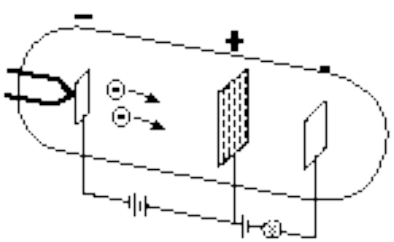
Franck-Hertz experiment, Bohr atom, de Broglie waves

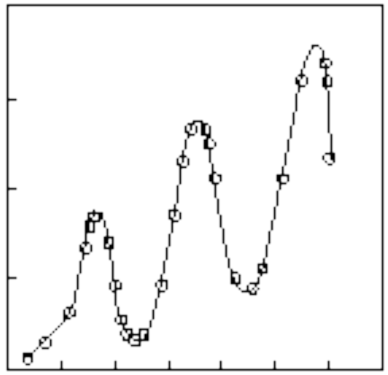
Announcements:

Problem solving sessions Tues. 1-3.

- Reading for Wednesday TZD 6.1-.4
- 2013 Nobel Prize Announcement Tomorrow
- Few slides on the Higgs Field and Particle



Accelerating Apparatus



Franck-Hertz Data

*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.

http://www.colorado.edu/physics/phys2170/

Want to be an LA?

Come to the **LA Info Session** to learn more about becoming a *Learning Assistant*.

When: Monday, October 7, 2013, at 5:30 p.m.

Where: Center for Community (C4C) Abrams Room

Refreshments will be served, while they last.

Applications for Spring 2014 available October 7 – 21

Goto: https://laprogram.colorado.edu/applications

Get more information from faculty and LAs in these departments:

Applied Math	Math	Education
MCDBiology	ATOC	Chemistry
EBIO	Astronomy	Physics

Learning Assistant (LA) Model

UNIVERSITY OF COLORADO **BOULDER**

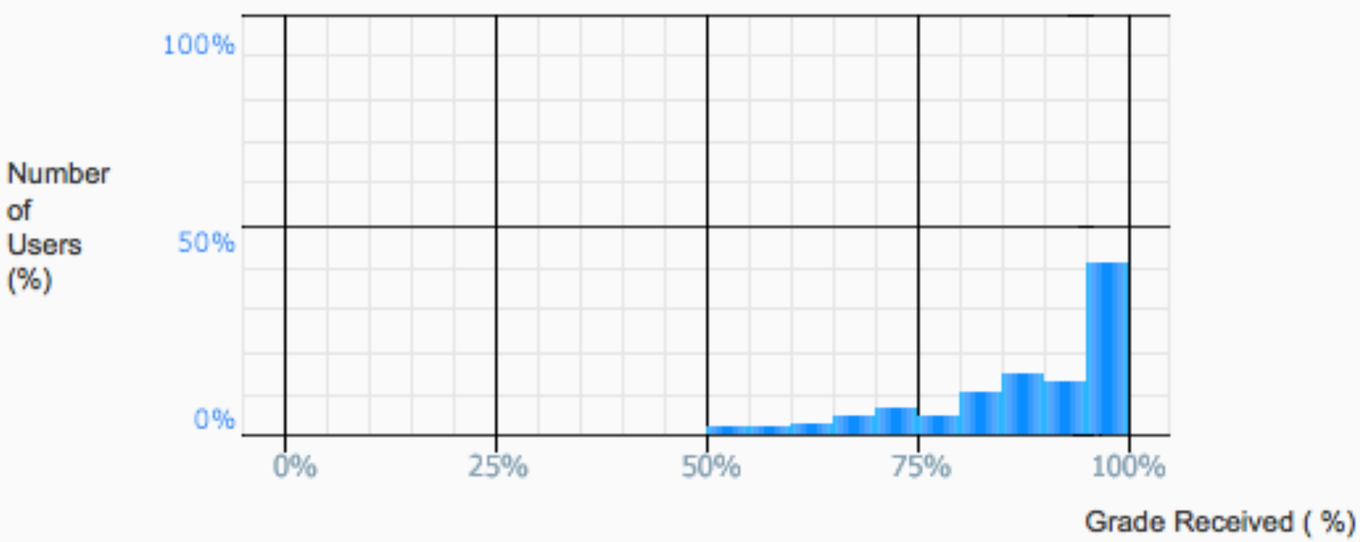
http

Homework #4

HW4 Class Statistics

Number of submitted grades: 111 / 126
Minimum: 50 %
Maximum: 100 %
Average: 87.73 %
Mode: 100 %
Median: 90 %
Standard Deviation: 12.56 %

