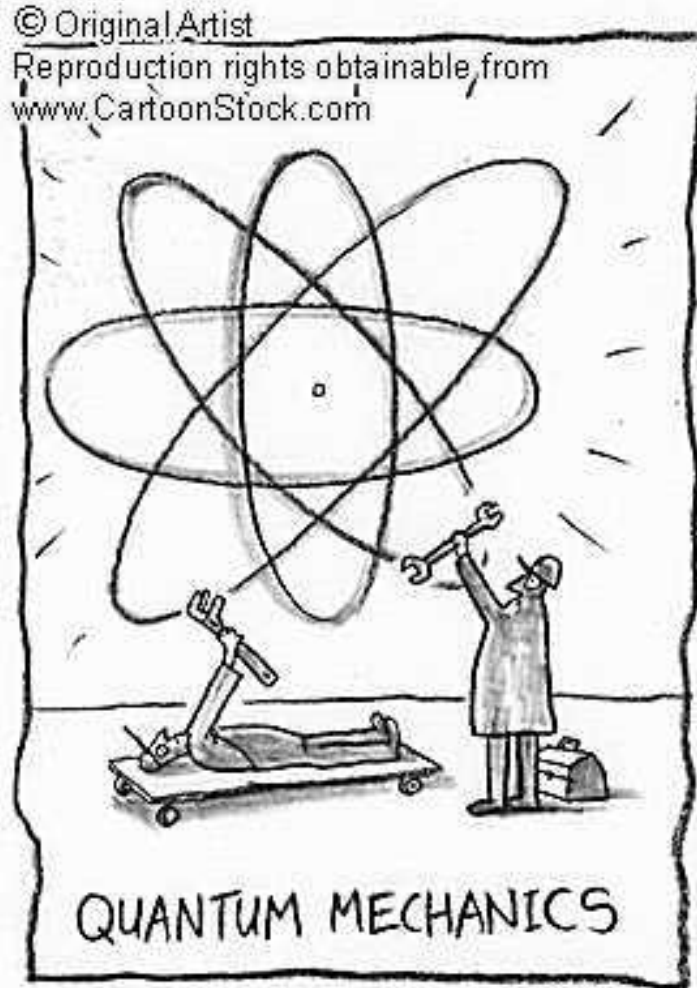


# The Quantum Model of the Atom



[https://www.cartoonstock.com/directory/q/quantum\\_mechanics.asp](https://www.cartoonstock.com/directory/q/quantum_mechanics.asp)

## Outcomes:

Outline the historical development of the Quantum Mechanical Model of the atom.

# Previous Models of the Atom

In previous courses we have looked at the progression of the atomic model.

## Democritus (440 B.C.)

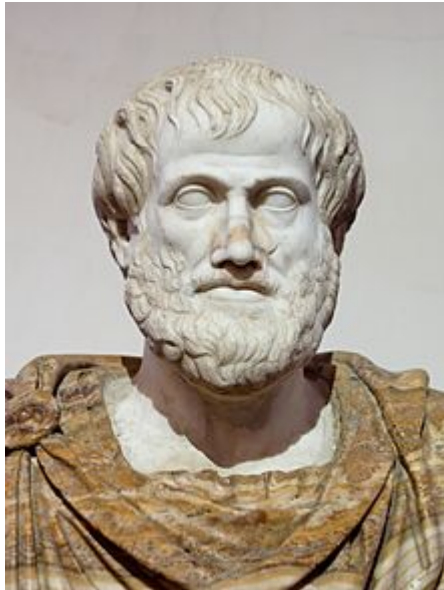
- Said matter was made of **INDESTRUCTIBLE** particles called **ATOMS** (from **ATOMOS** – meaning indestructible)



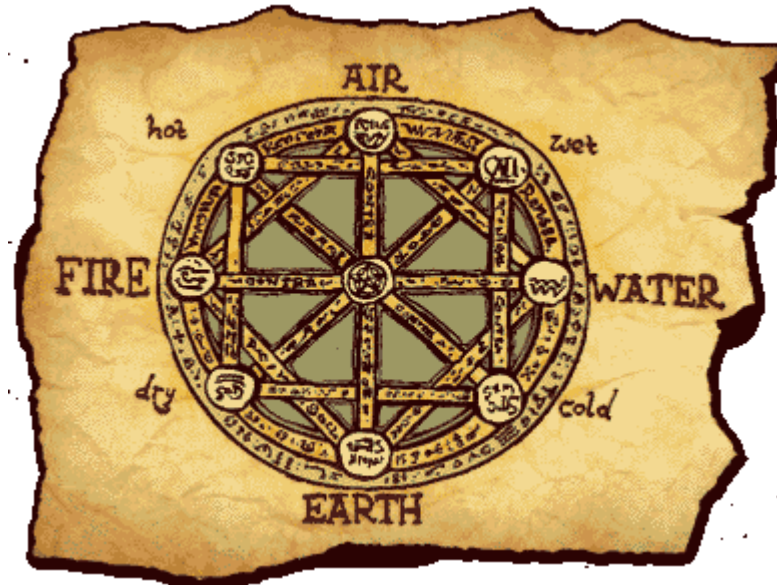
# Previous Models of the Atom

## Aristotle (around 540 B.C.)

- Didn't believe in the ATOMIC model.
- Said matter was made of four elements: EARTH, AIR, WATER and FIRE.
- This was the belief for several hundred years.



