Chemistry 3P51 – Fall 2013
Quantum Chemistry

Lecture No. 2
Sep 6th, 2013

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Objective

- To provide the student a brief review of the wave-particle duality.
- To provide the student general information about historical experiments that support the wave-particle duality.
- To show simple examples in order to clarify when the wave-particle duality comes into play.

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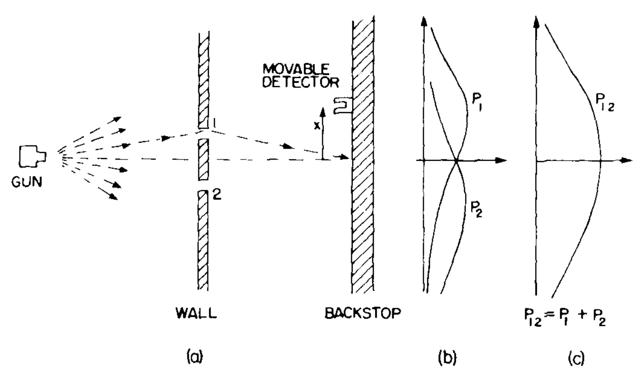
Wave-particle duality of matter

- In most experiments light behaves like a wave. In some cases, however, it shows a particle-like behaviour. That is, as if it was a stream of particles.
- The *converse* of the former statement is also true. Indeed, matter also behaves as waves at times.
- Evidence of **the wave-particle duality of matter** has been verified experimentally. This is the so-called **double slit experiment.**
- In this experiment beams of light or streams of particles pass through a screen with two narrow slits and then travel to a second screen.
- To understand these behaviour let us analyze the experiment in three different cases: bullets, waves and electrons.

3

Double-slit experiment with bullets

R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lectures on Physics vol. 3,* page 1-2 (Addison-Wesley, Reading, 1965)



(b) Result of firing bullets when only one of the slits is open. The curves $P_1(x)$ and $P_2(x)$ are the probability densities that a bullet passes through slit 1 or 2 and strikes the screen near *x.*

(c) Result of firing bullets when both slits is open. The curves $P_{12}(x)$ represents the probability density of a bullet striking the screen near *x.*

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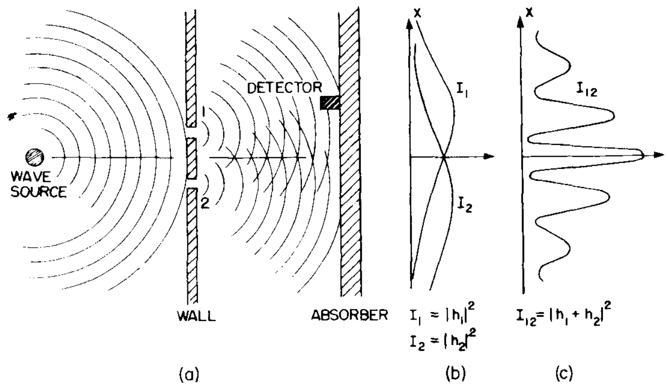
Double-slit experiment with waves

R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lectures on Physics vol. 3,* page 1-3 (Addison-Wesley, Reading, 1965)



(b) Result of keeping one of the slits open. In each case the intensity of the wave arriving at the screen has a single broad maximum.

(c) Result of keeping both slits open. In this case the wave passes through both slits simultaneously and forms two secondary waves that interfere with each other.

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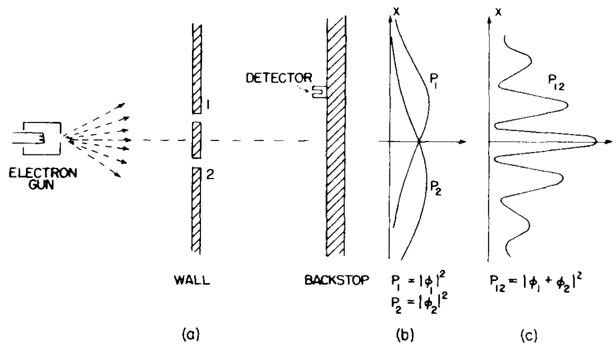
Double-slit experiment with electrons

R. P. Feynman, R. B. Leighton and M. Sands, *The Feynman Lectures on Physics vol. 3,* page 1-4 (Addison-Wesley, Reading, 1965)



(b) Result of firing one electron at a time when only one slit is open. Electrons strike the screen near point *x* with probability $P_1(x)$ or $P_2(x)$.

