The Search for the Smallest Thing

AN INTRODUCTION TO PARTICLE PHYSICS

Today's Topic:

Harmony and Quantum Leaps!

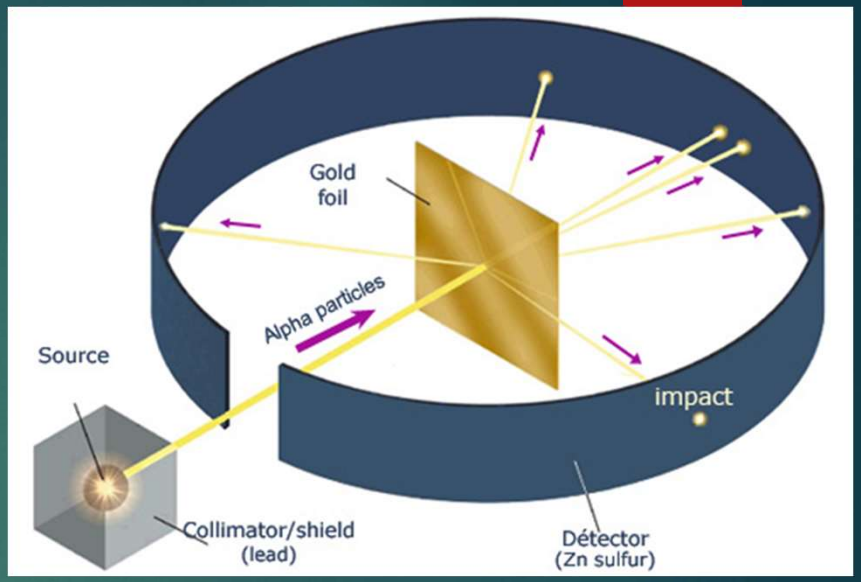
Mentalfloss.com

Connolly Music

To Review – Ernest Rutherford led an experiment which shot alpha particles (which are helium nuclei) through a thin gold foil.

To his astonishment, some of the alpha particles bounced off something hard in the gold!

The conclusion was: atoms have a hard nucleus.



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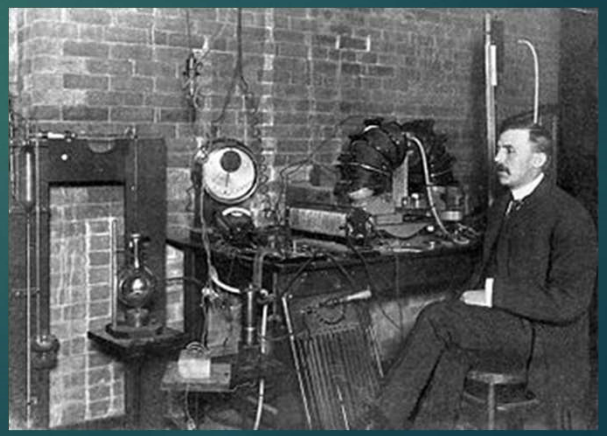
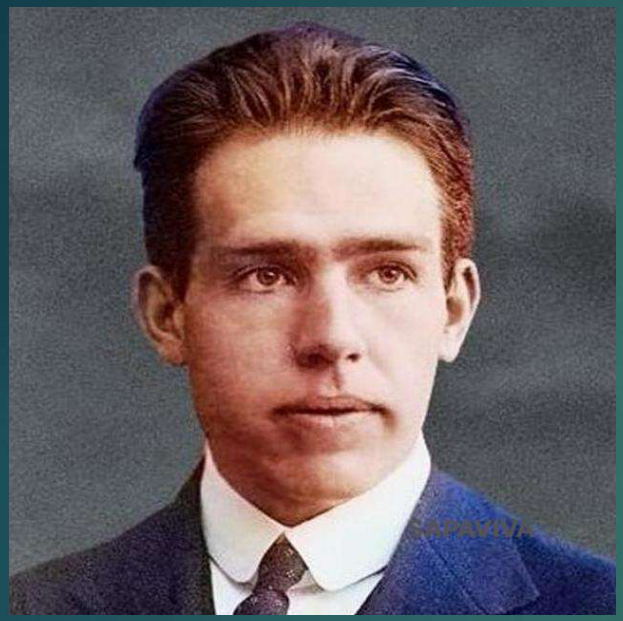


Wikipedia.org

Niels Bohr 1885 - 1962

Niels fixed some of the problems in Rutherford's model and came up with the Bohr model of the atom.



