USESO 2021

Astronomy

Instructions:

- Section I consists of 10 multiple choice questions with each question worth 2 points. There is only one correct option on multiple choice questions.
- Section II consists of 2 multipart, free-response questions.
- A non-graphing, non-programmable calculator is allowed; show all work for calculations.
- Recommended time management: 30 minutes on each section.

Section I

1. (2 points) A Northern Hemisphere observer records a low tide at solar noon. Assuming a semidiurnal tidal pattern, what could the observer see in the sky six hours later? (*Note*: Assume equilibrium tides)

Photo A Photo B

I) The moon in Photo A high in the sky

II) The moon in Photo B high in the sky

III) No moon visible

A. I only

B. II only

C. III only

D. I or II

E. I or III

F. II or III

2. (2 points) You travel to a parallel universe. Through your astronomical wisdom, you realize that the alternate Earth experiences retrograde motion, the eccentricity of the its orbit is decreasing from 0.01 to 0.002, its axial tilt is increasing from 20.5° to 29°, and, incredibly, it lacks axial precession. Assuming all other things equal, how might global climate change on the alternate Earth?

A. Milder seasons and overall warming trend

B. More extreme seasons and overall warming trend

C. Milder seasons and overall cooling trend

D. More extreme seasons and overall cooling trend

3. (2 points) Mars is thought to be currently dominated by cold-based glaciers, glaciers that exist in subfreezing temperatures and have minimal meltwater. From this information, which of the following is most reasonable to infer?

A. Compared to glaciers on Earth, internal deformation within these glaciers is very low.

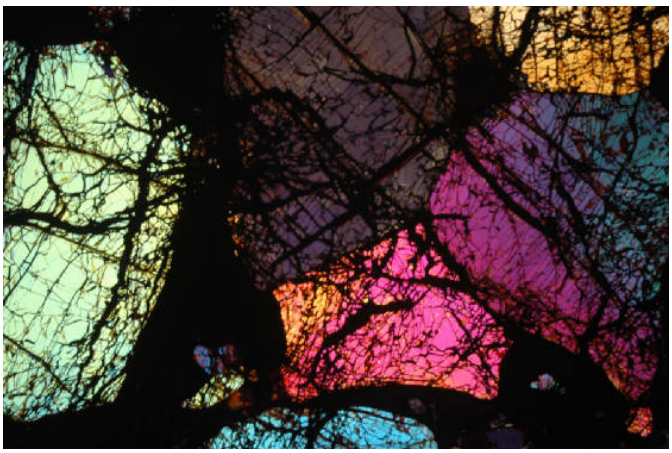
B. There is little alteration of the topography underneath the glaciers.

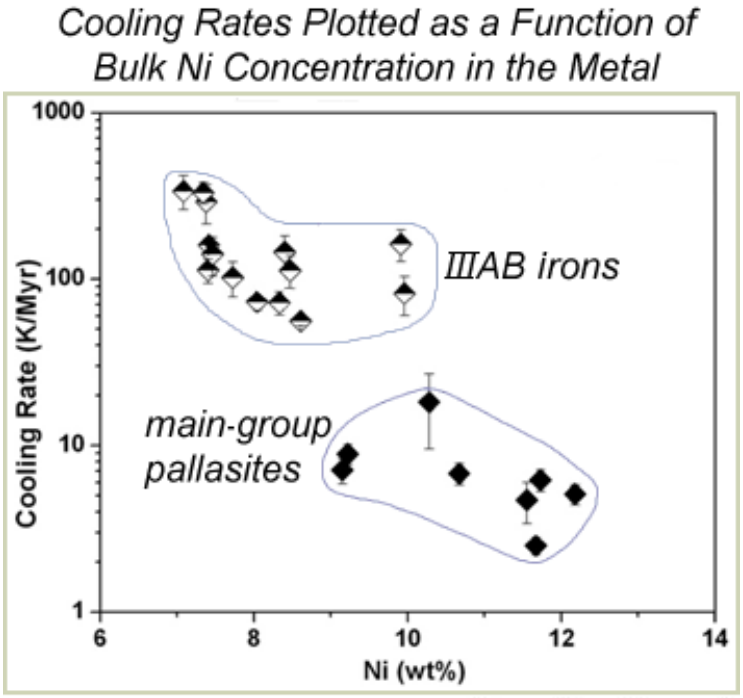
C. Glaciers on Mars are mostly static as they do not easily flow.

