The Hydrogen Atom

Sam McKagan

August 4, 2006

Draft 1

Learning Goals

- Visualize different models of the hydrogen atom.
- Explain the similarities for each model.
- Explain what experimental predictions each model makes.
- Explain why people believed in each model and why each historical model was inadequate.
- Explain the difference between the physical picture of the orbits and the energy level diagram of an electron.
- Gain a sense for how scientists build models.

Overview

- There is a gun which students can use to perform experiments on the atom, including shooting light (white or single color), electrons, or alpha particles at it.
- Students can switch between “experiment” mode, in which they see the outcome of a real experiment on the atom but cannot see inside the atom, and “prediction” mode, in which the model of the atom is explicit, and they can observe what each model would predict for the outcome of an experiment. The only case in which all predictions match the real experiment is for the Schrodinger model.
- Students can change the settings of the gun, but settings should not change when switching between models or between experiment and prediction.
- There is a spectrometer like the one in Discharge Lamps that records the number of photons of each color emitted by the atom. The user should be able to copy the spectrometer like the screen in QWI so they can compare the results of two different models.

Visualization

- Photons should be represented as little balls with tails as in other sims:
- Electrons (both in atoms and from gun) should be represented as little blue spheres as in other sims:
- Alpha particles should be represented as a glob of two red spheres and two gray spheres as in Nuclear Physics:

Gun

- Gun should look like the gun from QWI, with gun controls similar to those in High Intensity panel.
- Particles should come in a wide beam out of all parts of the wide mouth of the gun.
- There is an on/off button on the gun.
- There is an intensity slider for all particles. At minimum intensity, gun shoots one particle at a time, at maximum it shoots many.
- For photons, there is a wavelength slider and a checkbox for white light. If white light is checked (default), slider control removed from wavelength slider and all colors of photons come out of gun. If unchecked, only the color selected by slider comes out. Wavelength slider should include wavelengths in UV & IR that are part of hydrogen spectrum.
- For electrons, there is a velocity slider.
- For alpha particles, no controls other than intensity.

Models

- Billiard Ball – giant solid sphere
- Plum Pudding – squishy blob of positive goo with electron jiggling around in it. Should look as gooey and cartoonish as possible, not jagged like the picture here.
- Solar System – electron orbiting around tiny nucleus. If it is not being bombarded with particles, it will spiral into the nucleus, emitting a steady stream of photons tangent to its path. When it reaches the nucleus, there should be a huge explosion, and atom should be replaced with a note that says "Your atom has been destroyed" and a reset button, which will bring it back.
- Bohr – (see http://hyperphysics.phy-astr.gsu.edu/hbase/hyde.html for details) electron orbiting around tiny nucleus along fixed paths (dotted lines). If it is in higher orbit, it can spontaneously decay to lower orbit, emitting a photon.
- deBroglie – there is no experimental difference between Bohr and deBroglie, but here electrons are represented as waves around a ring rather than electrons orbiting around a ring, with intensity represented by brightness.
- Schrodinger – electrons represented as 3d probability waves.

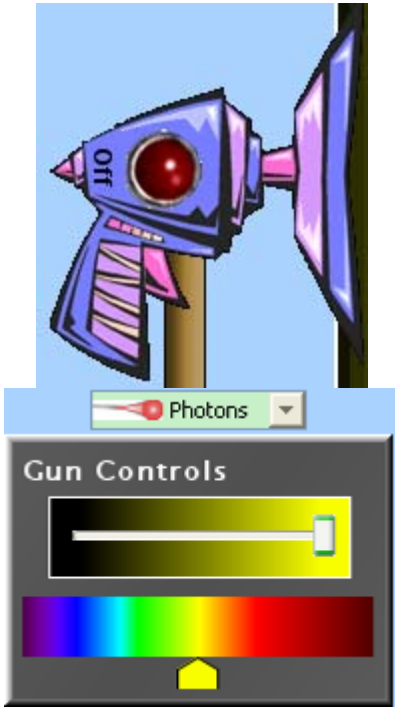
The Hydrogen Atom

File Developer Help

Experiment
(what really happens)

Prediction
(what this model predicts)

Atomic Model



shine white light

Photons emitted

Simulation Speed

slow fast

Java Application Window

The Hydrogen Atom

File Developer Help

Experiment
(what really happens)

