1. Show how you calculate the work done in lifting an object with given mass from the ground to a table top. (Use RS VI.)

2. Define "energy".

3. How is the work in #1 related to the object's change in gravitational potential energy?

4. Mr. A believes the object in #1 has zero potential energy on the ground. Ms. B insists that the object has zero potential energy only when it is at the center of the earth. Will their answers to #1 differ?

5. Have you ever discovered any law or formula that involves gravitational potential energy (GPE) itself, rather than *change* in GPE? _____ *If so, please state the law.* -Does #4 contradict #5? ___

6. Suppose you want to remove an object from a planet. That will require some energy.
   a. Will that required energy be positive, negative, or zero? ____
   b. How is that energy related to the kinetic energy of an identical object after falling freely to the surface from an unmeasurably great altitude?_________ (Review page 60 or #8 & 9 on RSVI.)
   c. Suppose you throw an object from an airless planet, giving the object a kinetic energy greater than the one described in 6b. Will the object fall back down, or will it escape from the planet? ______

7. Imagine an object moving *downward* in a gravitational field. (That's opposite to the motion in #6.)
   a. Does its GPE increase, decrease, or remain the same? _______
   b. Does that change in GPE depend on the field strength? _______ -Does #1 agree? ___
   c. Are the gravitational field strengths of all planets equal? _______

8. Suppose an object is moved from the surface of one planet to the surface of a different planet.
   a. Do you expect its change in potential energy to be zero? ____
   b. Is it convenient to define zero GPE as the potential energy of an object when it is at the surface of a planet? ____ *If so, how do we decide which planet to use?*

9. Suppose an object is moved from one place to another deep in space, very far from all other objects:
   a. What can you predict about its change in potential energy in this case? **ΔPE =** ___
   b. Is it fair to say that the potential energy of an object is zero when it is infinitely far from any planet or other source of gravitational attraction?_____
   c. Would the residents of any planet be correct if they claimed that such a choice is unfair? ___

10. Starting at zero (as in 9b) and ___creasing the P.E. (as in 7a) leads to a ____tive final value. Therefore the GPE of *any* object on *any* planet must be ____tive if we use the most convenient zero point.

11. How was the elastic potential energy formula in #4 on RS VI discovered? Sketch graphs to illustrate your explanation. (Use 1 & 5 on RS VI.)
   * a. We generalized that trick into a "New and Improved" definition of work on RS VI. -What was that new definition? (Recorded in # __ on RS VI.)
   b. The process that transforms a force vs displacement graph into a graph of potential energy vs displacement is known as "_________tion".

12. Suppose you want to lift an object to such a tremendous altitude that the gravitational force you are working against decreases significantly on the way up. You can't calculate the required work by multiplying force times displacement, because the restoring force which you are working against is not uniform; it __creases as you go up. (See #1 on page 114 or #3 on RS XIII or #2 on p. 60 or #1 on p. 60b or 1 & 5 on RS VI.) *How* can we use 11a to create an improved formula for G.P.E.? Describe your method with as much detail as you can. Include sketches of graphs, equations describing them (if possible) and names of procedures being used. Also remember to use #10. This is an easy calculus problem, but you can also do it *without* calculus by the method on page 115b.

1. According to #5 on RS VI, a change in GPE is equivalent to the corresponding *area* under a graph of ______ vs displacement.
   a. The process of calculating such an area is called "________tion". (Copy from RS II.)
   b. The *opposite* of that process is called "__________tion". (Copy from RS II.)

2. If we had the equation of an object's GPE vs displacement graph, we could create a formula for the gravitational *force* on it by ____________ing. (Use 1b above, or use #6 on RS VI.) That means we could draw a tangent line at any point on the curved GPE vs D graph, and the slope of that tangent line would represent the gravitational ______ which acts on the object when it is at that location.

3. Sketch a graph of gravitational potential energy (GPE) of an object vs its distance from a planet or star, as on page 115:
   a. Some students suspect that this gravitational potential energy is proportional to the reciprocal of the distance between the object and the star, so that GPE = -k/d. If that is the case, then a one-percent increase in the distance should cause a __-percent __crease in the GPE. (See 17f on RS II.)
   b. The signs of ΔD and ΔGPE are ___________ *(alike, opposite)* because lifting an object __creases its gravitational potential energy. Therefore the slope of the graph is _____tive.
   c. Let D_1 represent the original distance: The change in distance described in 3a is then 0.01(__).
   d. In terms of "k" and D_1, the original potential energy can be written as E_1 = _______.
   e. Using 3a with 3d, the *change* in GPE is then _______.
   f. To calculate the slope of the tangent line as in #2, we must __________ the change in _________ by the corresponding change in __________. After simplifying, the result is _________.

4. As you mentioned in #2, that slope represents the gravitational ________ exerted on the object by the planet when the distance between their centers is ____. According to Newton's gravitation law, (#2 on RS XIII) that force is given by the formula _________ in terms of G, M, m, and D_1.
   a. Do the two formulas agree about the relation between force and distance? ____
   b. What can we conclude about the guess in 3a? ____
   c. Set the slope formula in 3f equal to the force formula in #4.
      Don't forget the signs mentioned in 3a.
   d. Solve for the unknown constant and make a conclusion about the complete GPE formula.
      Be sure to save it for future reference.

5. Show how your new GPE formula can be used to calculate an "escape velocity", i.e. the speed with which you must throw an object upward so that it never comes back down if air drag can be ignored.

6. Use #3 on page 114 to eliminate the "GM" from the potential energy formula and from the escape velocity formula. (Replace the GM in each equation with an expression involving the radius of the planet and the gravitational field strength at its surface.)

7. Use #6 to estimate the escape velocity for the earth. Explain your estimate clearly, and show how it is converted from SI units to more convenient and familiar units that can be understood by the general public.

8. Suppose an object is thrown diagonally upward from an airless planet:
   Does its escape velocity depend on the direction of its initial velocity? (Explain)