Grade Distribution



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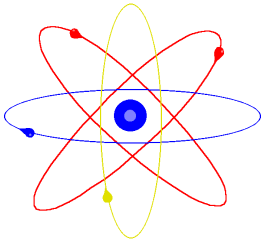
Fundamental forces

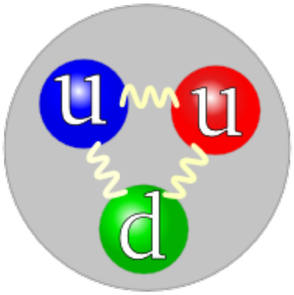
We know of four forces between particles.

Gravity – important for big objects and long distances; negligible in particle physics

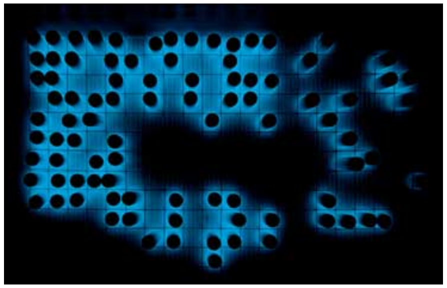


Electromagnetism – causes opposite charges to attract (keeps negative electrons from escaping the positive nucleus).

Strong force – causes quarks to attract, keeps quarks inside proton and neutron and keeps protons and neutrons inside the nucleus.



Unified



Weak force – Causes radioactive decay; some particles only interact via the weak force.

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Unified Electroweak Theory

Believed that weak forces closely related to EM forces.

At very short distances (about 10^{-18} meters) the strength of the weak interaction is comparable to the electromagnetic.

At thirty times that distance (3×10^{-17} m) the strength of the weak interaction is 1/10,000th than that of the electromagnetic interaction.

Concluded that the weak and EM forces have essentially equal strengths. The strength of interaction depends strongly on both the mass of force carrier and distance of the interaction.

- Difference between the observed strengths is due to the huge difference in mass between the W and Z particles, which are massive, and the massless photon.
- Mixing parameter occurs between the Z and photon

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Electroweak Theory – more detail

Mixing parameter between photon and Z predicts many observables.

A) Ratio of the W and Z masses

B) Ratio of coupling strength of EM and weak forces

C) How often electrons or quarks spin one way versus another when they come from a decaying Z particle.

Measurements so precise that a theory initiative was needed to calculate the small quantum effects so theory could be compared at similar accuracy.

At high energy (~1 TeV) the EW theory had problems due to divergences.

A "fix" was to add a single new field (and therefore, a particle H). If a particle like H exists, and it interacts with the known particles, then it must be included to calculate scattering cross sections. Introducing H changed the results of the scattering calculation and gave sensible results.

In the mid-1960s, physicists wrote down theories in which a force carrier could get a mass due to the existence of a new field. In 1967, this effect was incorporated to produce a consistent, unified electroweak theory. It included a new particle, the Higgs boson, which makes up the Standard Model.

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A Mechanism for Mass

Higgs field interacts with all particles, and affects the space particles travel in a dramatic way: It gives them mass. The bigger the coupling between a particle and the Higgs, the bigger the effect, and thus the bigger the particle's mass.

Not only do weak force carriers pick up a mass, so do the fundamental fermions—quarks and leptons—of the SM. Even the neutrino masses require the Higgs effect in order to exist. Which is why we say that the Higgs boson is the **origin of mass**.