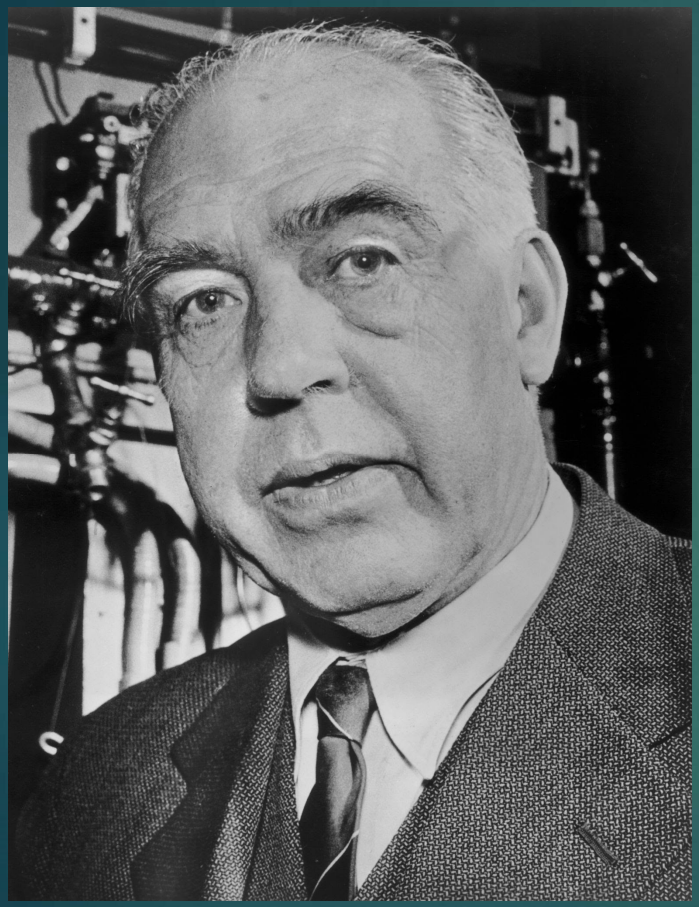
sapaviva.com

This is the famous picture of the atom that most people have in mind to this day.

Wikidata.org

But, it doesn't work. Bohr failed to deal with the electrons repelling each other inside the atom (remember, opposites attract and likes repel?)

Niels Bohr in Later Years



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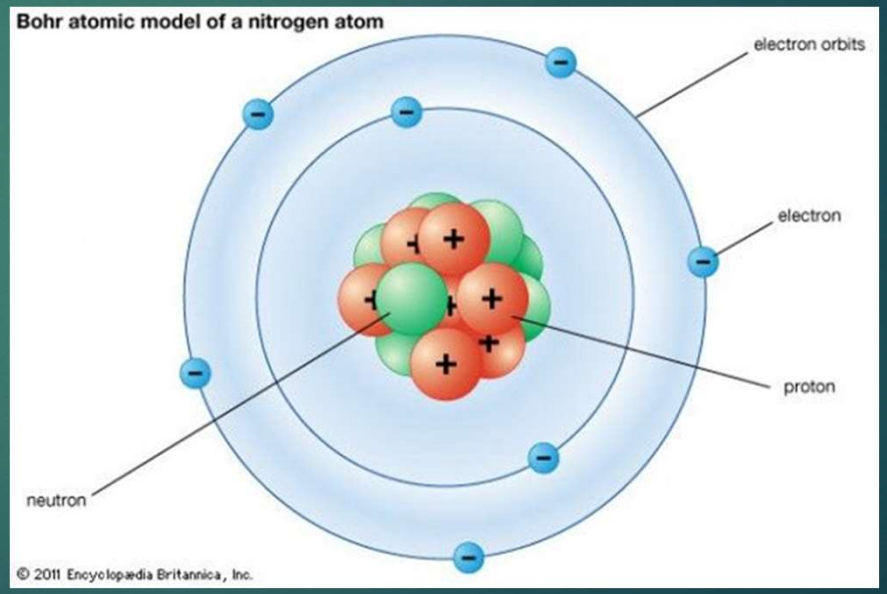
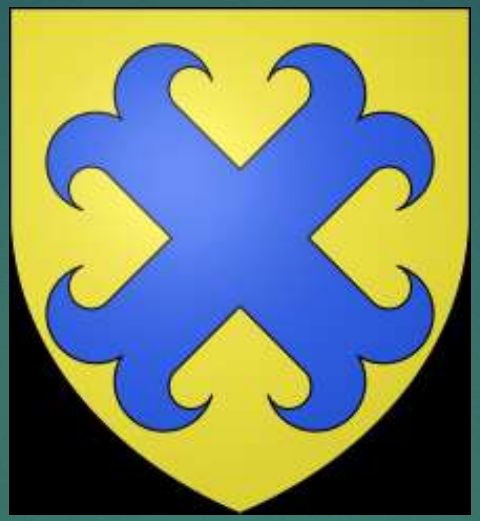
The other lingering question was why were some orbits allowed for the electrons, and others weren't?



Encyclopedia.org

To deal with the orbital problem, a French Prince named Louis de Broglie (1892-1987) had a new idea.