D. Eskers are actively forming depositional features.

E. If the glaciers were to sublimate and retreat, the most prominent glacial features would be erosional.

4. (2 points) The figure below is a thin section of the Huckitta pallasite, a main group pallasite meteorite. The colored mineral is forsterite (Mg-rich olivine), while the black mineral is an iron-nickel alloy.





(Adapted from Yang *et al.*, 2010, *GCA*, doi:10.1016/j.gca.2010.04.016.)

IIIAB irons are a population of iron meteorites, which are composed of an iron-nickel alloy of kamacite and taenite. IIIAB irons and main-group pallasites are plotted above in terms of their cooling rate and nickel content. Which of the following can be reasonably inferred?

I) Main-group pallasites originate from the core-mantle boundary of a differentiated parent body

II) IIIAB irons and main-group pallasites originated from the same parent body

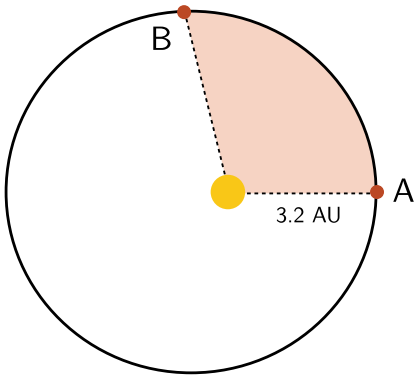
A. I only

B. II only

C. I and II

D. Neither I nor II

5. (2 points) A planet P orbits the Sun with a semi-major axis of 4 astronomical units (AU). At time $t = 0$, planet P is at perihelion (location "A"), 3.2 AU from the sun. At $t = 1.5$ years, planet P is at location B in its orbit.



What is the area between the following boundaries: B-Sun, A-Sun, and the orbital path from A to B (shown in figure above). Give your answer to the nearest tenth in terms of π. (*Note*: The area of an ellipse is given by $A = \pi ab$ where a and b are the semimajor and semiminor axes, respectively)

A. 2.4π AU^2

B. 2.8π AU^2

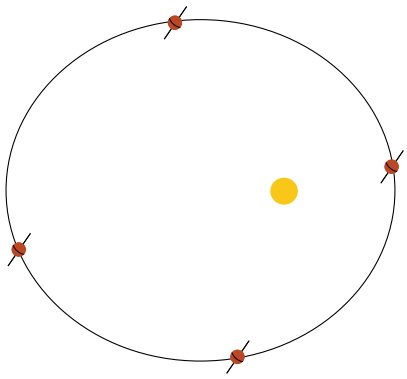
C. 2.9π AU^2

D. 3.6π AU^2

E. 3.8π AU^2

F. 4.0π AU^2

6. (2 points) Close to the solstices, Mars's atmospheric circulation is characterized by a large cross-equatorial Hadley cell. Its orbit (eccentricity exaggerated), as well as its rotational axis during the equinoxes and solstices, is shown below.



Which of the following is **not** true about Mars's seasons and atmospheric dynamics?

A. Southern summer is warmer than northern summer.

B. Southern winter is longer than northern winter.

C. During the equinoxes, there are two Hadley cells with rising air near the equator.

D. Hadley circulation during southern summer is stronger than northern summer because the southern hemisphere is significantly elevated relative to the northern hemisphere.

E. The northern ice cap is significantly larger than the southern ice cap due to net northward water vapor advection by climatological mean atmospheric circulation.