The vast majority of mass in our world comes from the mass of the proton and neutron, and thus comes from the confinement of the strong interactions. Yet, the Higgs mechanism is responsible for the electron's mass, which keeps it from moving at the speed of light and therefore allows atoms to exist. Thus, we can say that the Higgs is the **origin of structure.**

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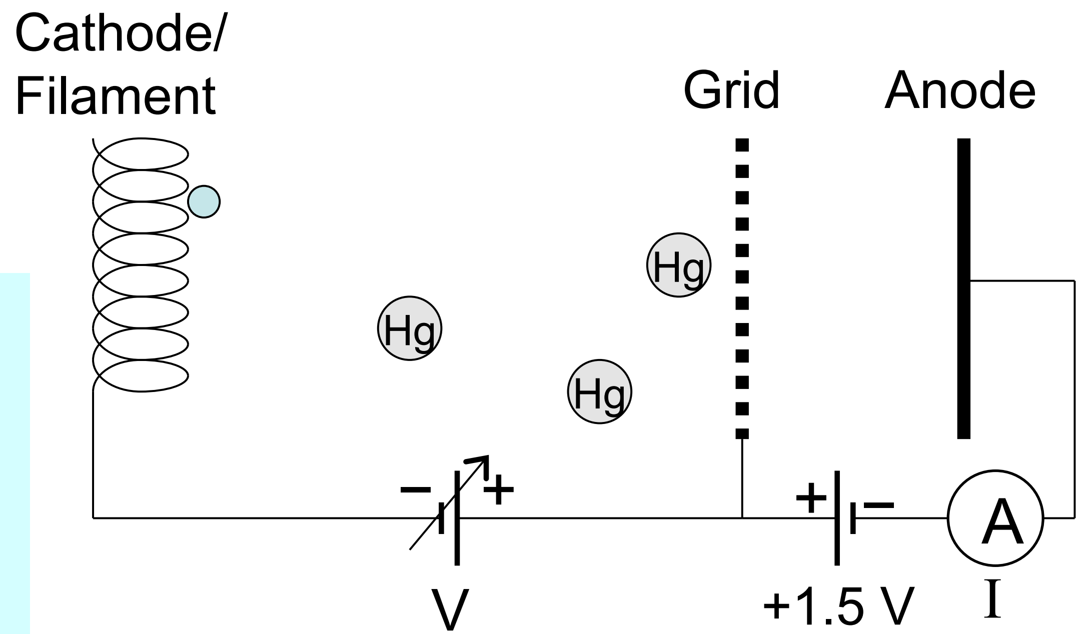
Franck-Hertz experiment

Electrons boil off the cathode and accelerate toward the grid



If e- 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.

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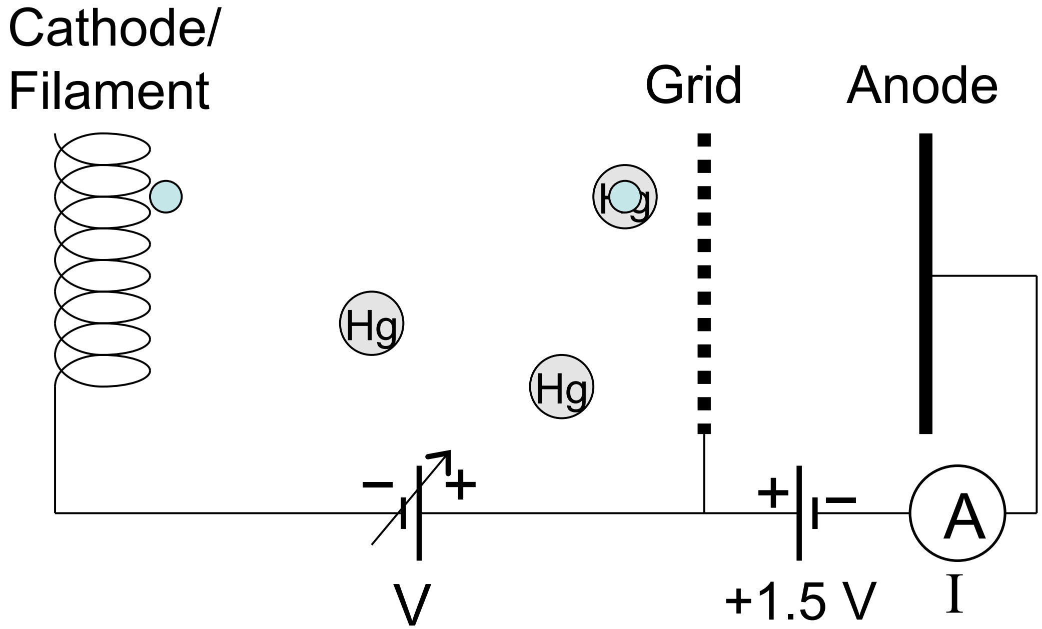
Franck-Hertz experiment