<https://en.wikipedia.org/wiki/Aristotle>



<http://recuerdosdepandora.com/ciencia/fisica/la-gravedad-segun-aristoteles/>

# Previous Models of the Atom

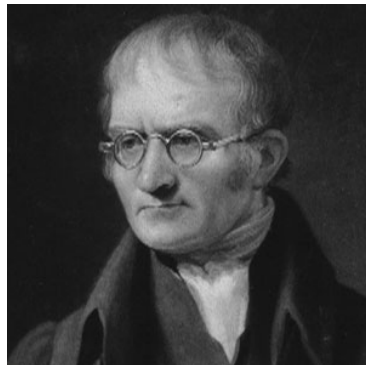
## Robert Boyle & Sir Isaac Newton (16-1700's)

- Revived the ATOMIC MODEL of matter.



## John Dalton (1803)

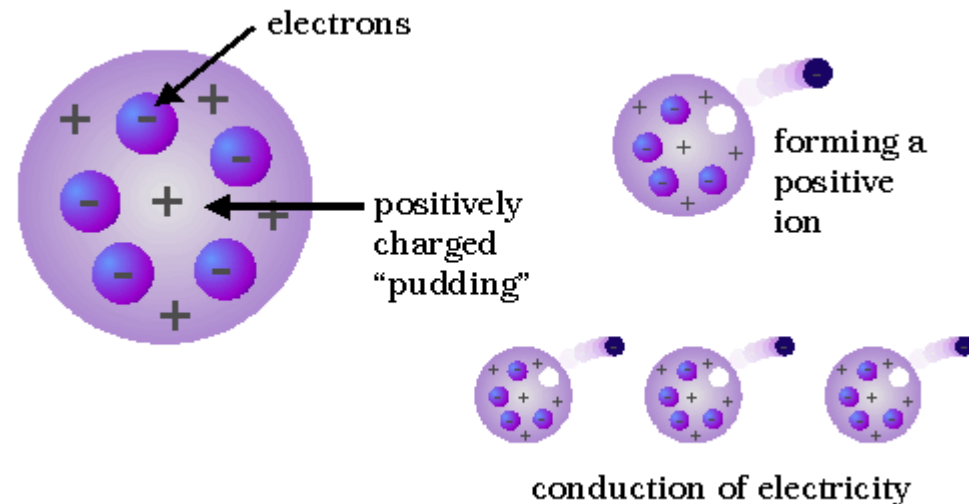
- The atom was a SOLID INDESTRUCTIBLE SPHERE
- *"The billiard ball model"*



# Previous Models of the Atom

## J.J. Thomson (1897)

- The atom is a sphere of **POSITIVE CHARGE** with negatively charged **ELECTRONS** stuck inside
- **“The raisin bun”** or **“plum pudding”** model.

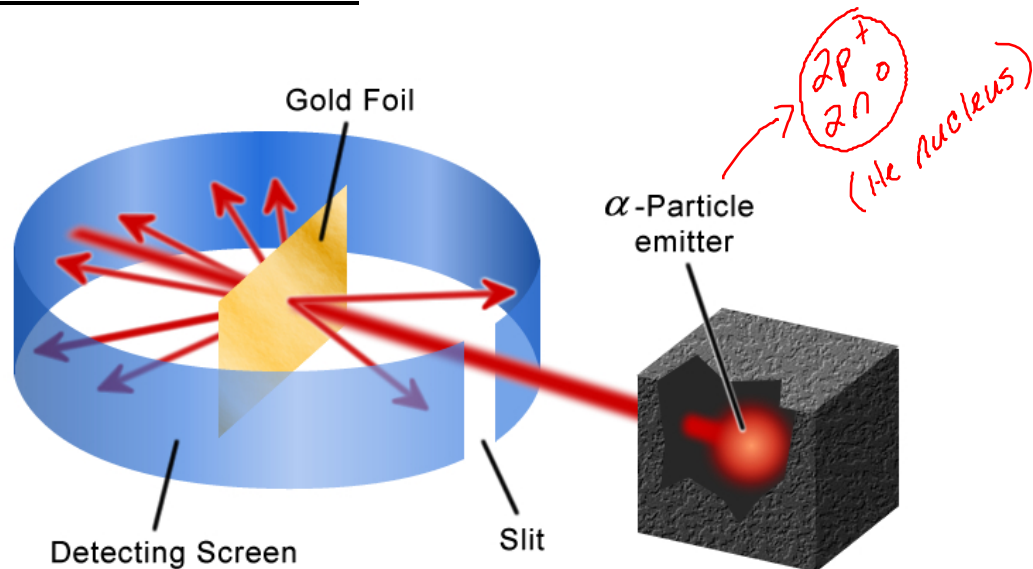


[http://abyss.uoregon.edu/~js/21st\\_century\\_science/lectures/lec11.html](http://abyss.uoregon.edu/~js/21st_century_science/lectures/lec11.html)

