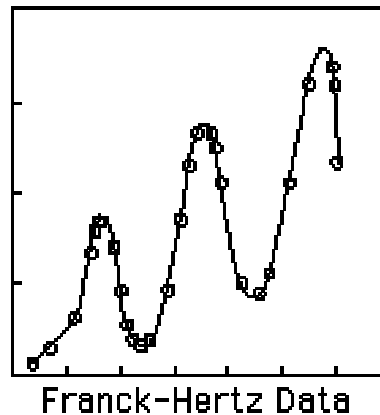
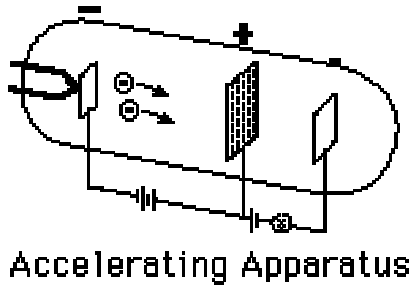


Franck-Hertz experiment, Bohr atom, de Broglie waves

Announcements:

- Homework solutions for Homework 6 are on CULearn
- Homework 7 is available on the website
- Problem solving sessions M3-5, T3-5.



*Nobel prize
in physics,
1925



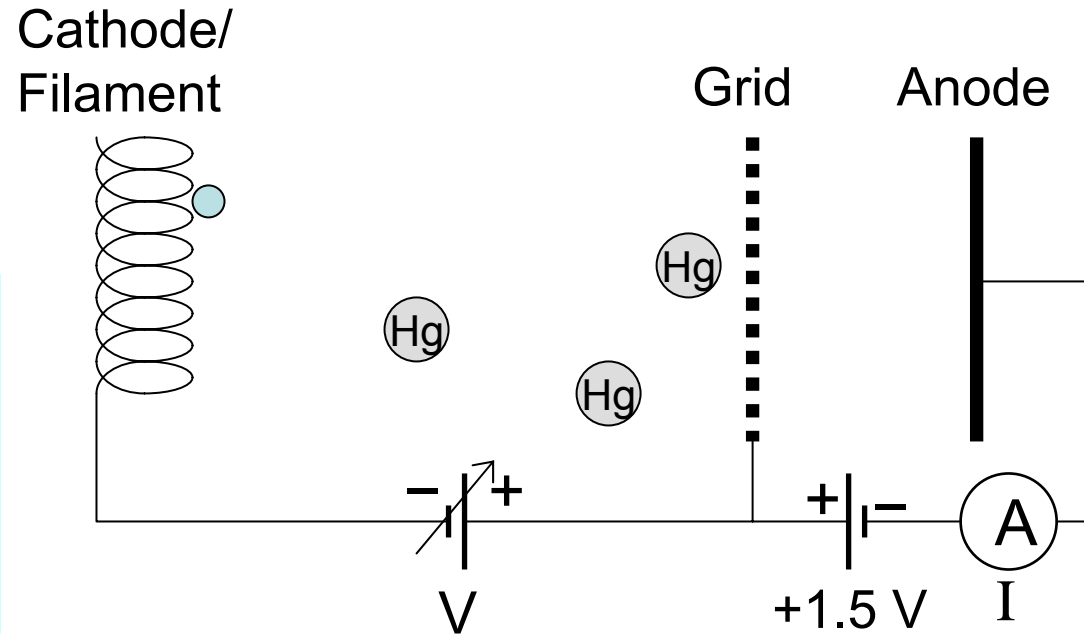
Louis de Broglie:
1892 – 1987

Today we will go over the Franck-Hertz experiment, summarize the Bohr model and move onto de Broglie waves.

Franck-Hertz experiment

Electrons boil off the cathode and accelerate toward the grid

If it has enough kinetic energy after passing the grid it may make it past the 1.5 V retarding voltage and hit the anode causing a current.