F. None of the above.

7. (2 points) Rachmaninoff Crater (**Figure 1a**) is a peak-ring crater on Mercury, hypothesized to show recent (1.0 Ga) volcanic activity. Concentric graben and ridge structures have also been observed within the peak-ring (**Figure 1b**).

Though not yet confirmed, assume that volcanism associated with Rachmaninoff Crater originated from within the peak-ring structure (at B) and flowed out into the space between the peak-ring and the outer crater rim (at A).

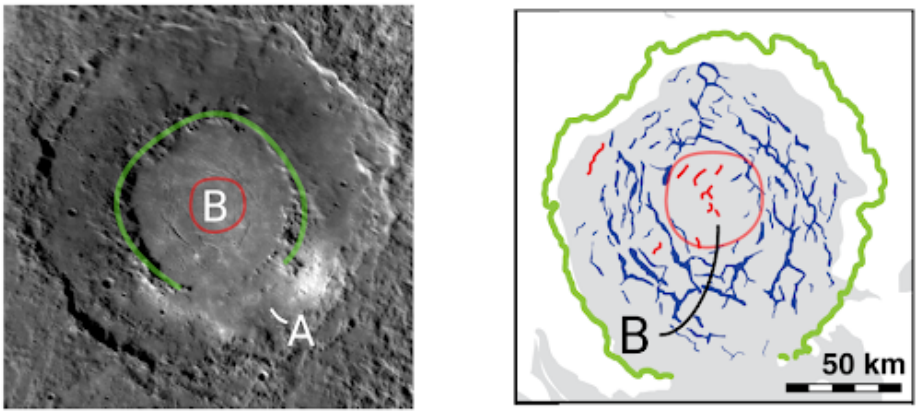


Figure 1 [modified after Blair et al.]: (a) Shows a mosaic of the Rachmaninoff impact basin. Note the peak-ring structure, highlighted in green, and a cooled lava flow denoted with letter A. The green and red outlines correspond to (b). (b) Shows the graben (blue) and wrinkle ridge (red) structures within the peak-ring (green).

Magmas of Rachmaninoff Crater are low in Fe and can be approximately characterized by a CMS (CaO-MgO-SiO_2) three-component system. Which of the following is true?

I) Thermal contraction of cooling lava arising from B generates large extensional stresses in the rest of the peak-ring.

II) Rachmaninoff Crater is undergoing rapid crustal subsidence.

III) The composition of rocks at A is characterized by a higher CaO + MgO to SiO_2 ratio than rocks at B.

A. I only

B. II only

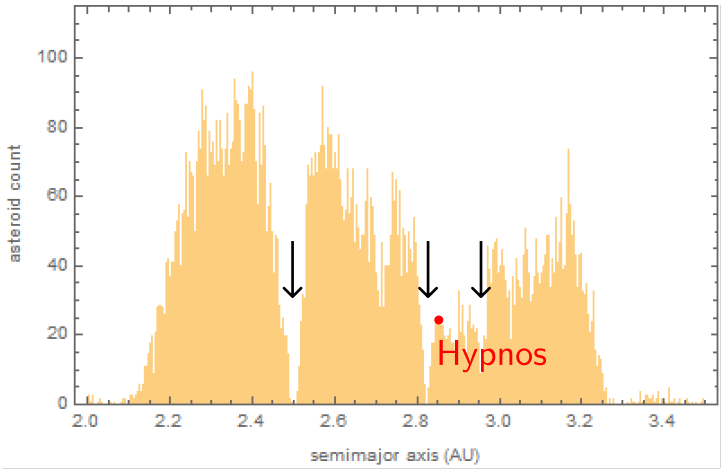
C. III only

D. I and II

E. I and III

F. II and III

8. (2 points) The figure below shows the distribution of main-belt asteroids.



(a) Which of the following accounts for the gaps in the distribution, as marked by the arrows?