New Statesman



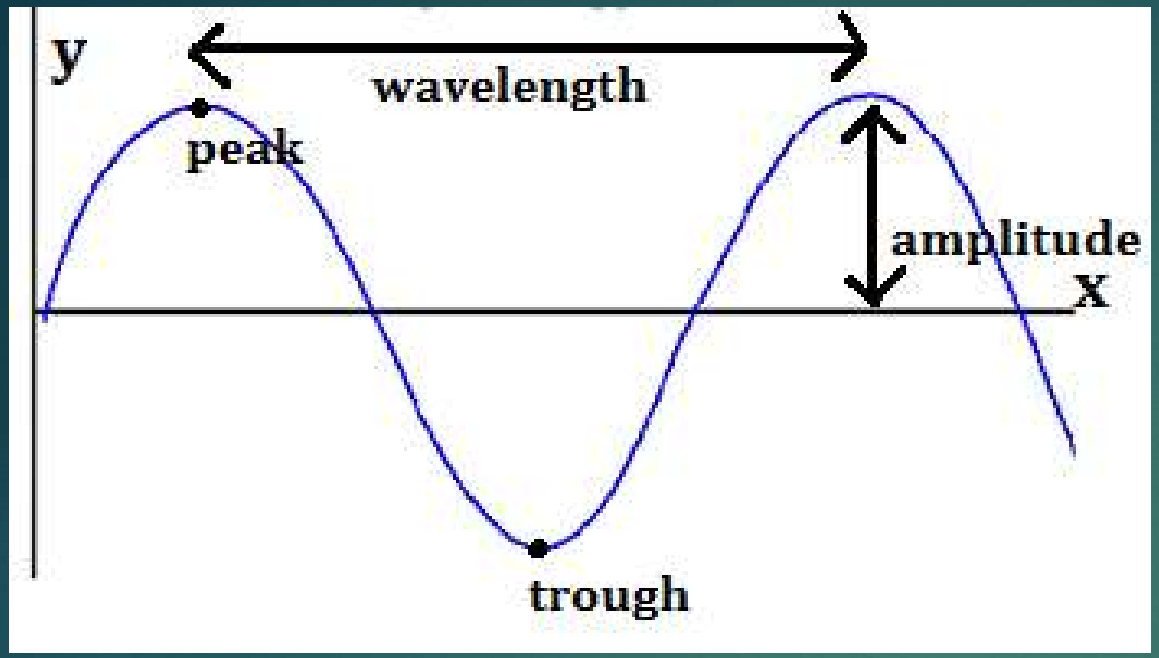
Wikipedia.org

The Broglie Coat of Arms

Wikipedia.org

The Real French Prince

To explore de Broglie's idea, we need to take a little field trip and talk about sound, waves, and musical instruments.



Study.com

A single wave goes back and forth once, ending back where it started.

The wavelength is the horizontal distance the wave goes.

The frequency is the number of waves that happen per second.
Longer wavelengths mean lower frequency.
Shorter wavelengths mean higher frequency.

The Strad

A "standing wave" happens when a string is attached at both ends, as with a violin.

The string vibrates back and forth, but the string doesn't go anywhere (unless the violin breaks).

High speed picture of a violin string vibrating!

But did you know standing waves can make quantum leaps? Would you like to experience this?

Time out for a demonstration!

Amazon.com

Ordinarily, I'd let everyone in class try this out for themselves, but sadly I have no way of getting the equipment to you.

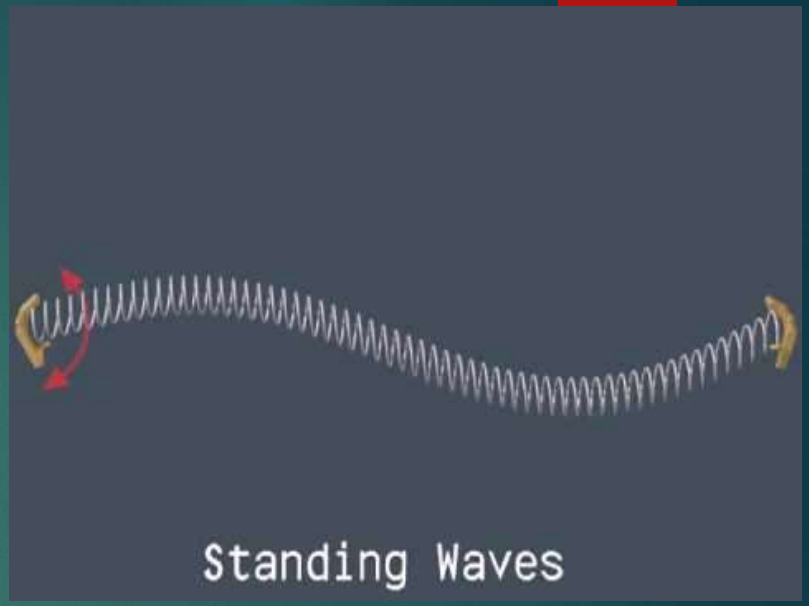
But if you have a grandchild of elementary school age, these make a great birthday gift!

