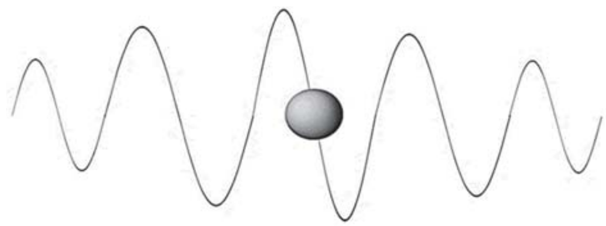
MATTER WAVES AND ITS PROPERTIES

Matter waves:

In the realm of quantum mechanics, the behavior of matter is delineated by wavefunctions, intricate constructs that delineate the likelihood of locating a particle within a specific spatial position. This conceptual framework, which underpins the probabilistic nature of quantum mechanics, was first proposed by Louis de Broglie in 1924. He postulated that akin to the dual nature of light, which can manifest as both waves and particles, matter too can exhibit this duality.



ach particle in motion is accompanied by an associated wave, aptly termed a matter-wave. Unlike tangible objects, these waves serve as carriers of information or energy, akin to ethereal signals traversing from one point to another without any discernible substance.

Much like light, whose behavior can be characterized by both particle-like and wave-like attributes, it is theorized that all moving particles possess this dual disposition, capable of exhibiting wave-like tendencies under specific conditions.

These waves, intricately entwined with the motion of particles, are commonly referred to as Matter waves or De Broglie waves, paying homage to their progenitor. Their defining feature, the wavelength symbolized as λ (lambda), is termed the De Broglie wavelength.

The significance of matter's wave-like characteristics becomes pronounced when the De Broglie wavelength aligns with the spatial dimensions of the matter involved, illuminating the nuanced interplay between the inherent particle and wave properties.

De-Broglie Wavelength:

The energy associated with a photon, characterized by its frequency ν and wavelength λ, is determined by the following formula:

$$E = hv = \frac{hc}{\lambda}$$

As per Einstein's energy-mass equivalence principle, the corresponding mass $E = mc^2$ of a photon is calculated through the equation:

$$m = \frac{E}{c^2} = \frac{hv}{c^2} = \frac{h}{\lambda c} \quad \text{... (i)}$$

or

$$\lambda = \frac{h}{mc}\lambda = \frac{h}{p} \quad \text{... (ii)}$$

Drawing on the analogy introduced by de Broglie, when a particle of mass m moves at a velocity v, it displays wave-like traits, notably appearing as waves with a wavelength symbolized as λ (referred to as the de Broglie wavelength).

This can be represented mathematically as:

$$\lambda = \frac{h}{mv} = \frac{h}{p} \quad \text{... (iii)}$$

The momentum p of a particle is linked to its kinetic energy by means of the equation:

$$P = \sqrt{2km}$$

When a charge q undergoes acceleration due to a potential difference V, it acquires a kinetic energy $K = qV$. Integrating all these relationships, Equation (iii) can be expressed as:

$$\lambda = \frac{h}{mv} = \frac{h}{p} = \frac{h}{\sqrt{2km}} = \frac{h}{\sqrt{2qvm}} \quad \text{... (iv)}$$

The de Broglie wavelength pertaining to an electron, bearing a charge e and experiencing acceleration due to a potential V, thereby acquiring kinetic energy, can be articulated in the following manner: $K = eV$

Upon inserting the values of Planck's constant (h), mass (m), and charge (q) into Equation (iv), we derive a simple formula for calculating the de Broglie wavelength of an electron.

$$\lambda\left(\text{in } \mathring{A}\right) = \sqrt{\frac{150}{V(\text{in volts})}}$$

Properties of matter waves:

1. Matter waves lack electromagnetic properties, distinguishing them from other types of waves.
2. The electron microscope's design revolves around the principles of de Broglie waves.
3. A matter-wave serves as a representation of the probability of locating a particle within spacetime.
4. The presence of a charge in a material component does not influence the behavior of matter waves.
5. While matter waves have the capacity to propagate through a vacuum, they do not conform to the characteristics of mechanical waves.
6. It is possible for the phase velocity of matter waves to surpass the speed of light under certain conditions.
7. The behavior of matter waves remains unaffected by the charge of the particle they are associated with.
8. The significance of the wave-like properties of matter becomes apparent when the De Broglie wavelength closely matches the dimensions of the matter.
9. The wave-particle duality dictates that the wave and particle attributes of moving bodies cannot be simultaneously observed.
10. Matter waves provide insight into the probability distribution of finding a particle within a given space.

