Chem3615 Quantum Mechanics Practice Problems

These problems will not be handed in but are to help you prepare for the midterm

1. Find the results of operating with $\hat{A} = x - \frac{d}{dx}$ and $\hat{B} = x + \frac{d}{dx}$ on the function $f(x) = e^{-\frac{x^2}{2}}$

$$\hat{A}F(x) = \left(x - \frac{d}{dx}\right)e^{-\frac{x^2}{2}} = xe^{-\frac{x^2}{2}} + xe^{-\frac{x^2}{2}} = 2xe^{-\frac{x^2}{2}}$$

$$\hat{B}F(x) = \left(x + \frac{d}{dx}\right)e^{-\frac{x^2}{2}} = xe^{-\frac{x^2}{2}} - xe^{-\frac{x^2}{2}} = 0$$

2. Which of the following functions is an eigenfunction of the operator $\frac{d}{dx}$? Give the eigenvalue where appropriate. k is a constant.

   a. k $\frac{d}{dx}(k) = 0 = 0(k)$ ∴ k is an eigenfunction with eigenvalues of 0

   b. kx^2 $\frac{d}{dx}(kx^2) = 2kx \neq c(kx^2)$ ∴ kx^2 is not an eigenfunction

   c. $\sin(kx)$ $\frac{d}{dx}(\sin(kx)) = k\cos(kx) \neq c(\sin(kx))$ ∴ $\sin(kx)$ is not an eigenfunction

   d. e^{kx} $\frac{d}{dx}(e^{kx}) = k(e^{kx})$ ∴ k is an eigenfunction with eigenvalues of k

   e. e^{kx^2} $\frac{d}{dx}(e^{kx^2}) = 2kxe^{kx^2} \neq c(e^{kx^2})$ ∴ e^{kx^2} is not an eigenfunction

   f. e^{ikx} $\frac{d}{dx}(e^{ikx}) = ik(e^{ikx})$ ∴ k is an eigenfunction with eigenvalues of ik

3. What is the value of the following commutators

   a. $[\hat{x}, \hat{p}_x]f = \left[x\left(-i\hbar\frac{\partial}{\partial x}\right) - \left(-i\hbar\frac{\partial}{\partial x}\right)x\right]f = -i\hbar\left[x\frac{\partial f}{\partial x} - \frac{\partial(xf)}{\partial x}\right]$

   $[\hat{x}, \hat{p}_x]f = -i\hbar\left[x\frac{\partial f}{\partial x} - f - x\frac{\partial f}{\partial x}\right] = i\hbar f$

   ∴ $[\hat{x}, \hat{p}_x] = i\hbar$

   b. $[\hat{x}, \hat{p}_x^2]f = \left[x\left(-\hbar^2\frac{\partial^2}{\partial x^2}\right) - \left(-\hbar^2\frac{\partial^2}{\partial x^2}\right)x\right]f = -\hbar^2\left[x\frac{\partial^2 f}{\partial x^2} - \frac{\partial^2(xf)}{\partial x^2}\right]$

   $[\hat{x}, \hat{p}_x^2]f = -\hbar^2\left[x\frac{\partial^2 f}{\partial x^2} - \frac{\partial}{\partial x}\left(f + x\frac{\partial f}{\partial x}\right)\right] = -\hbar^2\left[x\frac{\partial^2 f}{\partial x^2} - \frac{\partial f}{\partial x} - \frac{\partial f}{\partial x} - x\frac{\partial^2 f}{\partial x^2}\right]$

   $[\hat{x}, \hat{p}_x^2]f = 2\hbar^2\frac{\partial f}{\partial x}$

   ∴ $[\hat{x}, \hat{p}_x^2] = 2\hbar^2\frac{\partial}{\partial x}$

   c. $[\hat{x}, \hat{p}_y]f = \left[x\left(-i\hbar\frac{\partial}{\partial y}\right) - \left(-i\hbar\frac{\partial}{\partial y}\right)x\right]f = -i\hbar\left[x\frac{\partial f}{\partial y} - x\frac{\partial(f)}{\partial y}\right] = 0$

   ∴ $[\hat{x}, \hat{p}_y] = 0$

4. Angular momentum, L, is given by the cross product r x p. So the angular momentum in the x axis, L_x, is given by $yp_z - zp_y$, what is the operator $\hat{L}_x$?

$$\hat{L}_x = y\left(-i\hbar\frac{\partial}{\partial z}\right) - z\left(-i\hbar\frac{\partial}{\partial y}\right) = -i\hbar\left(y\frac{\partial}{\partial z} - z\frac{\partial}{\partial y}\right)$$

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