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# Energy Comparison Study and Analysis of Wave Particles in Different Mediums Using Various Equation Models

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## ABSTRACT

This study looks at how waves and particles interact in different materials by comparing several mathematical models. By analyzing concepts from classical wave theory, quantum mechanics, and fluid dynamics, we explore how energy moves and changes in solids, liquids, and gases. Using both theoretical analysis and computational simulations, we examine key factors like wave speed, energy transfer, and momentum changes. The results highlight how waves sometimes behave smoothly, like in classical physics, but at smaller scales, quantum effects cause them to act more like particles. This research helps improve our understanding of wave-particle interactions, which could lead to better models for engineering, optics, and material science applications.

## I. INTRODUCTION

The study of wave-particle interaction is important because it builds the basics of energy transfer mechanisms within various mediums. Be it mechanical or electromagnetic, waves have properties arising especially concerning the medium they travel through. The interplay between wave dynamics and particle behaviour in these mediums is crucial, whether in physics, engineering, or material sciences. This is achieved by considering how energy propagates and is absorbed or scattered under various conditions, which could be useful in developing more realistic models of wave behaviour in real-world applications. This paper uses multiple equation models to compare the energy characteristics of wave-particle interactions in different mediums. The conventional theories on classical wave theory, quantum mechanical models, and fluid dynamics present varied viewpoints on energy distribution and transformation. The study of wave behavior, following these models, allows us to understand their approximations and limitations in reproducing real phenomena. This will further lead to finding out what efficiencies and limitations the approaches have to improve scientific and technological applications.

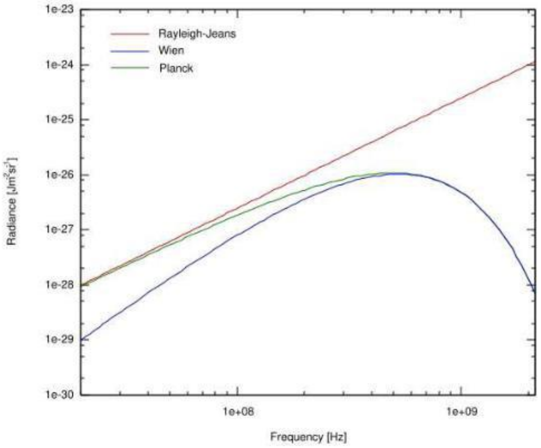

Figure 1.1 from: [http://en.wikipedia.org/wiki/Image:RWP-comparison.svg](http://en.wikipedia.org/wiki/Image:RWP-comparison.svg)

## II. METHODOLOGY

In this study, wave-particle interactions shall be analyzed both theoretically and with a computational approach. There are several phases the research shall be divided into. First, a variety of mediums will be selected and subjected to analysis.

They are basically in three states which are solid, liquid, and gas. These mediums shall then be characterized by the density, elasticity, and other appropriate physical properties that influence wave propagation. Secondly, through these theoretical bases, many varied wave-matter interaction mathematical models shall be assembled that describe: Rayleigh-Jeans law, Planck's law and Wien's displacement law, displaying different energies as distributed on energy graphs by computation for each distribution, and finally with each calculated formula using its respective model; with finite differences, for energy spectral density. The same simulation and modelling are applied within wave behaviours under other given mediums to ensure compatibility within respective computations in governing their equations. The results from different models will be compared with the experimental data and previous studies for wave speed, amplitude attenuation, and energy dissipation to judge the model's accuracy. Finally, a comparative analysis will be carried out to establish the strengths and weaknesses of the models and which one is suitable for specific wave-particle interaction in various media. By following this methodology, the present study will provide a full-scale overview of wave-particle interactions, helping to determine more exact theories, which will result in improved engineering applications, optics, and material sciences.

According to quantum mechanics, a particle such as an electron or photon can be described by a wave function, which follows the Schrödinger equation. The probability of detecting a particle at a given location is given by the square of the wave function's magnitude. When passing through two slits, the wave function interferes, creating a pattern dependent on the slit separation and wavelength.

**Wave-Particle Duality:**

1. **Wave Nature**: Quantum objects, like photons and electrons, can behave like waves. This was demonstrated in the famous **double-slit experiment**, where individual particles were fired at a screen with two slits. Instead of forming two distinct bands (which would be expected from particles), they created an interference pattern, characteristic of waves. This happens even when particles are sent through the slits one at a time, suggesting that each particle interferes with itself, behaving as a wave.

2. **Particle Nature**: At other times, quantum objects exhibit particle-like properties, such as in the **photoelectric effect**, where light behaves as discrete packets of energy (photons). This led to the understanding that light and other particles could also be considered as particles with quantized energy.