(c) Result of firing one electrons when both slits are open. The strike frequency $P_{12}(x)$ has the same interference pattern as in the case of waves.

Electrons travel like waves

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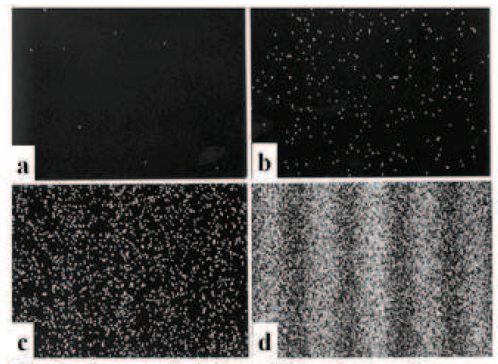
Experimental evidence of wave-particle duality

A. Tonomura *et.al., Am. J. Phys.* **57**, *117 (1989)*

- If an electron is fired at the two slits there is just a single "blip" on the screen. Over 20 minutes many single-electron events build up create an interference pattern.



Single-electron Build-up of Interference Pattern

(a) 8 electrons;
(b) 270 electrons;
(c) 2,000 electrons;
(d) 60,000 electrons

Electrons travel like waves but arrive at the screen as particles

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De Broglie waves

- Louis De Broglie hypothesized in 1924 the existence of matter waves.
- De Broglie postulated that a *free particle* of linear momentum ***p = mv*** is associated with a wave of wavelength λ given by

$$\boxed{\lambda = \frac{h}{p}}$$

h **is the Planck constant**

- Davidson and Germer experimentally confirmed De Broglie's hypothesis in 1927

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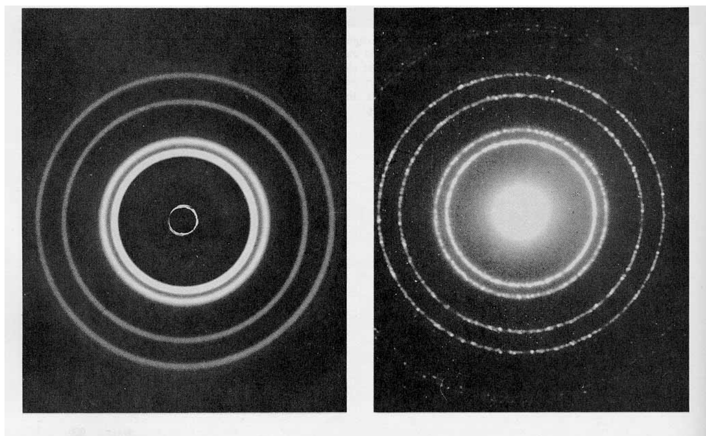
The Davisson-Germer experiment

- When a beam of electrons is scattered from a metal surface, a diffraction pattern similar to that of X-rays is observed

electrons **X-rays**



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Wave-particle duality and its relationship with mass

- Wave-particle duality of matter comes into play only for very small masses

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

Particle	**Mass** (kg)	**Speed** (m/s)	**Wavelength** (pm)
Electron accelerated through 100 V	9.11×10^{-31}	5.9×10^{6}	120 (atomic and molecular distances)
Alpha particle ejected from radium	6.68×10^{-27}	1.5×10^{7}	6.6×10^{-3} (smaller than an atom)
Bullet	1.9×10^{-3}	3.2×10^{2}	1.1×10^{-21} (smaller than a nucleus)

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