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De-Broglie Wavelength

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ABSTRACT

In quantum mechanics, de Broglie wavelength is an important concept . The wavelength (λ) that is associated with an object in relation to its momentum and mass is known as de Broglie wavelength. A particle's de Broglie wavelength is usually inversely proportional to its force. It is said that matter has a dual nature of wave-particles. de Broglie waves, named after the discoverer Louis de Broglie, is the property of a material object that varies in time or space while behaving similar to waves. It is also called matter-waves. It holds great similarity to the dual nature of light which behaves as particle and wave, which has been proven experimentally. The physicist Louis de Broglie suggested that particles might have both wave properties and particle properties. The wave nature of electrons was also detected experimentally to substantiate the suggestion of Louis de Broglie. The objects which we see in day-to-day life have wavelengths which are very small and invisible, hence, we do not experience them as waves. However, de Broglie wavelengths are quite visible in the case of subatomic particles. In the case of electrons going in circles around the nuclei in atoms, the de Broglie waves exist as a closed-loop, such that they can exist only as standing waves, and fit evenly around the loop. Because of this requirement, the electrons in atoms circle the nucleus in particular configurations, or states, which are called stationary orbits.

KEYWORDS: *de Broglie, wavelength, waves, orbits, configurations, particle, quantum, mechanics*

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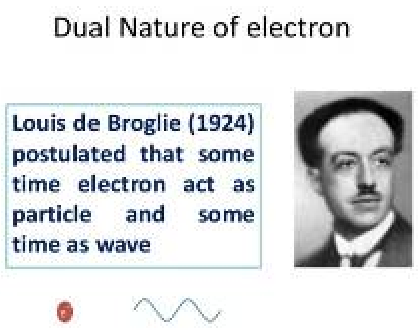
INTRODUCTION

In quantum mechanics, de Broglie reasoned that matter also can show wave-particle duality, just like light, since light can behave both as a wave (it can be diffracted and it has a wavelength) and as a particle (it contains packets of energy hν).



And also reasoned that matter would follow the same equation for wavelength as light namely,[1,2]

λ = h / p

Where p is the linear momentum, as shown by Einstein.

de Broglie derived the above relationship as follows:
1. E = hν for a photon and λν = c for an electromagnetic wave.
2. $E = mc^2$, means λ = h/mc, which is equivalent to λ = h/p.

Note: m is the relativistic mass, and not the rest mass; since the rest mass of a photon is zero.

Now, if a particle is moving with a velocity v, the momentum p = mv and hence λ = h / mv

Therefore, the de Broglie wavelength formula is expressed as;

λ = h / mv

1. The wave properties of matter are only observable for very small objects, de Broglie wavelength of a double-slit interference pattern is produced by using electrons as the source. 10 eV electrons (which is the typical energy of an electron in an electron microscope): de Broglie wavelength = 3.9×10^{-10} m.

This is comparable to the spacing between atoms. Therefore, a crystal acts as a diffraction grating for electrons. The diffraction pattern allows the crystal structure to be determined.[3,4]

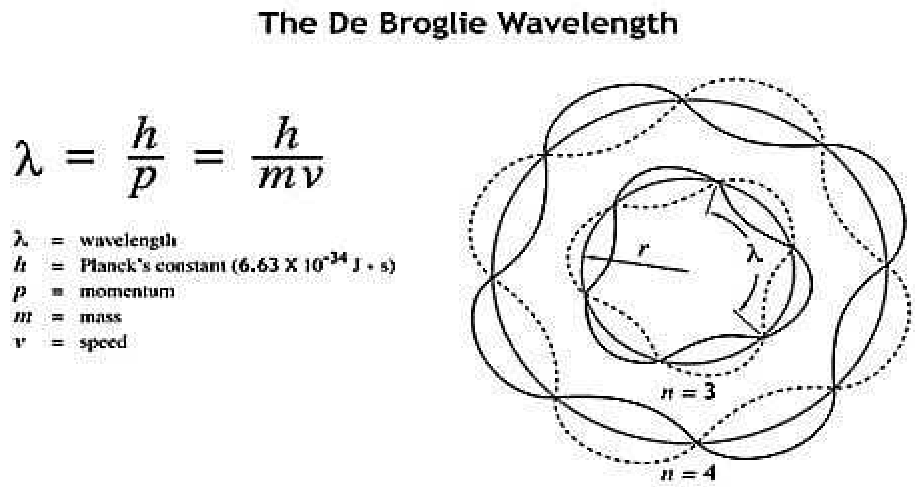
2. In a microscope, the size of the smallest features we can see is limited by the wavelength used. With visible light, the smallest wavelength is 400 nm = 4×10^{-7} m. Typical electron microscopes use wavelengths 1000 times smaller and can be used to study very fine details.

