Wave-Particle Duality

Unit: Quantum and Particle Physics

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS4-3

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 6.G.1.1, 6.G.2.1, 6.G.2.2, 7.C.1.1, 7.C.2.1

Mastery Objective(s): (Students will be able to…)

- Explain the de Broglie model of the atom.
- Calculate the de Broglie wavelength of a moving particle such as an electron.

Success Criteria:

- Descriptions & explanations are accurate and account for observed behavior.

Language Objectives:

- Explain the important features of each model of the atom.

Tier 2 Vocabulary: model, quantum

Notes:

In 1924, French physicist Louis de Broglie determined that quanta of light could be considered to particles with very small mass moving at relativistic speeds (*i.e.,* close to the speed of light.)

From this, de Broglie concluded that any moving particle or object must therefore be able to be characterized with some periodic frequency, $f=\frac{E}{h}$, from Planck's equation. This means that the wavelength of any moving object is therefore:

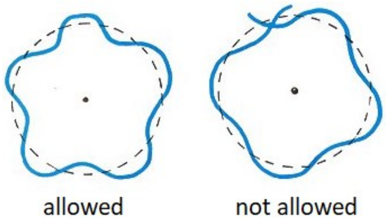
$$\lambda=\frac{h}{p}=\frac{h}{mv}$$

where:

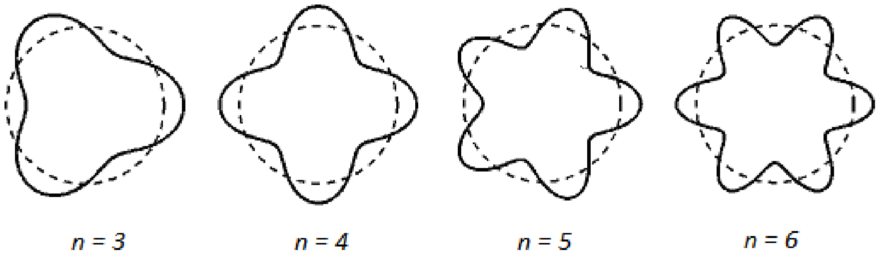
λ = de Broglie wavelength (m)
h = Planck's constant = $6.626\times10^{-34}\,\text{J}\cdot\text{s}$
p = momentum (N·s)
m = mass (kg)
v = velocity $\left(\frac{\text{m}}{\text{s}}\right)$

Every moving object has a de Broglie wavelength, though wavelengths of large objects are too small to be detectable.

de Broglie theorized that if waves were considered to be electrons, then the reason that only certain wavelengths were possible was because the wave produced by an electron would only be stable if the path length as it orbited the nucleus was an integer multiple of the wavelength.



Different quantum amounts of energy were possible with de Broglie's theory, but were restricted to amounts that produced an integer number of wavelengths.



Homework Problems

1. **(M)** What is the de Broglie wavelength associated with an electron moving at 0.5*c*? (You will need to look up the mass of the electron and the speed of light in a vacuum in *Table FF. Constants Used in Nuclear Physics* on page 482 of your Physics Reference Tables.)

   Answer: $4.8\times10^{-12}\,\text{m} = 0.0048\,\text{nm}$

2. **(M)** How fast would that same electron need to be moving in order to produce a wavelength of visible light of 500 nm (which equals $5\times10^{-7}\,\text{m}$)?

   Answer: $1450\,\frac{\text{m}}{\text{s}}$