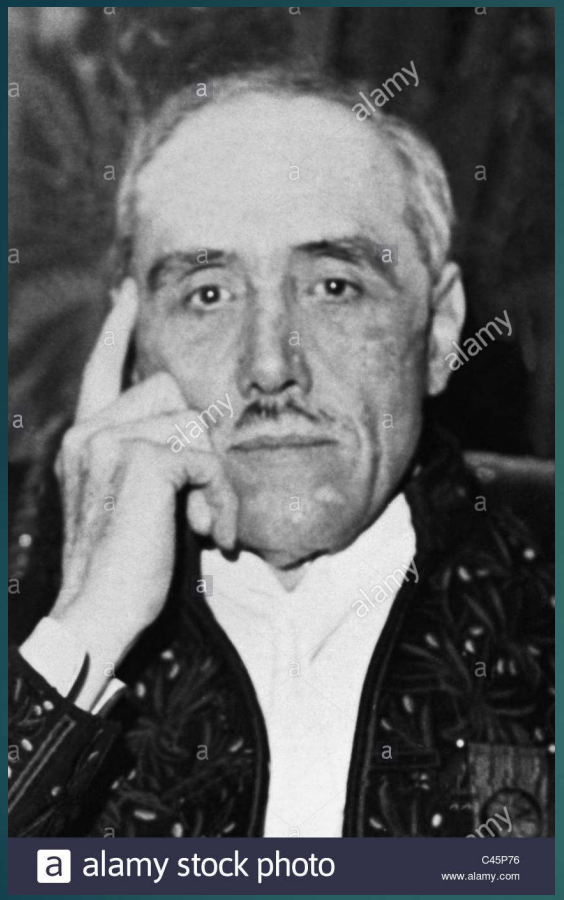
That sudden shift in pitch you hear is a quantum leap in frequency!

The point is, that standing waves all have to be half or full numbers of waves!

They will not change frequency until they get exactly the right energy to go to the next harmonic.

This is a quantum leap!





Louis de Broglie in later years

In his doctoral thesis, De Broglie suggested that electrons in atoms vibrate through the atom like standing waves!

But wait, the electron is a particle!

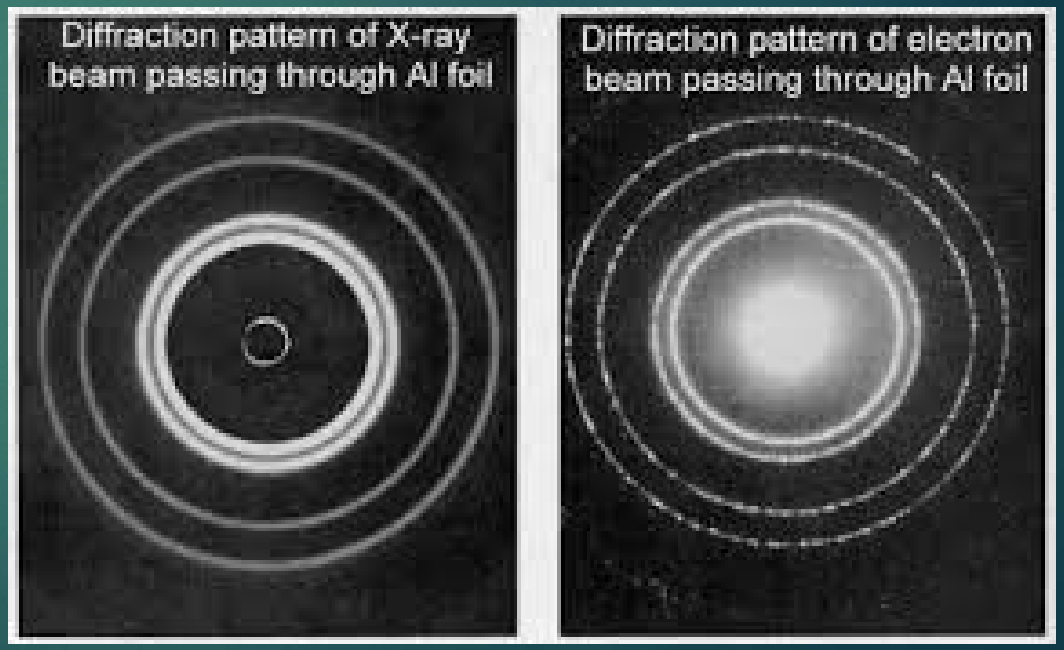
How can it be a wave, too?

Wikimedia Commons

Well, remember, we have a test to see whether something is a wave or a particle. We shoot it through a small hole!

What happens if we shoot an electron through a small hole?

