Uncertainty Principle

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Heisenberg's Uncertainty Principle

It is impossible to specify simultaneously, with arbitrary precision, both the momentum and the position of a particle.

$$\Delta x \, \Delta p_x \geq \frac{\hbar}{2}$$

$$\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34} \text{ J s}$$

Heisenberg's Uncertainty Principle

The uncertainty principle restricts the precision with which complementary observables may be specified and measured simultaneously.

$$\Delta x \propto \frac{1}{\Delta p_x}$$

Heisenberg's Uncertainty Principle

Calculate the momentum uncertainty of (a) a tennis ball constrained to be in a fence enclosure of length 35 m surrounding the court and (b) an electron within the smallest diameter of a hydrogen atom.

The radius of the first orbit of hydrogen atom is 0.529 Å.

Uncertainty Principle

Solution (a) If we insert the uncertainty of the location of the tennis ball, $\Delta x = (35\ \text{m})/2$, into $\Delta p_x \Delta x \geq \hbar/2$, we have

$$\Delta p_x \geq \frac{1}{2}\frac{\hbar}{\Delta x} = \frac{1.05 \times 10^{-34}\ \text{J}\cdot\text{s}}{2(35\ \text{m})/2} = 3 \times 10^{-36}\ \text{kg}\cdot\text{m/s}$$

Uncertainty Principle

(b) The diameter of the hydrogen atom in its lowest energy state (smallest radius) is $2a_0$. We arbitrarily take the uncertainty Δx to be half the diameter or equal to the radius, $\Delta x = a_0$.

$$\Delta x = a_0 = 0.529 \times 10^{-10}\ \text{m}$$

$$\Delta p_x \geq \frac{1}{2}\frac{\hbar}{\Delta x} = \frac{1.05 \times 10^{-34}\ \text{J} \cdot \text{s}}{2(0.529 \times 10^{-10}\ \text{m})}$$

$$= 1 \times 10^{-24}\ \text{kg} \cdot \text{m/s}$$

Uncertainty Principle

This may seem like a small momentum, but for an electron with a mass of about 10^{-30} kg, it corresponds to a speed of about 10^6 m/s, which is not insignificant!

Heisenberg's Uncertainty Principle

$$\Delta x \Delta p_x \geq \frac{\hbar}{2}, \qquad \Delta y \Delta p_y \geq \frac{\hbar}{2}, \qquad \Delta z \Delta p_z \geq \frac{\hbar}{2}.$$

Constraints of the uncertainty principle

	Variable 1					
Variable 2	x	y	z	p_x	p_y	p_z
x						
y						
z						
p_x						
p_y						
p_z						

Energy-Time Uncertainty Principle

$$\Delta E \, \Delta t \geq \frac{\hbar}{2}$$

Uncertainty Principle

This relation states that if we make two measurements of the energy of a system and if these measurements are separated by a time interval Δt, the measured energies will differ by an mount ΔE which can in no way be smaller than $\hbar/\Delta t$. If the time interval between the two measurements is large, the energy difference will be small.

Uncertainty Principle

We must emphasize that the uncertainties are intrinsic. They are not due to our inability to construct better measuring equipment. No matter how well we can measure, no matter how accurate an instrument we build, and no matter how long we measure, we can never do any better than the uncertainty principle allows.

Thank You

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