Physics 451/551 **Winter 2026**

Homework #3

(due Wednesday, January 28, 2026)

1. (10 pts) McIntyre 9.16
2. (10 pts) A charged particle subject to a 1D harmonic oscillator potential is initially in a state $|\psi(0)\rangle$ that is an equal superposition of two (arbitrary) energy eigenstates $|n\rangle$ and $|m\rangle$ (but the coefficients are not necessarily real, so there could be a relative phase shift).

   (a) Write down the time-evolved state $|\psi(t)\rangle$

   (b) Find the expectation value of the electric dipole moment operator qX, where q is the charge and X is the position operator, in the state $|\psi(t)\rangle$.

   (c) Interpret your result of (b) – how does the average dipole moment behave in time?

   (d) What are the possible outcomes of energy measurement and their probabilities? Do they depend on time?

3. (10 pts) Consider 1D harmonic oscillator. Using the number representation, find the expectation value of X^4 in an arbitrary energy eigenstate $|n\rangle$.

4. Reading: Ch. 9 and 10.1-10.3 of McIntyre.

   The following questions are for practice and general information related to the applications related to quantum harmonic oscillator (not for submission):

   1. McIntyre 9.4, 9.17
   2. **Extra challenge**: McIntyre 9.20
   3. Reading (**class website**): Roy Glauber's Nobel Prize 2005 – coherent states of harmonic oscillator in quantum optics (ChemPhysChem 7, 1618 (2006)); David Wineland's Nobel Prize 2012 – note that Prof. Wineland is currently leading a research group at the U of O ! – laser-trapped ions as harmonic oscillators (arXiv 1997)