1. Let "M" represent the mass of a planet. Let "m" represent the mass of a satellite in orbit around it. Let "D" represent the *center-to-center* distance between the planet and satellite, and let "G" represent the universal gravitational constant. Using #2 on RS XIII, show how the attractive force between the planet and the satellite can be calculated. **F = ____**

2. The strength of a planet's gravity at any given location must depend on the planet's _____ and the distance between that location and the ______ of the planet. Use the universal gravitation law with the definition of "g" (RS III, RS V, & p. 112) to create a new formula describing that relation: **g =** ___

3. Although it is difficult to measure G and M, it is easy to determine the *product* of those unknowns with considerable precision. Begin by solving equation 2 for the unknown product: **GM =** ______
   a. Plug in the well-known values of the earth's radius and gravitational field strength at its surface to determine the product of G and M for the earth. Keep 3 significant digits. $\mathbf{GM_e}$ **=** _______ _____
   b. Use the data on page 112 to determine the GM product for the sun: $\mathbf{GM_s}$ = ________ ______
   c. Use 3a and 3b to determine the ratio of the sun's mass to the earth's mass: $\mathbf{M_s/M_e}$ = ________
   d. We can use similar reasoning to determine the relative masses of certain other planets, such as Jupiter and Mars. Why can't this method be applied to *all* planets without resorting to space travel?

* 4. Some people say that there is no gravitational attraction between ordinary objects such as basketballs because the universal law of gravitation does not apply to them. Do you agree? Explain your reasons.

5. In 1798 Henry Cavendish measured the gravitational attraction between two lead balls in his lab. With that result it became possible to calculate the "universal gravitation constant", known as "G".
   a. Consult a textbook to see how he made that measurement. Write the result here *and* on RS XIII.
   G = ______ ______ **per**_____
   * b. Cavendish used the results of his experiment to calculate the mass of the earth. Show how.
   * c. Use 5b to calculate the average density of the earth in SI units. *Show how. Round off properly.*
   d. Is it more than the density water? ____ -of lead? ____
   e. Give the densities of lead and water in the same units used in 5c. *Don't confuse "g" with "grams".*

* 6. The width of a car is roughly ___ m. We normally park about ____ m. from the next car in a parking lot. Show how that information can be used with #1 and 5a to *estimate* the gravitational attraction between two adjacent cars in a parking lot. *Begin with a diagram. Remember to round off properly.*

* 7. Suppose the parking lot suddenly became frictionless: Roughly how long would it take for the attractive force estimated in #6 to move the cars together into contact? State your assumptions clearly and explain your reasoning. Convert your estimate to convenient time units and discard bogus digits.

8. Let "v" represent the speed of the satellite. How must the centripetal force on it be related to the gravitational force if its orbit is circular? ______ (Planetary orbits are *approximately* circular.)
   a. Use the symbols defined above to write that equation: _____ = _______
   b. Solve equation 8a to show how the orbit speed depends on G, M, and R: **v =** ________
   c. Replace the speed in 8b with an equivalent expression from #1 on RS VII involving the period and the orbit radius. Then solve for the period and *simplify*. **P =** ______
   * d. Explain how #4 on RS XIII verifies or refutes equation 8c. If the theory and observations do agree then use the constant in that equation with 3b to determine the mass of the sun. If you know any other way to determine that mass, (other than copying from someone else) please explain.
   e. Does eq. 8c describe elliptical orbits as well as circular ones? ___ *If so, explain exactly what the "R" must represent. Significant extra credit will given for a clear & simple proof.*

* 9. In 1945 an author named Arthur C. Clarke showed that it is possible for a communication satellite to remain directly above a fixed point on the earth's equator. (After 1700 anyone could have done it.)
   a. Explain how we know that the period of such a "synchronous" satellite must be roughly 10^5 seconds.
   b. Use #8c, 9a &3a to show that the orbit radius must be roughly 4 x 10^7 m. *Keep 3 significant digits.*
   c. Why can't we have a synchronous satellite directly above Connecticut?
   d. Use 9b *with a diagram*. to figure out how far north of the equator a satellite dish can be used.

10. Is equation 2 valid for all objects, regardless of shape? ____ If so, explain how you can be sure. If not, please describe and explain the limitations of the evidence that lead to your formula.

1. Imagine Buck Rogers orbiting around Planet "X". When his orbit radius is one million kilometers his centripetal acceleration is 0.50 m/s^2. He has the same centripetal acceleration when orbiting Planet "Y" at TWO million kilometers.
   a. Which planet has the greater mass?
   b. How strong is the gravitational field two million kilometers from planet Y?
   c. How strong must planet Y's gravity be at a distance of ONE million km. from that planet?
   d. Calculate the ratio of the masses of these two planets.

2. Now suppose planets X and Y drift closer together. You are in a space station at point "P", ONE million kilometers from X and TWO million kilometers from Y, with line PX perpendicular to XY.
   a. Draw and label a scale diagram showing the relative positions of P, X, and Y.
   b. Calculate the sum of the two gravitational field vectors at P.
   c. Show how the angle between that vector sum and line PX is calculated.

3. Buck Rogers intends to position his space craft at a point close to the middle of a strange dumbell-shaped planet resembling two identical spheres connected by a massless rod. P is the location of the spacecraft, and C is the midpoint of the rod. *Make a diagram to illustrate.*
   a. When the spacecraft is equidistant from the two spheres, gravitational attraction will pull the spaceship toward point ___. *Illustrate your answer.*
   b. He wants to use the universal gravitation law to predict the strength of the gravitational attraction between his spacecraft and the planet. His robot says he should use distance PC in that formula. Do you agree? __
   c. His lovely travelling companion suggests that he should calculate the force pulling the craft toward sphere A (using distance PA), then find the force pulling the craft toward sphere B (using PB), and finally use vector addition to find the total force exerted by the planet on the ship. -Do you agree?

4. Suppose PA and PB are each twice as long as PC in #3:
   a. Draw a diagram fitting that description.
   b. Determine the degree measures of the angles in that diagram.
   c. Let the symbol __ represent the mass of the dumbell planet. The mass of each sphere is then ___.
   d. Choose a different symbol to represent the mass of the spacecraft: ____
   e. Express the gravitational attraction between the spacecraft and sphere A in terms of distance PC, G, and the masses: **Fa =** _____
   f. Express the vector sum of the forces exerted on the spacecraft by A and B in terms of those same symbols: **Fa + Fb =** _________
   g. Is that the method proposed by the robot in #3, or by the lovely companion? ____
   h. Use the same symbols to show what the other method in #3 predicts: **F =** _____

* 5. Does the universal gravitation law work for non-spherical objects, or is restricted to spheres and particles? (In this context a "particle" is an object whose length is insignificant compared to distance from one object to the other. For example, the length of Buck's spacecraft is much less than PC, so we can consider the spacecraft to be a particle. We cannot consider the dumbell-planet to be a particle, because distance AB is *not* small compared to _______.)

6. Imagine a set of planets with equal densities but different sizes:
   a. For members of that set, volume is proportional to the ___ power of radius.
   b. Mass is proportional to the ____ power of radius.
   c. The strength of the planet's gravity at its surface is proportional to the ___ power of radius.
   d. Increasing the diameter of a planet by one percent (by adding similar material to the planet) will cause its surface gravity to become ___ percent stronger. (Use 17f on RS II.)

* 7. Journalists in 1798 popularized Cavendish as "the man who weighed the earth". (Science reporting was just as garbled then as it is today.) Why is it absurd to say that the earth's weight is equal to its mass multiplied by 9.8 N/kg or by 2.2 pounds per kg?