# Previous Models of the Atom

## Ernest Rutherford (1911)

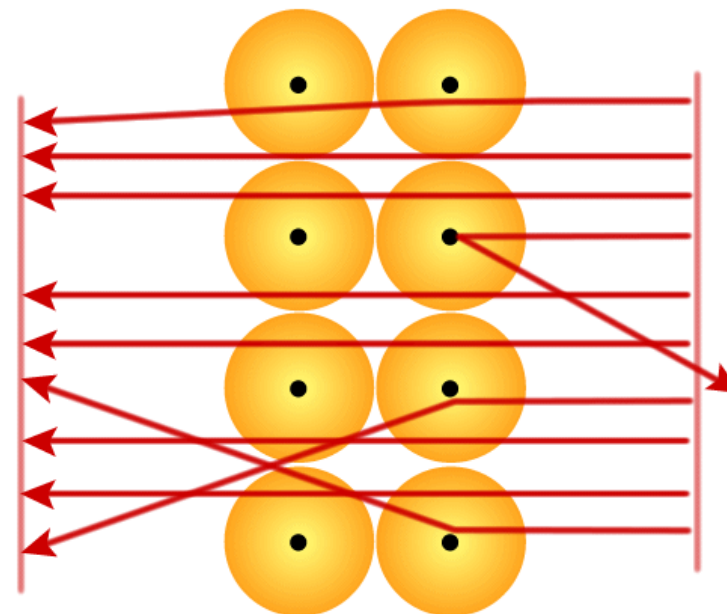
- Performed the famous “**GOLD FOIL**” experiment
- Said the atom had a dense **POSITIVE NUCLEUS**, with **NEGATIVE** electrons moving around **OUTSIDE**.
- “**The nuclear model**”



**Gold Foil**

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<http://www.dlt.ncssm.edu/tiger/chem1.htm>



**Gold Description**

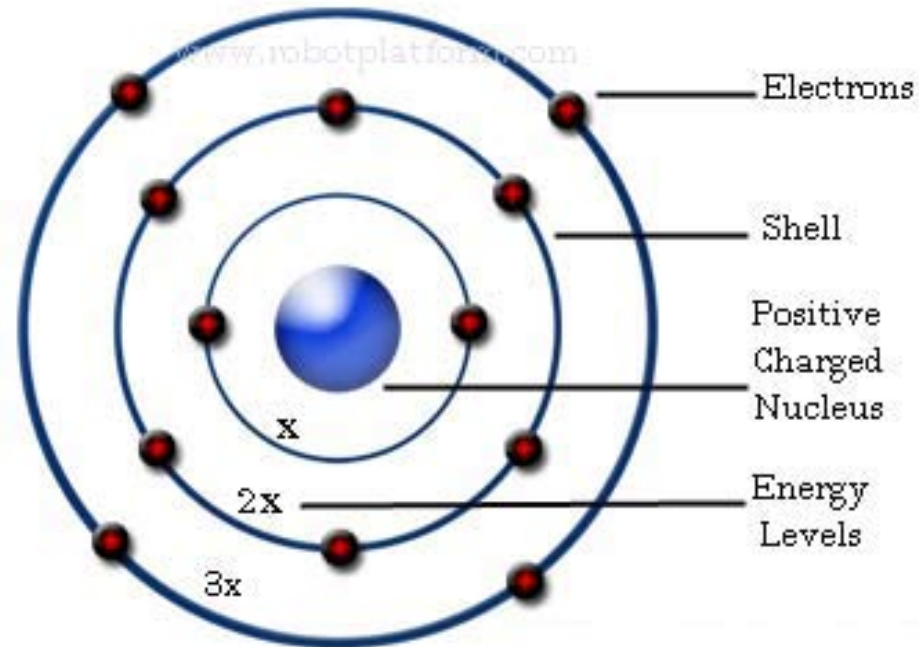
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<http://www.dlt.ncssm.edu/tiger/chem1.htm>

# Previous Models of the Atom

## Neils Bohr (1922)

- Put the electrons into ORBITS around the nucleus.
- The “*planetary model*”

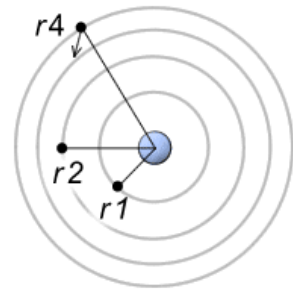


<http://thehistoryoftheatom.weebly.com/niels-bohr.html>

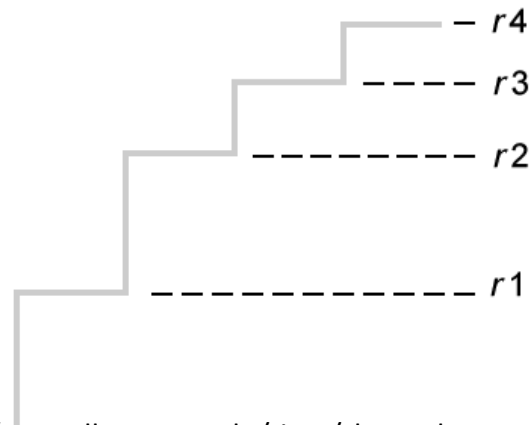
# Bohr's Model & Line Spectra

Bohr's model was able to explain hydrogen's **LINE SPECTRA**.

