Physics 451 **Winter 2026**

Homework #2

(due Wednesday, January 21, 2026)

1. (10 pts) McIntyre 9.9
2. (10 pts) McIntyre 9.14a (not 9.14b !)
3. (10 pts)
   (a) Show that the following commutator relations are true.

   $$\left[\hat{A},\left(\hat{B}+\hat{C}\right)\right]=\left[\hat{A},\hat{B}\right]+\left[\hat{A},\hat{C}\right]$$

   $$\left[\hat{A},\hat{B}\hat{C}\right]=\left[\hat{A},\hat{B}\right]\hat{C}+\hat{B}\left[\hat{A},\hat{C}\right]$$

   (b) Show that
   $$\left[\hat{x},\hat{p}\right]=i\hbar$$
   Hint: operate on a general wave function and use the position representation of the operators.

4. (10 pts) **Create a table for the H.O.** (p. 2) similar to the that in HW #1 in which you represent the important quantities for the HO in ket (abstract), wave function, graphical and matrix notation.
5. Reading: Ch. 9.1-9.7 of McIntyre.

Harmonic oscillator	Ket Representation	Wave Function Representation	Matrix Representation
Hamiltonian			
Eigenvalues of Hamiltonian			
Normalized eigenstates of Hamiltonian			
Matrix element/matrix of position operator	Xnm = <n|X|m> =	Xnm = (integral) =	X ·= (matrix)
Matrix element/matrix of momentum operator	Pnm = <n|P|m> =	Pnm = (integral) =	P ·= (matrix)

The following questions are for practice (not for submission):

1. **McIntyre 9.13**
2. **More practice with commutators**

$$\left[\hat{A},\hat{A}^n\right]=0 \qquad \left[\hat{A},\hat{B}\right]=-\left[\hat{B},\hat{A}\right]$$

$$\left[\hat{A},c\hat{B}\right]=c\left[\hat{A},\hat{B}\right] \qquad \left[\hat{A},\left[\hat{B},\hat{C}\right]\right]+\left[\hat{B},\left[\hat{C},\hat{A}\right]\right]+\left[\hat{C},\left[\hat{A},\hat{B}\right]\right]=0$$

3. **The 2-D Quantum HO**

The Hamiltonian for a 2-dimensional isotropic harmonic oscillator is $H=\frac{p_x^2}{2m}+\frac{p_y^2}{2m}+\frac{1}{2}m\omega^2\left(x^2+y^2\right)$.

(a) Find the energy eigenvalues for the system.
(b) What is the degeneracy?
(c) What is the ground state eigenfunction?

4. Momentum-space wavefunction practice:

Consider 1D harmonic oscillator. By setting up an eigenvalue equation in the momentum space and direct comparison with that in the position space, infer the momentum space eigenfunctions Φ(p) (you don't have to solve anything here !).