Lecture Outline

Chapter 32: The Atom and the Quantum



This lecture will help you understand:

- Discovery of the Atomic Nucleus
- Discovery of the Electron
- Atomic Spectra: Clues to Atomic Structure
- Bohr's Model of the Atom
- Explanation of Quantized Energy Levels: Electron Waves
- Quantum Mechanics
- Correspondence Principle

Discovery of the Atomic Nucleus

- In Rutherford's experiment, a beam of positively charged alpha particles was directed through a thin gold foil.
 - Nearly all alpha particles passed through with little or no deflection.
 - Some particles were deflected from their straight-line paths.
 - A few alpha particles were widely deflected, and
 - A very small number were even scattered backward!



Discovery of the Atomic Nucleus, Continued

- These alpha particles must have hit something relatively massive—but what?
- Rutherford reasoned that the undeflected particles traveled through empty space in regions of the gold foil,
- While the small number of deflected particles were repelled from extremely dense, positively charged central cores.
- Each atom, he concluded, must contain one of these cores, which he named the **atomic nucleus**.

Discovery of the Electron

- Electrodes in a cathoderay tube under low pressure are connected to a voltage source, causing the gas to glow due to a "ray" emerging from the negative terminal (the *cathode*).
- Slits could make the ray narrow and plates could prevent the ray from reaching the positive terminal (the anode).



Discovery of the Electron, Continued

- When electric charges were brought near the tube, the ray bent toward positive charges and away from negative charges.
- The ray was also deflected by the presence of a magnet.
- These findings indicated that the ray consisted of negatively charged particles.



Discovery of the Electron, Continued-1

- Thomson reasoned that the amount of the beams' deflection depended on the mass of the particles and their electrical charge.
 - The greater each particle's mass, the greater the inertia and the less the deflection.
 - The greater each particle's charge, the greater the force and the greater the deflection.
 - The greater the speed, the less the deflection.

Discovery of the Electron, Continued-2

- Millikan sprayed tiny oil droplets into a chamber between electrically charged plates—into an *electric field*.
- He adjusted the field so that droplets hovered motionless, i.e., when downward force of gravity was balanced by upward electrical force.
- He found that the charge on each drop was always some multiple of a single value – the charge of each electron.



Atomic Spectra: Clues to Atomic Structure

- An important sequence of lines in the hydrogen spectrum starts with a line in the red region, followed by one in the blue, then by several lines in the violet, and many in the ultraviolet.
- Spacing between successive lines becomes smaller and smaller from the first in the red to the last in the ultraviolet, until the lines become so close that they seem to merge.



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Atomic Spectra: Clues to Atomic Structure, Continued

- Balmer first expressed the wavelengths of these lines in a single mathematical formula.
 - He was unable to provide a reason why his formula worked so successfully.
- Rydberg noticed that the frequencies of lines in certain series in other elements followed a formula that the sum of the frequencies of two lines in such series often equals the frequency of a third line.
 - This relationship was later advanced as a general principle by Ritz and is called the Ritz combination principle.

Bohr's Model of the Atom

- Bohr reasoned that electrons occupy "stationary" states (of fixed energy, not fixed position) at different distances from the nucleus.
- Electrons can make "quantum jumps" from one energy state to another.
- Light is emitted when such a quantum jump occurs (from a higher to a lower energy state).
- Frequency of emitted radiation is determined by

$$E = hf$$

here *E* is the difference in the atom's energy when the electron is in the different orbits.



Bohr's Model of the Atom, Continued

- According to classical theory, an electron accelerating around its orbit should continuously emit radiation.
- This loss of energy should cause it to spiral rapidly into the nucleus.
- But this does not happen.



Explanation of Quantized Energy Levels: Electron Waves

- Louis de Broglie hypothesized that a wave is associated with every particle.
 - The wavelength of a matter wave is inversely related to a particle's momentum.
- de Broglie showed that a Bohr orbit exists where an electron wave closes on itself constructively.
 - The electron wave becomes a standing wave, like a wave on a musical string.

 In this view, the electron is thought of not as a particle located at some point in the atom but as if its mass and charge were spread out into a standing wave surrounding the atomic nucleus with an integral number of wavelengths fitting evenly into the circumferences of the orbits.



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- a) An orbiting electron forms a standing wave only when the circumference of its orbit is equal to a wholenumber multiple of the wavelength.
- b) When the wave does not close in on itself in phase, it undergoes destructive interference. Hence, orbits exist only where waves close in on themselves in phase.



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- The circumference of the innermost orbit, according to this picture, is equal to one wavelength.
 - The second has a circumference of two electron wavelengths.
 - The third orbit has a circumference of three electron wavelengths, and so forth.

- The electron orbits in an atom have discrete radii because the circumferences of the orbits are whole-number multiples of the electron wavelength.
- This results in a discrete energy state for each
 orbit.
 The circumferences of
 olastron orbits from



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- This model explains why electrons don't spiral closer and closer to the nucleus, causing atoms to shrink to the size of the tiny nucleus.
- If each electron orbit is described by a standing wave, the circumference of the smallest orbit can be no smaller than one wavelength.
 - No fraction of a wavelength is possible in a circular (or elliptical) standing wave.
- As long as an electron carries the momentum necessary for wave behavior, atoms don't shrink in on themselves.

Quantum Mechanics

 The fundamental equation of quantum mechanics is Schrödinger's wave equation, which is:

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

(Details of this equation are beyond the scope of this course.)

Quantum Mechanics, Continued

- Quantum Mechanics
 - In Schrödinger's wave equation, the thing that "waves" is the nonmaterial matter wave amplitude—a mathematical entity called a wave function, represented by the symbol ψ (the Greek letter psi). All the information about the matter waves is contained in the wave function.

Quantum Mechanics, Continued-1

 Progression from the Bohr model of the atom to the modified model with de Broglie waves to the Schrödinger model



Quantum Mechanics CHECK YOUR NEIGHBOR

As to why electrons orbit in only certain orbits, a compelling explanation views orbital electrons as

- A. particles that morph into waves.
- B. standing waves.
- C. planetary particles.
- D. quantum particles.

Quantum Mechanics CHECK YOUR ANSWER

As to why electrons orbit in only certain orbits, a compelling explanation views orbital electrons as

B. standing waves.

Explanation:

Standing waves are stable and close in on themselves in phase.

Correspondence Principle

- Correspondence principle
 - The correspondence principle, first stated by Niels Bohr is:
 - If a new theory is valid, it must account for the verified results of the old theory.
 - New theory and old must correspond; that is, they must overlap and agree in the region where the results of the old theory have been fully verified.

Correspondence Principle CHECK YOUR NEIGHBOR

To which of these does the correspondence principle apply?

- A. The Schrödinger equation leads to Newton's equations for orbital motion of satellites.
- B. The energy of a particle can be expressed as $E = mc^2$.
- C. Diffraction can be explained with either particles or photons.
- D. All of the above.

Correspondence Principle CHECK YOUR ANSWER

To which of these does the correspondence principle apply?

D. All of the above.

Explanation:

Unlike Heisenberg's uncertainty principle, the correspondence principle is a general rule. Old and new theory must overlap where both are valid.