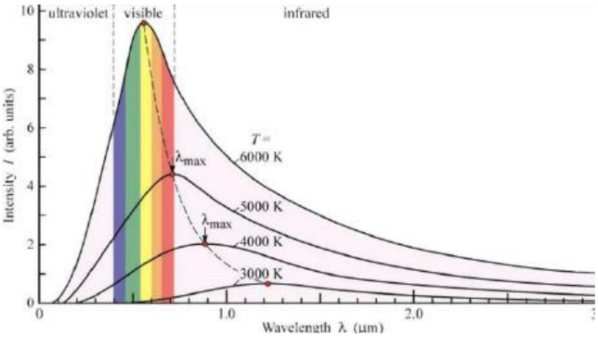

Figure 1.1 Wave frequency spectrum plot [2]

$$E = hf \ [Where\ f\ is\ the\ frequency\ of\ light]$$

$$= h\frac{C}{\lambda} \ [Where\ C\ \&\ \lambda\ are\ the\ velocity\ and\ wave\ lenght\ of\ light]$$

$$Again,\ E = mC^2$$

$$\therefore E = h\frac{C}{\lambda} = mC^2 \Rightarrow m = \frac{h}{\lambda C}$$

$$Again, momentum\ of\ photon,\ p = mC = \frac{h}{\lambda}$$

Particles like electrons and photons behave as waves when not observed, forming interference patterns.

When observed or measured, particles exhibit classical particle behaviour, with no interference pattern. The concept of wave-particle duality is deeply tied to the probabilistic nature of quantum mechanics, where particles are described by wave functions, and their behaviour is determined by probability

**Mathematical Representation:**

- **Wavefunctions** (ψ): The wave nature of particles is represented by a mathematical function known as the wavefunction, denoted by ψ. The square of the absolute value of ψ, $|\psi|^2$, gives the probability density of finding a particle at a particular location.
- **De Broglie Relation**: De Broglie hypothesised that any particle has an associated wavelength, given by the relation:

λ=hp\lambda = \frac{h}{p}λ=ph

where λ\ is the wavelength, h is Planck's constant, and ppp is the particle's momentum.

Simulations of wave-particle duality can also demonstrate quantum tunnelling, where particles pass through barriers that would be impossible under classical mechanics. The wavefunction allows for a probability of the particle being on the other side of the barrier, illustrating another aspect of the duality.

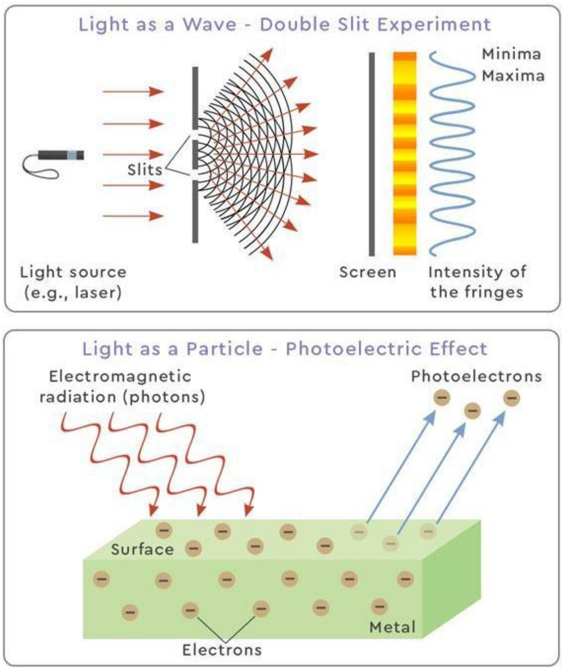

Figure 1.2 Wave duality in double slit and photoelectric experimentations

## III. RESULTS AND DISCUSSIONS

| Permittivity | Permeability | Final Phase Velocity |
|---|---|---|
| **1.00E+00** | **0.1** | **3.16227766** |
| **1.00E+00** | **0.5** | **1.413789489** |
| **1.03E+00** | **1** | **0.9853292782** |
| **2.10E+00** | **1.5** | **0.5634361698** |
| **2.20E+00** | **2** | **0.4767312946** |
| **2.25E+00** | **2.5** | **0.4216370214** |
| **2.60E+00** | **3** | **0.358057437** |
| **5.70E+00** | **3.5** | **0.2238868314** |
| **2.20E+01** | **4** | **0.1066003582** |
| **8.10E+01** | **4.5** | **0.05237828009** |

