

## Physics 402 Quiz 2, February, 2019

1) For a harmonic oscillator system, the state  $x^2|2\rangle$  can be written as a superposition of harmonic oscillator energy eigenstates. Which of the following states is not part of this superposition?

- a)  $|0\rangle$
- b)  $|1\rangle$
- c)  $|2\rangle$
- d)  $|4\rangle$

2) For a harmonic oscillator system, the expectation value  $\langle n|p|n\rangle$  is

- a) Zero for all energy eigenstates  $|n\rangle$ .
- b) Zero for some energy eigenstates and nonzero for some energy eigenstates  $|n\rangle$ .
- c) Nonzero for all energy eigenstates  $|n\rangle$ .

3) If we add a perturbation  $\lambda p^2$  to the harmonic oscillator Hamiltonian, the shift in energy of the first excited state is

a)

$$\lambda\langle 0|p^2|0\rangle$$

b)

$$\lambda \sum_n \frac{\langle 0|p^2|n\rangle}{E_n - E_0}$$

c)

$$\lambda \sum_n \frac{|\langle n|p^2|1\rangle|^2}{E_n - E_0}$$

d)

$$\lambda\langle 1|p^2|1\rangle$$

e)

zero

4) If a Hamiltonian  $H_0$  has two degenerate states  $|A\rangle$  and  $|B\rangle$  and we add a perturbation  $H_1$  to the system such that  $\langle A|H_1|A\rangle = \langle B|H_1|B\rangle = 0$  we can say that

a) the energies of these states will be unchanged to first order in perturbation theory, so there will still be a degeneracy at this order.

b) the energies may be split at first order in perturbation theory; to find out, we only need to calculate  $\langle A|H_1|B\rangle$  and/or  $\langle B|H_1|A\rangle$ .

c) the energies may be split at first order in perturbation theory; to find out, we only need to calculate  $\langle E_i|H_1|A\rangle$  and  $\langle E_i|H_1|B\rangle$  for all the other energy eigenstates  $|E_i\rangle$ .

d) the energies may be split at first order in perturbation theory; to find out, we need to calculate  $\langle A|H_1|B\rangle$  and  $\langle E_i|H_1|A\rangle$  and  $\langle E_i|H_1|B\rangle$  for all the other energy eigenstates  $|E_i\rangle$ .

5) A particle is in the ground state of an infinite square well potential located on the interval  $[-L, L]$ ; call the wavefunction for this particle  $\psi_0(x)$ . If we perturb the system by adding a potential  $\lambda V(x)$ , the first order shift in ground state energy will be equal to zero if

a)  $V(0) = 0$

b)  $\int_{-L}^L dx V(x) = 0$

c)  $\int_{-L}^L dx V(x) \psi_0(x) = 0$

d)  $\int_{-L}^L dx V(x) |\psi_0(x)|^2 = 0$

6) For a harmonic oscillator, we have  $\langle n|x^4|n\rangle = \hbar^2/(2m\omega)^2(6n^2 + 6n + 3)$ . If we add a perturbation  $\lambda x^4$  to the harmonic oscillator potential for some small  $\lambda$  and calculate the eigenstate energies to first order in  $\lambda$ , we would expect the result to be closer to the exact result for the energy for

a) smaller values of  $n$ .

b) larger values of  $n$ .

c) Neither: the first order approximation will have similar accuracy for any value of  $n$ .