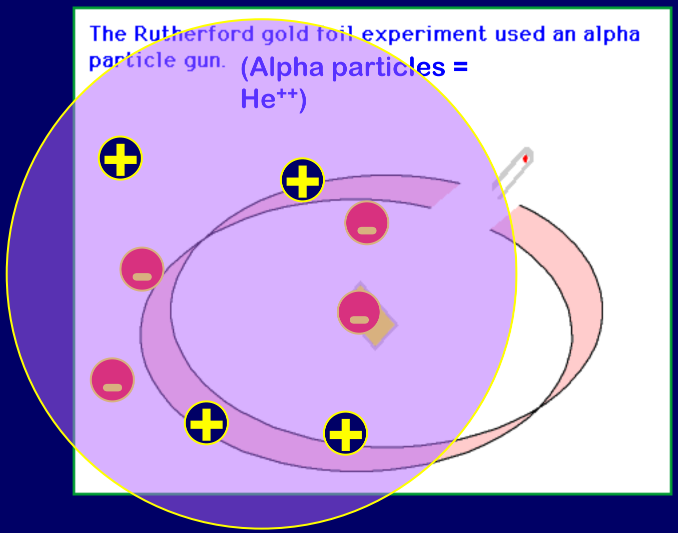


But how can you look inside an atom 10^{-10} m across?

Light (visible)	$\lambda = 10^{-7}$ m
Electron (1 eV)	$\lambda = 10^{-9}$ m
Helium atom	$\lambda = 10^{-11}$ m

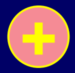
Rutherford Scattering

Scattering He^{++} atoms off of gold. Mostly go through, some scattered back!



Plum pudding theory:
+ and – charges uniformly distributed→ electric field felt by alpha never gets too large

To scatter at large angles, need postive charge concentrated in small region (the nucleus)



Atom is mostly empty space with a small (r = 10^{-15} m) positively charged nucleus surrounded by cloud of electrons (r = 10^{-10} m)

Nuclear Atom (Rutherford)

Large angle scatterings → nuclear atom

Classic nuclear atom is not stable!

Electrons will radiate and spiral into nucleus

Need quantum theory

Recap

- Photons carry momentum $p=h/\lambda$
- Everything has wavelength $\lambda=h/p$
- Uncertainty Principle $\Delta p \Delta x > h/(2\pi)$

- Atom
  - Positive nucleus 10^{-15} m
  - Electrons "orbit" 10^{-10} m
  - Classical E+M doesn't give stable orbit
  - Need Quantum Mechanics!

Some Numerology

- h (Planck's constant) = 6.63×10^{-34} J-s
- 1 eV = kinetic energy of an electron that has been accelerated through a potential difference of 1 V

  1 eV = $q \times \Delta V = 1.6 \times 10^{-19}$ J

  hc = 1240 nm-eV
- m = mass of electron = 9.1×10^{-31} kg

  mc^2 = 511,000 eV

  $2\pi ke^2/(hc) = 1/137$ (dimensionless)

Science fiction

The Bohr model is complete nonsense.

Electrons do not circle the nucleus in little planet-like orbits.

The assumptions injected into the Bohr model have no basis in physical reality.

BUT the model does get some of the numbers right for SIMPLE atoms…

Hydrogen-Like Atoms

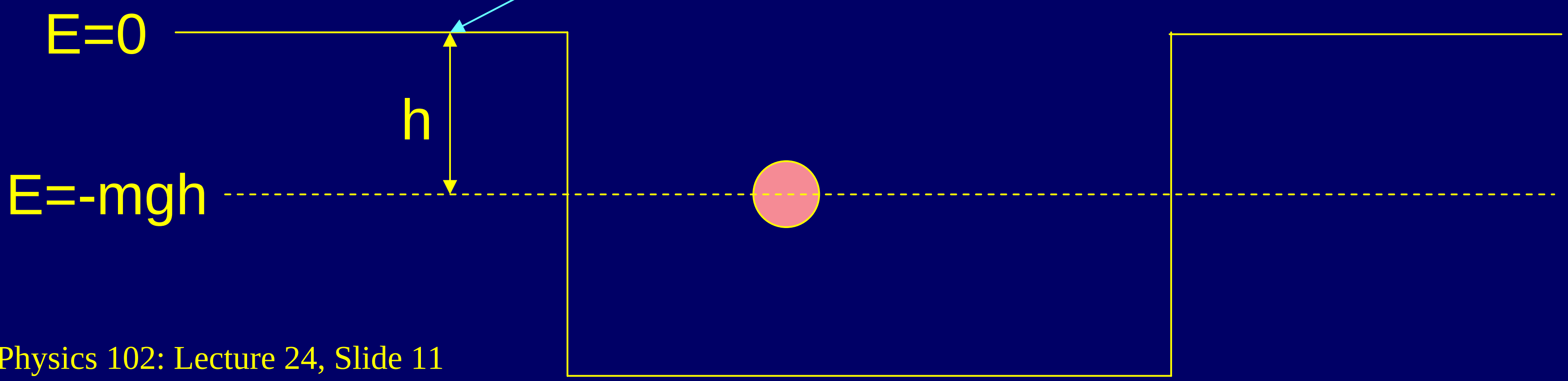
single electron with charge -e

nucleus with charge +Ze
(Z protons)