Oh, my gosh, the electron expands as it goes through the hole! The picture compares it to an x-ray, which we know is a light wave. There's a remarkable similarity!

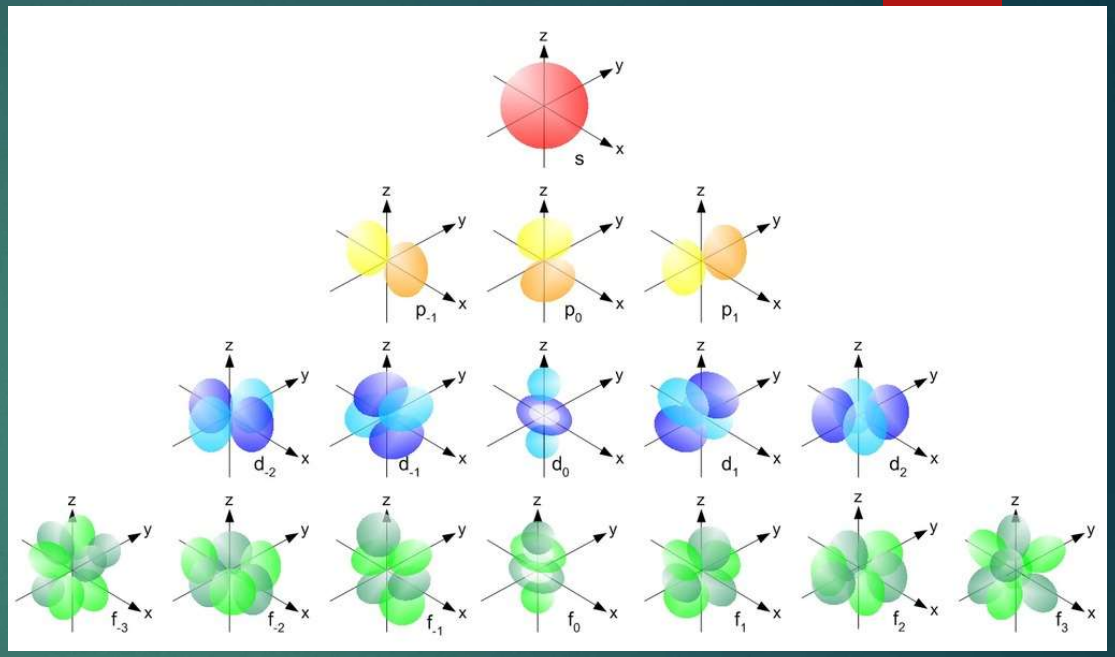


Courses.Washington.edu

So now, we have a new model of the atom! The nucleus is in the center, and the electrons vibrate like standing waves through the atom.

Quantum leaps occur because the electrons change harmonics when they get the right energy, just like a slinky!

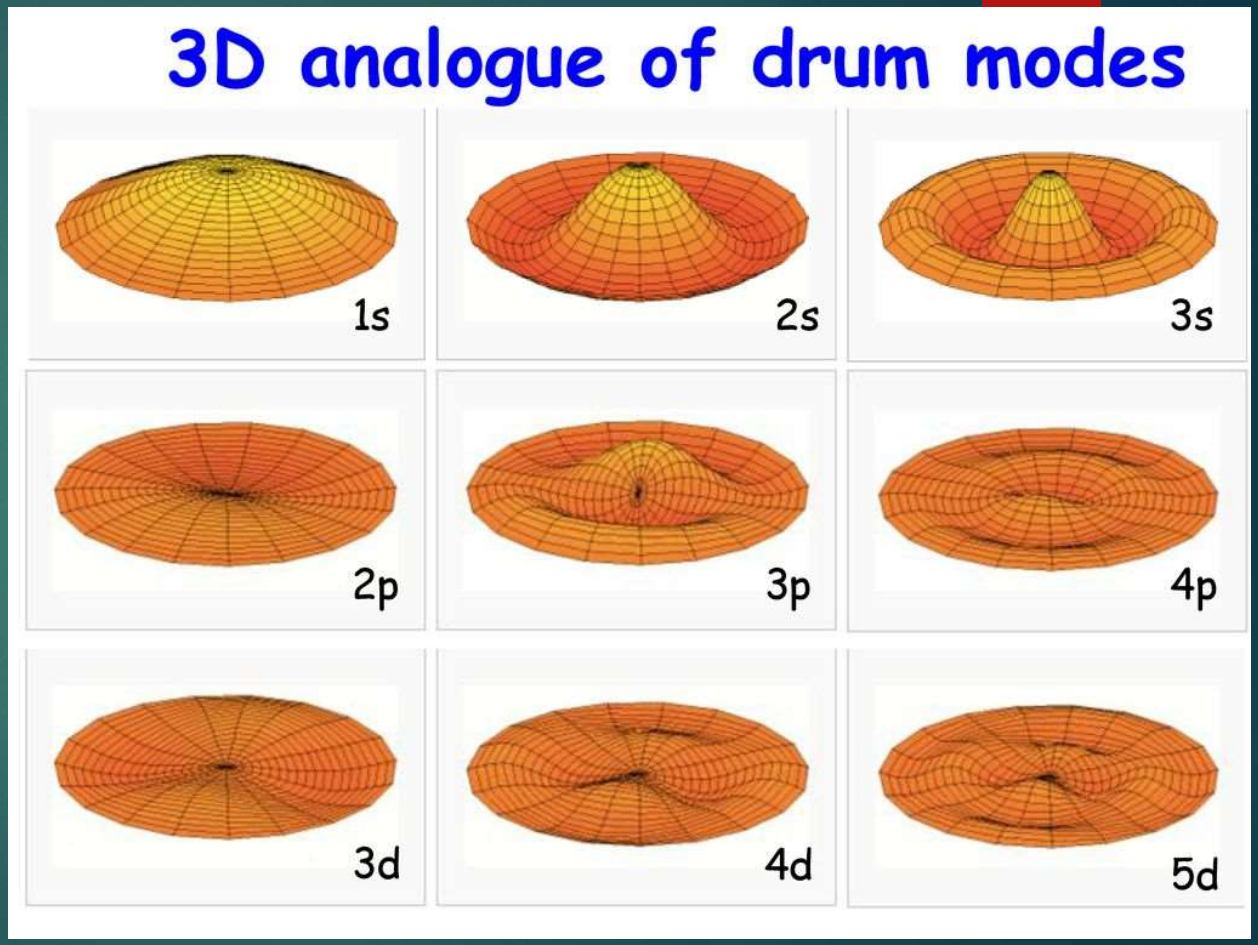
quizlet.com/264762739/electron-orbitals-diagram/



