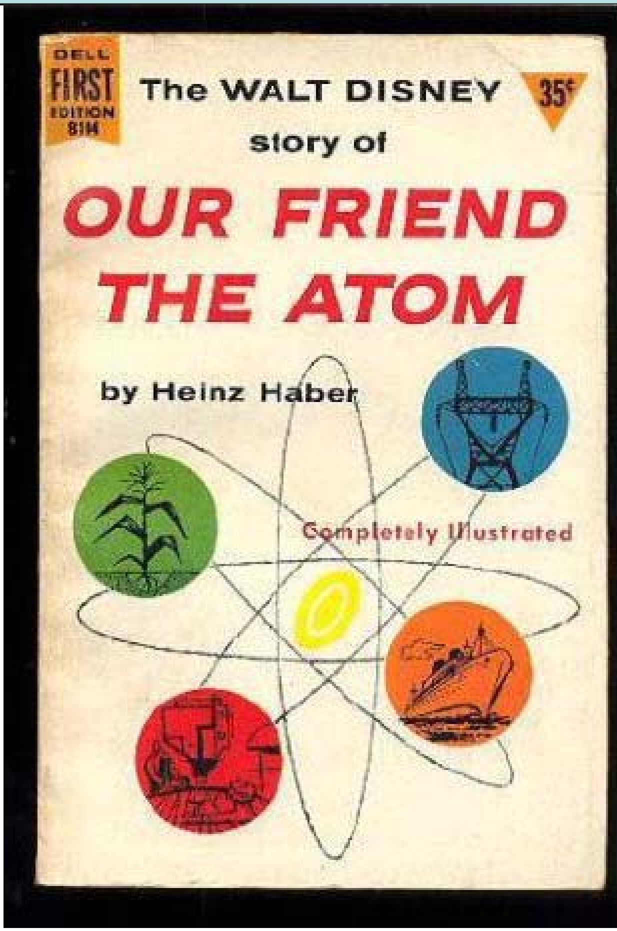
OUR FRIEND THE ATOM

Announcements:

- First midterm is 7:30pm on 2/17/09
- Problem solving sessions M3-5 and T3-4,5-6.

Plan for next few lectures:

- Today – overview of the atom; a survey of 3.1-3.6 and 3.10-3.12.
  - You are responsible for the ideas and vocabulary but not all of the math that goes with the experiments



- Next week will be Chapter 4 which covers the ideas and experiments that lead to quantum mechanics.

Why is the atom so important?

Special relativity has effects that are typically not observable except when objects move very fast (close to the speed of light).

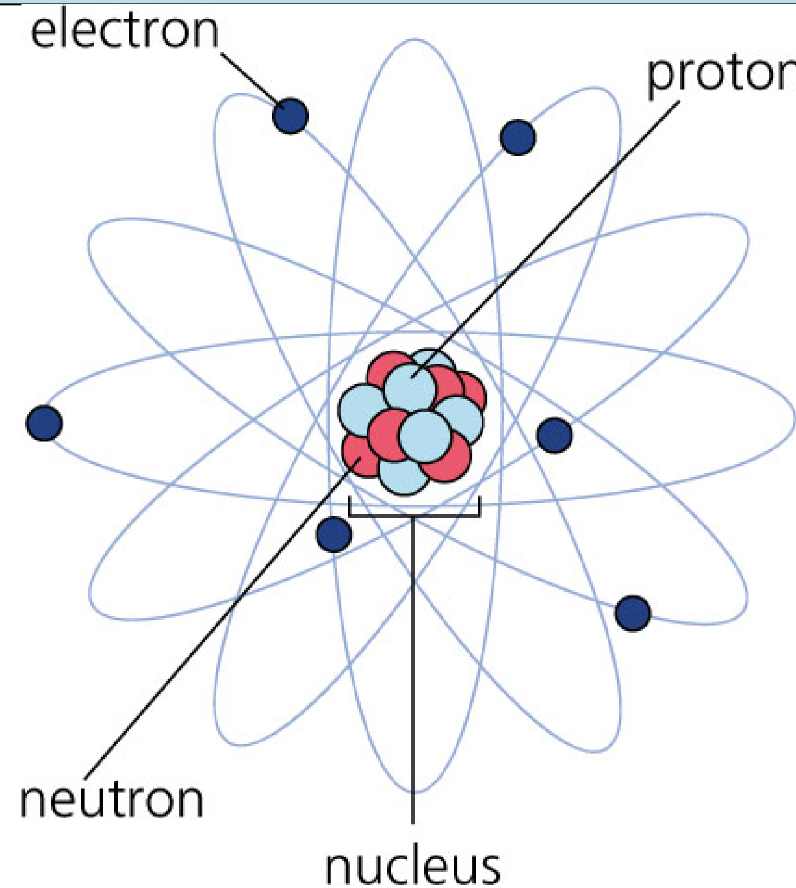
One exception is rest mass energy which exists no matter what the speed.

