

### Extra credit problem for Physics 371

Due: 10am Monday, April 25

Open book; open notes; show your work for full credit.

#### Expectation values for a harmonic oscillator (worth 10 exam points)

Consider a harmonic oscillator with the following wavefunction

$$\psi(x) = \alpha\psi_n(x) + \beta\psi_{n+1}(x),$$

where  $\alpha$  and  $\beta$  are complex numbers, and  $\psi_n$  is an energy eigenfunction.

(a) Calculate the expectation values

$$\langle x \rangle = \langle \psi | x | \psi \rangle,$$

$$\langle p_x \rangle = \langle \psi | p_x | \psi \rangle.$$

(b) Calculate the uncertainties  $\Delta x$  and  $\Delta p_x$ , and verify that the uncertainty principle is satisfied.

(c) For  $\alpha = \beta = 1/\sqrt{2}$ , find  $\langle x(t) \rangle$  and  $\langle p_x(t) \rangle$ . Check that the Ehrenfest theorem is satisfied.