- Bohr proposed that the electrons in a hydrogen atom are arranged in **STABLE ORBITS** around the nucleus depending on their **ENERGY**.
- He said the orbits were like a **LADDER** with unequally spaced rungs. Or a **STAIRWAY** with **UNEQUAL STAIRS**.



Electron  
Energy Levels



<http://www.dlt.ncssm.edu/tiger/chem1.htm>

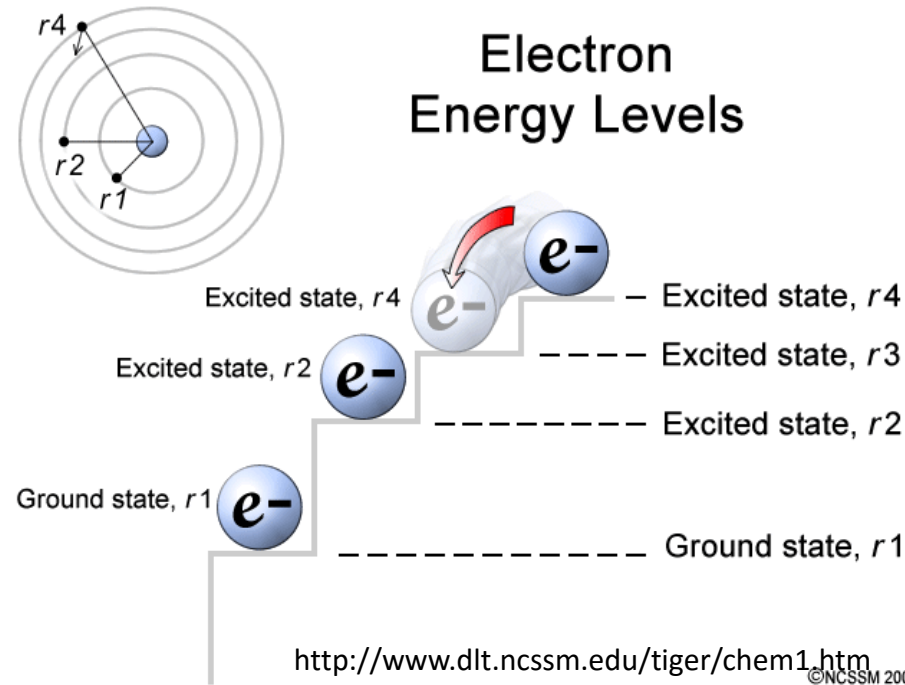
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- When energy is absorbed by an atom, an electron can jump from its **GROUND** (resting) **STATE** to an **EXCITED STATE**.



# Bohr's Model & Line Spectra

- Since this excited state is **UNSTABLE**, the electron will eventually **FALL** back down to its ground state, **RELEASING ENERGY** in the form of **LIGHT**.



- Only certain, distinct lines appear because the electrons are only able to occupy **CERTAIN** energy levels.
- This means that only **SPECIFIC AMOUNTS** or **QUANTA** of energy are released.
- This is true for the other elements but gets much more complicated.

[Animation of Bohr's Model](#)

# Bohr's Model & Line Spectra

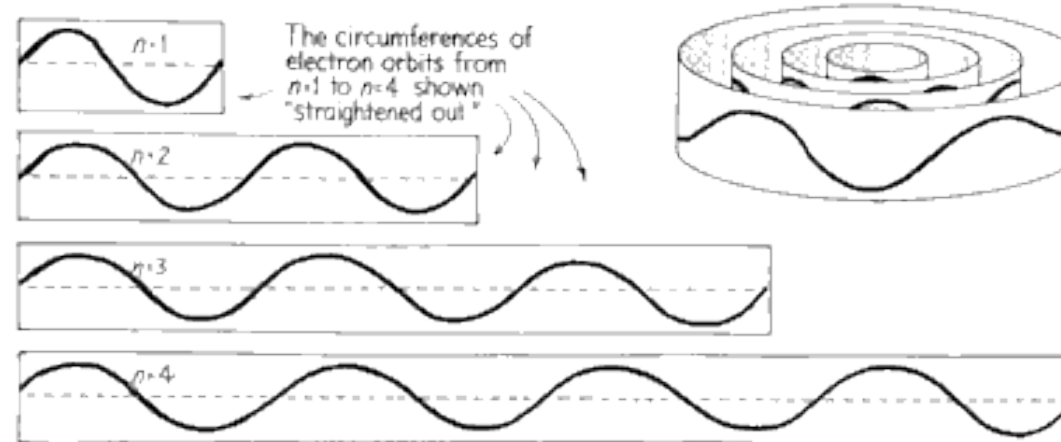
Bohr's model works well for hydrogen because it only has one electron, but it left chemists and physicists with many questions...