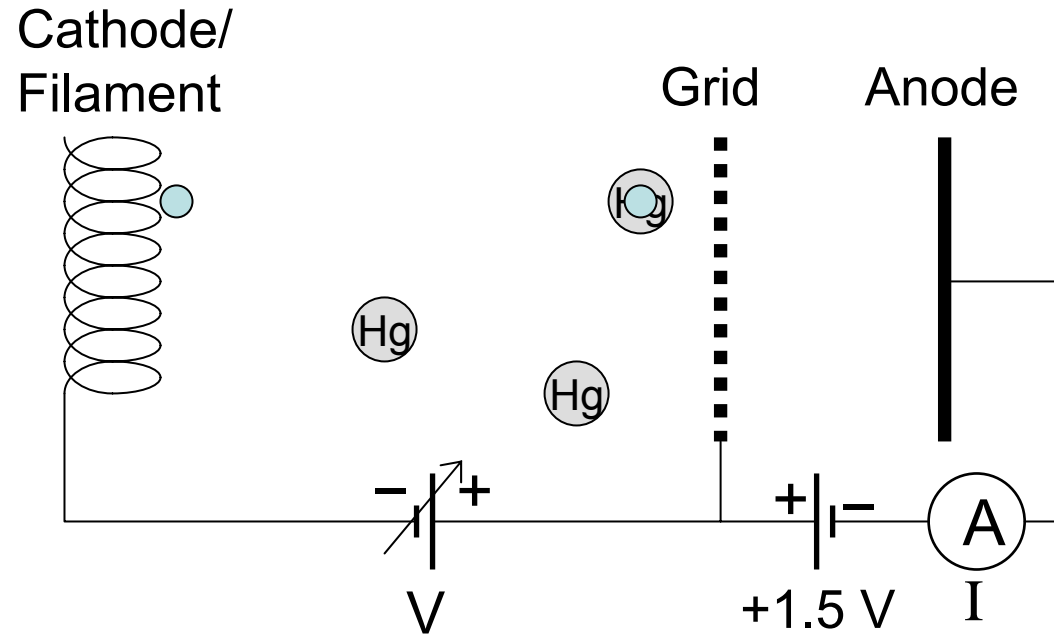


Mercury atoms inside need 4.9 eV to excite from ground level to the next energy level

If electron never has 4.9 eV of kinetic energy it will only elastically scatter off the mercury atoms, losing very little energy.

Franck-Hertz experiment

If the electron kinetic energy exceeds 4.9 eV, it can inelastically collide with a mercury atom and transfer 4.9 eV to it, losing 4.9 eV of kinetic energy in the process.



After the collision, the electron may not gain enough kinetic energy to reach the anode so the current will drop.

As the accelerating voltage increases, the electron can excite multiple mercury atoms.

This experiment gives more proof for the existence of atomic energy levels. Performed in 1914; Nobel prize in 1925.

Summary and implications of Bohr model

Electrons orbit the nucleus at particular radii corresponding to particular energies. These energies are called energy levels or states.

The only allowed electron energy transitions are between these energy levels.

There always exists one lowest energy state called the ground state to which the electron will always return.

Free electrons with enough kinetic energy can excite atomic electrons. From conservation of energy, the free electron loses the same amount of kinetic energy as the atomic electron gains.

Photons are emitted *and* absorbed only with energies corresponding to transitions between energy levels.

Successes of the Bohr model

Explains the Balmer formula $\frac{1}{\lambda} = R\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$ and predicts the empirical constant R using fundamental constants: $R = \frac{2\pi^2m(ke^2)^2}{ch^3}$

Explains the spectrum for other single electron atoms like singly ionized helium or double ionized lithium.

Predicts the approximate size of the hydrogen atom (orbit radius)

Sort of explains why atoms emit discrete spectral lines

Sort of explains why electrons don't spiral into the nucleus.

Remaining issue with the Bohr model

- **Why** is angular momentum quantized?
- **Why** don't electrons radiate when they are in fixed orbitals?
- How does electron know which level to jump to? (i.e. how to predict intensities of spectral lines)
- Can't be generalized to more complex (multi-electron) atoms
- Shapes of molecular orbits and how bonds work
- Can't explain doublet spectral lines

Please answer this question on your own.
No discussion until after.

De Broglie proposed which of the following?