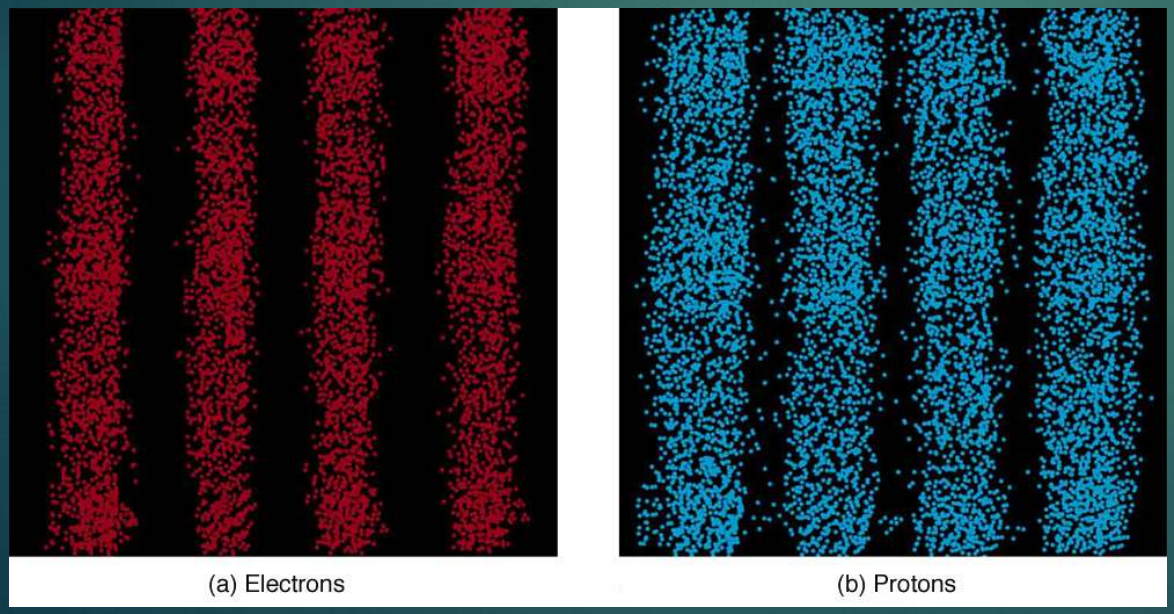
This diagram shows how electrons vibrate within an atom!

Maybe this will help. If you play drums, you know you can get a lot of different pitches (harmonics) out of a drum depending on where you hit the drumhead.

This is what those harmonics look like! This gives you an idea of what electrons look like as they vibrate through atoms!



We know light moves like a wave but collides like a particle. But things we always thought were particles move like waves! It's not just electrons! All particles move as waves! This is the great triumph of the theory of wave-particle duality!