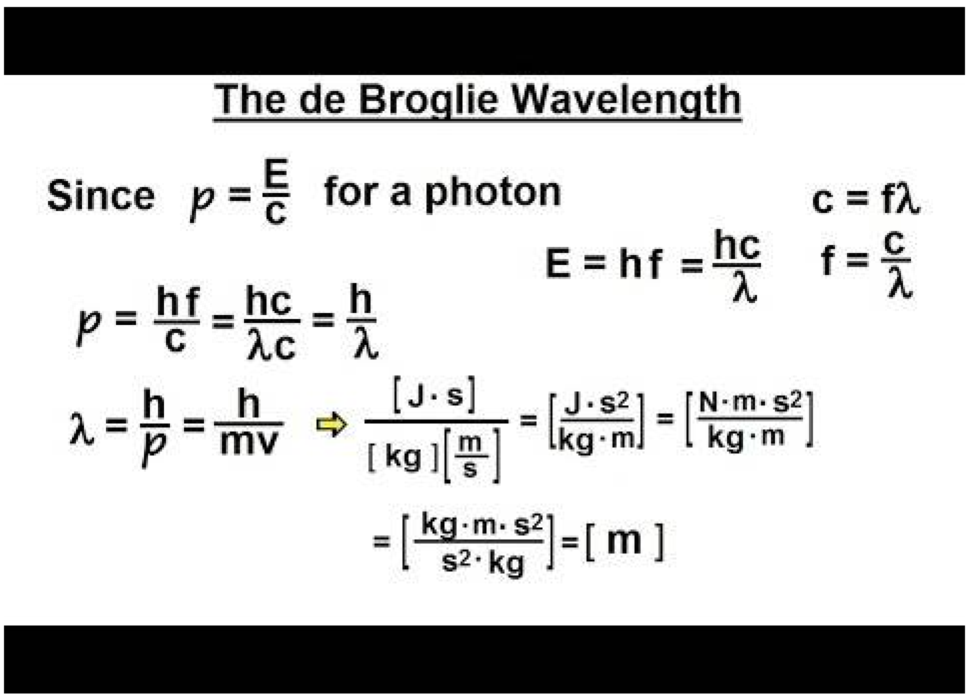
The thermal de Broglie wavelength (λ_{th}) is approximately the average de Broglie wavelength of the gas particles in an ideal gas at the specified temperature.

The thermal de Broglie wavelength is given by the expression:

$\lambda_D = h / \sqrt{2 \pi m k_B T}$

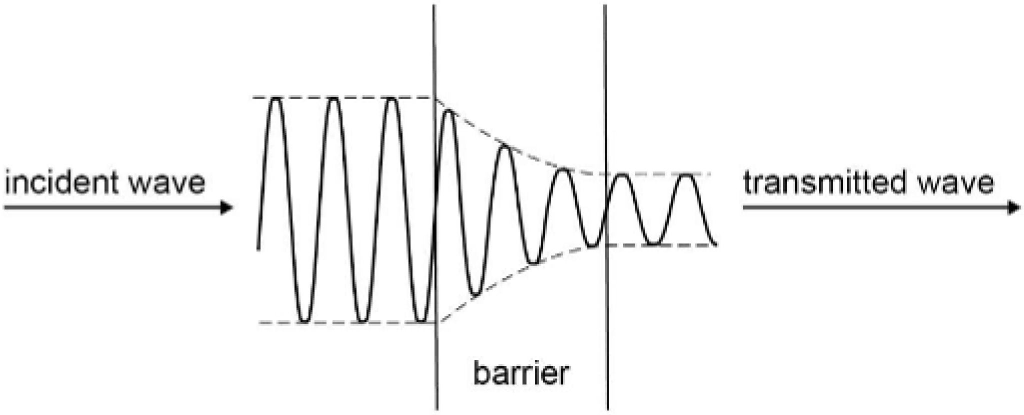
where,
h = Planck constant,
m = mass of a gas particle,
k_B = Boltzmann constant,
T = temperature of the gas,
$\lambda_D = \lambda_{th}$ = thermal de Broglie wavelength of the gas particles.[5,6]



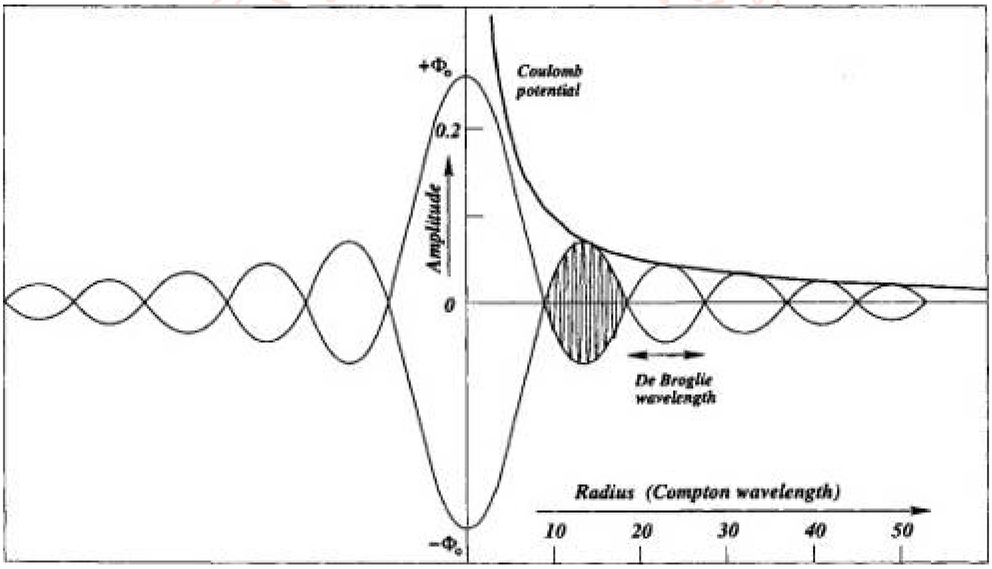


Discussion

Matter waves are a central part of the theory of quantum mechanics, being an example of wave–particle duality. All matter exhibits wave-like behavior. For example, a beam of electrons can be diffracted just like a beam of light or a water wave. In most cases, however, the wavelength is too small to have a practical impact on day-to-day activities. The concept that matter behaves like a wave was proposed by French physicist Louis de Broglie in 1924. It is also referred to as the de Broglie hypothesis. Matter waves are referred to as de Broglie waves. Wave-like behavior of matter was first experimentally demonstrated by George Paget Thomson's thin metal diffraction experiment, and independently in the Davisson–Germer experiment, both using electrons; and it has also been confirmed for other elementary particles, neutral atoms and even molecules. [7,8]