$$e = 1.6 \times 10^{-19}\ \text{C}$$

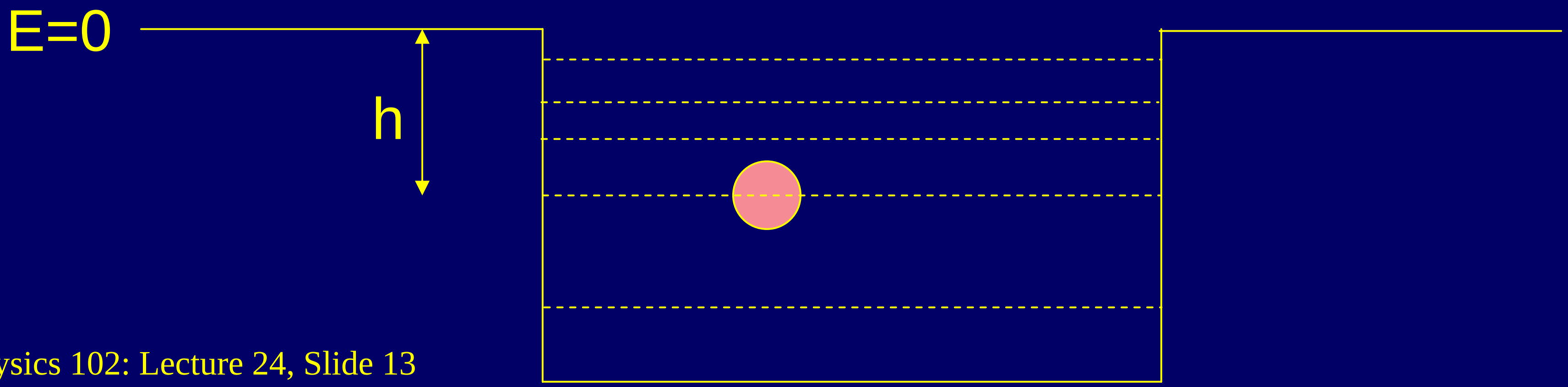
An analogy: Particle in Hole

- The particle is trapped in the hole
- To free the particle, need to provide energy mgh
- Relative to the surface, energy = -mgh
  - a particle that is "just free" has 0 energy



An analogy: Particle in Hole

- Quantized: only fixed discrete heights of particle allowed
- Lowest energy (deepest hole) state is called the “ground state”



For Hydrogen-like atoms:

Energy levels (relative to a "just free" electron):

$$E_n = -\frac{mk^2e^4}{2\hbar^2}\frac{Z^2}{n^2} \approx -\frac{13.6 \cdot Z^2}{n^2}\ \text{eV}\ \left(\text{where } \hbar \equiv h/2\pi\right)$$

Radius of orbit:

$$r_n = \left(\frac{h}{2\pi}\right)^2 \frac{1}{mke^2}\frac{n^2}{Z} = \left(0.0529\ \text{nm}\right)\frac{n^2}{Z}$$

Preflight 24.1

$$r_n = \left(\frac{h}{2\pi}\right)^2 \frac{1}{mke^2} \frac{n^2}{Z} = \underbrace{(0.0529nm)}_{\text{Bohr radius}} \frac{n^2}{Z}$$

If the electron in the hydrogen atom was 207 times heavier (a muon), the Bohr radius would be

1) 207 Times Larger
2) Same Size
3) 207 Times Smaller

ACT/Preflight 24.2

A single electron is orbiting around a nucleus with charge +3. What is its ground state (n=1) energy? (Recall for charge +1, E= -13.6 eV)

1) E = 9 (-13.6 eV)
2) E = 3 (-13.6 eV)
3) E = 1 (-13.6 eV)

ACT: What about the radius?

Z=3, n=1

1. larger than H aton
2. same as H atom
3. smaller than H atom

Transitions + Energy Conservation

- Each orbit has a specific energy:

$$E_n = -13.6\ Z^2/n^2$$

- Photon emitted when electron jumps from high energy to low energy orbit. Photon absorbed when electron jumps from low energy to high energy:

$$E_2 - E_1 = h\,f = h\,c\,/\,\lambda$$

JAVA

Line Spectra

In addition to the continuous blackbody spectrum, elements emit a discrete set of wavelengths which show up as lines in a diffraction grating.

This is how neon signs work!

Better yet…

Wavelengths can be predicted!

ACT/Preflight 24.3

Electron A falls from energy level n=2 to energy level n=1 (ground state), causing a photon to be emitted.

Electron B falls from energy level n=3 to energy level n=1 (ground state), causing a photon to be emitted.

Which photon has more energy?