- *Why should electrons be confined to only specified energy levels?*
- *Why don't electrons give off light all of the time?*
- *Why could only two electrons fit in the first shell and why eight electrons in each shell after that?*
- *What was so special about two and eight?*

Obviously, the Bohr model was missing something!

# Louis de Broglie (1924)

- Suggested that, like light, electrons could act as both **PARTICLES** and **WAVES**
- This was soon confirmed in experiments that showed electron beams could be diffracted or bent as they passed through a slit much like light could.
- So the waves produced by an electron confined in its orbit about the nucleus sets up a **STANDING WAVE** of specific **WAVELENGTH**, **ENERGY** and **FREQUENCY** (i.e., Bohr's **ENERGY LEVELS**)
  - *Much like a guitar string sets up a standing wave when plucked.*



[http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear\\_deBroglieMatterWaves.xml](http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear_deBroglieMatterWaves.xml)

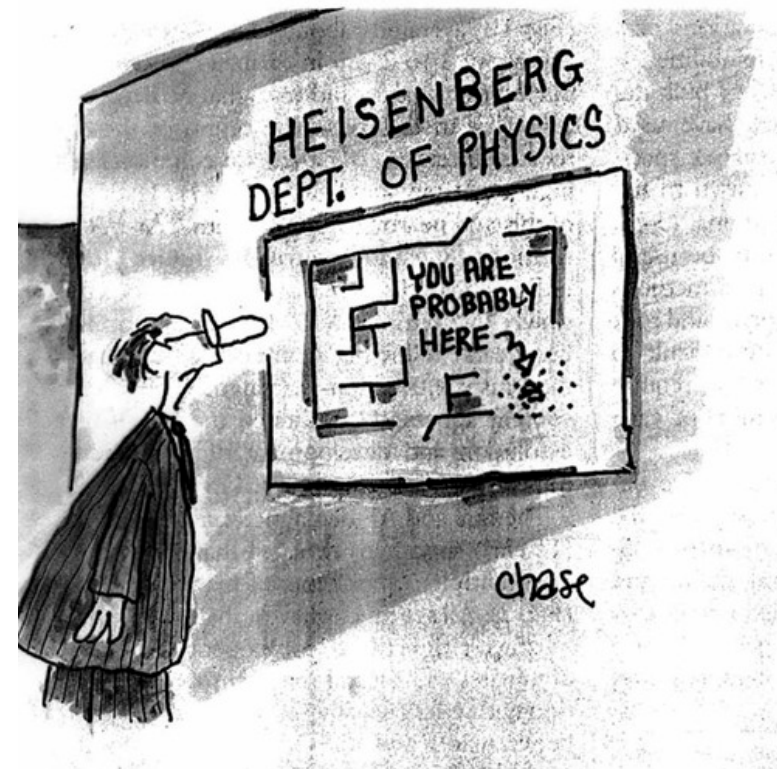
## Wave Interference Animation

***If an electron traveled as a wave, could you locate the precise position of the electron within the wave?***

# Werner Heisenberg



- The **HEISENBERG UNCERTAINTY PRINCIPLE**:
  - *“it is impossible to know simultaneously the momentum and position of a particle with certainty”*
- In other words, it is impossible to determine the **EXACT LOCATION** of an electron, but we can determine a **PROBABLE** location.



# Erwin Schrodinger

- Derived a set of equations or **WAVE FUNCTIONS** in 1926 for electrons.

For a single particle in three dimensions:

$$i\hbar \frac{\partial}{\partial t} \psi = -\frac{\hbar^2}{2m} \nabla^2 \psi + V(x, y, z) \psi$$

where

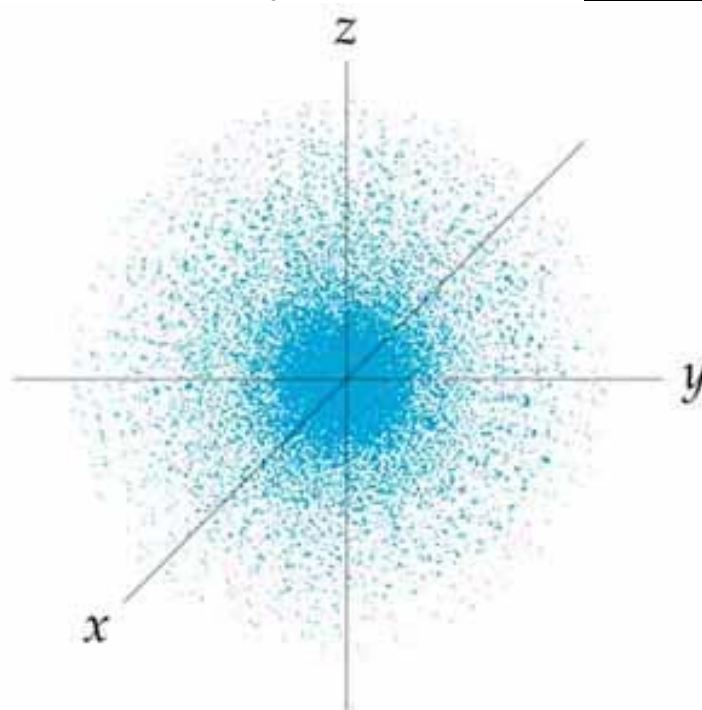
- $\psi$  is the wavefunction, which is the amplitude for the particle
- $m$  is the mass of the particle.
- $V(x,y,z)$  is the potential energy the particle has at each position.

