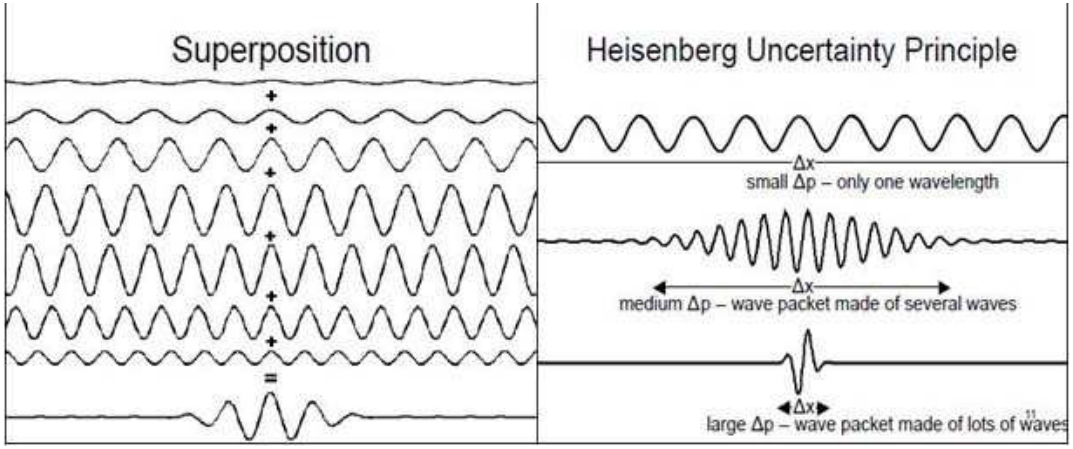
Uncertainty principle



- Wave packets are constructed from a series of plane waves
  → superposition principle
- The more spatially localized the wave packet, the less uncertainty in position.
- With less uncertainty in position comes a greater uncertainty in momentum.

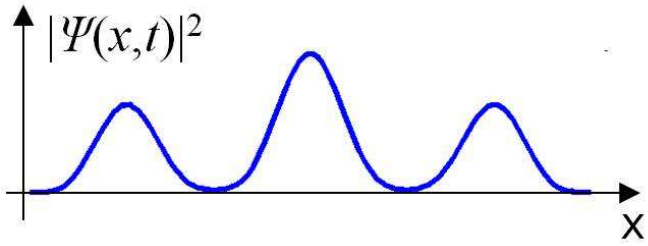
Uncertainty principle

In math: $\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$

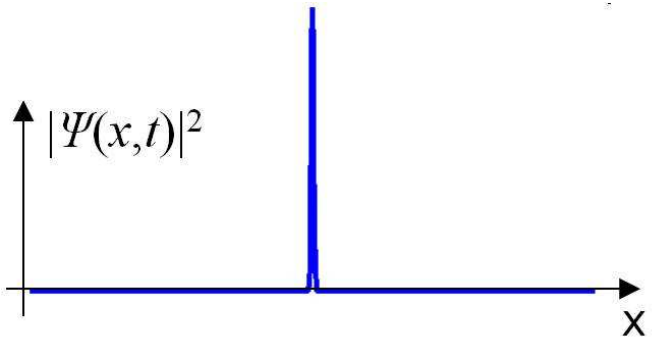
In words:
The position and momentum of a particle cannot **both** be determined with complete precision at the same time.

The more precisely one is determined, the less precisely the other is determined.

Before measurement:

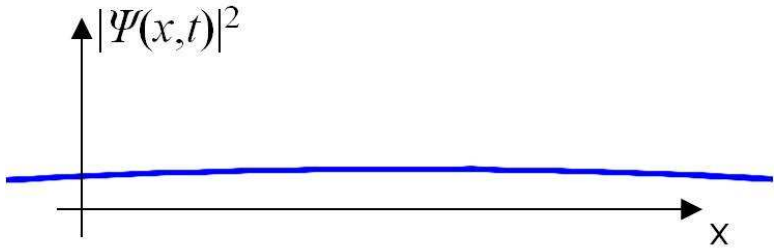


After position measurement:



small Δx
large Δp

After momentum measurement:



large Δx
small Δp

Remember: Wavefunction is different for each of these probability densities. Act of measurement changes the wavefunction. Schrödinger equation describes everything before and after the measurement, but not the measurement itself (discontinuous process).

Summary

- Particles have wave properties (interference) and are described by wave functions.

- Physically, what we measure is probability density for finding a particle in a particular place (or with a a particular momentum, energy, …) at a particular time: probabilistic, not deterministic

- Simultaneous measurements of x and p are constrained by the Uncertainty Principle

- After a measurement of the position (momentum) of a particle, the wave function of the particle is localized (delocalized).