A. Mean motion resonance with Mars

B. Mean motion resonance with Jupiter

C. Shepherding (i.e., orbit clearing) by large asteroids like Ceres and Pallas

D. Radiation pressure from solar wind

(b) The asteroid Hypnos has been proposed to be an "extinct" or possibly dormant comet whose surface volatiles have at least mostly sublimated. Which of the following about Hypnos supports its status as a comet nucleus?

A. Diameter: 520 meters

B. Albedo: 0.057

C. Inclination: 1.981°

D. Perihelion/aphelion: 0.949/4.732 AU

E. Orbital period: 4.97 years

9. (2 points) On June 3rd, 2020, the phase of the Earth is full as observed from Venus, and the phase of Venus is new as observed from Earth. When is next time Earth will be in its full phase as observed from Venus?

Earth orbital period	365.25 days
Venus orbital period	224.65 days

A. October 5, 2020

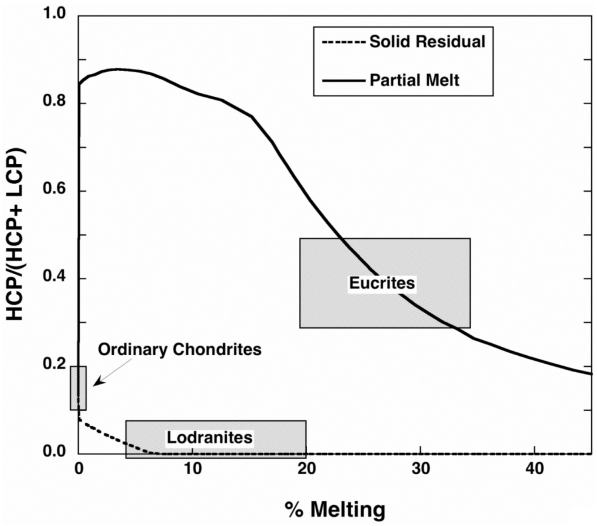
B. January 13, 2021

C. March 22, 2021

D. August 25, 2021

E. January 7, 2022

10. (2 points) High-calcium pyroxene (HCP) and low-calcium pyroxene (LCP) are spectrally detectable, making them useful indicators in extraterrestrial igneous studies. Spectroscopic pyroxene analysis has been applied in studies of both S-type asteroids (**Figure 1**) and Martian paleovolcanism (**Figure 2**).



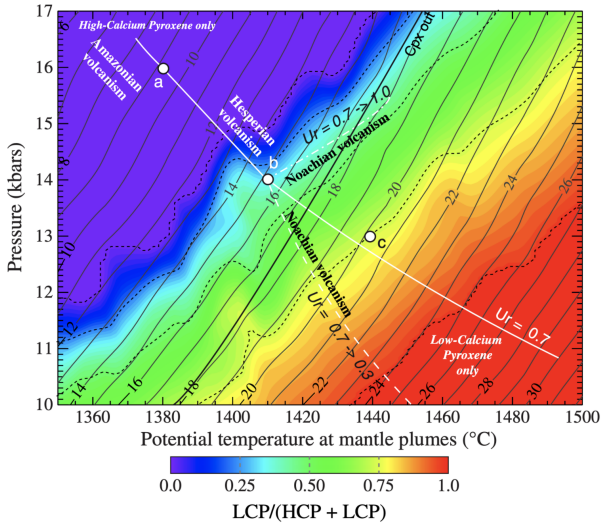


Figure 1, left: Calculations based on two achondritic meteorite groups, eucrites and lodranites, used to determine the relationship between the extent of partial melting and the ratio of high-calcium pyroxene to total pyroxene. **Figure 2**, right: Pyroxene composition, represented by the ratio of low-calcium pyroxene to total pyroxene, corresponding to volcanic deposits from the Noachian, Hesperian, and Amazonian Periods of the Martian Geologic Time Scale.

(a) Based on the general relationship shown in **Figure 1**, which of the following is true?

