Solve the problems listed below, and write up your answers clearly and completely. Do not turn in rough work – instead, make a clean copy after checking your calculations. Use English sentences and phrases to explain your solution and describe key equations. Show your work!

1. Introductory astronomy textbooks often claim that the Moon always keeps the same side to the Earth. Our book is more accurate; the Moon’s various “librations” are discussed in Chapter 4.5. A video displaying libration in longitude and latitude is available at http://www.ifa.hawaii.edu/faculty/barnes/ast241/moon.mpg. In this video, libration in latitude makes the Moon appear to nod up and down, while libration in longitude makes the Moon appear to nod left and right. (Diurnal libration is not shown.)
   (a) From the video, how many degrees in longitude does the Moon appear to swing as it orbits the Earth? Make a rough measurement by tracking a specific feature on the Moon over one cycle, ignoring libration in latitude.
   (b) Given that the Moon’s orbit has an eccentricity \( e \approx 0.055 \), estimate how many degrees left-and-right you expect the Moon to swing. Is this consistent with what you see in the video? (Note the word estimate. If you’re working out integrals, you’re being too precise!)

2. Given that (1) the Sun is \( \sim 400 \) times further away than the Moon, and (2) the Sun’s mass is \( \sim 3 \times 10^5 \) times the Earth’s mass, which produces a greater gravitational force on the Moon, the Earth or the Sun? Compute the ratio of these forces (a precision of \( \sim 10\% \) is adequate). Are you surprised by your result?

3. Recall that (1) the Sun is \( \sim 400 \) times further away than the Moon, and (2) the Sun’s mass is \( \sim 2.5 \times 10^7 \) times the Moon’s mass.
   (a) Which produces a greater tidal force on the Earth, the Sun or the Moon? Compute the ratio of these forces.
   (b) Using the same style as Fig. 4.5, diagram the tidal forces due to the Moon and the Sun on the Earth when the Moon is (i) New, (ii) at First Quarter, (iii) Full, and (iii) at Third Quarter. To keep things straight, use one color for the Moon’s tidal forces, and another for the Sun’s. Then diagram the total tidal force. How would you expect tide heights to depend on the phase of the Moon?
   (c) The Earth’s orbit around the Sun has eccentricity \( e_E \approx 0.017 \). How many times stronger is the Sun’s tidal force when the Earth is at perihelion compared to aphelion?
   (d) The Moon’s orbit around the Earth has eccentricity \( e_M \approx 0.055 \). How many times stronger is the Moon’s tidal force when it’s at pericenter compared to apocenter?