Quantum mechanics has effects that are typically not observable except when objects are very small (like atomic sizes).

Thus, the development and understanding of quantum mechanics is intimately tied to the discovery and understanding of the atom.

A useful picture of atoms

The center of the atom is composed of **protons** and **neutrons** bound together in a very small **nucleus**



Nuclei radii range from about 1 to 8 fermi (1 fermi = 1 fm = 1×10^{-15} m)

The rest of the atom is basically empty with **electrons** flying around.

The electrons extend out to ~0.1 nm, aka 1 ångström (1 Å)

Electrons have $q = -1.6 \times 10^{-19}$ C and protons have $q = +1.6 \times 10^{-19}$ C.

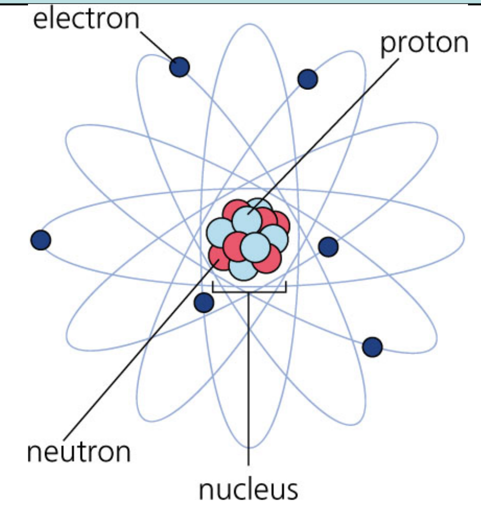
Protons and neutrons have about the same mass (938.3 MeV/c^2 and 939.6 MeV/c^2); electrons are ~1800 times lighter (0.511 MeV/c^2).

A useful picture of atoms

Atomic number **Z** gives # of protons (and # of electrons for a neutral atom).

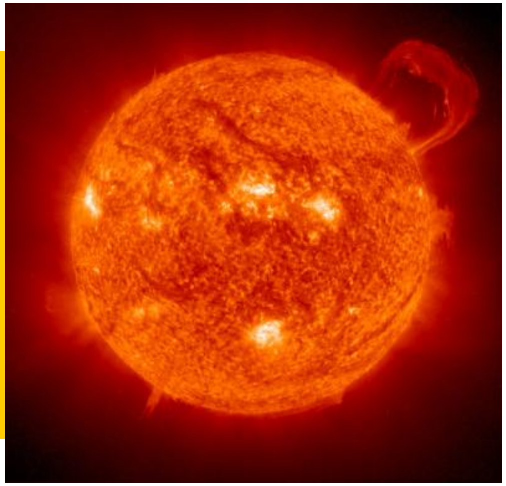
Atomic mass number **A** gives number of **nucleons** (protons + neutrons)

The actual atomic mass is *not* just the sum of the masses of protons, neutrons, and electrons. Why?



Binding energy (of protons and neutrons together) reduces the mass.

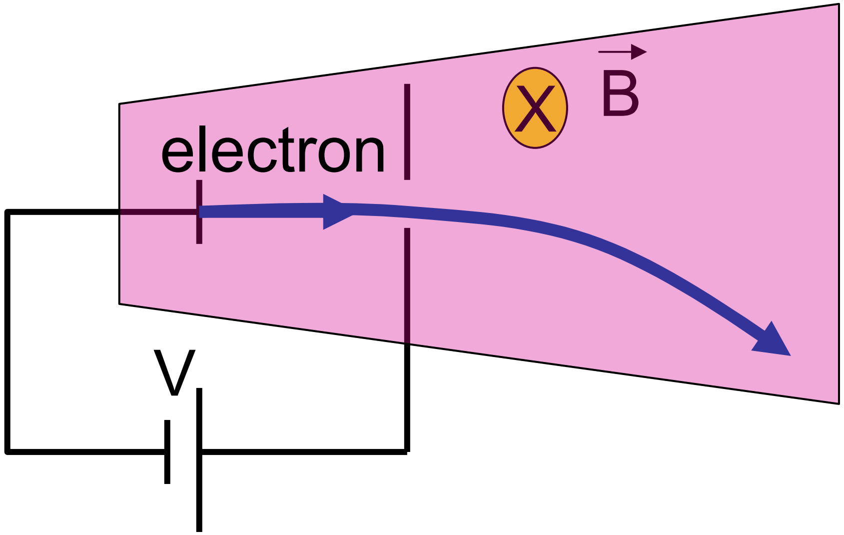
When protons and neutrons fuse (nuclear fusion) energy is released (which is made up for by the loss of mass). This is what powers the sun (and the hydrogen bomb).