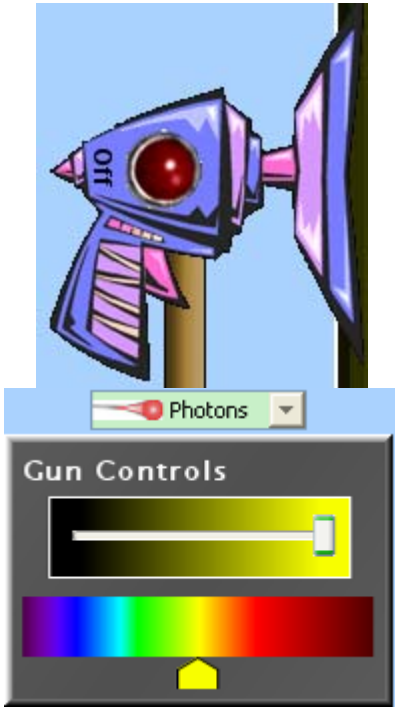
Atomic Model

Classical — Quantum

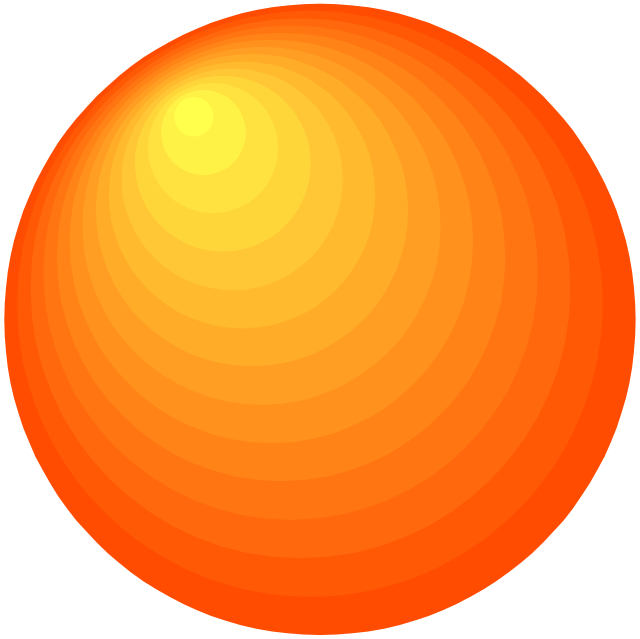
Billiard Ball | Plum Pudding | Solar System | Bohr | deBroglie | Schrodinger

Prediction
(what this model predicts)

Note: Models are not to scale.



shine white light



Photons emitted

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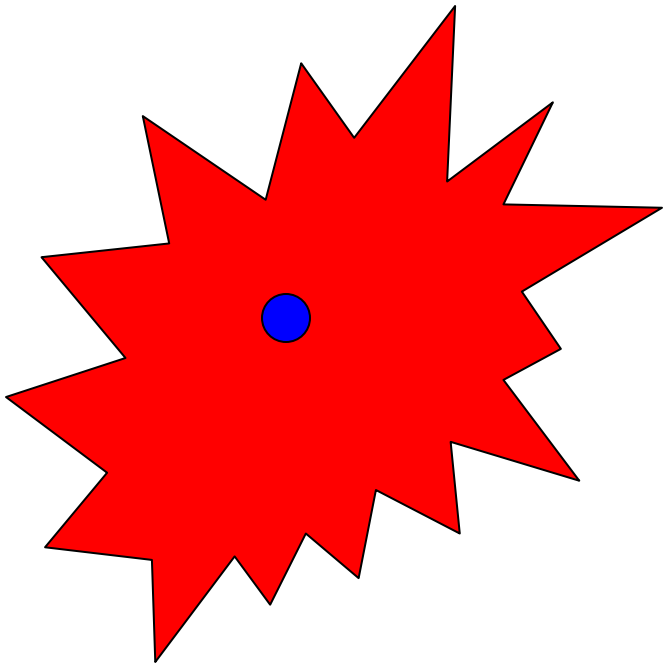

