

Week 7 Worksheet

(Nondegenerate) Perturbation Theory

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Exercise 1. Let $H(\lambda) = H^0 + \lambda H'$ be a perturbed hamiltonian. Suppose we know

$$H^0 \psi_n^0 = E_n^0 \psi_n^0,$$

where the ψ_n^0 are unperturbed, orthonormal, nondegenerate eigenfunctions.

- Write the ψ_n and E_n as power series in λ .
- Write the Schrödinger equation for $H(\lambda)$ in terms of the above power series.
- Truncate the above equation to first order, and derive the first order corrections to the energies. You should get

$$E_n^1 = \langle \psi_n^0 | H' | \psi_n^0 \rangle.$$

- Along the way to solving (c), you should have come up with the equation

$$H^0 \psi_n^1 + H' \psi_n^0 = E_n^1 \psi_n^0 + E_n^0 \psi_n^1.$$

Rewrite this as an inhomogeneous differential equation for ψ_n^1 , and solve it via the power series method, thus obtaining the first order corrections to the wavefunctions.

- Derive the second order corrections to the energies, E_n^2 .

Exercise 2. Suppose you want to calculate the expectation value of some observable A in the n^{th} energy eigenstate of a system perturbed by H' ,

$$\langle A \rangle = \langle \psi_n | A | \psi_n \rangle.$$

Suppose further that all eigenstates are nondegenerate.

- Replace ψ_n by its perturbation expansion, and write down the formula for the first order correction to $\langle A \rangle$.

b) Use the first order corrections to the wavefunctions,

$$\psi_n^1 = \sum_{m \neq n} \frac{\langle \psi_m^0 | H' | \psi_n^0 \rangle}{E_n^0 - E_m^0} \psi_m^0, \quad (0.1)$$

to rewrite $\langle A \rangle^1$ in terms of the unperturbed eigenstates.

c) If $A = H'$, what does the result of (b) tell you? Explain why this is consistent with Equation 1.