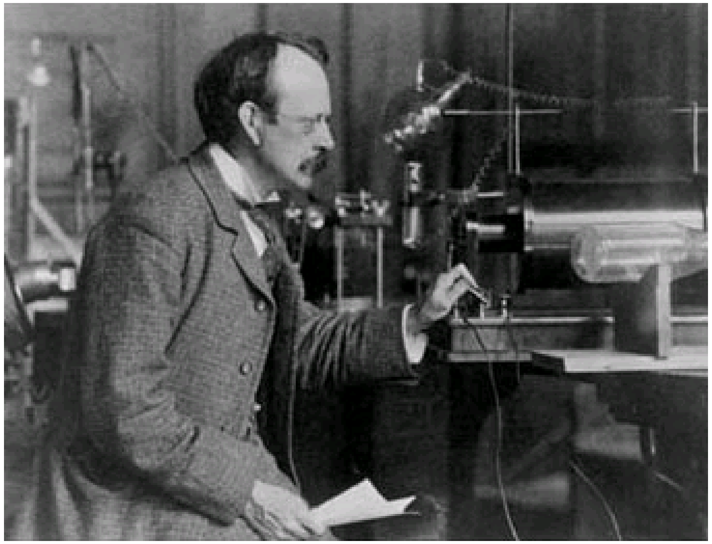
Atomic mass unit **u** is used to measure atomic masses. It has a value of 931.5 MeV/c^2.

Clicker question 1

Set frequency to DA



J.J. Thomson discovered the electron in 1897



How will the electron be deflected in the B-field?

A. Into the page
B. Out of the page
C. Upwards
D. Downwards
E. No deflection at all

Hint: Remember $\vec{F} = q\vec{v} \times \vec{B}$

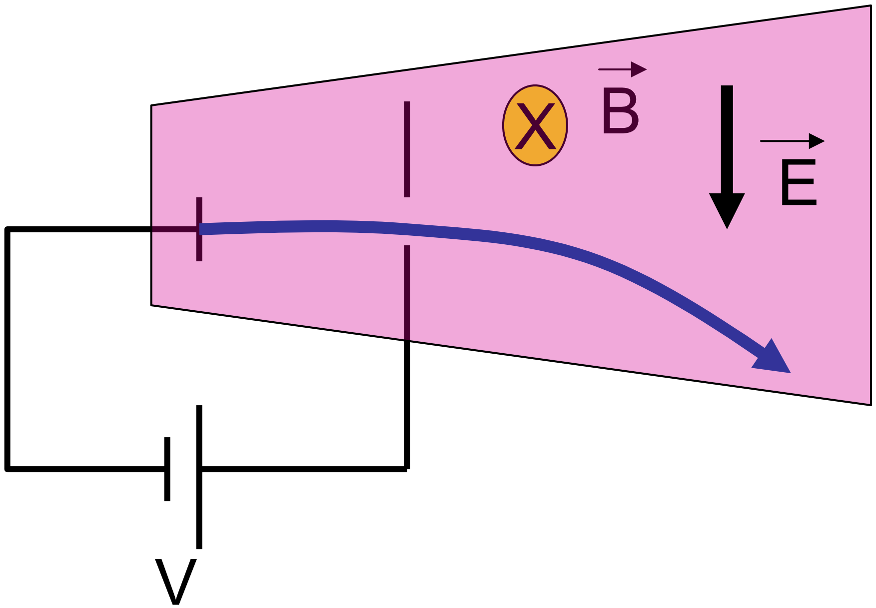
Thomson observes the particle bending downward which means negative electric charge (from the right hand rule).