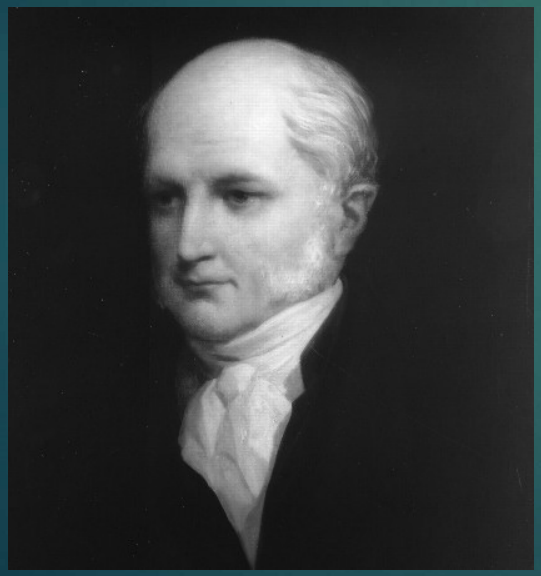


Pictures of electrons (red) and protons (blue) after going through two narrow slits

courses.lumenlearning.com

By the way, about those protons and neutrons…

How were they discovered?



Meet William Prout (1785 – 1850)

In 1815, he noted that the atomic masses all seemed to be very close to multiples of the mass of hydrogen atoms.

He suggested that all atoms were actually made of hydrogen atoms! Not quite right, but a good start!

edu.glogster.com

Ernest Rutherford:

"If you can't explain your physics to a barmaid, it probably isn't very good physics…."

Rutherford shot alpha particles into pure nitrogen gas, and to his surprise hydrogen nuclei came out!

He decided that nitrogen nuclei were actually made out of hydrogen nuclei.

Rutherford already had determined that alpha particles were helium nuclei, and they had a charge exactly twice that of a hydrogen nuclei.

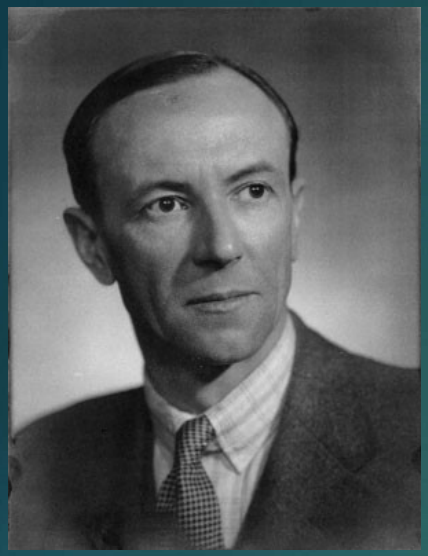
It was a short step to conclude that all nuclei were made out of hydrogen nuclei!

Rutherford decided to give the hydrogen nuclei a special name – the Proton!

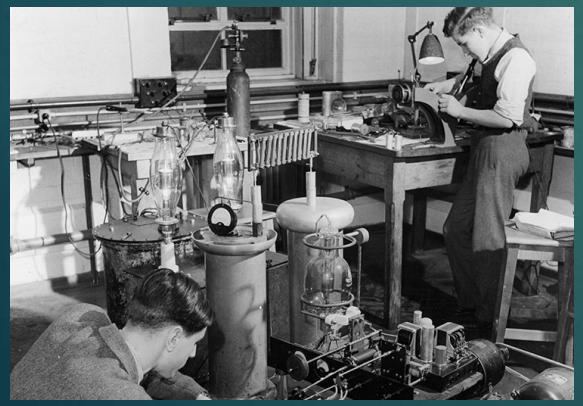
Naturally, there was an immediate problem. If the nuclei of atoms are made of protons, and all protons are positively charged, then they will all repel each other. Atomic nuclei should blow up instantly! What keeps them together!

Fortunately, James Chadwick was working on it!

James Chadwick (1891 – 1974)



AIP Emilio Segre Visual Archives



history.aip.org

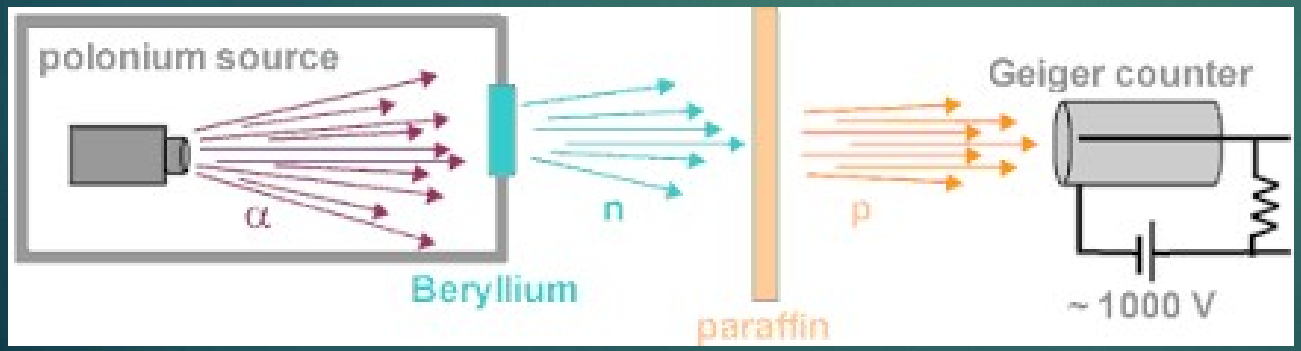
James was raised in Manchester, and became an assistant to Rutherford. In 1913 he went off to study physics with Hans Geiger (remember the gold foil experiment?) in Germany.

