1) Consider the Hamiltonian for a quantum mechanical pendulum

\[ H = -\frac{\hbar^2}{2ml^2} \frac{\partial^2}{\partial \theta^2} + mgl(1 - \cos(\theta)) \]

in perturbation theory. Find the energies of all the states of the pendulum assuming that the problem is mostly a harmonic oscillator, and the \( \theta^4 \) term in the expansion of the cosine is the perturbation. **Hint:** It is easier to do this problem if you use the creation/annihilation operators of the harmonic oscillator, \( x = \sqrt{\hbar/2m\omega}(a + a^\dagger) \)

2) a) Start with Griffiths 6.35a - you don’t have to derive the Kramer’s formula, just obtain the expectations values.

b) Now repeat the problem from last week with the perturbing potential \( H_1 = \sigma r \) but calculate the first order energy correction for all states, not only the ground state. The interesting thing here is the dependence on the angular momentum quantum number \( l \).

3) Griffith 6.36

4) Consider the 3 state system described by the Hamiltonian

\[
H = \begin{pmatrix}
\epsilon_1 & c & 0 \\
c^* & \epsilon_1 & d \\
0 & d^* & \epsilon_2
\end{pmatrix}
\]

where \( c, d \ll \epsilon_{1,2} \). Treating \( c, d \) as perturbation, calculate the the energy at first order in perturbation theory. Find the correct 0th order eigenkets as well. Compare your perturbative result for the energy with the exact one.