Quantum Mechanics

Covered Topics

- Wave Aspect of Particles
- Wave particle duality
- Dual nature of matter and radiation
- de Broglie's Hypothesis: Matter Waves
- References

Wave Aspect of Particles

- The behavior of a "microscopic" particle is very different from that of a classical particle:
  - ➔ in some experiments it resembles the behavior of a classical wave (not localized in space)
  - ➔ in other experiments it behaves as a classical particle (localized in space)
- Corpuscular theories of light treat light as though it were composed of particles, but can not explain DIFRACTION and INTERFERENCE.
- Maxwell's theory of electromagnetic radiation can explain these two phenomena, which was the reason why the corpuscular theory of light was abandoned.

Wave Aspect of Particles

Wave – Particle Duality

- Newton thought light consisted of "corpuscles".
- Huygens believed that it was a wave.
- By the end of the 19th century, everyone "knew" it was a wave : Young's Slits:
- Photoelectric effect – photons (particles!).
- Compton Effect: particles!

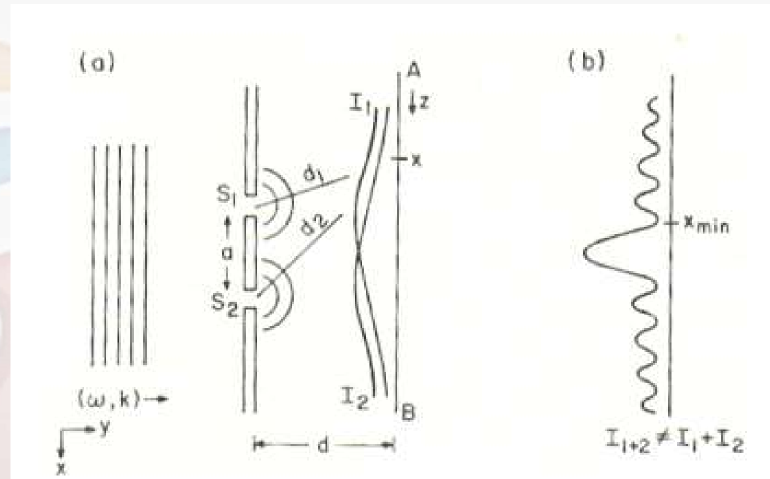
	Waves	Particles
Reflection	✓	✓
Refraction	✓	✓
Interference	✓	×
Diffraction	✓	×
Photoelectric effect	×	✓

- Bohr - principle of complementarity: It is impossible to observe both the wave and particle aspects simultaneously.
- Light can be used as either wave or particle explanation : Need to be aware of both (Wave particle duality).

Thomas Young (1773-1829)

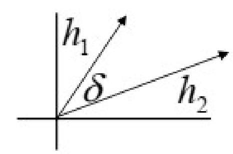
Niels Bohr

1885-1962



- Mathematically, if the (complex) wave functions are h_1, h_2,then the energy arriving when slit i is open is $|h_i|^2$, and the energy arriving when both are open is **NOT** $|h_1|^2 + |h_2|^2$, but

$$|h_1 + h_2|^2 = |h_1|^2 + |h_2|^2 + \underbrace{2|h_1||h_2|\cos(\delta)}_{\text{interference term}}$$

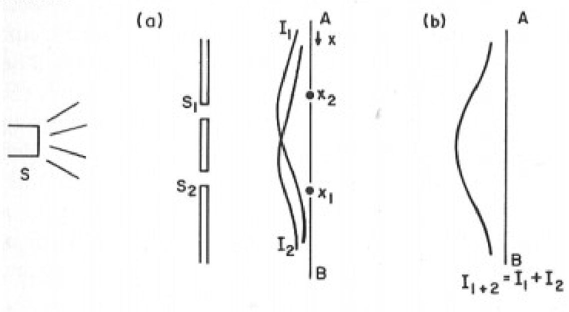


So far so good – but it turns out that the wave model fails to explain certain phenomena.

Dual nature of matter and radiation

It also turns out that not only don't the lightwaves behave like waves – also, particles don't behave like particles.

