(Useful constant: \( h = 6.626 \times 10^{-34} \text{ J s} \))

1. (5%)
   The DVD player uses shorter wavelength lasers to read the digital pits in the rings, thus increasing the accuracy of reading the more densely packed data. If the laser emits red light of wavelength 635 nm. How many photons does it emit every second if its power is 0.05 W?

2. (20%)
   (a) Derive the expressions for the eigenfunctions and eigenvalues of a particle in a two-dimensional box with \( 2L_x = L_y = L \) (Express your result in L)
   (b) What are the quantum numbers and energies of the ground state and the first excited state?
   (c) Show contour plots of the wavefunction and the probability of these two states. Use solid and dotted lines to specify positive and negative values, respectively.
   (d) Write down the eigenvalues, wavefunction and the quantum numbers \( n_x \) and \( n_y \) for the lowest doubly degenerate states.

3. (5%)
   What are the numbers of vibration normal modes for \( \text{CH}_4 \) and \( \text{H-EC-H} \)?

4. (5%)
   What are the simplified secular equations for the linear \( C_1 \) and cyclic \( C_6 \) conjugate hydrocarbon based on the Hückel theory?

5. (5%)
   Illustrate absorption, fluorescence, phosphorescence, inter-system conversion, non-radiative internal relaxation with the Jablonski diagram.
6. (10%)
   (a) What does the word, *laser*, stand for?
   (b) It is easier to achieve population inversion for a four-level system than a
       three-level one. Illustrate the essential features for an effective laser operation
       with the energy diagram of a four-level system.
   (c) A mode-locked laser produces pulses at a repetition rate of 100 MHz. If each
       pulse is 10 fs in duration and has a pulse energy of 10 nJ. What are the peak-
       power and the averaged power?

7. (10%)
   Give the attractive interaction(s) and compare their strengths between two
   gaseous molecules: (a) CH₄ and Ar; (b) CO₂ and HCl; (c) HCl and HCl.

8. (10%)
   (a) Describe the physical significance of the molecular partition function.
   (b) What are the relative populations \( \rho_1/\rho_2 \) of the states of a two-level
       system \( E_1 < E_2 \) when the temperature is 0 K? and infinite?

9. (10%)
   (a) Distinguish between reaction order and molecularity. (b) Define the terms in
       and limit the generality of the Arrhenius equation.

10. (10%)
    (a) Relate the Helmholtz energy to the criteria of spontaneity and equilibrium.
    (b) Suggest a physical interpretation of the dependence of the Gibbs energy on
        the temperature.

11. (10%)
    (a) What is *internal pressure*? What is its value for an ideal gas? Explain.
    (b) Predict the contribution to the heat capacity \( C_{V,m} \) made by molecular motions
        for HCl and SO₂.