A. Noachian volcanic deposits exhibit a higher degree of partial melting than Hesperian deposits

B. Hesperian volcanic deposits exhibit a higher degree of partial melting than Noachian deposits

C. Both Noachian and Hesperian volcanic deposits exhibit the same degree of partial melting

D. Neither Noachian nor Hesperian volcanic deposits exhibit partial melting

(b) Which of the following is a plausible explanation for the change in pyroxene composition between the Noachian and Hesperian periods?

A. Shock heating from supernovae occurred during the Hesperian Period

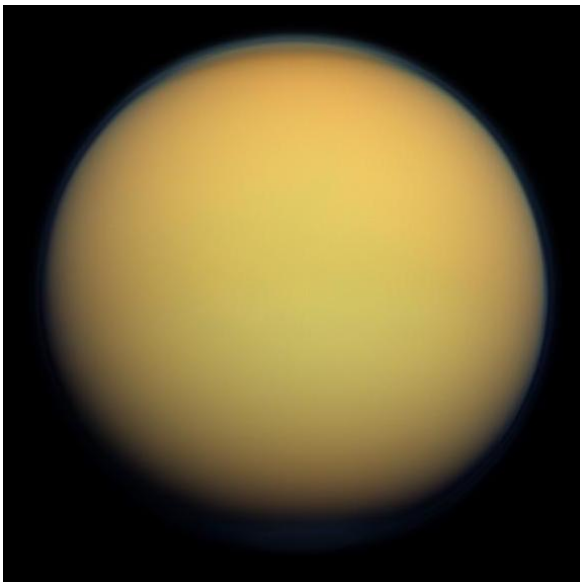
B. Tidal heating due to interactions with Phobos during was strong during the Hesperian Period

C. Mantle pressures were greater during the Noachian Period

D. Mantle temperatures were greater during the Noachian Period

Section II: Problem 1

Question	1	2	3	4	5	6	7	Total
Points	3	2	3	2	2	1	2	15 (30%)



Titan, shown above, is a moon of Saturn. It has a thick atmosphere and its surface is modified by (hydrocarbon) hydrologic processes akin to those on Earth.

1. (3 points) Using the orbital parameters given below, calculate the orbital period, to the nearest day, of Titan.
   - Semi-major axis of Titan = 1.22 * 10^9 m
   - The gravitational constant G = 6.67 * 10^{-11} N * m/kg^2
   - Mass of Saturn = 5.683 * 10^{26} kg
   - Mass of Titan = 1.345 * 10^{23} kg

   Note: if you could not complete question 1, use 15 days as the orbital period of Titan for the following questions.

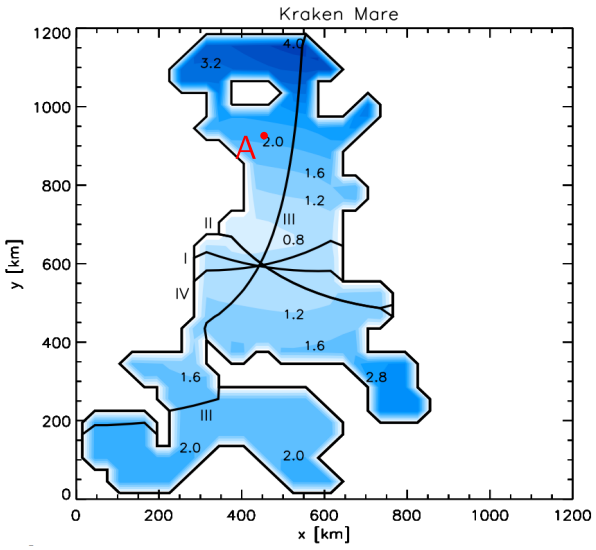
Titan is tidally locked and rotates synchronously with Saturn (similar to the Earth's moon), but it still exhibits considerable tides due to its eccentricity ($e = 0.0288$). This eccentricity tide can be broken into two components: (1) the radial tide, due to variations in distance from Saturn; (2) the librational tide, which we'll explore later.

