

6 de Broglie's wave particle duality

1. We have seen, the spin states are analogous to polarized light (that are *waves*).
2. We have seen, the *vectorial nature* of polarized light (plane- and circular-) influences this analogy a great deal.
3. We have encountered *complex numbers* right here in this simple one electron case, in a magnetic field.
4. These three factors are fundamental to quantum mechanics.
5. There is also a wave characteristic involved here. As we have noted earlier for the case of plane-polarized light, the electric and magnetic fields in light are themselves waves of the kind: $E = E_0 \hat{x} \cos(kz - \omega t)$
6. Based on all these ideas, de Broglie (for his Ph.D. thesis) proposed that particles have a wave character and waves have a particle character. It was known earlier through Einstein's solution to the phot-electric effect problem, that light also has a "dual" nature and behaves as a wave and also as a particle. The particle nature of light leads to the description of discrete packets of energy known as photons. In fact earlier, Newton's corpuscles and Huygens' wavefronts. It was the wave nature of particles that came as a surprise, but as we have seen from the Stern-Gerlach experiments, it was really no surprise.
7. One otehr significant step was the Davisson-Germer experiment, where they showed that electrons when they scatter off a Nickel-foil lead to interference patterns. Interference patterns were thought to arise as part of a double-slit experiment on waves. Thus it appeared that particles behave as waves too.
8. de Broglie put all this together and proposed that every particle has a wave nature, and the wavelength corresponding to this wave nature is give by:

$$\lambda = \frac{h}{p} \quad (6.1)$$

where h was known as the Planck's constant and p is the momentum of the particle.

9. This equation suggests that every particle has a wave-nature, with a wavelength given by the above equation.

10. **Homework** We have just been through the olympics. Usain Bolt, arguably one of the greatest athletes (along with Michael Pelpps) has been the world record holder in the 100 meter dash track and field event. He is a Jamaican sprinter who has several Olympic gold medals. He holds the world record for the 100 metres and the 200 metres sprint. His record stands at 100 meters in 9.58 secs. At this speed, what is the wavelength corresponding to his wave nature (assume his weight to be 180 pounds). *Be careful with units.* How does Bolt's wavelength compare with the wavelength of an electron traveling at a 1000th of a speed of light. (Assume the momentum of the electron to be equal to its mass times its velocity.) Can you perform a similar calculation for an electron moving at half the velocity of light? How do you compare the wave nature of the faster electron with the fast Usain Bolt?
11. Small mass (and momentum) particles have measurable wavelengths. Consequently these particles need to be studied using a quantum theory. For particles that do not have large wavelengths, classical mechanics is sufficient.
12. **What is a small wavelength and what is a large wavelength**, is completely determined by what can be measured and what cannot. For example, if a particle has a wave-nature dominated by a wavelength of 10^{-30} meters, this clearly cannot be measured (or seen) and hence the quantum nature of such a particle is not perceivable. This obviously will not be the case for a particle whose de Broglie wavelength is 10^{-8} m (of the order of Angstroms), since this is the approximate length of a chemical bond!!
13. For a qualitative perspective: a wavelength of 10^{-8} m is basically equivalent to an electron travelling at a "velocity" of $\approx \frac{h}{\lambda m_e} = \frac{6.63 \times 10^{-34}}{10^{-8} \times 9.1 \times 10^{-31}} = 72814 m/s$.
14. So the wavenlength of something like the electron would be important. **Homework: What is the wavelength of a proton traveling at the speed of one angstroms per picosecond?** Pretty significant as you will find. Proton transfer in biological ion channels, enzymes, condensed phase and atmospheric clusters occurs \approx angstroms per picosecond. At that rate the wavelength of a proton would still have measurable effects!! Important in many biological enzyme experiments. Under the same conditions what is the wavelength of deuterium? Tritium?
15. **Homework:** In hydrogen transfer reactions, that are ubiquitous in atmospheric, biological, and materials chemistry, the hydrogen nucleus which undergoes the transfer may, under some conditions have a wavelength of about 1\AA !! What are the implications of this to chemical kinetics? (If you are curious, please see the book: "Reviews of Reactive Intermediate Chemistry" by Matthew Platz, Robert A. Moss and Maitland Jones, Jr. Specifically the chapter by R. Sheridan.