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.

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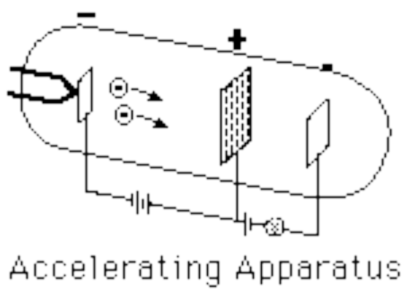
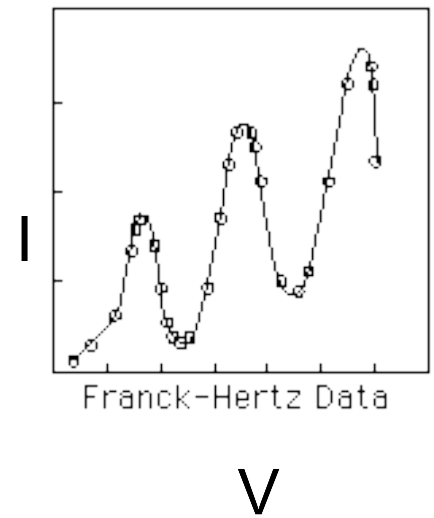
Franck-Hertz experiment cont.





Franck and Hertz found a line in the spectrum of mercury nearly equal to their difference in peaks, namely 4.9eV. It provided a direct measurement of energy differences between quantum states using the dial of a voltmeter.

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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: $R = \frac{2\pi^2 m(ke^2)^2}{ch^3}$

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 issues 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