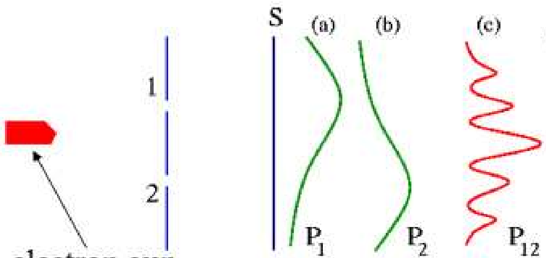
Let's go back to the two slit experiment. How will it look with particles (electrons)? We may assume it will look like



i.e., the number of electrons hitting any specific point on the wall when both slits are open, will be the sum of the numbers when only the first/second slit is open.

But that doesn't happen; the electrons also interfere. That is, at some points, LESS electrons hit when BOTH slits are open!! This happens even if the electrons are fired very slowly (one at a time).

- Fortunately, the simple model that describes wave interference ($|h_1 + h_2|^2$) also explains particle interference. The problem is, of course, to compute the so-called "probability amplitudes" h_1, h_2.



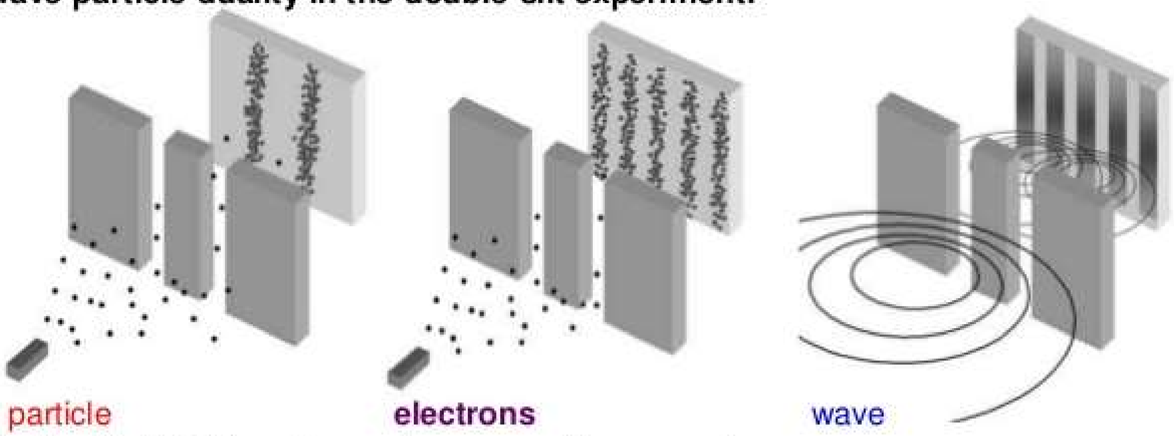
There are h_1, h_2 such that $P_i = |h_i|^2$ and $P_{12} = |h_1 + h_2|^2$.

de Broglie's Hypothesis: Matter Waves

"A moving particle whatever its nature has wave property associated with it"

$$\lambda = \frac{h}{p}, \qquad \vec{k} = \frac{\vec{p}}{\hbar},$$

Wave-particle duality in the double-slit experiment:



de Broglie (1924) matter can have wave-like properties:

$$\lambda = \frac{h}{mv}$$

Particle	Mass (kg)	Speed (m/s)	λ (pm)
accelerated electron	9.1×10^{-31}	5.9×10^{6}	120
fullerene (C_{60})	1.2×10^{-24}	220	2.5
golf ball	0.045	30	4.9×10^{-22}

Photon momentum

- ✓ If the photon is a particle with a known energy, it must have some momentum associated with it.
- ✓ Photon has no mass

$$E^2 = p^2c^2 + m_o^2c^4$$

$$E = pc$$

$$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$$

References:

1. NouredineZettili,Quantum Mechanics: concepts and applications, 2nd Edition, Wiley, UK, 2009f
2. Introduction to Quantum Mechanics, D.J. Griffith, 2ndEd. 2005, Pearson Education
3. Quantum Mechanics, Robert Eisberg and Robert Resnick, 2ndEd., 2002, Wiley.
4. Quantum Mechanics, Leonard I. Schiff, 3rdEd. 2010, Tata McGraw Hill.
5. Modern Thermodynamics with Statistical Mechanics, Carl S. Helrich, Springer