Measuring q/m for the electron (e/m)

The force by a magnetic field is perpendicular to the velocity so it causes centripetal acceleration.

$$\frac{mv^2}{r} = q\vec{v} \times \vec{B} \Rightarrow \frac{q}{m} = \frac{v}{rB}$$

If we knew the electron velocity we could find q/m.



Solution: Add an external downward E-field and adjust until the particle goes straight.

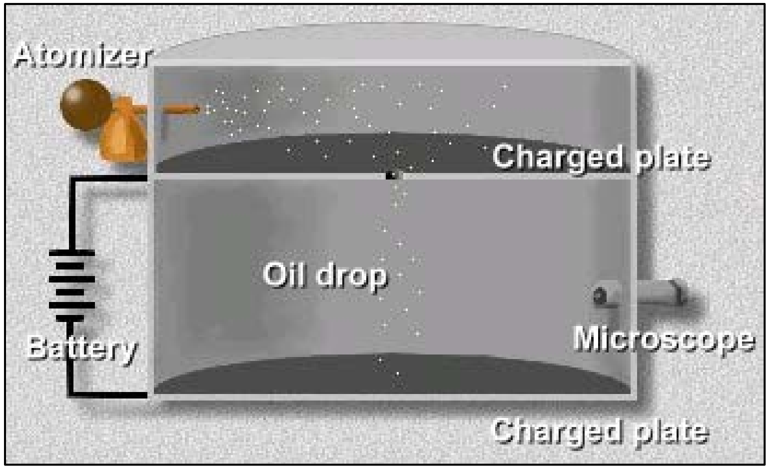
$$\vec{F}_{net} = q\vec{v} \times \vec{B} + q\vec{E} = 0$$

$$|\vec{v}| = |\vec{E}| / |\vec{B}|$$

Millikan oil drop experiment (1911)

Thus, Thomson knew it was a negatively charged particle, and the e/m ratio (but not the charge or mass separately).

Enter the Millikan oil drop experiment in 1911



Oil is ionized by the atomizer. Can adjust the electric field so the drop is stationary. Then

$$F_{net} = q_{\text{drop}}E - m_{\text{drop}}g = 0$$

so $$q_{\text{drop}} = m_{\text{drop}}g / E$$

Find mass by measuring the terminal velocity in air.

Drop 1: $Q_{drop1} = n_{drop1} \times e$
Drop 2: $Q_{drop2} = n_{drop2} \times e$
After many trials, one can determine the fundamental smallest charge $e = 1.6 \times 10^{-19}$ Coulombs.

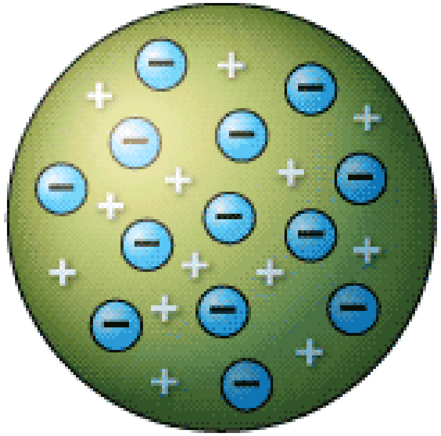
MMMmmmm, plum pudding (aka raisin cake)

What was known about atoms in 1900:

1. Atoms are heavy and electrically neutral
2. Electrons are light and negatively charged

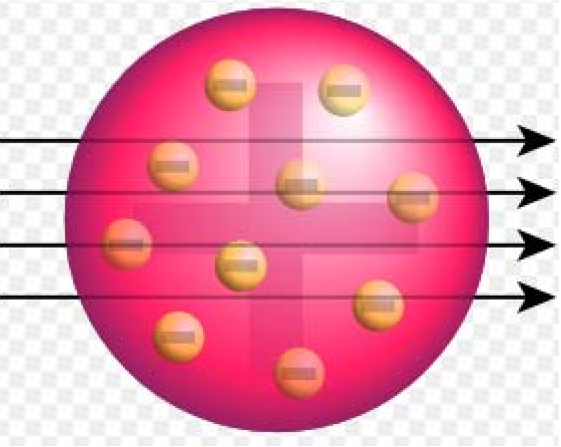
With this knowledge and knowing that like charges repel and opposite charges attract, Thompson proposes the Plum Pudding model of the atom.

The electrons are like little negative raisins inside the heavy positive pudding.



Rutherford scattering experiment (1911)

In 1911, Rutherford (with his assistants Geiger and Marsden) did scattering experiments to test the Thomson Plum Pudding atom model.