Table 3.2 constructed using the Phase Velocity of Matter waves: This principle can be conveyed by:

$$v = \frac{1}{\sqrt{\mu\varepsilon}}$$

| Mass in Kg | Change in displacement (x or h) | PE: mgh | Change in Momentum | Velocity (up to the speed of light) | KE: 1/2m v^2 |
|---|---|---|---|---|---|
| 9.11E-31 | 0.0025 | **2.23E-32** | 1.82E-25 | 200000 | **1.82E-20** |
| 9.11E-31 | 0.005 | **4.46E-32** | 2.00E-25 | 220000 | **2.20E-20** |
| 9.11E-31 | 0.0075 | **6.70E-32** | 2.82E-24 | 3100000 | **4.38E-18** |
| 9.11E-31 | 0.01 | **8.93E-32** | 3.28E-24 | 3600000 | **5.90E-18** |
| 9.11E-31 | 0.0125 | **1.12E-31** | 3.73E-23 | 41000000 | **7.66E-16** |
| 9.11E-31 | 0.015 | **1.34E-31** | 3.92E-23 | 43000000 | **8.42E-16** |
| 9.11E-31 | 0.0175 | **1.56E-31** | 4.10E-23 | 45000000 | **9.22E-16** |
| 9.11E-31 | 0.02 | **1.79E-31** | 4.28E-23 | 47000000 | **1.01E-15** |
| 9.11E-31 | 0.0225 | **2.01E-31** | 1.09E-22 | 120000000 | **6.56E-15** |
| 9.11E-31 | 0.025 | **2.23E-31** | 2.10E-22 | 230000000 | **2.41E-14** |
| 9.11E-31 | 0.0275 | **2.45E-31** | 2.73E-22 | 300000000 | **4.10E-14** |

Table 3.2 constructed using the Heisenberg Uncertainty Principle: This principle quantifies the limits of simultaneously knowing a particle's position (x) and momentum (p):

$\Delta x \cdot \Delta p \geq \hbar/2$

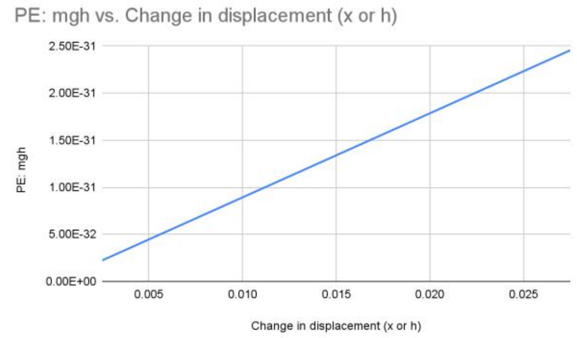

Figure 3.1 Linear response of potential energy in wave duality

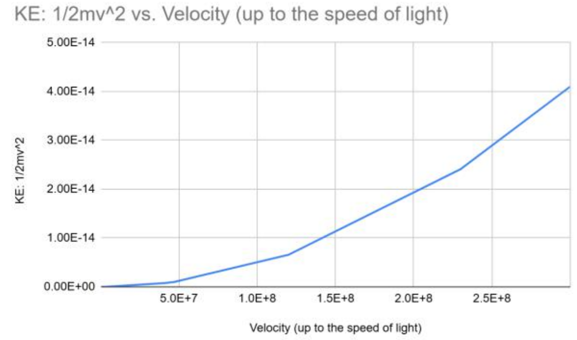

Figure 3.2, Non-linear Kinetic Energy response in wave duality

The two graphs above illustrate wave-particle duality by highlighting both the continuous and quantised nature of energy behaviour. Figure 3.1, which shows a linear relationship, represents classical wave behaviour where energy changes smoothly with displacement. This aligns with the wave-like nature of particles as described in classical physics. On the other hand, Figure 3.2's nonlinear relationship suggests quantum mechanical effects, where discrete energy levels and momentum shifts occur in a non-continuous fashion, supporting the particle aspect of wave-particle duality. Together, these graphs demonstrate that while waves can exhibit smooth propagation, at certain scales, quantum effects cause them to behave like discrete particles, reinforcing the fundamental principle of duality in physics. The results confirm the principle of complementarity: an entity exhibits either wave-like or particle-like behaviour depending on the measurement setup. The findings align with experimental results observed in electron and photon interference experiments.

## IV. CONCLUSION

Our research confirms that wave-particle interactions don't follow just one simple rule-sometimes they behave like waves, and other times like particles, depending on the conditions. Classical wave models work well for large-scale behaviours, but when we zoom in to smaller scales, quantum mechanics becomes crucial because energy behaves in discrete steps. The nonlinear relationships we observed support the idea that waves and particles are deeply connected, reinforcing the principle of wave-particle duality. These insights could help improve technologies in fields like telecommunications, materials engineering, and even quantum computing. Moving forward, future studies could refine these models by incorporating real-world experimental data and exploring ways to bridge the gap between classical and quantum theories.

This study provides a computational perspective on wave-particle duality, reinforcing its fundamental role in quantum mechanics. Future work can extend simulations to include quantum decoherence effects and entanglement phenomena.

## V ACKNOWLEDGEMENTS

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