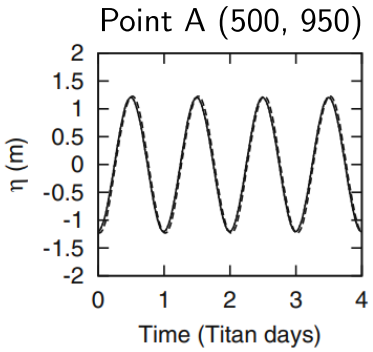
2. (2 points) What is the period of the radial tide? Briefly explain.

3. (3 points) How much greater is the maximum tidal force than the minimum tidal force of Titan's radial tide? Give your answer as a percentage. (*Hint:* $\frac{r_a}{r_p} = \frac{1-e}{1+e}$)

4. (2 points) The librational tide arises from the interesting fact that Titan rotates such that it always faces the empty focus, not Saturn itself. Hence, the tidal bulge oscillates (librates) along Titan's equator. What is the period of the librational tide? Briefly explain.

uplevelTitan has several lakes composed of hydrocarbons like methane and ethane. The largest of these lakes, Kraken Mare, is located in the Northern Hemisphere and faces Saturn. Tokano (2010) performed a simulation of the tides generated in Kraken Mare, shown in the figure below. The bold lines are cotidal lines, while the shading shows the tidal range.





5. (2 points) In Titan and Earth days respectively, what is the time elapsed between two neighboring cotidal lines? (*Note:* cotidal lines are equally spaced in time)

6. (1 point) The tide at Point A is:

   A. Semidiurnal

   B. Diurnal

   C. Mixed semidiurnal

   D. Mixed diurnal

7. (2 points) Titan is less massive than the Earth, meaning it has less gravitational pull. Despite this, Titan's surface atmospheric pressure is 50% higher than Earth. Briefly account for this observation.

Section II: Problem 2

Question	1	2	3	4	5	6	Total
Points	2	2	3	3	3	2	15 (30%)

The early histories of Mars and Earth may have been quite similar (active hydrologic cycle, primitive atmosphere, etc.) before their paths diverged. One of the factors that contributed to this divergence is the disappearance of the Martian magnetic field.

1. (2 points) In addition to core convection, give another criterion necessary for a planetary body to maintain a magnetic field.

2. (2 points) Core convection may be maintained through thermally-driven instability or compositionally-driven instability. The latter may be dominant in small planetary bodies and is a result of the presence of lighter elements, namely sulfur, in the iron-dominated core. We will explore one hypothetical regime of compositionally driven convection.