Reading quiz 1 | Set frequency to AD

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

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E. None of the above

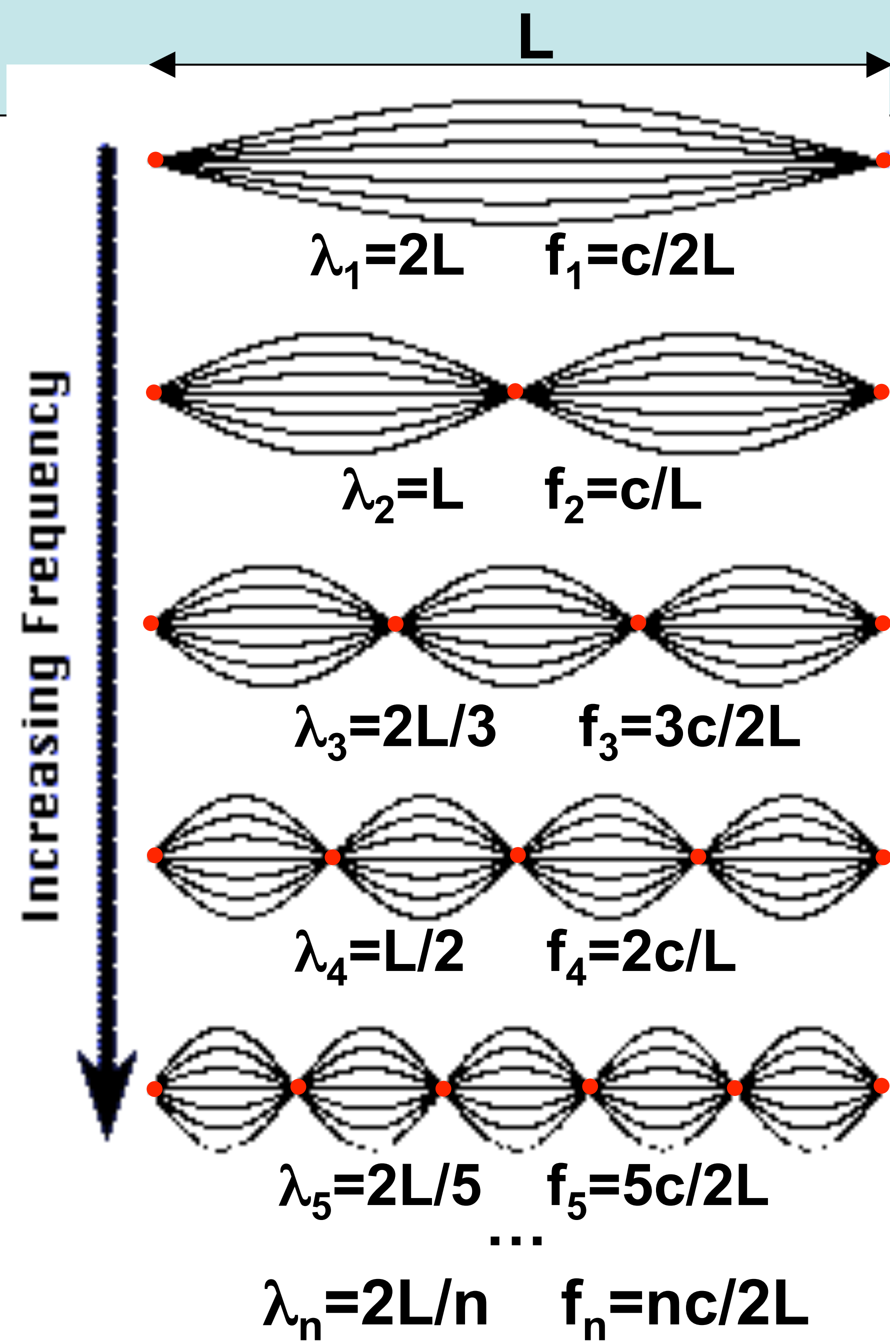
Compton showed that photons have momentum (A)

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.

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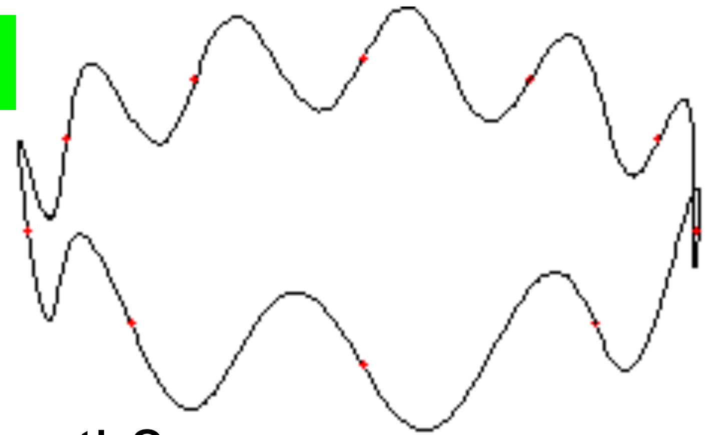
Clicker question 1