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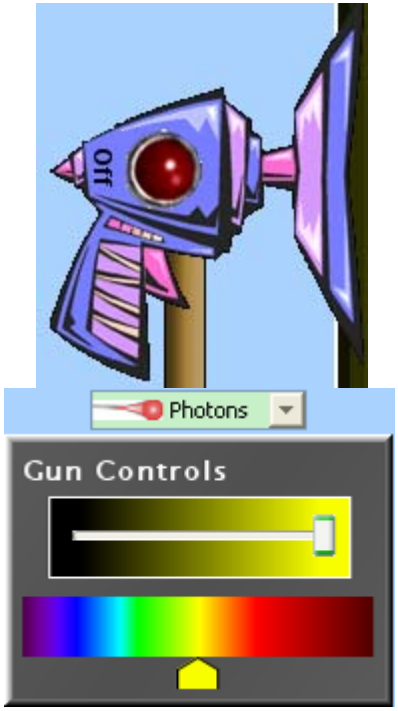

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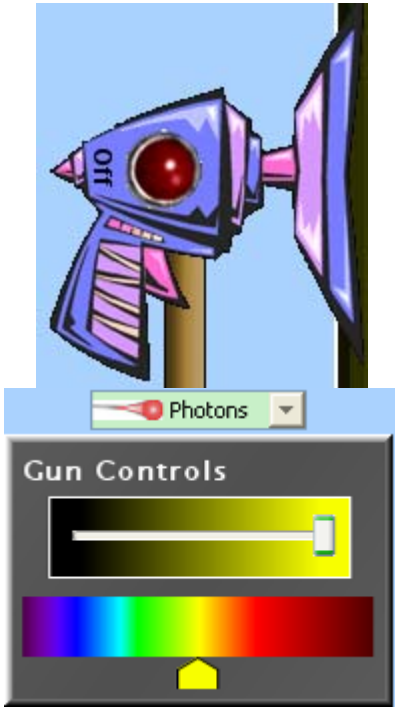

shine white light

Photons emitted

Show energy level diagram

Simulation Speed

slow fast

Java Application Window

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File Developer Help

Experiment
(what really happens)

Atomic Model

Classical ← → Quantum

Billiard Ball Plum Pudding Solar System Bohr deBroglie Schrodinger

Prediction
(what this model predicts)

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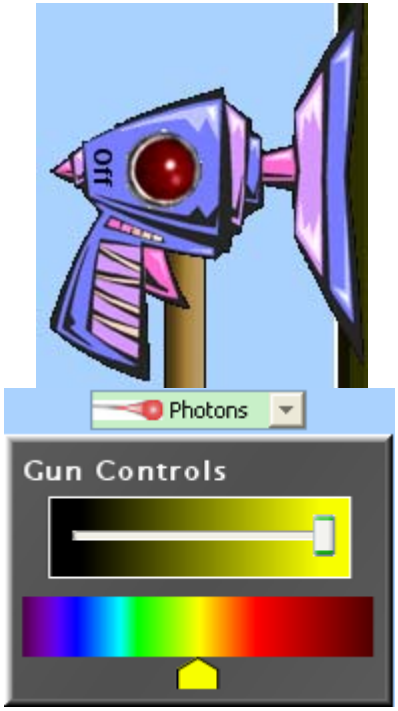

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(what really happens)

