

### 3 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. de Broglie (for his Ph.D. thesis) proposed that particles have a wave character and waves have a particle character.
6. The latter was already suspected, in regards to light. (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 (and also the double slit experiment), it was really no surprise.
7. de Broglie proposed that every particle has a wave nature, and the wavelength corresponding to this wave nature is give by:

$$\lambda = \frac{h}{p} \quad (3.1)$$

where  $h$  is Planck's constant and  $p$  is the momentum of the particle.

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

**Homework** Usain Bolt is now the world record holder in the 100 meter dash track and field event. He is a Jamaican sprinter and a three-time Olympic gold medalist. He holds the world record for the 100 metres, the 200 metres and, along with his teammates, the 4x100 metres relay. 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.)

9. 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.
10. **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 relevant. This obviously will not be the case for a particle whose de Broglie wavelength is  $10^{-8}$  m (of the order of Angstroms).
11. For a qualitative perspective: a wavelength of  $10^{-8}$  m is basically equivalent to an electron travelling at a "velocity" of  $\approx \frac{h}{\lambda m_e} = \frac{6.63 \times 10^{-34}}{10^{-8} \times 9.1 \times 10^{-31}} = 72814 m/s$ .

12. So the wavenature 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 deuteron? Triton?