<http://functionspace.com/topic/498/What-are-the-most-fundamental-laws-principles-in-Physics->

- Electrons confined in their **ENERGY LEVELS** would set up standing waves and you could describe only the **PROBABILITY** of where an electron could be.

# Erwin Schrodinger

- The **DISTRIBUTIONS** of these **PROBABILITIES** formed regions of space about the nucleus were called **ORBITALS**.
- Orbitals could be described as **ELECTRON DENSITY CLOUDS**
- The **DENSEST** area of the cloud is where you have the **GREATEST PROBABILITY** of finding the electron.



<http://wps.prenhall.com/wps/media/objects/3311/3390683/blb0605.html>

- Bohr's orbits or energy levels become **PRINCIPAL QUANTUM NUMBERS (n)**, also called **PRINCIPAL ENERGY LEVELS**.

# Energy Levels & Orbitals

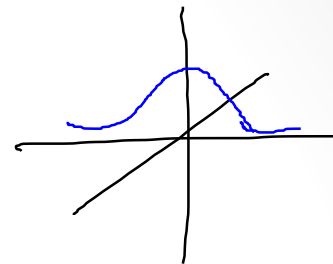
- Within each energy level are a set of orbitals or sublevels.
- In the Bohr atom the “orbit” was a **PATH** the electron would follow.
- Now, orbitals represent **REGIONS** in space around the nucleus that the electron will **PROBABLY** be **FOUND**.
- The **PRINCIPAL QUANTUM NUMBER** will indicate the **SIZE** and **ENERGY** of each orbital.
  - *The lowest energy level is  $n=1$  and the highest is  $n=7$ .*
- As the value of  $n$  **INCREASES** the energy levels become **LARGER** and the electrons spend more time **FURTHER** from the nucleus.

[Models of the Hydrogen Atom](#)

# Electron Orbitals

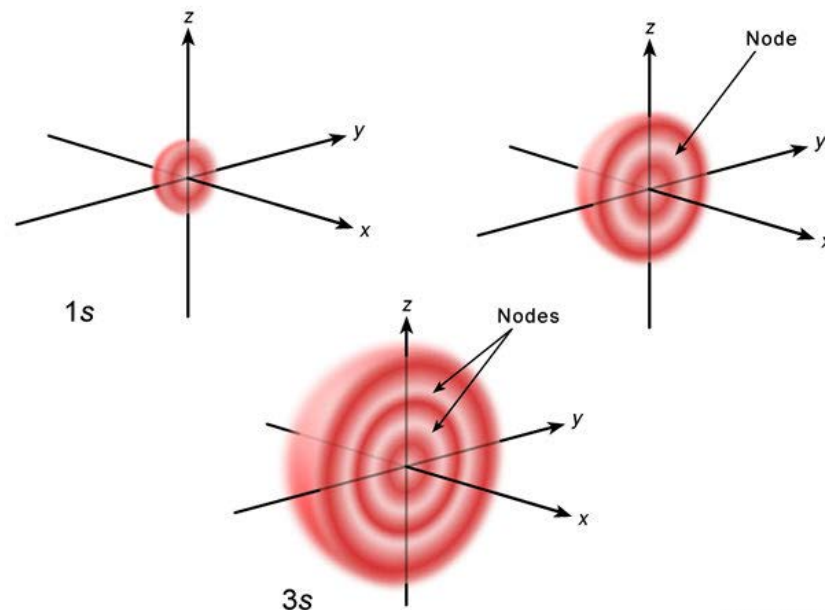
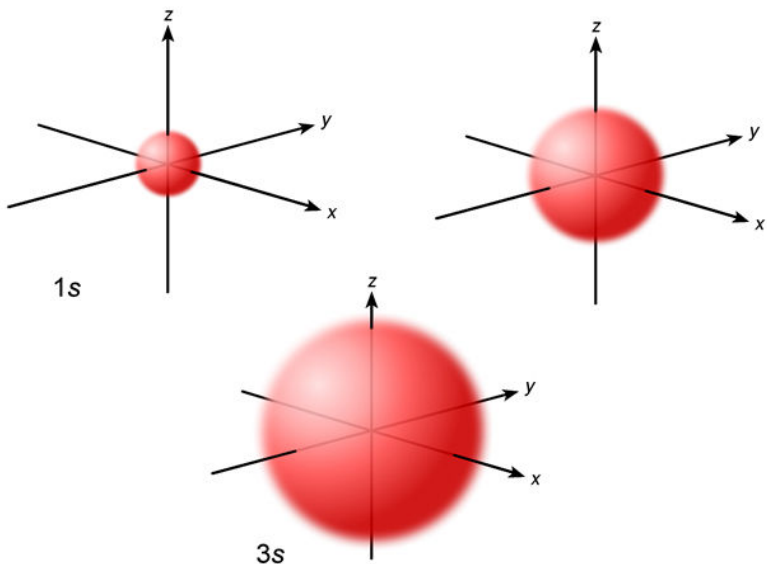
There are 4 main types of orbitals with different regions of probability.

