ESS 312 Geochemistry – Practice midterm exam questions

1. Short-answer questions

Provide short definitions or explanations (either in words or formulae) to show you understand the meaning of the following concepts:

1. Why are the heavy rare earth elements (e.g., Yb, Lu) compatible with garnet in the mantle, but incompatible with other mantle minerals such as olivine and orthopyroxene?

2. Why are the heat of formation (H) and free energy of formation (G) for nitrogen (N_2) gas at room temperature and pressure equal to zero, while they are not zero for ozone (O_3) gas at room temperature and pressure?

3. How do you calculate the free energy of a reaction (ΔG_{rxn}) at standard temperature but at any pressure?

4. Explain mathematically why, for any substance its free energy (G) increases with increasing pressure (P). If, in a G (y axis) vs. P (x axis) diagram, phase A has a greater slope than phase B, which will be the stable phase at high pressure? Explain.

5. Do you expect the bonds in potassium bromide (KBr) to be primarily ionic or covalent in nature? **Why**?

6. Explain the difference between equilibrium (batch) crystallization, and fractional (Rayleigh) crystallization of a melt.

7. Given the following thermodynamic data for andalusite and sillimanite, does the equilibrium boundary between these minerals in P-T space have a positive of negative slope? Why?

Mineral	**Volume (cm^3)**	**Entropy (J/K)**	**Enthalpy (kJ)**
Andalusite	52.29	245.1	-2,515.2
Sillimanite	50.23	246.9	-2,512.8

8. List three trace elements that are concentrated in the Earth's crust relative to the mantle, and explain why.

9. ^{146}Sm is radioactive and decays by alpha decay with a decay constant $\lambda = 6.73 \times 10^{-9}$ yr^{-1}. [Note – this is not a typo for ^{147}Sm. The isotope ^{146}Sm is also radioactive].

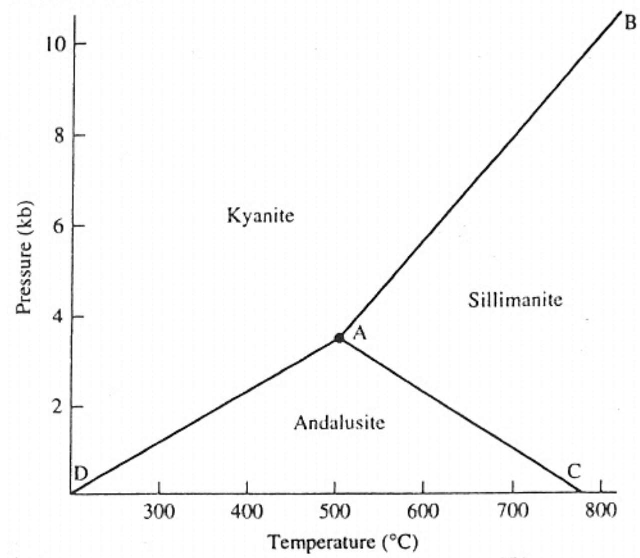
   (a) Write a reaction for the decay of ^{146}Sm, indicating the daughter isotope.

   (b) What is the half-life of ^{146}Sm?

Longer (multi-part) questions

Thermodynamics and mineral equilibria

Shown below is the phase diagram for the Al_2SiO_5 system:



Sketch a **G vs P** diagram for a constant temperature of **600°C**. Make P the x-axis, with pressures running from 0 – 10 kilobars. Make G the y-axis, but do not use a numerical scale.

Hint: $\left(\frac{\partial G}{\partial P}\right)_T = V$

Draw a **V versus P** diagram, assuming a constant temperature of 600°C. Make P the x-axis, with pressure running from 0 – 10 kilobars. Put V on the y-axis.

Given that the entropy of andalusite is 251.31 J mol^{-1} K^{-1} and that of kyanite is 242.42 J mol^{-1} K^{1}, determine the ***difference*** in molar volume between kyanite and andalusite.

Hints: Determine the slope of the andalusite-kyanite univariant line. The triple point (A) is located at 500°C and 3.76 kbar. Use the Clapeyron equation. Keep careful track of units – and remember that 1 cm^3 = 0.1 J bar^{-1}.

Arrange the minerals in order of *increasing* molar volume and explain briefly why you put them in that order.

Trace element partitioning

For the following problem, we will model the melting and crystallization processes that control trace element abundances in magmas formed over an ocean island hot spot in the Pacific.

Assume that the mantle in the magma source region has a mineralogy of:

Olivine:	65%
Orthopyroxene:	20%
Clinopyroxene:	10%
Garnet:	5%

Use the following values for the distribution coefficients:

	% mineral	Ni	Cr	Rb	Th	Ce	Yb
Olivine	65	10	20	0.001	0.001	0.001	0.002
Orthopyroxene	20	4	9	0.001	0.001	0.003	0.05
Clinopyroxene	10	2	6	0.001	0.001	0.1	0.3
Garnet	5	0.04	2	0.001	0.001	0.02	4

a) For a 10% batch partial melt, what is the Ce/Yb ratio of the resulting magma?

b) This magma sits in a magma chamber and undergoes 5% fractional crystallization of olivine only. Draw a diagram of element concentration (y axis) *vs* F (x axis) showing how the concentrations of Ni, Rb and Th change as crystallization proceeds. You don't need to show values for the concentrations, just the trends in concentration as F (the fraction of liquid remaining) runs from 1.0 to 0.9.

c) On a similar diagram with F as the x axis, show how the ratio of Th/Rb evolves as crystallization proceeds.

d) Assume the magma starts with an initial Cr concentration of 400 ppm. What is the final Cr concentration after 5% fractional crystallization of olivine.

Radioactive isotopes and geologic dating methods

The isotope ^{87}Rb decays to ^{87}Sr, with a decay constant $\lambda_{87Rb} = 1.42 \times 10^{-11}$ yr^{-1}.

To a first approximation the solar system condensed to form the planets at about 4.55 billion years ago. But in detail, we can determine that different planetary bodies formed at slightly different times. For example, different types of meteorites (from different planetary bodies) appear to preserve different formation times. One way to determine this is by using the evolution of ^{87}Sr/^{86}Sr (due to the decay of ^{87}Rb) in the early solar system.

a) (? points) Below are Rb and Sr isotope data for several minerals from the meteorite Juvinas. Calculate the **crystallization age** of the meteorite, and the **initial ^{87}Sr/^{86}Sr** isotope ratio at the time of its formation. Show your calculations

Sample	**^{87}Rb/^{86}Sr**	**^{87}Sr/^{86}Sr**
Glass	0.0876	0.70473
Tridymite	0.0231	0.70063
Plagioclase	0.00301	0.69914
Pyroxene	0.00714	0.69950
Total rock	0.00407	0.69927