Alpha particles are Helium nuclei (2 protons + 2 neutrons)

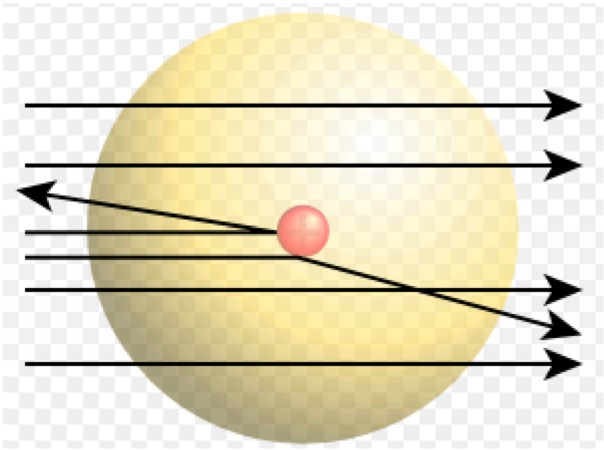
Rutherford sent alpha particles through very thin foils of metal.

Plum pudding model prediction: The alpha particles should bend very little since there is a balance of Coulomb forces between positive (pudding) and negative (plum) particles.

Most of the alpha particles behaved exactly that way…

Rutherford's solar system model of the atom

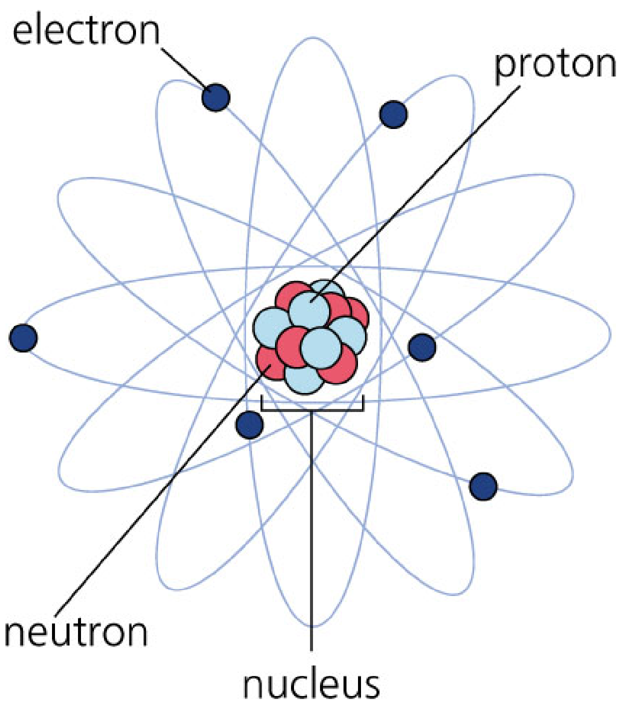
To his great surprise, some alpha particles scattered at very large angles, some almost straight back.



There must be a much larger electric field present. This led to the…

Rutherford (solar system) model:

1. The positive charges in the atom are concentrated in a nucleus that contains nearly all of the mass.
2. The negatively charged electrons surround the nucleus in large orbits.

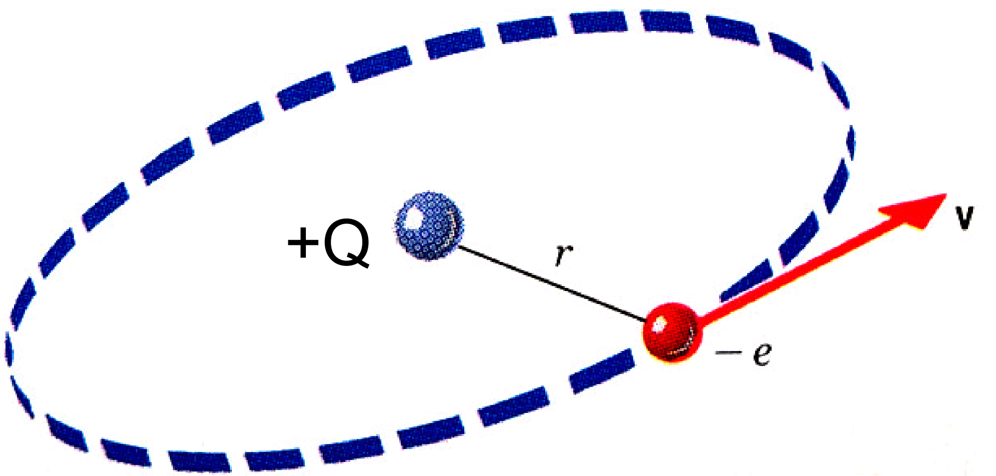


Rutherford's solar system model of the atom

Electrons are held in orbit around the positive nucleus by the Coulomb force.