Experimental Verification of Dual Nature of Matter:

Some of the key experiments demonstrating the wave-particle duality of matter include:

Electron Diffraction:

In 1927, Clinton Davisson and Lester Germer performed an experiment where they observed diffraction patterns when electrons were scattered by a crystalline nickel target. This experiment confirmed that electrons, which were previously thought to be particles, also exhibit wave-like behavior similar to light.

Double-Slit Experiment with Electrons:

Similar to the famous double-slit experiment with light, scientists have conducted experiments with electrons. When electrons are fired one at a time through a double slit, an interference pattern emerges on the detection screen, indicating that electrons can interfere with themselves, demonstrating their wave-like nature.

Electron Tunneling:

Electron tunneling is a phenomenon where electrons can pass through a potential barrier that they classically do not have enough energy to overcome. This phenomenon is explained by treating electrons as waves that can penetrate barriers, further supporting their wave-like behavior.

Davisson-Germer Experiment: In addition to their electron diffraction experiment, Davisson and Germer also performed experiments where they varied the angle of incidence of the electrons on the nickel target. They found that the diffraction pattern changed as the angle was adjusted, providing further evidence for the wave-like behavior of electrons.

Atomic Force Microscopy:

Atomic force microscopy (AFM) is a technique used to image surfaces with atomic resolution. In AFM, a sharp tip is moved close to a surface, and the forces between the tip and the atoms on the surface are measured. This technique has provided direct evidence of the wave-like nature of atoms and molecules.

These experiments, among others, provide strong empirical evidence for the wave-particle duality of matter, demonstrating that particles such as electrons and atoms can exhibit both wave-like and particle-like behavior depending on the experimental conditions.

Bohr's Model:

Neil Bohr introduced the Bohr atomic model in 1915, which served as an enhancement to Ernest Rutherford's earlier atomic model. Rutherford's initial model put forward the concept of the nuclear model of an atom, illustrating a nucleus possessing a positive charge and enveloped by electrons carrying a negative charge.

Modification of Rutherford's Model:

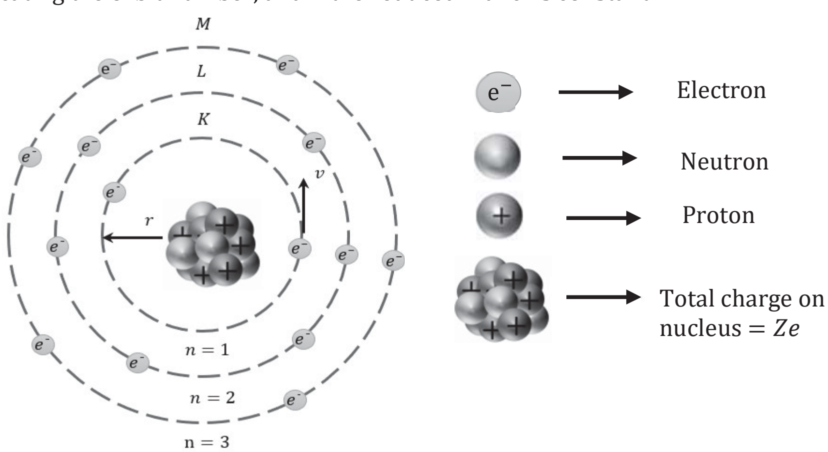
Bohr's theory brought about a paradigm shift in atomic understanding by suggesting that electrons traverse distinct, fixed pathways or shells encircling the nucleus, a departure from Rutherford's model where electrons were depicted as capable of occupying any position around the nucleus. Moreover, Bohr expanded upon this concept by detailing that each orbit or shell corresponds to a precise energy level, thereby enhancing Rutherford's depiction of the nucleus to encompass the notion of electrons and their associated energy states.

Description of Bohr's Model:

In Bohr's atomic model, a centrally located nucleus carries a positive charge, surrounded by negatively charged electrons orbiting in defined paths. Bohr noted a distinctive pattern: electrons positioned farther from the nucleus have elevated energy levels, whereas those in closer proximity to the nucleus demonstrate lower energy states.

Quantization of Electron Orbits:

Bohr presented the notion that electrons are constrained to orbit the nucleus solely in predetermined orbits where their angular momentum conforms to a quantized value, which is a multiple of $\frac{h}{2\pi}$ (Planck's constant divided by 2π). This principle is mathematically expressed as $mvr = \frac{nh}{2\pi}$, wherein m denotes the mass of the electron, v its velocity, r the radius of the orbit, n an integer indicating the orbit number, and $\hbar$ the reduced Planck's constant.



Stability of Electron Orbits:

As electrons move in their orbits, they do not emit energy, which contributes to the stability of their orbits. Bohr theorized that electrons in stable orbits exhibit behavior reminiscent of standing waves within these orbitals, effectively preserving their energy levels without undergoing energy dissipation.