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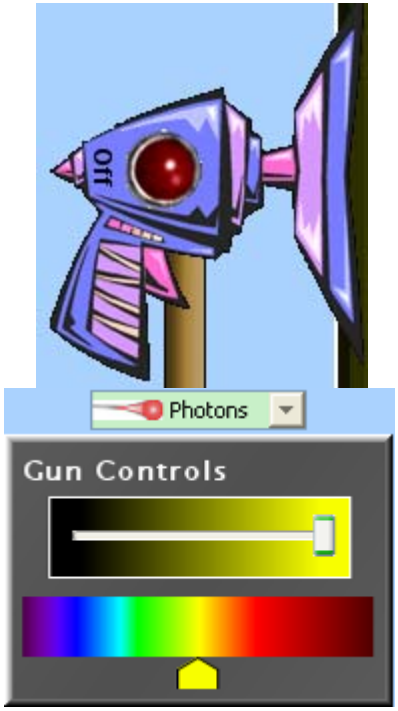
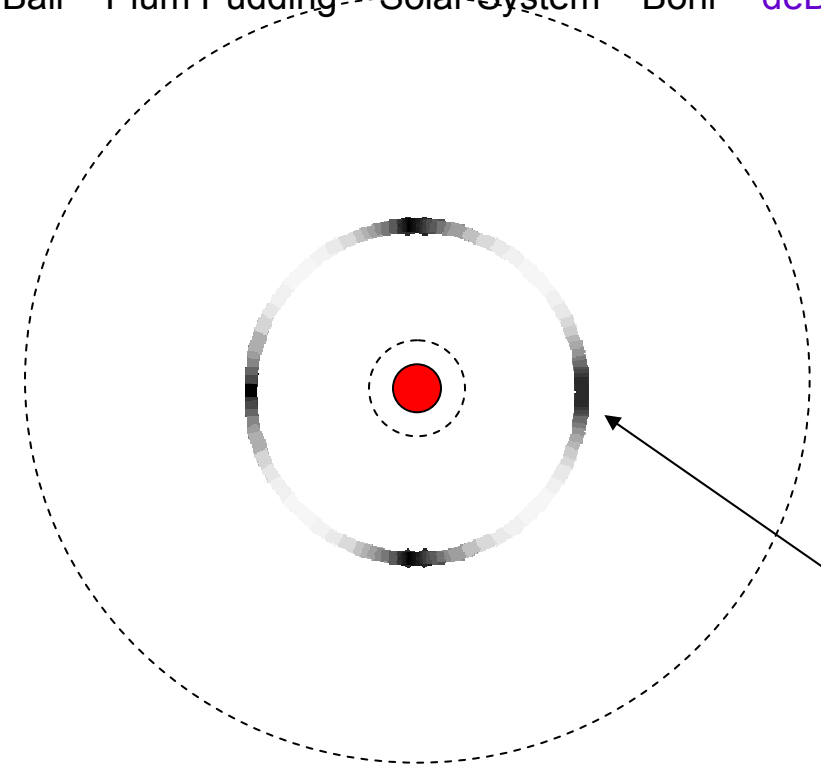


shine white light



(This wave should be blue, but I can't figure out how to draw it that way.)

Show energy level diagram

Simulation Speed

slow fast

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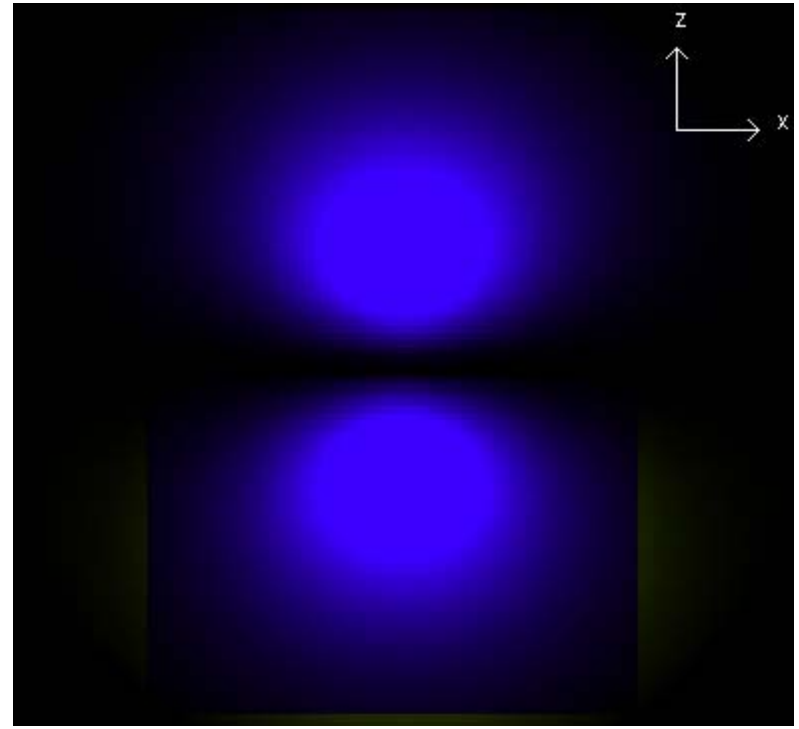

