Problem 1: (40 points)

1. **Phase diagram, the critical point:** The equation of state of van der Waals gas is \( P = \frac{a}{v^2} \left(v - b\right) = RT \), where \( a \) and \( b \) are characteristic constants for a given gas, and \( P, v, T \) and \( R \) are pressure, specific volume, temperature and gas constant, respectively. When we regard the above van der Waals equation as \( P = P(v, T) \)

(a) what are the three conditions at the critical point in the critical isotherm \((T = T_C)\) on a \( P-v \) diagram? [15 points]

(b) Express the critical specific volume, \( v_C \), the critical temperature, \( T_C \), and the critical pressure, \( P_C \), at the critical point, in terms of the constants \( a \) and \( b \). [25 points]

Problem 2: (40 points)

A metal ring is dipped into a soapy solution (index of refraction \( n_s \)) and held in a vertical plane so that a wedge-shaped film formed under the influence of gravity. At near-normal illumination with blue-green light (wavelength \( \lambda_{bg} \)) from an argon laser, one can see \( N \) fringes per cm. Determine the wedge angle of the soap film. (Note: assume that the wedge angle is very small).
Problem 3: (40 points)

2. A pi-mu atom consists of a pion and a muon bound in a Hydrogen-like atom.

(a) What are the energy levels for such an atom compared to those for Hydrogen expressed in terms of the electron, pion, and muon masses? [20 points]

(b) The pi-mu atoms are produced in $K_L$ decays

$$K_L \rightarrow \text{pi-mu atom} + \text{neutrino}.$$  

If the $K_L$ has $\beta = 0.8$, what are the minimum and maximum energies of the pi-mu atom in the moving frame of the $K_L$? (express these energies in terms of the particle masses) [20 points]

Problem 4: (40 points)

Briefly explain or describe 4 of the following 6 phenomena (in no more than 200 words for each phenomena): [10 points each]

(a) Electromagnetic structures of the neutron and proton

(b) The laser

(c) C, P, T, and CP symmetry (and any possible well known violations)

(d) The transistor

(e) The $J/\psi$ particle

(f) Superconductivity
Problem 5: (40 points)

A system consisting of \( N \) (a very large number) identical weakly interacting particles is in equilibrium with a heat bath. The total number of individual states available to each particle is \( 2N \). Of these, \( N \) states are degenerate with energy 0, and \( N \) states are degenerate with energy \( \varepsilon \).

\[
\begin{align*}
\varepsilon & \quad \text{\( N \) states} \\
0 & \quad \text{\( N \) states}
\end{align*}
\]

It is found by observation that the total energy of the system is \( \frac{1}{3} N \varepsilon \). Find the temperature of the heat bath under three different assumptions:

(a) That the particles are bosons. [10 points]

(b) That the particles are fermions. [10 points]

(c) That the particles obey the (unphysical) Boltzmann distribution. [10 points]

(d) You should find from Parts (a), (b), and (c) that

\[
T(\text{boson}) > T(\text{Boltzmann}) > T(\text{fermion})
\]

Explain why this is so. [10 points]