- They have the letter names: **s, p, d and f.**
- These regions of probability result in **FUZZY** electron **CLOUDS** that have different **SHAPES:**



## S-Orbitals

- The s-orbitals are **SPHERICAL** in shape and are found in **ALL** energy levels.
- The s-orbital in the first energy level is given the designation 1s, the s-orbital in the second energy level has the designation 2s, etc.

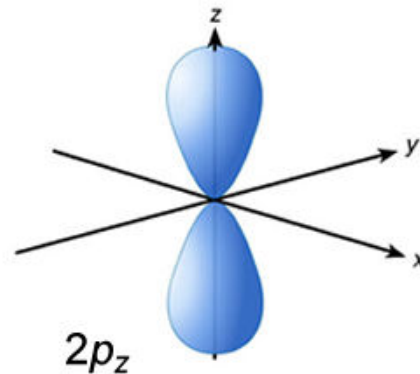
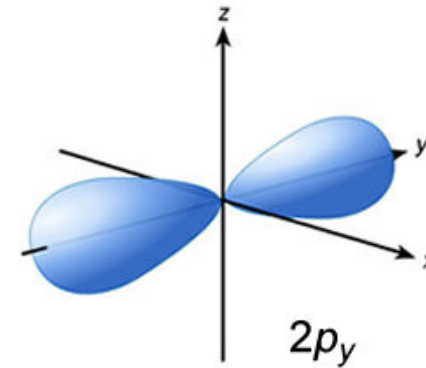
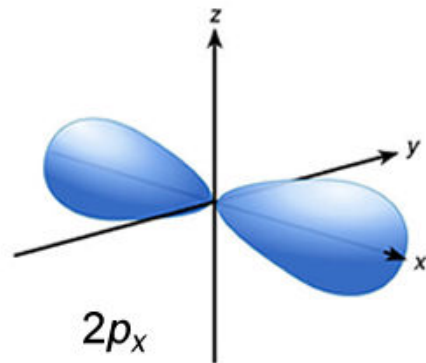
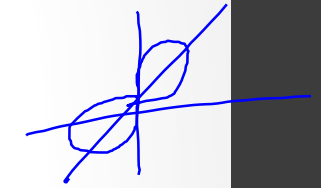
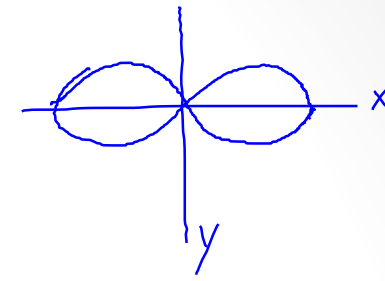




# Electron Orbitals

## P-Orbitals:

- The p-orbitals are **DUMBBELL-SHAPED** and each has two regions or **LOBES** of high probability.
- Are only found in the **SECOND** energy level and **UP**.