- A. Photons have momentum of h/λ .
- B. The angular momentum of atomic electrons is quantized
- C. Matter particles have a wavelength
- D. The position and momentum of an object cannot both be measured to arbitrary accuracy at the same time.
- E. None of the above

Compton showed that photons have momentum (A)

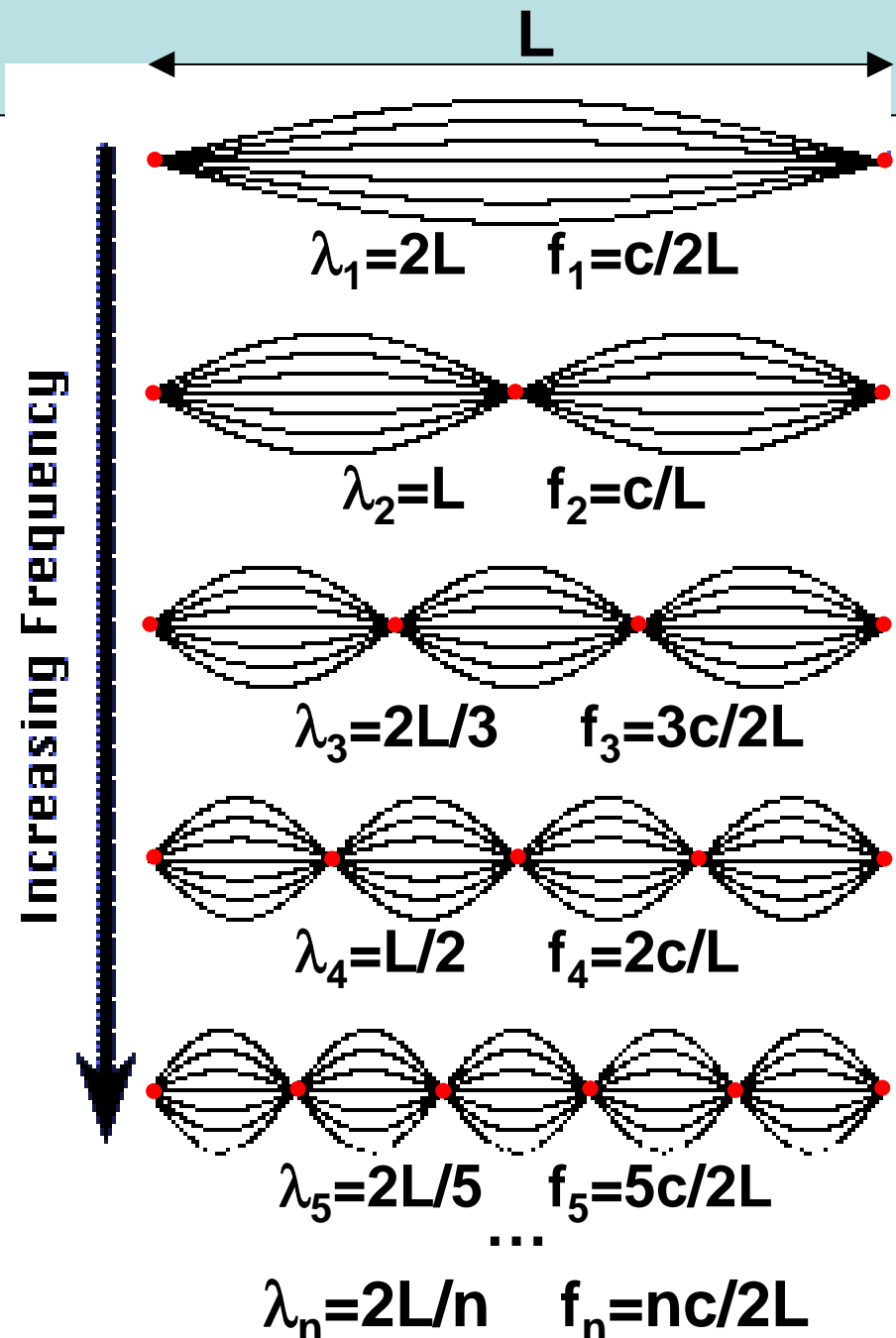
Bohr postulated quantization of angular momentum (B)

Heisenberg came up with the uncertainty principle (D)

