

**PHYS-4617: Quantum Physics**  
**Problem Set 2 (Due: 17 March 2005)**

1. (30 pts) Starting with the expectation value of momentum (see Eq. II-47 in your notes),

$$\langle p \rangle = -i\hbar \int_{-\infty}^{+\infty} \left( \Psi^* \frac{\partial \Psi}{\partial x} \right) dx,$$

prove Ehrenfest's theorem,

$$\frac{d\langle p \rangle}{dt} = \left\langle -\frac{\partial V}{\partial x} \right\rangle,$$

using integral calculus with quantum mechanics.

2. (25 pts) Calculate  $\langle x \rangle$ ,  $\langle x^2 \rangle$ ,  $\langle p \rangle$ ,  $\langle p^2 \rangle$ ,  $\sigma_x$ , and  $\sigma_p$ , for the  $n$ th state of the infinite square well. Check that the uncertainty principle is satisfied. Which state come closest to the uncertainty limit?

3. (25 pts) A particle in the harmonic oscillator potential has the initial wave function

$$\Psi(x, 0) = A[\psi_0(x) + \psi_1(x)]$$

for some constant  $A$ .

- (a) Normalize  $\Psi(x, 0)$ .
- (b) Find  $\Psi(x, t)$ , and  $|\Psi(x, t)|^2$ .
- (c) Find the expectation value of  $x$  as a function of time. Notice that it oscillates sinusoidally. What is the amplitude of the oscillation? What is the (angular) frequency?
- (d) Use your result in (c) to determine  $\langle p \rangle$ .