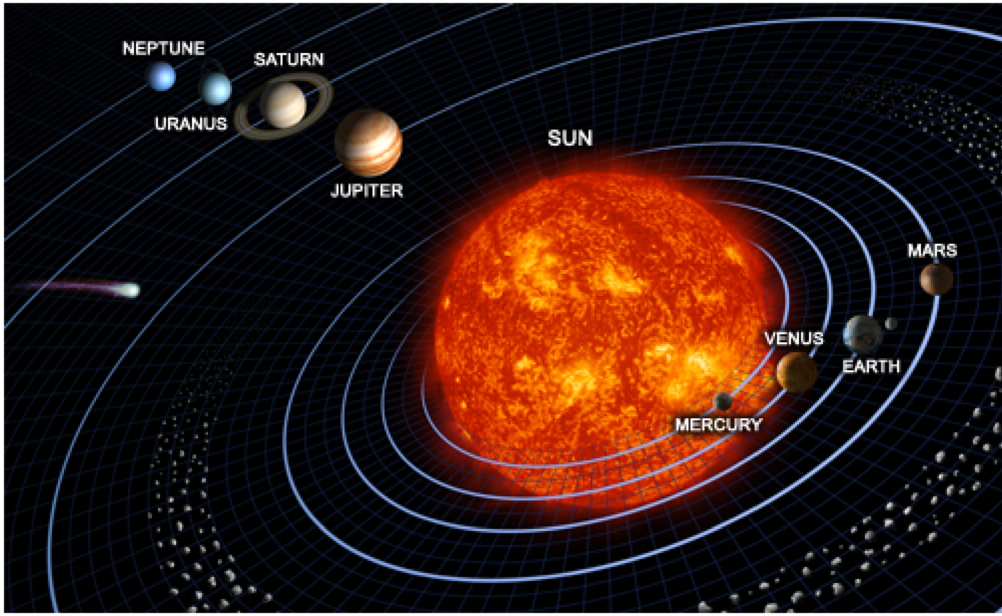
$$F = \frac{kq_1q_2}{r^2} = \frac{mv^2}{r}$$

$$F = \frac{k(+Ze)(-e)}{r^2} = \frac{m_e v^2}{r}$$



Just like gravity acts on planets in the solar system:

$$F_G = \frac{GM_{\text{sun}}M_{\text{planet}}}{r^2} = \frac{m_{\text{planet}}v^2}{r}$$

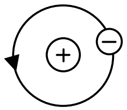


Clicker question 2

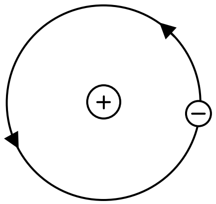
Set frequency to DA

Which electron orbit has the smaller frequency?

Orbit 1



Orbit 2



A. Orbit 1 has the smaller frequency
B. Orbit 2 has the smaller frequency
C. Orbit 1 and 2 both have the same frequency
D. Impossible to determine from the information give.

Just as Mercury goes around the Sun faster than the Earth (88 days compared to 365 days).

Higher energy → larger radius orbit → longer period T → smaller frequency f

Lower energy → smaller radius orbit → shorter period T → larger frequency f

Issues with Rutherford's model of the atom

Classical electricity and magnetism theory combined with classical mechanics theory allow for these orbits.

That's the good news.

There were two problems, both of which come from classical EM theory which states that any charged particle that experiences acceleration must radiate electromagnetic waves.

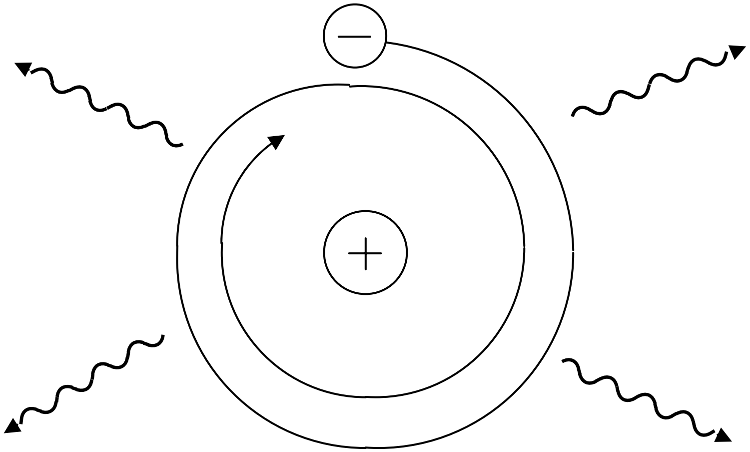
The frequency of this radiation is related to the frequency of the electron revolving around the nucleus.

