ME-351 THERMODYNAMICS AND ENERGETICS II

SPRING 2025

QUESTION 1

Consider a binary mixture with N_A atoms of the chemical element A, N_B atoms of the chemical element B mixed together at a temperature T and pressure p.

1. Write down the expression for the characteristic potential of this system.
2. Express the Hessian of this characteristic potential with respect to the experimentally controlled state variables.
3. Use the Maxwell relations to identify the independent terms in the Hessian matrix
4. Recall that response functions are typically defined as proportional to the partial derivative of an extensive variable with respect to an intensive variable. Let $\chi_{ij} = \frac{\partial N_i}{\partial \mu_j}$. Express the Hessian in terms of suitably defined response functions that are "easy" to measure.

QUESTION 2

The pressure-temperature phase diagram of a single-component element is shown in fig. 1. Schematically sketch the Gibbs free energy as a function of temperature for the solid, liquid and gas phases at the 4 pressures labeled in the figure. Be sure to label the solid-liquid, solid-gas and liquid-gas phase transition temperatures at each pressure on both the phase diagram and your free energy plots.

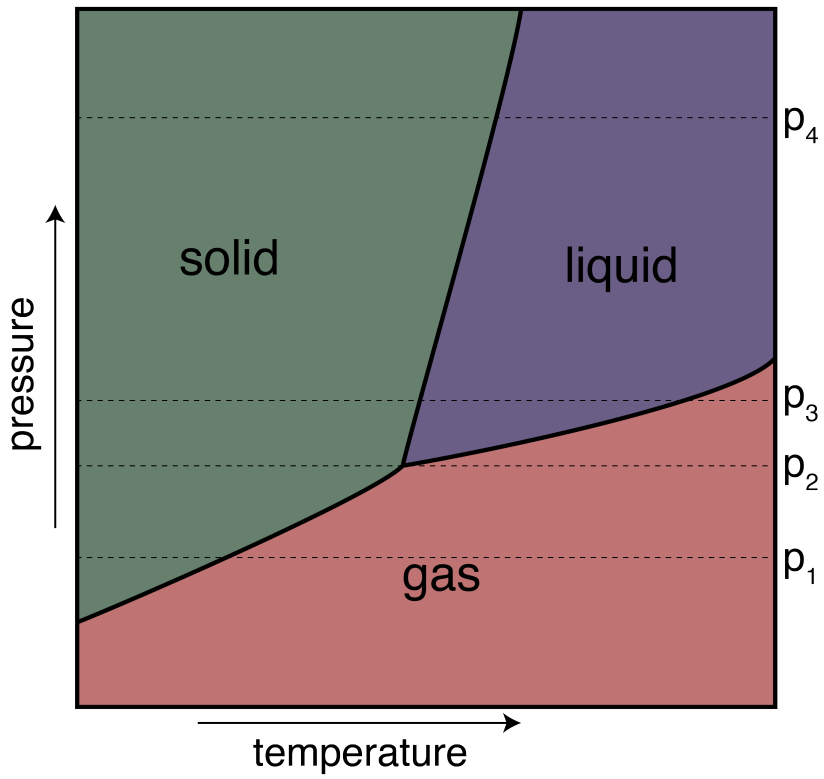

Figure 1

QUESTION 3

The heat of evaporation of water at 100℃ and 1 atm is 2261 J/g. The density of water vapor at 100℃ and 1 atm pressure is 0.597 kg/m^3

1. What percentage of that energy is used as work done by the vapor?
2. What is the internal energy change for the evaporation of water?

QUESTION 4

Titanium forms an hcp phase (α) at room-temperature. At elevated temperatures, titanium transforms into the bcc phase (β) at 1155K. The β phase is found to melt at 1943 K. Calculate the metastable melting point of α. The metastable melting point is the temperature at which α would melt assuming that the β phase is never formed. You can assume that the enthalpies and entropies of the individual phases are insensitive to temperature.

Data

$\Delta S^{\beta\rightarrow\text{liquid}} = 9.6$J/mol-K

$\Delta S^{\alpha\rightarrow\beta} = 3.43$J/mol-K

QUESTION 5

A magnetic material that undergoes a ferromagnetic (α-phase) to paramagnetic (β-phase) phase transition is clamped along the x and y directions as shown in fig. 2. The stress acting on the material (σ_{zz}) is controlled by varying the pressure of the gas surrounding the material.

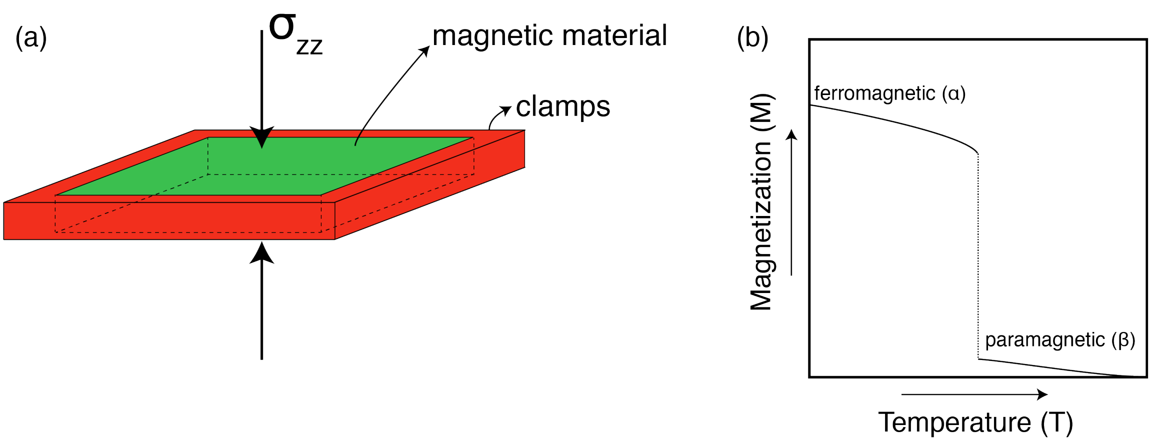

Figure 2

1. Sketch the magnetic field (H) versus temperature (T) phase diagram for this material. Clearly indicate the single-phase and two-phase regions.
2. Experiments on this material reveal that the material expands along the z-direction when it undergoes a phase transition from $\alpha \rightarrow \beta$. Draw the stress (σ_{zz}) versus magnetic field (H) phase diagram for this material
3. The paramagnetic (β) phase is enclosed in an *adiabatic* chamber and a magnetic field is applied to it. Would the temperature of the material increase or decrease if the magnetic field applied to the material is reversibly switched off?