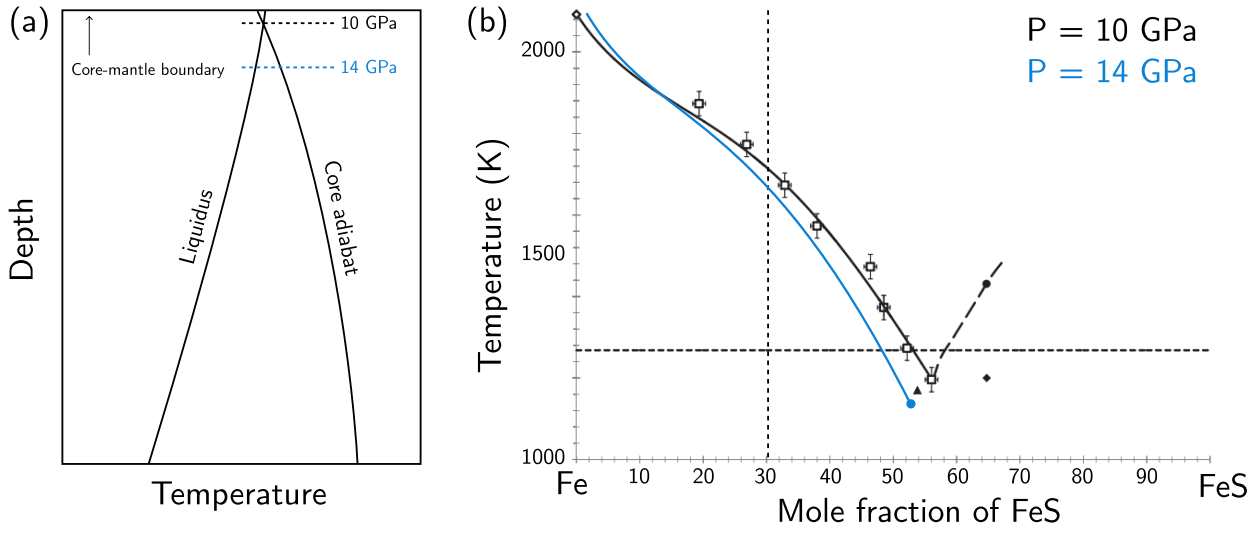


Figure 1: (a) a depth profile of an outer core. The core adiabat is the temperature of the outer core. Sulfur concentration is constant (30% FeS) with depth. **(b)** liquidus curves of the Fe-FeS system at two pressures.

Consider the outer core given by Figure 1(a). This will be the *initial* condition. If the core-mantle boundary (CMB), where the liquidus and the core adiabat intersect, is at a pressure of 10 GPa, which of the following is true?

I) At the constant sulfur concentration, the liquidus temperature decreases with increasing pressure.

II) Solid Fe will precipitate from the core-mantle boundary.

III) Solid FeS will precipitate from the core-mantle boundary.

A. II only

B. III only

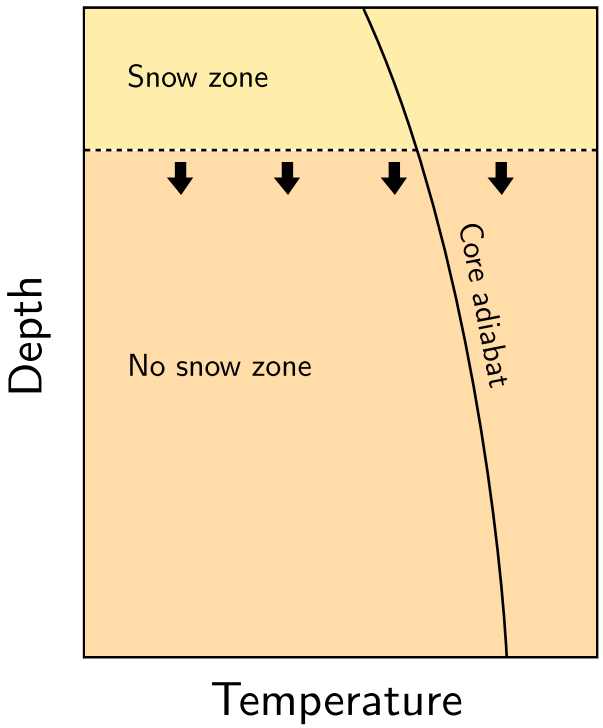
C. II and III

D. I and II

E. I and III

F. I, II, and III

3. (3 points) Let us now consider what will happen after this initial condition. Following the precipitation of solid, sulfur concentration will no longer be constant with depth. In terms of the phase change processes, describe how the sulfur concentration will vary with depth after the initial precipitation. (*Hint*: consider fractional crystallization)



4. (3 points) Let's call the depths in which the solid is precipitating the "snow zone." The extent of the snow zone is ultimately controlled by the intersection of the adiabat with the liquidus. Considering your answer in 3, justify why the bottom limit of the snow zone grows deeper over time.

5. (3 points) Where does compositionally driven instability trigger convection, the snow zone, no-snow zone, or both? Justify your answer.

6. (2 points) It has been hypothesized that Mars may have generated a magnetic field in its past through this mechanism. Considering your answer in 5, briefly explain why Mars no longer has an active magnetic field.

END OF EXAM