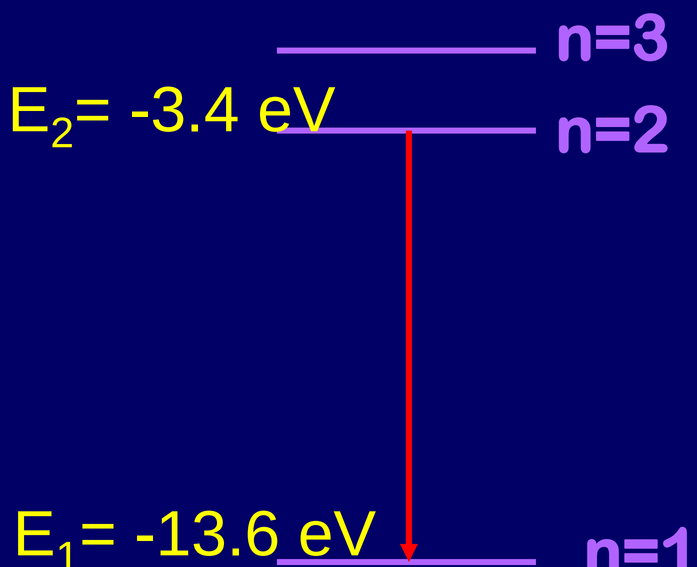
- **Photon A**
- **Photon B**

Example: Spectral Line Wavelengths

Calculate the wavelength of photon emitted when an electron in the hydrogen atom drops from the n=2 state to the ground state (n=1).

$$E_n = -13.6eV\frac{Z^2}{n^2}$$

$$hf = E_2 - E_1 = -3.4eV - (-13.6eV) = 10.2eV$$



$$E_{\text{photon}} = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{10.2eV} = \frac{1240}{10.2} \approx 124nm$$

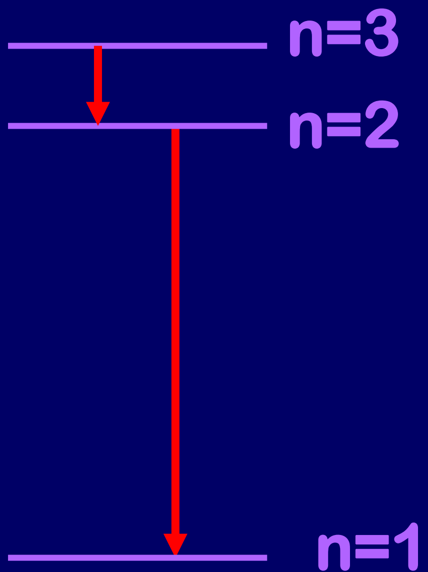
ACT: Spectral Line Wavelengths

Compare the wavelength of a photon produced from a transition from n=3 to n=2 with that of a photon produced from a transition n=2 to n=1.

(1) $\lambda_{32} < \lambda_{21}$

(2) $\lambda_{32} = \lambda_{21}$

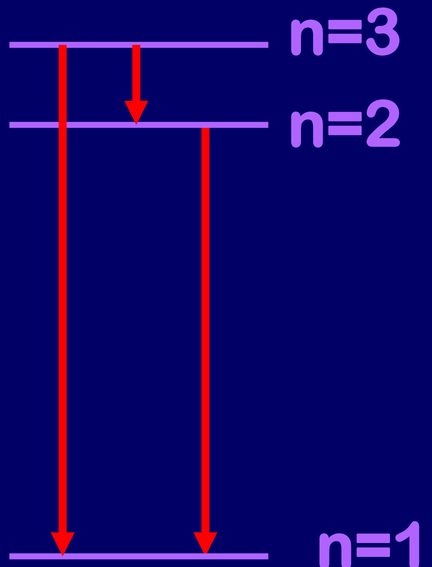
(3) $\lambda_{32} > \lambda_{21}$



ACT/Preflight 24.4

The electrons in a large group of hydrogen atoms are excited to the n=3 level. How many spectral lines will be produced?

1. 1
2. 2.
3. 3
4. 4
5. 5



Preflights 24.6, 24.8

So what keeps the electron from "sticking" to the nucleus?

- Centripetal Acceleration
- Pauli Exclusion Principle
- Heisenberg Uncertainty Principle

To be consistent with the Heisenberg Uncertainty Principle, which of these properties can not be quantized (have the exact value known)? (more than one answer can be correct)

- Electron Radius
- Electron Energy
- Electron Velocity
- Electron Angular Momentum

Quantum Mechanics

- Predicts available energy states agreeing with Bohr.
- Don't have definite electron position, only a probability function. Java
- Each orbital can have 0 angular momentum!
- Each electron state labeled by 4 numbers:

n = principal quantum number (1, 2, 3, …)

ℓ = angular momentum (0, 1, 2, … n-1)

m_ℓ = component of l ($-\ell < m_\ell < \ell$)

m_s = spin ($-\frac{1}{2}$, $+\frac{1}{2}$)

Coming Soon!

Summary

- **Bohr's Model gives accurate values for electron energy levels...**

- **But Quantum Mechanics is needed to describe electrons in atom.**

- **Electrons jump between states by emitting or absorbing photons of the appropriate energy.**

- **Each state has specific energy and is labeled by 4 quantum numbers (next time).**

JAVA Links

- Bohr Atom
- de Broglie Atom
- Schroedinger Atom