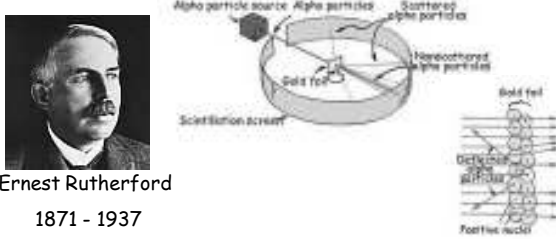


Atom and Quantum

Atomic Nucleus




The diagram illustrates Rutherford's Gold Foil Experiment. It shows an alpha particle source emitting alpha particles towards a central gold foil. Some particles pass straight through, some are deflected at an angle, and some are scattered back. A scintillation screen surrounds the foil to detect these particles. Labels include: Alpha particle source, Alpha particles, Scattered alpha particles, Deflected alpha particles, Gold foil, and Positive nuclei. A portrait of Ernest Rutherford is shown to the left.

Ernest Rutherford
1871 - 1937

- Rutherford's Gold Foil Experiment
- Deflection of alpha particles showed the atom to be mostly empty space with a concentration of mass at its center

Atomic Spectra



The photograph shows the Balmer Series of hydrogen, which consists of four visible spectral lines in the visible spectrum. The lines are labeled as H-alpha, H-beta, H-gamma, and H-delta from bottom to top. The caption reads: Balmer Series -- Hydrogen.

- Spacing between successive lines becomes smaller and smaller
- Balmer expressed the wavelengths of these lines in mathematical formula
- He predicted that there might be similar patterns in the spectra from other elements

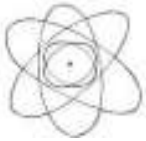
Rydberg and Ritz

- Rydberg - sum of the frequencies of two lines in spectrum of hydrogen often equals frequency of third line
- Later called Ritz combination principle
- **The spectral lines of any element include frequencies that are either the sum or the difference of the frequencies of two other lines.**
- Neither Balmer nor Ritz nor Rydberg could explain the regularity

Bohr Model

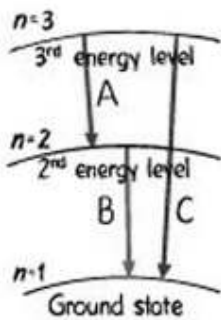


Niels Bohr
1885 -- 1962



- Planetary model - has defects and is oversimplification but is useful in understanding light emission
- Electrons occupy fixed energy (not position) states
- Electrons can make quantum jumps from state to another
- $E = hf$

Explanation of Ritz Combination



- Electron de-exciting from the $n = 3$ level can go from $n = 3$ to $n = 1$ or from $n = 3$ to $n = 2$ and then $n = 2$ to $n = 1$
- Bohr predicted x-ray frequencies that were later confirmed

Check Yourself

- What is the maximum number of paths for de-excitation available to a hydrogen atom excited to level number 3 in changing to the ground state?

Check Yourself

- What is the maximum number of paths for de-excitation available to a hydrogen atom excited to level number 3 in changing to the ground state?
- Two (a single jump and a double jump)

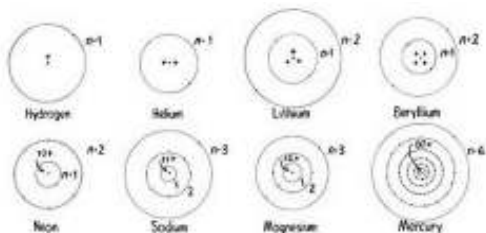
Check Yourself

- Two predominant spectral lines in the hydrogen spectrum, an infrared one and a red one, have frequencies 2.7×10^{14} Hz and 4.6×10^{14} Hz respectively. Can you predict a higher-frequency line in the hydrogen spectrum?