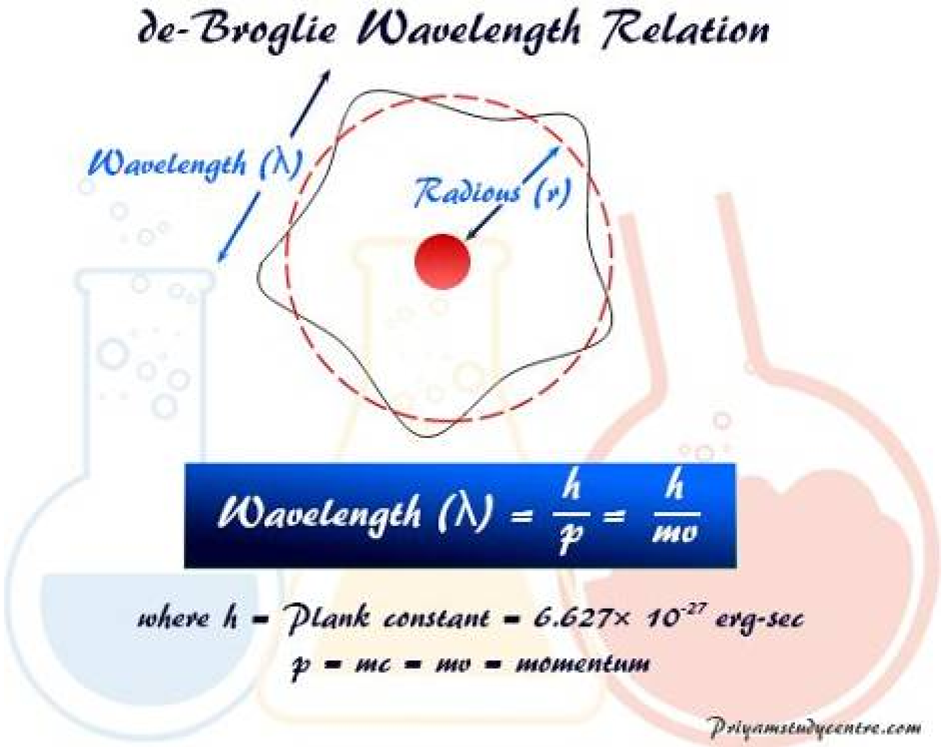
In 1927 at Bell Labs, Clinton Davisson and Lester Germer fired slow-moving electrons at a crystalline nickel target. The angular dependence of the diffracted electron intensity was measured, and was determined to have the same diffraction pattern as those predicted by Bragg for x-rays. At the same time George Paget Thomson at the University of Aberdeen was independently firing electrons at very thin metal foils to demonstrate the same effect. Before the acceptance of the de Broglie hypothesis, diffraction was a property that was thought to be exhibited only by waves. Therefore, the presence of any diffraction effects by matter demonstrated the wave-like nature of matter. When the de Broglie wavelength was inserted into the Bragg condition, the predicted diffraction pattern was observed, thereby experimentally confirming the de Broglie hypothesis for electrons. This was a pivotal result in the development of quantum mechanics. Just as the photoelectric effect demonstrated the particle nature of light, the Davisson–Germer experiment showed the wave-nature of matter, and completed the theory of wave–particle duality. For physicists this idea was important because it meant that not only could any particle exhibit wave characteristics, but that one could use wave equations to describe phenomena in matter if one used the de Broglie wavelength.[9,10]



Experiments with Fresnel diffraction and an atomic mirror for specular reflection of neutral atoms confirm the application of the de Broglie hypothesis to atoms, i.e. the existence of atomic waves which undergo diffraction, interference and allow quantum reflection by the tails of the attractive potential. Advances in laser cooling have allowed cooling of neutral atoms down to nanokelvin temperatures. At these temperatures, the thermal de Broglie wavelengths come into the micrometre range. Using Bragg diffraction of atoms and a Ramsey interferometry technique, the de Broglie wavelength of cold sodium atoms was explicitly measured and found to be consistent with the temperature measured by a different method. This effect has been used to demonstrate atomic holography, and it may allow the construction of an atom probe imaging system with nanometer resolution. The description of these phenomena is based on the wave properties of neutral atoms, confirming the de Broglie hypothesis. The effect has also been used to explain the spatial version of the quantum Zeno effect, in which an otherwise unstable object may be stabilised by rapidly repeated observations.[11,12]