Prediction 1: The electromagnetic radiation will cause the electron to lose energy and eventually fall into the nucleus.

Prediction 2: The light given off by the electron should be a continuous spectrum with all frequencies.

First problem – death spiral of the electron

Classically, an electron in an atom should radiate as it is accelerated around a circle. This causes it to lose energy and to spiral inward.



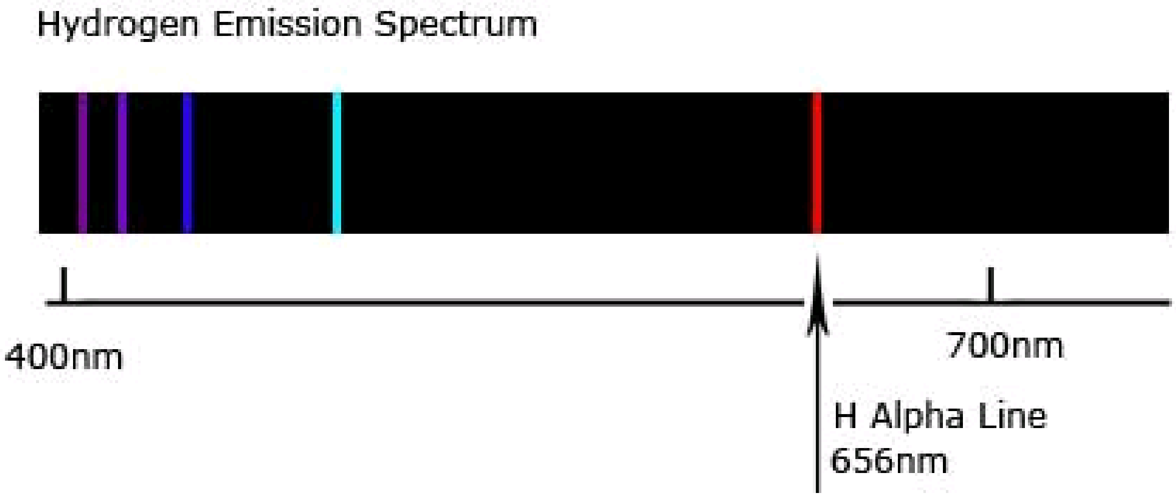
Calculations of the expected time for the electron to spiral in were done

The calculated time was 10^{-11} seconds.

Poof! There go all the atoms in the universe. That's not good!

2nd problem – atoms should emit continuous spectrum

Well before the model of the atom, people had heated up atomic matter and could study the emission of light.



Experimentally it was found that certain elements gave off light only at specific discrete wavelengths or frequencies.