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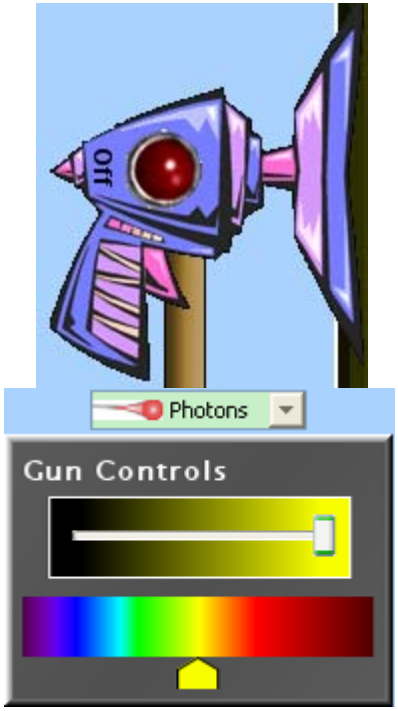


☐ shine white light

Photons emitted

☐ Show energy level diagram

Simulation Speed

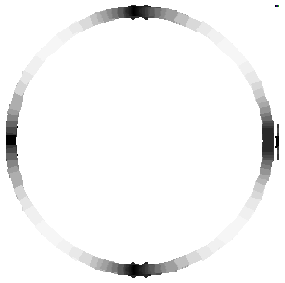
slow — fast

Java Application Window

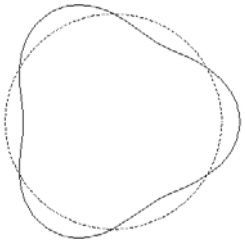
Representation of waves in deBroglie model.

There are several possible ways to represent standing waves on a ring:

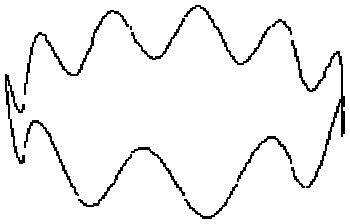
- Brightness = mag. of amplitude, bright = large mag (+ or -), dark = 0 (e.g. QWI, radio waves):
- Brightness = amplitude, bright = +, dark = -, grey = 0 (e.g. wave interference):



- Radial distance = amplitude:



- 3D perspective view, height = amplitude:



One of the brightness representations is probably best, but we have no interview data on how students will react to this representation alone. Ideally, it would be great to have all 4 representations available in an options menu and interview on them to see what works best.

Action of Firing Photons

- Billiard Ball – all photons bounce off.
- Plum Pudding – All photons are absorbed and cause the electron to jiggle around. Speed of jiggling proportional to frequency.
- Solar System – All photons are absorbed and cause the electron to jump to larger orbital radius. Radius proportional to frequency.
- Bohr – Only photons with correct energy are absorbed and cause electron to jump to higher level. (see table) Other photons go right through. All transitions are equally likely so spectrometer will show all colors that can be emitted building up equally.
- deBroglie – same as Bohr
- Schrodinger – same as Bohr, except that not all photons are absorbed even if they have the correct energy. Probability of photons being emitted is different for each color, so spectrometer builds up unevenly. (see table – relative intensity ~ probability of being absorbed)

Note: for all models with an electron, if the photons give the electron sufficient energy, it can be removed from atom. If this happens, electron should fly off and a note should come up that says “Your atom has been ionized. Hit OK to capture another electron.”

Spectral Line Table

From:

http://hyperphysics.phy-astr.gsu.edu/hbase/tables/hydspec.html#c1

And:

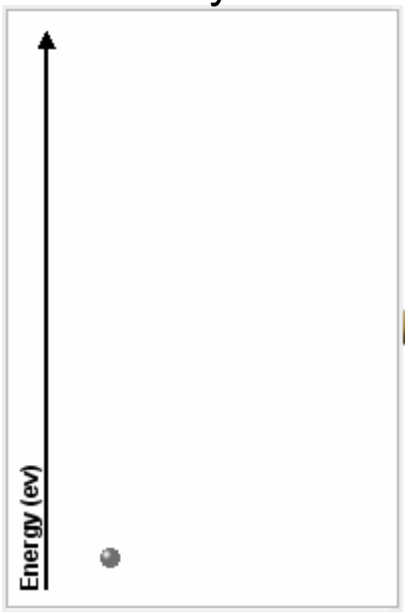
http://physics.nist.gov/PhysRefData/Handbook/Tables/hydrogentable2.htm