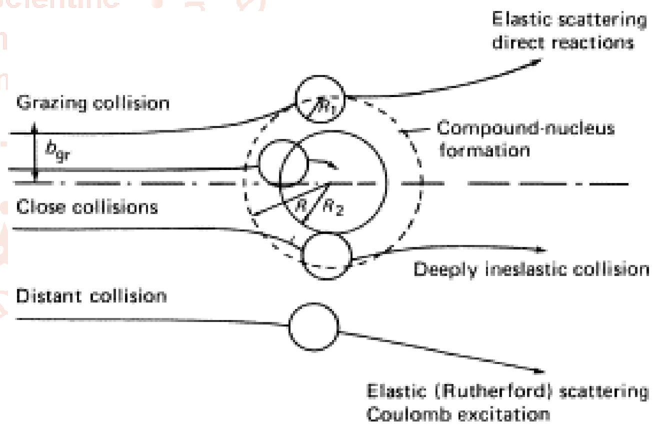
Results

Albert Einstein first explained the wave–particle duality of light in 1905. Louis de Broglie hypothesized that any particle should also exhibit such a duality. The velocity of a particle, he concluded, should always equal the group velocity of the corresponding wave. The magnitude of the group velocity is equal to the particle's speed. Both in relativistic and non-relativistic quantum physics, we can identify the group velocity of a particle's wave function with the particle velocity. Quantum mechanics has very accurately demonstrated this hypothesis, and the relation has been shown explicitly for particles as large as molecules.



De Broglie deduced that if the duality equations already known for light were the same for any particle, then his hypothesis would hold.

The thesis of de Broglie involved the hypothesis that a standing wave guided the electrons in the Bohr model of the atom. The thesis had an unusual analysis that higher energy photons obey the Wien Law and are particle-like while lower energy photons obey the Rayleigh–Jeans law and are wave-like. Particle physics tends to treat all forces by particle-particle interaction causing Richard Feynman to say that there are no waves just particles. And recently, there have been some theories that try to explain the Interpretations of quantum mechanics which try to resolve whether either the particle or the wave aspect is fundamental in nature, seeking to explain the other as an emergent property. Some interpretations, such as hidden variable theory, treat the wave and the particle as distinct entities. Yet others propose some intermediate entity that is neither quite wave nor quite particle but only appears as such when we measure one or the other property. The Copenhagen interpretation states that the nature of the underlying reality is unknowable and beyond the bounds of scientific inquiry. Schrödinger's acknowledges that his quantum mechanical equation is based in part on the thesis of de Broglie. Schrödinger emphasized that his equation was different in that it was in multi-dimensional space. In his lecture as both wave mechanics and matrix mechanics were both new concepts, he tries to imply his formula is superior as does Heisenberg in his speech.[13,14]



Conclusions

A matter wave clock is a type of clock whose principle of operation makes use of the apparent wavelike properties of matter.

Matter waves were first proposed by Louis de Broglie and are sometimes called de Broglie waves. They form a key aspect of wave–particle duality and experiments have since supported the idea. The wave associated with a particle of a given mass, such as an atom, has a defined frequency, and a fixed duration of one cycle from peak to peak that is sometimes called its Compton periodicity. Such a matter wave has the characteristics of a simple clock, in that it marks out fixed and equal intervals of time. The twins paradox arising from Albert Einstein's theory of relativity means that a moving particle will have a slightly different period from a stationary particle. Comparing two such particles allows the construction of a practical "Compton clock"[15]

De Broglie proposed that the frequency f of a matter wave equals E/h, where E is the total energy of the particle and h is Planck's constant. For a particle at rest, the relativistic equation $E=mc^2$ allows the derivation of the Compton frequency f for a stationary massive particle, equal to mc^2/h.

De Broglie also proposed that the wavelength λ for a moving particle was equal to h/p where p is the particle's momentum.

The period (one cycle of the wave) is equal to 1/f.

This precise Compton periodicity of a matter wave is said to be the necessary condition for a clock, with the implication that any such matter particle may be regarded as a fundamental clock. This proposal has been referred to as "A rock is a clock."[16]

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