Set frequency to DA

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. $2\pi r = \lambda/n$

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

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Clicker question 1

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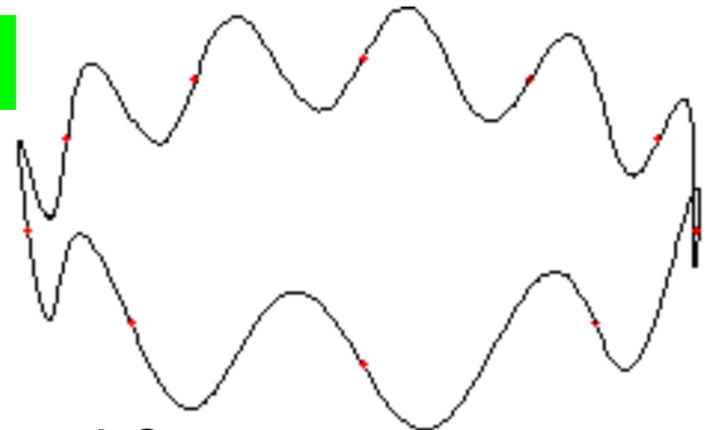

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E. $2\pi r = \lambda/n$

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

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 $2\pi r = n\lambda$.

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de Broglie Waves

Louis de Broglie:
1892 – 1987

- In 1923, French grad student Louis deBroglie 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?

