Homework 3
Advanced Materials Thermodynamics
Due Monday September 16, 2024

High entropy alloys are substitutional alloys with five or more components (https://en.wikipedia.org/wiki/High-entropy_alloy). A review article on this subject from 2019 has about 2000 citations indicating that this is an active field of research [George EP, Raabe D, Ritchie RO *High-entropy alloys* Nat. Rev. Mat. 1550755 (2019).] Zhang Y, Xu P, Zhu J, Yan S, Zhang J, Li L *The emergence of considerable room temperature magnetocaloric performances in the transition metal high-entropy alloys* Mat. Today Phys. **32** 101031 (2023) discuss high entropy alloys with significant room temperature magnetocaloric performance for magnetic refrigeration. The materials display a second order transition at the Curie point with a large change in entropy which is a necessary feature for magnetic refrigeration [Law JY, Franco V *Review on magnetocaloric high-entropy alloys: Design and analysis methods* J. Mat. Res. **38** 37-51 (2022)].

a) The basis for HE alloy MT materials is the Maxwell equation: $(dM/dT)_{B,V} = (dS/dH)_{T,V}$ where M is the magnetization and H is the magnetic field. Obtain this equation using a Legendre transformation and show how to obtain Zhang's equation 2 (Law's equation 1) from this Maxwell relationship. Why does this indicate a second-order transition (described by Law)?
b) Derive equation 2 of Law from the perspective of pressure, volume and from statistical mechanics.
c) Explain how the Arrott plots in Figures 4b and d can be used to determine the Curie temperature. How does this plot relate to the Landau theory for a second order phase transition? (https://en.wikipedia.org/wiki/Arrott_plot#). Where is T_c from these plots? (Consider also Banerjee SK *On a generalized approach to first and second order magnetic transitions* Phys. Letts. **12** 16-17 1963.)
d) Approximately how many grams of ice could be formed from water at 0°C from 1 kg of these high entropy alloys? Comment on the usefulness of this approach for refrigeration.
e) The name "high-entropy" alloys refers to the entropy associated with the random arrangement of the five components in the alloys studied by Zhang. Zhang calculates the entropy change in the second order transition as the source of magnetic refrigeration, figure 5. What is the relationship between the entropy change shown in figure 5 and the "high-entropy" in the name of the alloys? What advantage do HE alloys have over other MT materials?