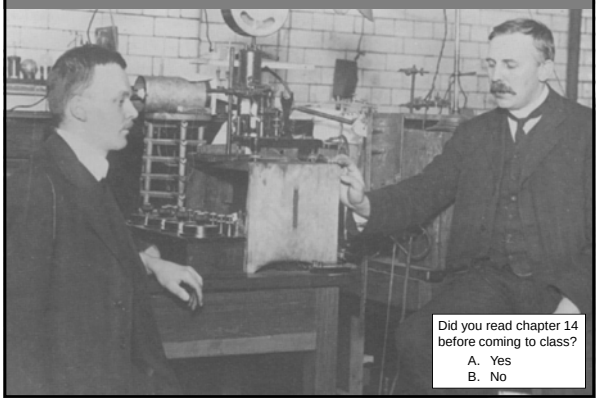
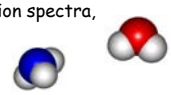
Chapter 14: The Nuclear Atom



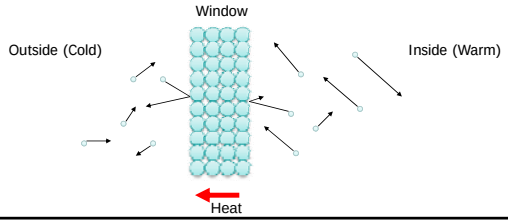
Review of Matter Models

- Continuous
  - Matter can be divided infinitely without changing it's basic character.
  - Doesn't explain Brownian motion, gas properties, temperature, heat flow, etc.
- Molecular
  - Matter is made up of small, unseen particles in constant motion obeying Newton's laws.
  - Doesn't explain plasmas, color, emission spectra, etc.



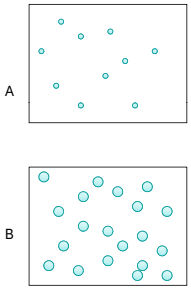
Explain how energy conducts from a warm house into the air outside through a window

- On average the molecules bounce from the glass with a *higher* speed than they had before bouncing, while the molecules on the inside bounce at a *lower* speed than they had before bouncing.



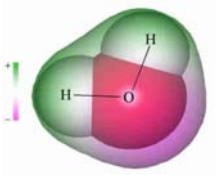
Explain the following using the molecular model

- How does a thermos bottle work?
- How about double pane windows?
- Suppose A and B are at the same temperature but B contains twice the particles and they are twice as massive.
  - Which properties are different? Which are the same?
    - Average speed and Pressure

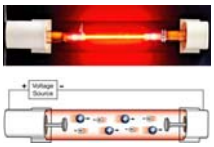


The molecular model of matter cannot explain the physical phenomenon of

a) Temperature
b) Pressure
c) Color
d) Heat conduction

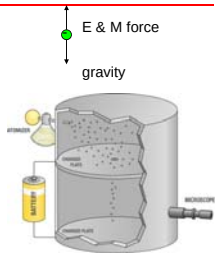


The atomic model: J. J. Thompson and Plasma Tubes



- Start with a neutral gas, heat it with an electrical current, and it breaks into positive and negative fragments.
- Negative particles are identical
  - small mass; called electrons
- Positive particles differ depending on gas
  - large mass; called ions
- *We need a new model!!*

Negative fragments - Electrons

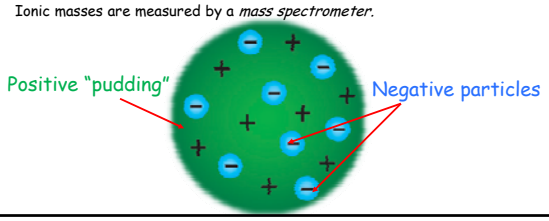


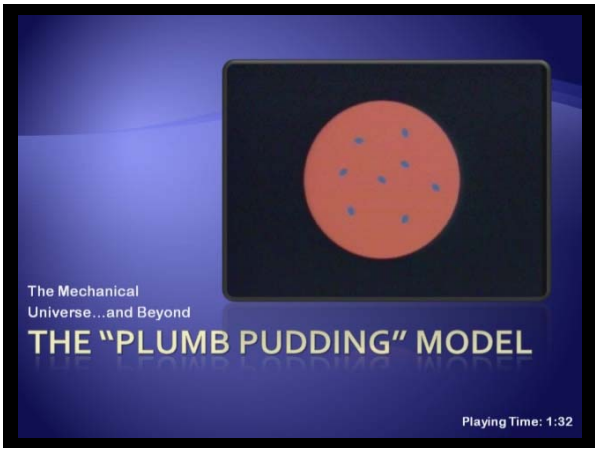
- *Electrons* were first introduced by this model.
- They are all discrete particle with the same mass and charge, regardless of where they came from.
- Their particle or "quantized" nature was proven by the Millikan oil drop experiment.