Wavelength (nm)	Relative Intensity	Transition	Color or region of EM spectrum
Lymann Series			
93.782	30	6 -> 1	UV
94.976	50	5 -> 1	UV
97.254	100	4 -> 1	UV
102.583	300	3 -> 1	UV
121.566	1500	2 -> 1	UV
Balmer Series			
383.5384	5	9 -> 2	Violet
388.9049	6	8 -> 2	Violet
397.0072	8	7 -> 2	Violet
410.174	15	6 -> 2	Violet
434.047	30	5 -> 2	Violet
486.133	100	4 -> 2	Bluegreen (cyan)
656.272	120	3 -> 2	Red
656.2852	180	3 -> 2	Red
Paschen Series			
954.62	5	8 -> 3	IR
1004.98	7	7 -> 3	IR
1093.8	12	6 -> 3	IR
1281.81	20	5 -> 3	IR
1875.01	40	4 -> 3	IR
Brackett Series			
2630	8	6 -> 4	IR
4050	15	5 -> 4	IR
Pfund Series			
7400	6	6 -> 5	IR

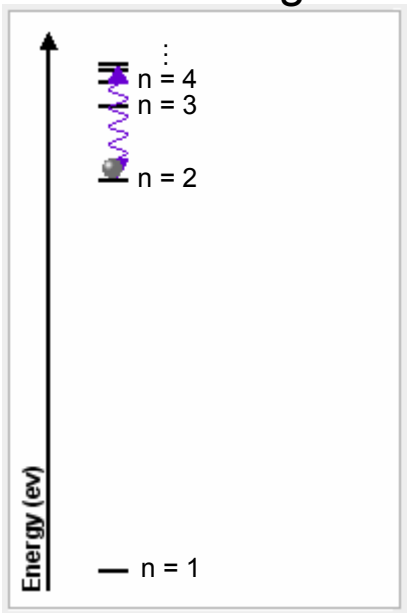
Energy Level Diagrams

- For last 4 models, when “show electron energy level diagram” is checked, a diagram should appear in a separate window. For Bohr/deBroglie, this diagram is identical to the one in Discharge Lamps. For Schrodinger, there are additional states corresponding to different angular momentum, For Solar System, electron energy can change continuously – no discrete energy levels.

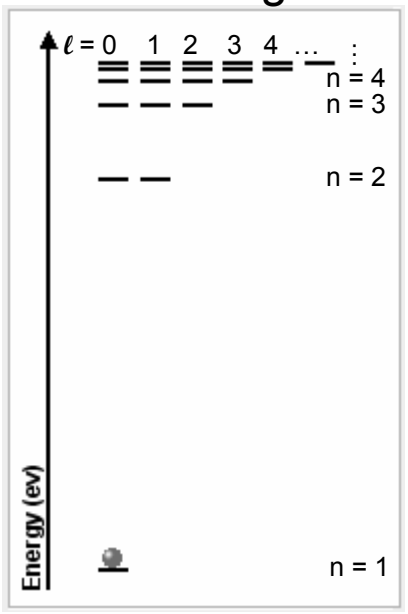
Solar System



Bohr/deBroglie



Schrodinger



Action of Firing Electrons

- Billiard Ball – electrons bounce off.
- Plum Pudding – When electrons hit electron in atom, they slow down, transferring energy to other electron, causing it to jiggle around. If electrons have enough energy, they can pop electrons out.
- Solar System – When electrons hit electron in atom, they slow down, transferring energy to other electron, causing it to jump to larger orbital radius. If electrons have enough energy, they can pop electrons out.
- Bohr – Same as solar system, except that only energies corresponding to difference between energy levels can be transferred.
- deBroglie – same as Bohr
- Schrodinger – same as Bohr

Action of Firing Alpha Particles

- Billiard Ball – Alpha particles bounce off atoms at all different angles.
- Plum Pudding – Alpha particles bounce off atoms at all different angles.
- Solar System – Most alpha particles go straight through. A few hit the nucleus and bounce straight back.
- Bohr – same as solar system
- deBroglie – same as solar system
- Schrodinger – same as solar system