Waves

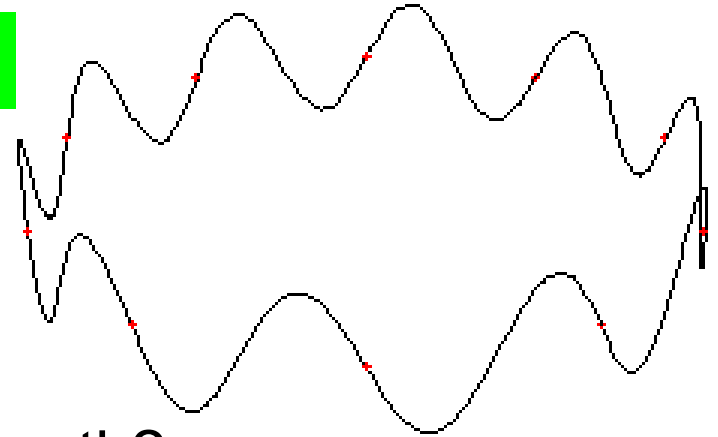
- Physicists at this time may have been confused about atoms, but they understood waves.
- They understood that for *standing waves*, boundary conditions mean that waves only have discrete modes.
- E.g. guitar strings

• = node = fixed point that doesn't move.



What about standing waves in a ring?

Just like a standing wave on a string but now the two ends of the string are joined together.



What are the restrictions on the wavelength?

- A. $r = \lambda$
- B. $r = n\lambda$
- C. $\pi r = n\lambda$
- D. $2\pi r = n\lambda$**
- E. $2\pi r = \lambda/n$

$$n = 1, 2, 3, \dots$$

If you start at a peak and go around the circle, you must end up at a peak. Otherwise you will not have a standing wave; it will change.

So going around the circle must take an integral number of wavelengths.

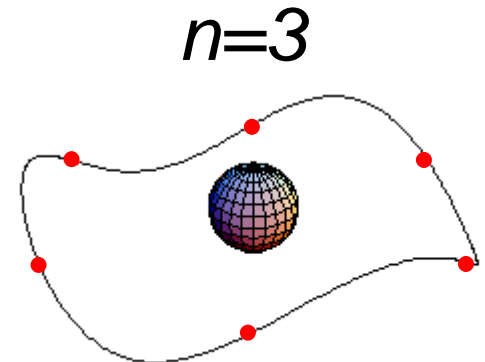
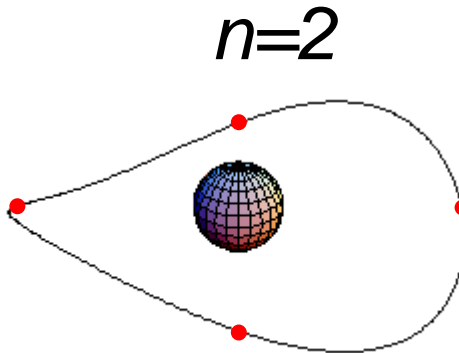
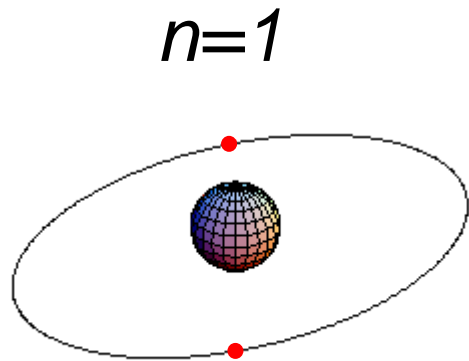
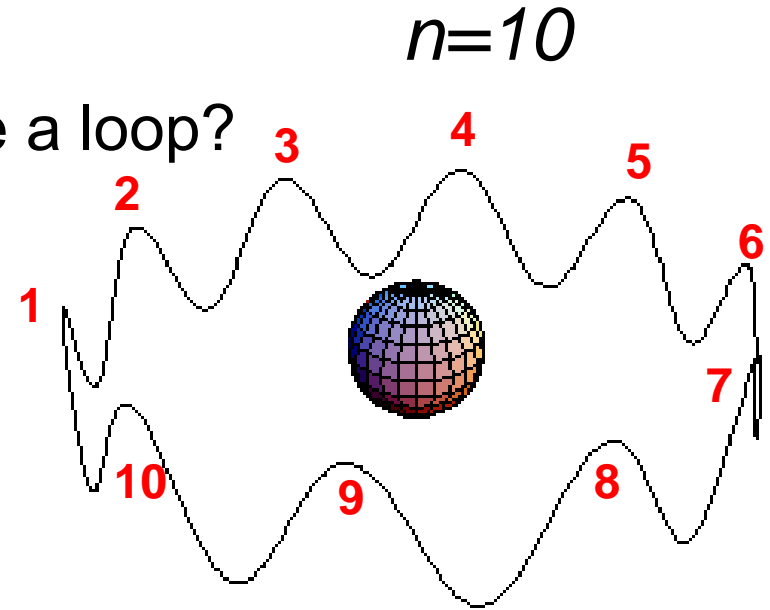
Circumference is $2\pi r$ so the condition is $2\pi r = n\lambda$.