Electron charge = 1.6×10^{-19} Coulombs (tiny!)

Thompson Model of the Atom (Plum Pudding)

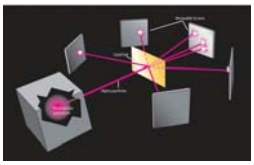
- Atoms consist of a thin positive fluid, which contains most of the mass, with embedded point-like negative electrons to balance the charge. The "pudding" part was hypothesized to be more massive but not very dense.
- It's extent defined the atomic diameter.
- Positive fragments were called "ions" and had nearly all the mass of the original atom.
- Ionic masses are measured by a *mass spectrometer*.





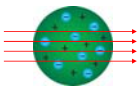
Death of Plum Pudding model

Rutherford, Geiger, and Marsden

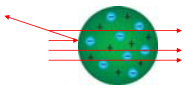


- A colleague of J. J. Thompson, Ernest Rutherford, set about to find out how dense the positive pudding was by firing newly discovered *alpha particles* at a thin gold foil.
- The idea was to measure how much they deflected as they passed through.

A Surprise!



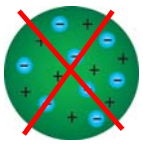
Expectation



Result

- "It was like shooting at ghosts!" As expected, most went right on through.
- *But, unexpectedly, a few bounced back!*
- Nothing in the model was dense enough to reflect alpha particles. *We need a new model again!*

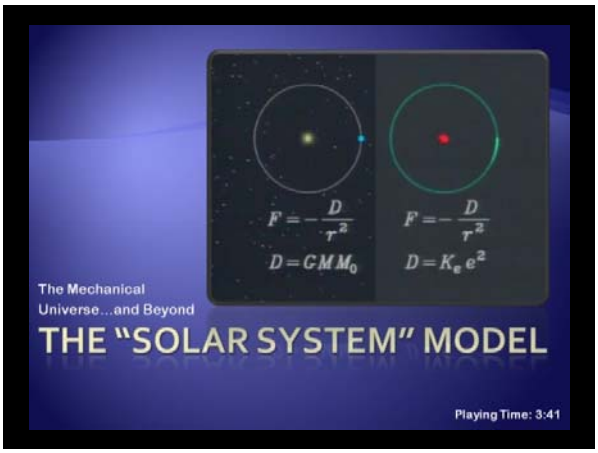
Another New Model: The Solar System Model



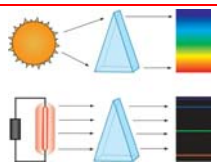
- Rutherford proposed replacing it with the "solar system" model. In this model
  - The positive portion is concentrated into a tiny ***nucleus*** at the atomic center
  - The negative electrons orbit about the nucleus in well-defined paths. The orbital radii define the atomic diameter instead of the positive pudding.

Problems at the start!

- Accelerating (orbiting) electrons should continually radiate, loose energy, and spiral into the nucleus
- However if electrons are stationary they would fall into the nucleus too.
- There was no fix for this. The model was created with flaws and soon died.



More clues from light spectra

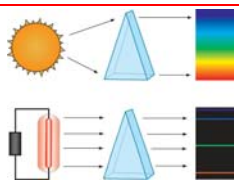


- **continuous spectrum** -- all colors

- **discrete spectrum** -- only a few specific colors

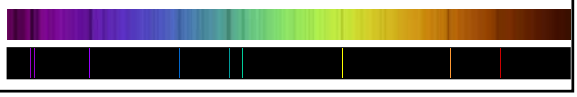
- Discrete absorption spectrum – All colors but a few lines

Rydberg proposed a formula that describe Hydrogen emission and absorption, but he couldn't explain it



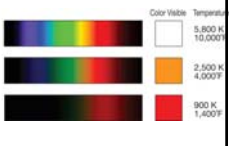
- Rydberg Formula

$$f = C[\,(1/n_1)^2 - (1/n_2)^2\,]$$



Max Planck made an unexpected discovery when studying glowing objects

- Objects glow with a characteristic color depending on temperature.
- In order to accurately describe the emission spectrum, you have to assume that light energy is quantized into bits
  - Energy = n x h x f



Which type of electromagnetic radiation has the highest energy per photon?