Complementary variables

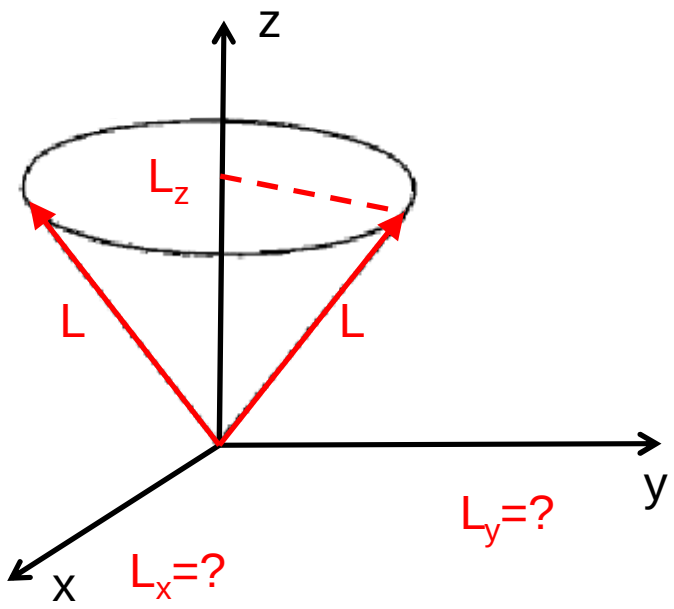
The

- position and momentum of a particle
- components of the angular momentum (L_x, L_y, L_z)
- components of the spin (S_x, S_y, S_z)

of a particle cannot be determined with complete precision simultaneously.

The more precisely one is determined, the less precisely the other(s) is (are) determined.

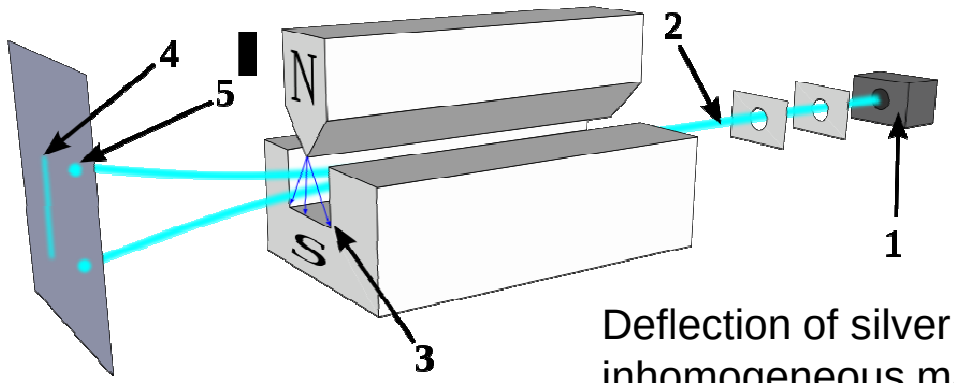
Uncertainty principle



We can measure magnitude and one component (say z) simultaneously with absolute precision, but not the other two components

→ orientation of angular momentum vector is undetermined

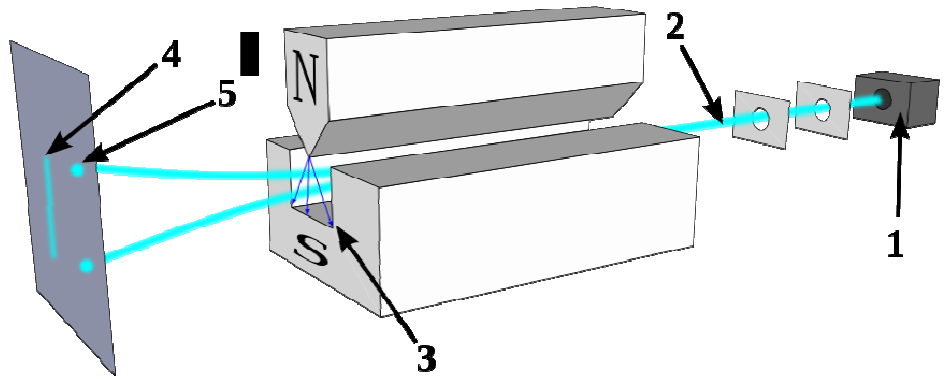
Stern-Gerlach experiment (1925)



Deflection of silver atoms in inhomogeneous magnetic field (picture: Wikipedia)

Observation: Discrete spectrum (5) and ***not*** classically expected continuous spectrum (4)

Stern-Gerlach experiment (1925)



- Atoms must have a quantized (projection/component of) magnetic moment
- Magnetic moment is due to orbital angular momentum and spin