de Broglie Waves

- In 1923, French grad student Louis de Broglie suggested that maybe electrons are actually little waves going around the nucleus.
- This seems plausible because...
 - Standing waves have quantized frequencies, might be related to quantized energies.
 - Einstein had shown that light, typically thought of as waves, have particle properties. Might not electrons, typically thought of as particles, have wave properties?

What is n in this picture? How many wavelengths does it take to complete a loop?

- A. 1
- B. 5
- C. 10**
- D. 20
- E. Cannot determine from picture



• = node = fixed point that doesn't move.

de Broglie waves

If we postulate that electron orbits are standing waves then there is a relationship between orbital radius and wavelength: $2\pi r = n\lambda$

But what is the wavelength of an electron?!

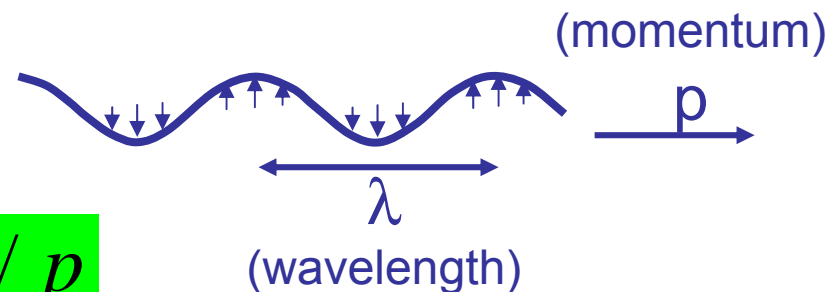
For photons we know how to relate momentum and wavelength

From photoelectric effect: $E_\gamma = hf = hc / \lambda$

From relativity: $E_\gamma = p_\gamma c$

Combined (and proven by Compton effect): $p_\gamma = h / \lambda$

de Broglie proposed the same relationship for massive particles



The de Broglie wavelength: $\lambda = h / p$

Amazing new idea: Particle have a wavelength!

Given the deBroglie wavelength ($\lambda = h/p$) and the condition for standing waves on a ring ($2\pi r = n\lambda$), what can you say about the angular momentum L of an electron if it is a de Broglie wave?

A. $L = n\hbar/r$

B. $L = n\hbar$

C. $L = n\hbar/2$

D. $L = 2n\hbar/r$

E. $L = n\hbar/2r$

Remember

$$\hbar = h/2\pi$$

Angular momentum: $\vec{L} = \vec{r} \times \vec{p}$

momentum: $\vec{p} = m\vec{v}$

Substitute de Broglie wavelength $\lambda = h/p$ into the standing wave equation $2\pi r = n\lambda$ to get

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

Can rearrange this as $rp = \frac{nh}{2\pi}$

which is $L = n\hbar$

So the de Broglie wavelength for an electron going around a nucleus **explains** the quantization of angular momentum proposed by Bohr and therefore explains quantization of energy.

de Broglie waves

So the idea of particles also being waves explains one of Bohr's postulates (quantization of angular momentum)

But is this idea correct?

How to tell?

To tell if something is a wave we look for interference.

We will start with the Davisson-Germer experiment on Monday.

Models of the Atom

- Thomson – Plum Pudding
 - Why? Known that negative charges can be removed from atom.
 - Problem: just a random guess
- Rutherford – Solar System
 - Why? Scattering showed hard core.
 - Problem: electrons should spiral into nucleus in $\sim 10^{-11}$ sec.
- Bohr – fixed energy levels
 - Why? Explains spectral lines.
 - Problem: No reason for fixed energy levels
- de Broglie – electron standing waves
 - Why? Explains fixed energy levels
 - Problem: still only works for Hydrogen.
- Schrodinger – quantum wave functions
 - Why? Explains everything!
 - Problem: None (except that it's hard to understand)