Check Yourself

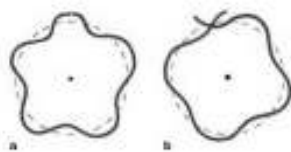
- Two predominant spectral lines in the hydrogen spectrum, an infrared one and a red one, have frequencies 2.7×10^{14} Hz and 4.6×10^{14} Hz respectively. Can you predict a higher-frequency line in the hydrogen spectrum?
- sum of the frequencies is $2.7 \times 10^{14} + 4.6 \times 10^{14} = 7.3 \times 10^{14}$ Hz, the frequency of a violet line in the hydrogen spectrum; infrared line -- a transition corresponds to path A; red line corresponds to path B; violet line corresponds to path C?

Relative Sizes of Atoms



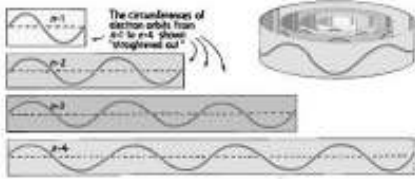
- Considering the 92 naturally occurring elements, 92 distinct patterns or electron orbital configurations—a different pattern for each element

Quantized Energy Levels



- orbiting electron forms a standing wave
- circumference of orbit is equal to a whole-number multiple of the wavelength
- when wave does not close in on itself in phase, destructive interference occurs
- orbits exist **only** where waves close in on themselves in phase.

Quantized Orbits



- electron orbits in an atom have discrete radii
- circumferences of the orbits are whole-number multiples of the electron wavelength.
- discrete energy state for each orbit.

Probability Waves

- electron waves also move toward and away from the nucleus.
- electron wave in three dimensions.
- electron "cloud"
- cloud of probability (not a cloud made up of a pulverized electron scattered over space)
- The electron, when detected, remains a point particle.

Wave Equation



Erwin Schrodinger
1887 -- 1961

- Matter Wave Amplitude
- wave function, represented by the symbol ψ (the Greek letter psi)
- represents the possibilities that can occur for a system
- electron's possible position and its probable position at a particular time are not the same

$$\left(-\frac{\hbar^2}{2m} \nabla^2 + V \right) \psi = i\hbar \frac{\partial \psi}{\partial t}$$

Probable Electron Position

- can calculate its probable position by multiplying the wave function by itself ($|\psi|^2$).
- result is second mathematical entity called a **probability density function**, which tells us at a given time the probability per unit volume for each of the possibilities represented by ψ
- "orbital" is in fact a 3-dimensional graphical picture of $|\psi|^2$

Electron Cloud

- Schrödinger equation does not predict where an electron can be found in an atom at any moment
- only predicts likelihood of finding it there
- an individual electron may at different times be detected anywhere in this probability cloud



Electron Cloud

an electron's position in its Bohr energy level (state) is repeatedly measured and each of its locations is plotted as a dot

Check Yourself

- Consider 100 photons diffracting through a thin slit to form a diffraction pattern. If we detect five photons in a certain region in the pattern, what is the probability (between 0 and 1) of detecting a photon in this region?

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- We have approximately a 0.05 probability of detecting a photon at this location. In quantum mechanics we say $|\psi|^2 \approx 0.05$. The true probability could be somewhat more or less than 0.05. Put the other way around, if the true probability is 0.05, the number of photons detected could be somewhat more or less than 5

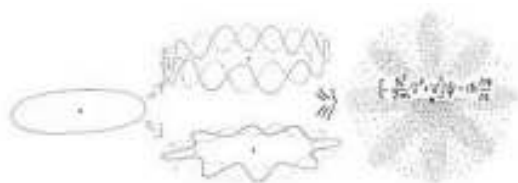
Check Yourself

- Open a second identical slit and the diffraction pattern is one of bright and dark bands. Suppose the region where 5 photons hit before now has none. A wave theory says waves that hit before are now canceled by waves from the other slit—that crests and troughs combine to 0. But our measurement is of photons that either make a hit or don't. How does quantum mechanics reconcile this?

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- Quantum mechanics says that photons propagate as waves and are absorbed as particles, with the probability of absorption governed by the maxima and minima of wave interference. Where the combined wave from the two slits has zero amplitude, the probability of a particle being absorbed is zero.

Bohr to de Broglie



- From the Bohr model of the atom to the modified model with de Broglie waves to a wave model with the electrons distributed in a "cloud" throughout the atomic volume.
