

UNCERTAINTY PRINCIPLE - EXAMPLES

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Reference: Griffiths, David J. (2005), Introduction to Quantum Mechanics, 2nd Edition; Pearson Education - Sec 3.5; Problem 3.14.

In this post we'll have a look at an example involving the uncertainty principle. This makes use of the generic uncertainty principle for two observables A and B :

$$(0.1) \quad \sigma_A^2 \sigma_B^2 \geq \left(\frac{1}{2i} \langle [\hat{A}, \hat{B}] \rangle \right)^2$$

We can calculate an expression for a 'position-energy' uncertainty relation. For this we'll need the commutator $[\hat{x}, \hat{H}]$, so we work that out first. Since H involves a derivative, we use a test function g on which to operate:

$$(0.2) \quad [\hat{x}, \hat{H}]g = -\frac{\hbar^2}{2m}x \frac{\partial^2 g}{\partial x^2} + xVg + -\frac{\hbar^2}{2m} \frac{\partial^2}{\partial x^2}(xg) - xVg$$

$$(0.3) \quad = \frac{\hbar^2}{2m} \left(-x \frac{\partial^2 g}{\partial x^2} + 2 \frac{\partial g}{\partial x} + x \frac{\partial^2 g}{\partial x^2} \right)$$

$$(0.4) \quad = \frac{\hbar^2}{m} \frac{\partial g}{\partial x}$$

$$(0.5) \quad = \frac{i\hbar}{m}(pg)$$

From 0.1 with $\hat{A} = \hat{x}$ and $\hat{B} = \hat{H}$ we have

$$(0.6) \quad \sigma_x^2 \sigma_H^2 \geq \left(\frac{1}{2i} \langle [\hat{x}, \hat{H}] \rangle \right)^2$$

$$(0.7) \quad = \frac{\hbar^2}{4m^2} \langle p \rangle^2$$

so the uncertainty principle here becomes

$$(0.8) \quad \sigma_x \sigma_H \geq \frac{\hbar}{2m} |\langle p \rangle|$$

For a stationary state, this doesn't tell you much because the average position of the particle doesn't change, so $\langle p \rangle = 0$. For linear combinations of stationary states, though, the average momentum will not be zero, so this condition is more than trivial.

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