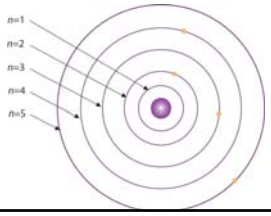
a) Radio Waves
b) Infrared
c) Ultraviolet
d) Green light
e) Red light

Wave Particle Duality

- Light is both a wave and a particle.
  - It behaves like a wave when unobserved
    - It travels through both slits like a wave
  - It is detected like a particle
    - It hits the screen as individual dots

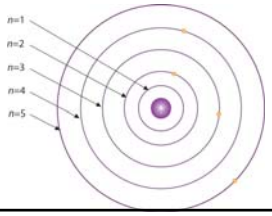
The Bohr Model

- The Rutherford model + a patch
  - In the atom electrons orbit the nucleus but only in very specific orbits.
  - To move from one orbit to another an electron must either gain or lose the exact amount of energy between the two levels



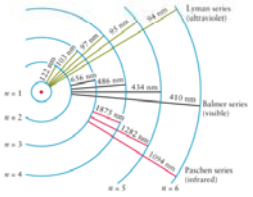
The Bohr Model

- Each electron has a characteristic energy depending on orbit; smaller radius, less energy. Just like gravitational potential energy.
- Electrons radiate (emit) only when they jump to an allowed orbit of lower energy.
- Electrons absorb energy only when they jump to a higher energy orbit.
- This model makes a profound break with Newton's laws of motion!

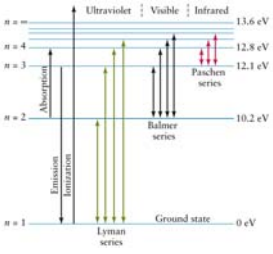


Energy and Wavelength

- Remember each wavelength of light has a specific amount of energy in its photons
- We can not emit or absorb partial photons.
- Therefore transitions between orbits correspond to specific wavelengths of light.

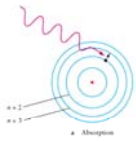


Hydrogen Atom

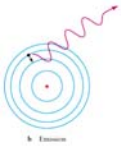


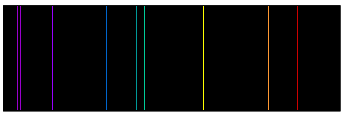
Energy Level Diagram

Absorption vs. Emission

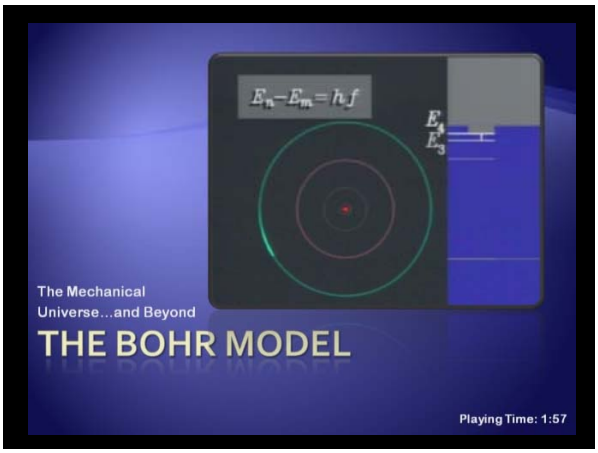


Absorption





Emission

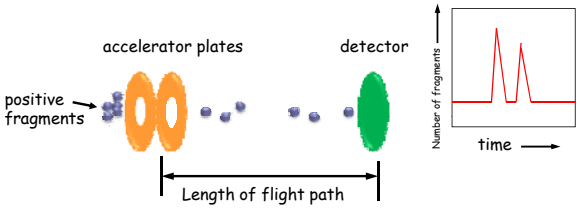


Problems with the "Bohr Model"

- Why are only certain orbits possible (not like a solar system!)
- Why doesn't the undisturbed atom radiate? (Why don't the electrons fall into the nucleus?)

'Because Bohr says so'
is not a good answer.
So we continue looking!

Time-of-Flight Mass Spectrometer



kinetic energy = $\frac{1}{2}$(mass)(speed)^2

If all fragments are given the same kinetic energy,
which particles get to the detector first?