Ch. 28 Part 3

Matter Waves and Uncertainty

28.4: Matter Waves

The central theme for today's class is exploring the implications of noting that particles have wave-like properties. Specifically, we start with the deBroglie relation that holds for both photons and particles:

$$p = \frac{h}{\lambda}\ , \ \text{or}\ \lambda = \frac{h}{p}$$

where λ = wavelength, p = momentum, and $h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$ = Planck's constant.

28.4: Matter Waves

Implications:

1. Interference and Diffraction Chapter 17
2. Energy Quantization covered last class
3. Uncertainty

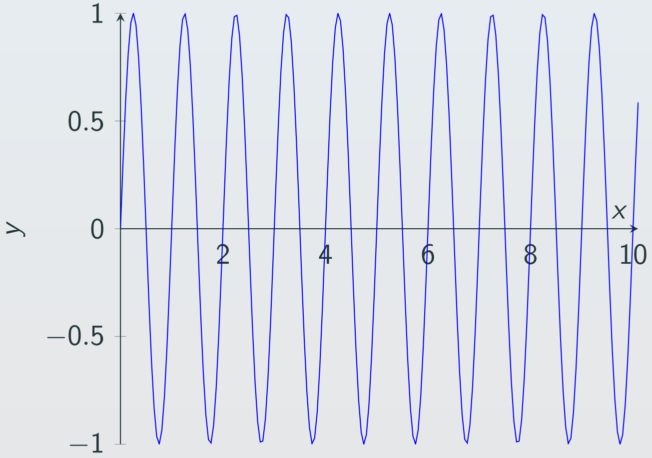
28.7: The Uncertainty Principle

Once we consider particles to have wave properties, the notions of specifying both the position and the momentum become more complicated. We can see this by considering the simpler problem of localizing a classical wave.

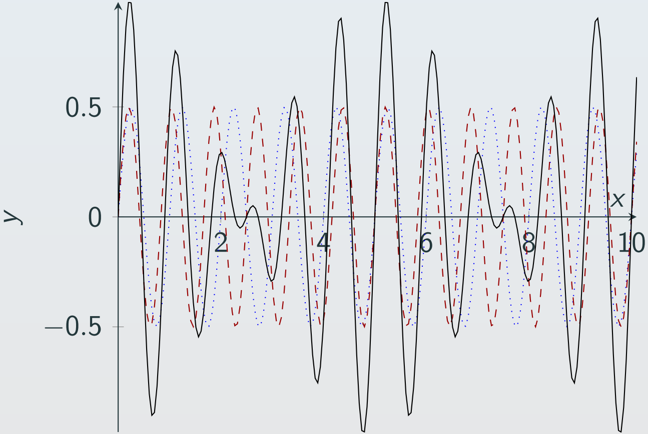
First, consider a snapshot of a portion of an infinite wave:

$$y(x, y) = A \sin\left(2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)\right)$$

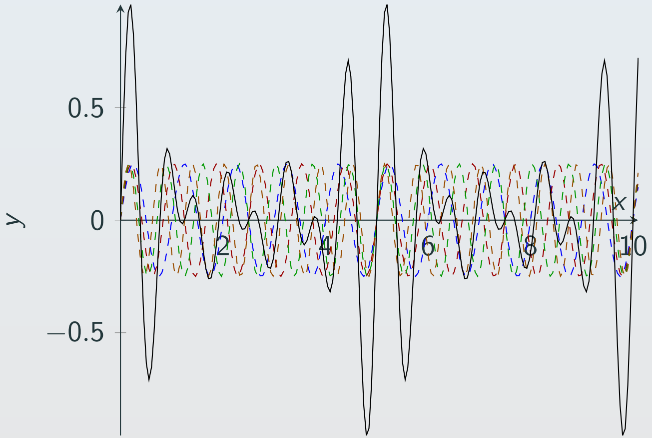
28.7: The Uncertainty Principle



Snapshot of a traveling sinusoidal wave moving to the right with speed $v = \lambda / T$. The wave extends infinitely in the $\pm x$ directions.



Superposition of two sinusoidal waves with slightly different wavelengths. Beats are visible. If we continue to add more different wavelengths, then the pulses get even more localized.



Superposition of four sinusoidal waves with slightly different wavelengths. As we add more different wavelengths, the pulses get even more localized, but the "wavelength" of the signal is no longer well-defined.

The Heisenberg Uncertainty Principle

Thus we see that even for classical waves, the notions of simultaneously specifying position and wavelength both entail some uncertainty. Since

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

that uncertainty can also be specified in terms of position x and momentum p. If Δx is the uncertainty in the position and Δp_x is the uncertainty in the $x-$component of the momentum, then the principle can be expressed:

$$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$

We will not concern ourselves with precise statistical definitions or interpretations of "Uncertainty".

Note that this is not just a limit on our ability to *measure* those quantities; it is a statement that there is an *inherent* uncertainty in those quantities. They are simply not precisely defined.

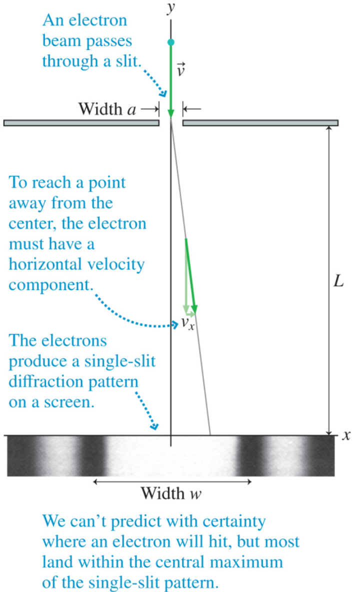


Figure 28.21 in the text illustrates another way to think about this. Waves diffract when passing through a narrow slit. If we know it passed through a narrow slit, then we know the x position had to be within that spacing *a*. However, it might have had some horizontal component of velocity (and hence momentum). As we make the slit *a* smaller, we know the central maximum of the diffraction pattern will get larger.

28.8: Applications and Implications of Quantum Theory

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- **Wave-particle Duality** Nature doesn't fit into our neat mental categories of "particle" or "wave." Instead, they are complementary ways to view nature.
- **Magnetic Resonance Imaging** We saw this back in Ch. 24. Quantum mechanics means that angular momentum is quantized, and hence the possible energies of magnetic moments in an external magnetic field are quantized. Example 28.16 pulls together these observations.

What's Next?

- Ch. 29: Atoms and Molecules. Quantized energy levels meant that only certain wavelength photons would be observed from a system. For atoms and molecules, use the observed photons from spectroscopy to learn about the structure of atoms.
- Ch. 30: Nuclear Physics. Look even deeper inside the atom at the nucleus.