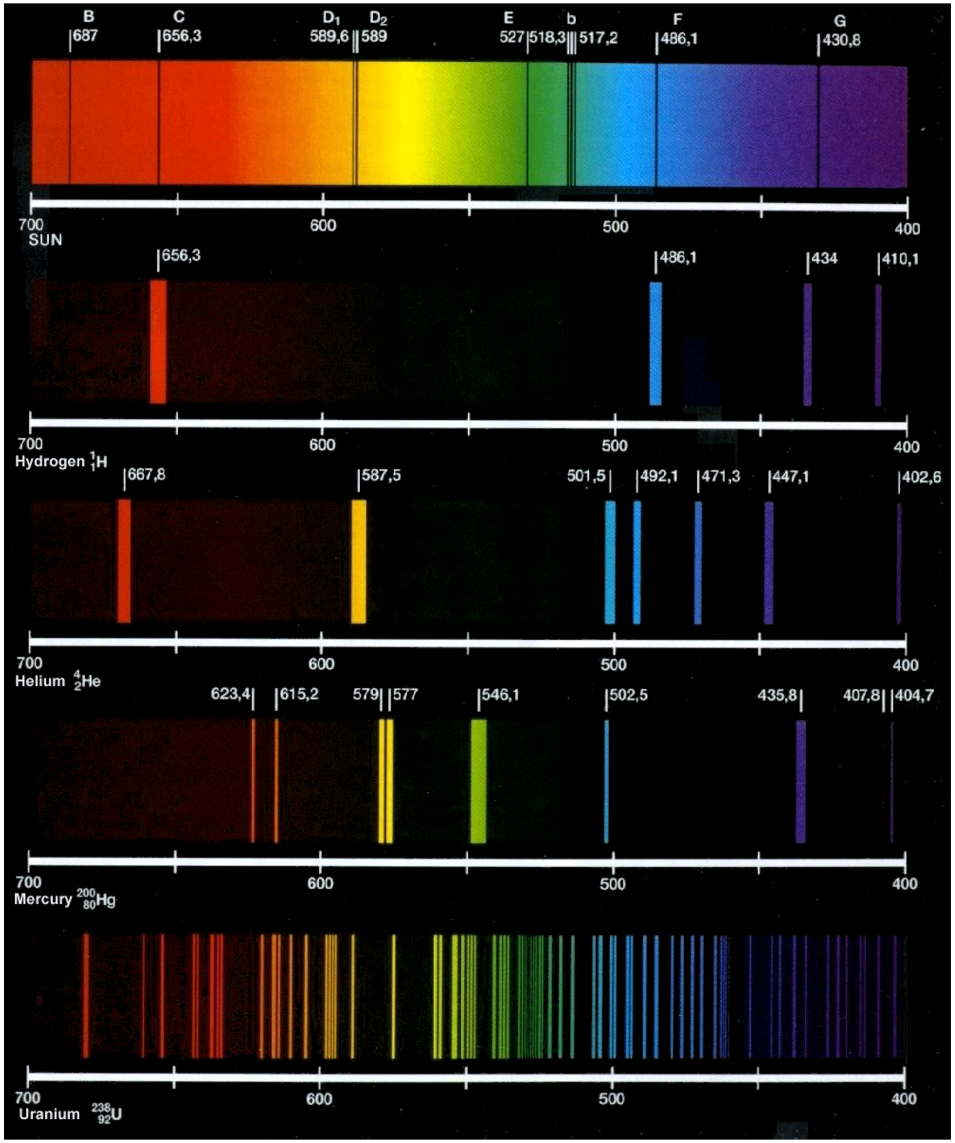
The electrons were *not* radiating a continuous spectrum.

Atomic spectra

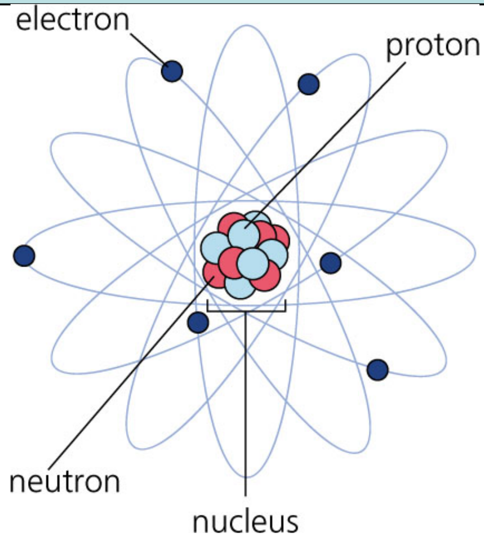
Heated matter emits radiation.

Thermal random motion yields spectrum of wavelengths of EM radiation.

Spectra were observed in 1800's without knowing how or why?



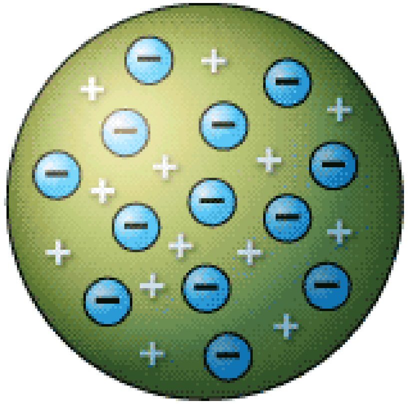
Final conundrum



The nucleus was full of positive particles which should all be repelling each other.

So what keeps the nucleus together?

In the Plum Pudding model the positive and negative charges were distributed throughout the atom so this was not a problem.



We will discuss this later, but there must be a stronger force than the Coulomb force holding the nucleus together

Not being too original, physicists end up calling this the strong force; also called the nuclear force or strong nuclear force.