Oops! World War I broke out, and being English James was held as a prisoner of war for the length of the war. He still managed to do physics research in prison camp! There was a popular brand of toothpaste in Germany which was radioactive, and James used that as a source of radiation!

Wikipedia.org

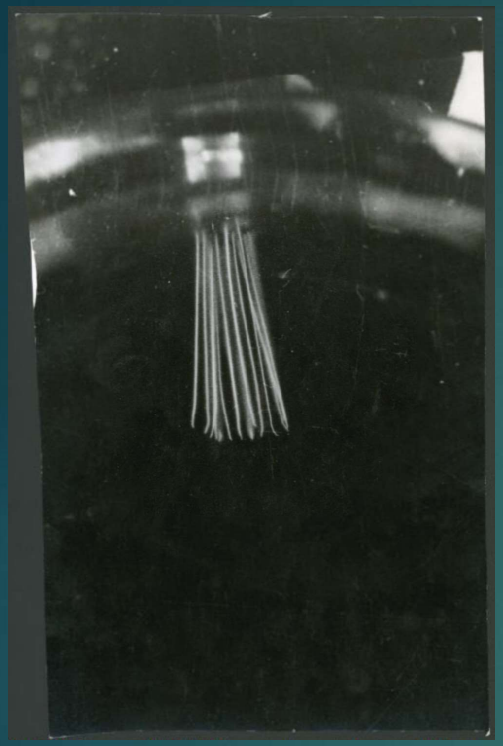
Marie and Irene Joliot-Curie had been shooting alpha particles at Beryllium and discovered something electrically neutral coming out of the Beryllium. Irene thought it was gamma rays.

Chadwick added a second target, paraffin (otherwise known as candle wax). A bunch of protons came out of the paraffin.



physicslab

Gamma rays wouldn't be strong enough to knock protons out of atoms, so Chadwick concluded there was an electrically neutral particle instead. He called it the Neutron!



nobelprize.org

Picture of alpha particles hitting the Beryllium target in Irene Joliot-Curie's lab.

Irene won the Nobel Prize in Chemistry in 1935. She died in 1956 of leukemia, as her mother had, almost certainly from radiation exposure.

nobelprize.org

Irene chatting with Albert

Today in Science History

Chadwick won the Nobel Prize in Physics in 1935.

Irene and James at Nobel Prize Ceremony

Quote from James Chadwick in 1932:

"I am afraid neutrons will not be of any use to any one."

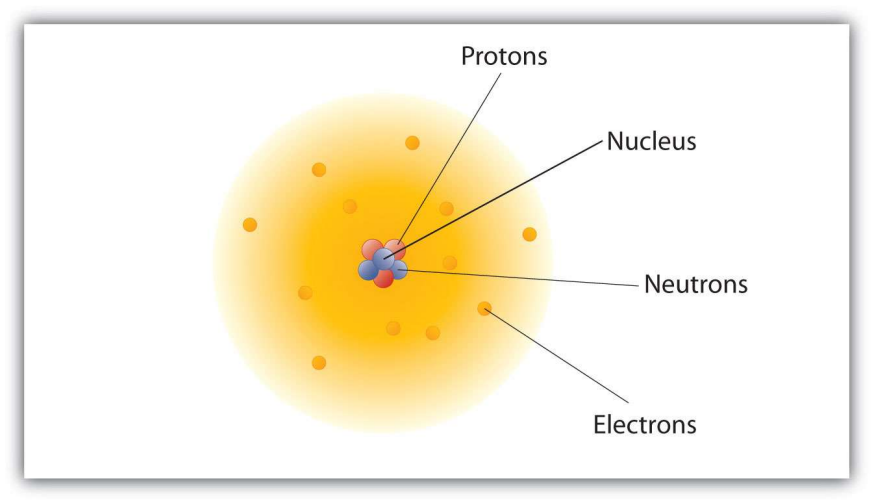
So, we now have a model of the atom that works.

There is a nucleus which contains protons, which attract the electrons and keep them from drifting out of the atom.

There are neutrons, which prevent the protons from repelling each other and blowing up the atom.

There are electrons, which vibrate through the atom as standing waves.

The harmonics of the electron vibrations produce the atomic spectra.



saylordotorg.github.io

Questions?

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