Part A

1. (15%) For a one-dimensional harmonic oscillator, find out $\langle E \rangle$ and $\langle E^2 \rangle - \langle E \rangle^2$ if its state is represented by the wave function $\varphi = \frac{1}{\sqrt{2}} (\varphi_0 + \varphi_1)$, where $\varphi_0$ and $\varphi_1$ are the first two energy eigenfunctions.

2. (10%) Consider a particle in a one-dimensional box of length $a$ with an additional linear potential term: $V(x) = \infty$, if $x < 0$ or $x > a$; $V(x) = bx$, if $0 < x < a$.

Using first-order perturbation, find a formula for the energy when the particle is in its ground state.

3. (15%) $[\hat{P}_x, \hat{X}] = ?$ $[\hat{L}_x, \hat{L}_y] = ?$ $[\hat{L}_x, \hat{P}_y] = ?$

4. (10%) What is the RRKM theory of unimolecular reactions?
Part B

1. (10%) Describe the first, the second and the third laws of thermodynamics.

2. (10%) Prove that the difference between heat capacity at constant pressure and the heat capacity at constant volume for an ideal gas equals to the gas constant \((C_p - C_v = R)\). Explain this phenomenon.

3. (10%) Compare and explain the following pairs of terms
   (a) Enthalpy and Entropy
   (b) Isothermal Process and Adiabatic Process
   (c) Condensation and Vapor Decomposition
   (d) Ideal Gas and Ideal Solution

4. (20%) The standard-state Gibbs energy for the following reaction is 130.90 kJ/mol.

\[
\text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g) \quad \Delta G^\circ = +130.90 \text{ kJ/mole}
\]

(a) Write the equilibrium constant quotient \((K)\) for this reaction.

(b) Calculate the equilibrium constant of this reaction at 298 K.

(c) Estimate the pressure of \(\text{CO}_2(g)\) at equilibrium with \(\text{CaO}(s)\) and \(\text{CaCO}_3(s)\) at 298 K.

(d) At 373 K the equilibrium constant of the reaction is \(2.3 \times 10^{-17}\). Try to estimate the standard-state enthalpy of the reaction.