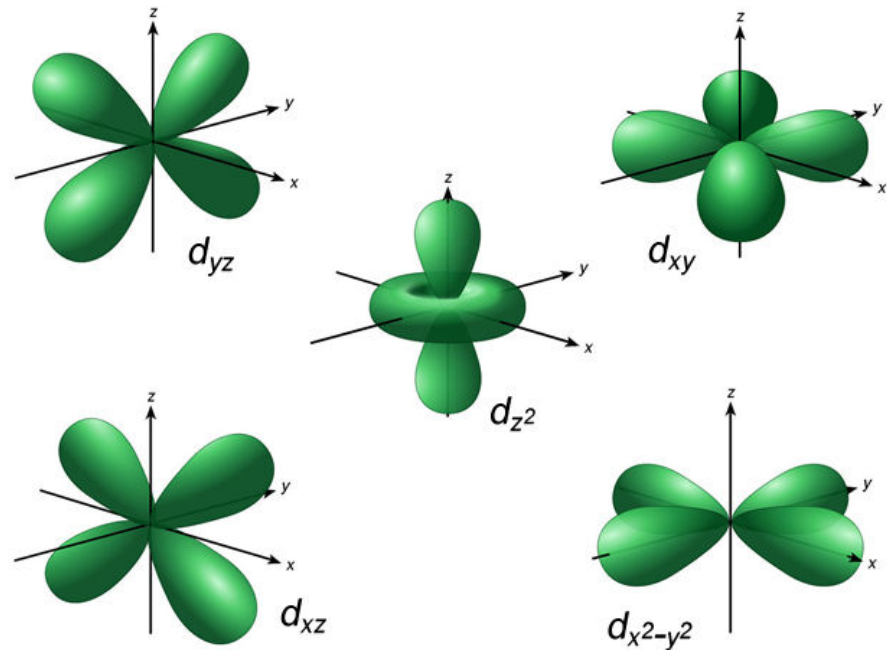


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# Electron Orbitals

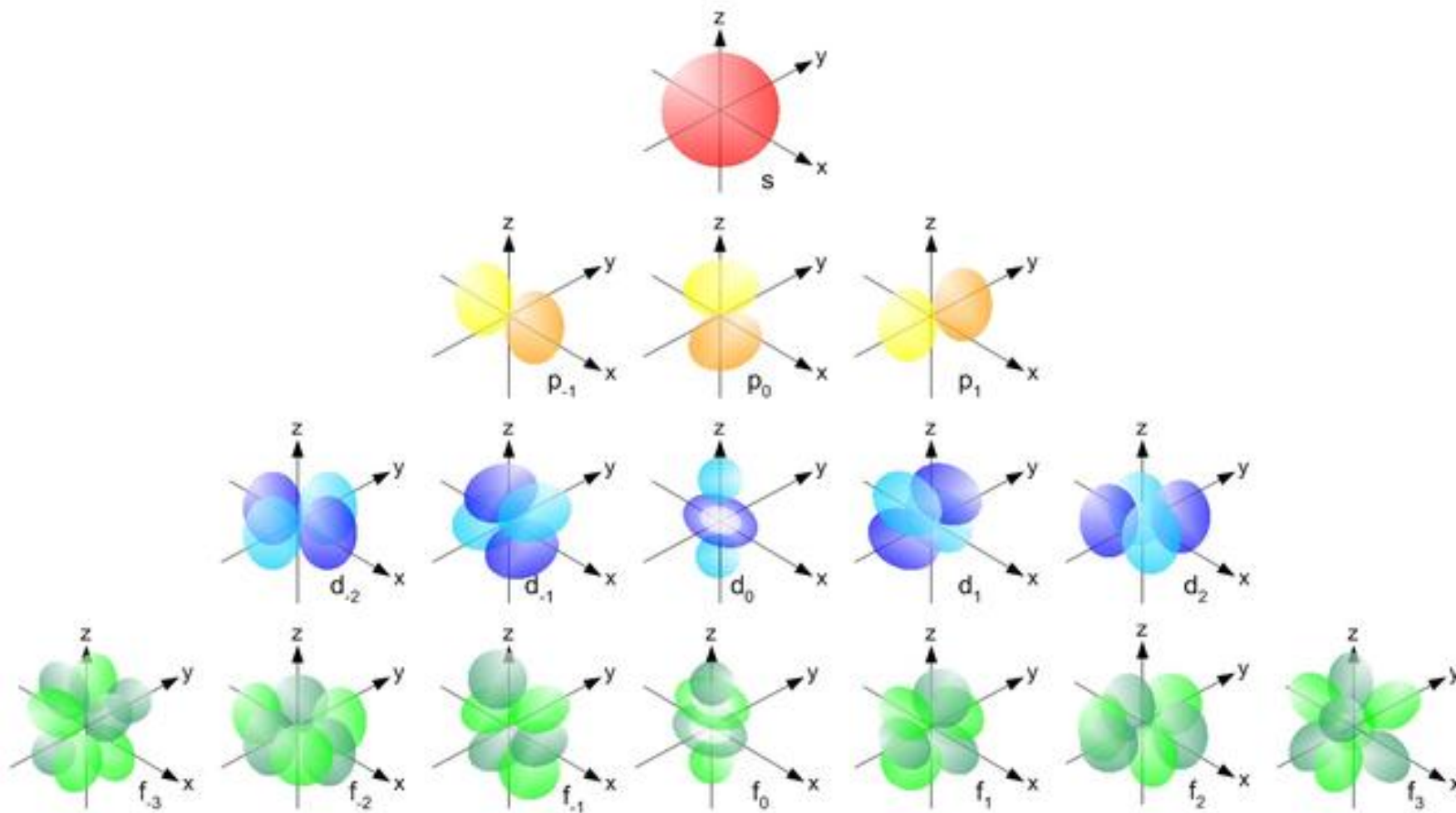
## D-Orbitals:

- d-orbitals are only present in the **THIRD** energy level and **UP**.
- As you can see, the shapes of the orbitals get much more complicated as you go up.



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# Electron Orbitals



<https://www.khanacademy.org/science/chemistry/electronic-structure-of-atoms/orbitals-and-electrons/v/quantum-numbers>