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Clicker question 2

Set frequency to DA

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

A. 1

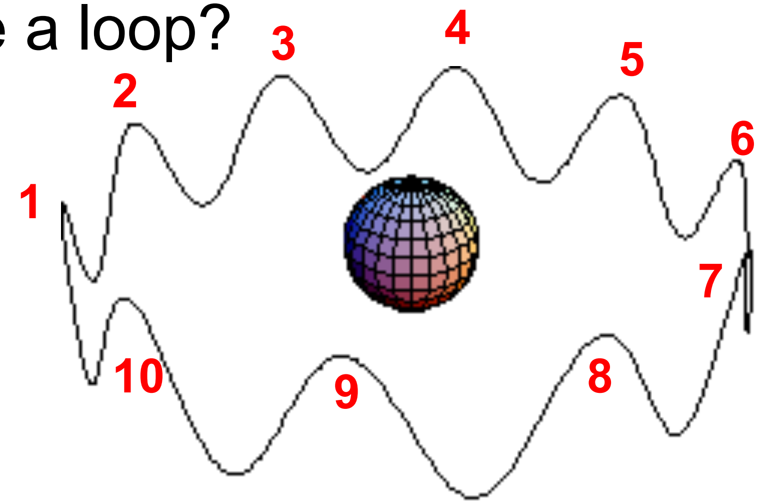
B. 5

C. 10

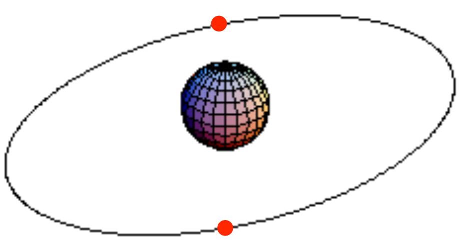
D. 20

E. Cannot determine from picture

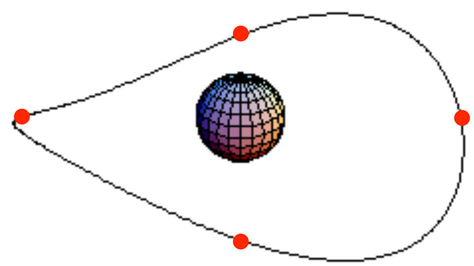
n=10



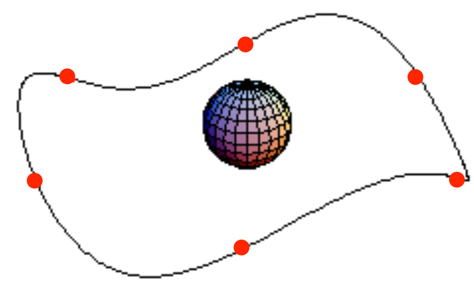
n=1



n=2



n=3



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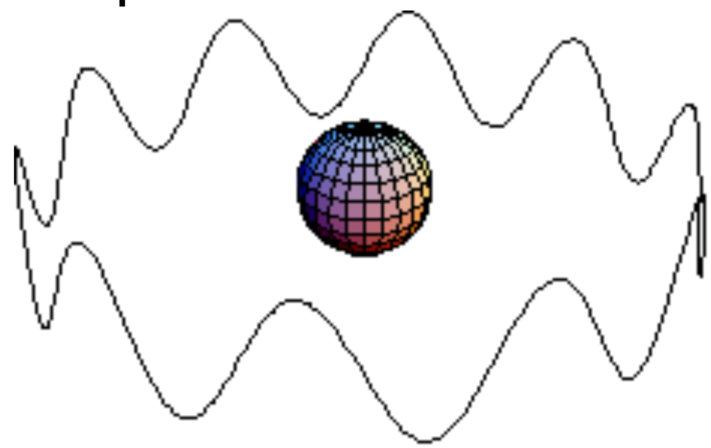

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de Broglie waves

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?!

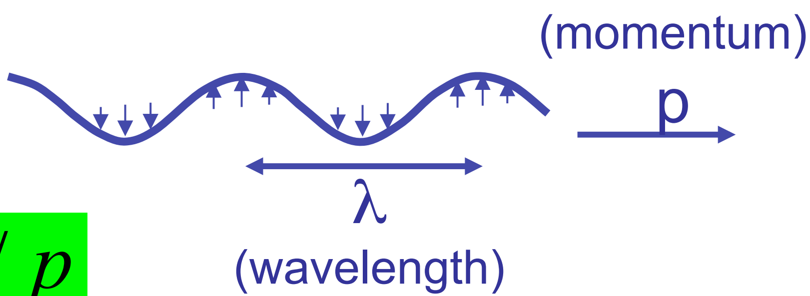
For photons we know how to relate momentum and wavelength

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!

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Clicker question 3 — Set frequency to DA

Given the deBroglie wavelength (**λ=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. $L = n\hbar/2r$

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

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

Clicker question 3 — Set frequency to DA

Given the deBroglie wavelength (**λ=h/p**) and the condition for standing waves on a ring (**2πr = nλ**), 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.

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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 Wednesday.

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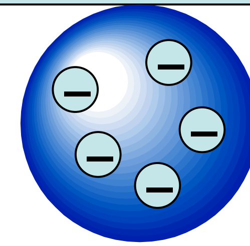
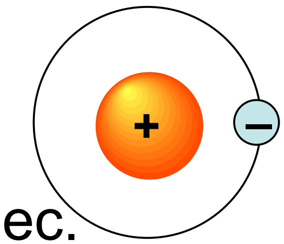
Models of the Atom

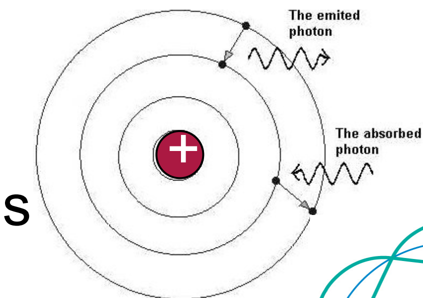
- Thomson – Plum Pudding
  - Why? Known that negative charges can be removed from atom.
  - Problem: just a random guess



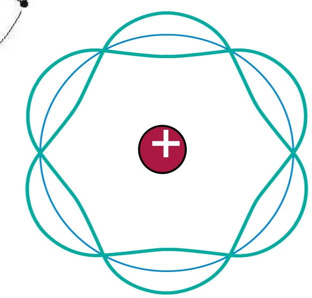
- Rutherford – Solar System
  - Why? Scattering showed hard core.
  - Problem: electrons should spiral into nucleus in ~10^{-11} sec.



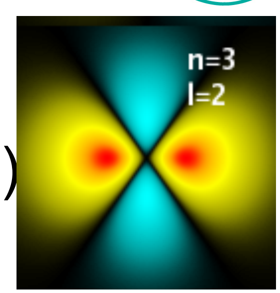
- Bohr – fixed energy levels
  - Why? Explains spectral lines.
  - Problem: No reason for fixed energy levels



- 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)



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