1. On pages 8 & 9 the acceleration of a freely-falling object was caused by a _____ward gravitational force exerted on the falling object by the ______. If that force were "balanced" (cancelled) by a parachute then the object would fall with a constant velocity. Its acceleration would then be _____.

2. In #4 on RS III you wrote that the acceleration of an object always has the same direction as the _____ force acting on the object. The acceleration is *zero* (as in #3 on RS III) if the ______ force on the object is zero. The example above involving the _________ illustrates that fact.

* 3. What kind of motion is produced by a steady, *unbalanced* (unopposed) force acting on an object? *Please answer with an opening statement.* Also describe two different experiments that we have already done which suggest that same conclusion. Illustrate by sketching velocity vs time graphs.

* 4. What would happen if the unbalanced force suddenly stopped acting while the object was still moving? Please illustrate by sketching new speed-time graphs. *Try not to contradict #1.*

* 5. A new experiment is needed because there is something that we don't yet know about the relation between acceleration and _______ force. (See #2.) Describe the purpose of this experiment *clearly*.

* 6. Explain how you will measure the acceleration of an object influenced by a steady adjustable force.

* 7. Invent a way to exert a steady, adjustable propelling force on a small wheeled vehicle. Describe and illustrate your method clearly enough so that anyone could duplicate your experiment easily.

* 8. Describe and illustrate a method for measuring or calculating that propelling force in SI *while* the vehicle is accelerating. Also explain what you do to improve the precision of that measurement. For example, if you use a spring scale then describe how you select the best scale for the job.

* 9. Does an object's acceleration at any given time depend on the forces acting on it at *that* time, or the forces acting at some *earlier* time? Please explain how #4 does or does not illustrate this answer.

*10. Make the mass of your group's vehicle *very different* from the masses used by other groups. Measure that mass and record it on the blackboard and in your notebook, in SI units. Then *explain* how that mass was measured, and how its uncertainty was estimated. (Use #8 on RS III.)

11. Measure the accelerations produced by several different propelling forces *without* changing the mass of the vehicle. Also do whatever is necessary to determine the strengths of those propelling forces.
    a. Repeat each measurement at least twice, recording *all* of your results.
    b. Use the *widest possible range* of propelling forces, and express each force in *range* form.
    c. Record the mass of your object *and the uncertainty of that mass* near that data table.

12. ***BEFORE*** you dismantle the apparatus, hand in the rough graph of raw data produced by your team while the experiment was in progress. *Every run that your team made should be recorded on that graph.* Also record the *mass* of the vehicle on that graph. Each member of your team must sign it to indicate that it is correct and that a complete copy of the data in #11 has been saved for future work.

13. Imagine letting the vehicle fall freely, starting from rest. (See #8 & 9 on RS III.)
    a. Show how the propelling force on the falling vehicle is calculated or measured in SI units.
    b. Its acceleration (in SI units) would be ____ _____, as recorded in #___ on RS I.

14. Make a new row in your copy of the data table and fill it in with the results from #13. Make a *new* graph (using the data from #11 *and* 13) to show how the vehicle's acceleration depends on the propelling force. Decide which point on that graph represents the most reliable data, and draw two reasonable lines *through that point* to describe the pattern that you perceive. *Use a ruler.* Staple your new graph to this page. When you begin page 51 you will need this graph's slope and force-intercept in *range* form, in SI units. You will also need the *mass* of your vehicle. Write ***ALL*** of that information (with units) *on* the graph. *Keep a copy* for pages 49 & 51.

15. Read your report orally to a parent or other adult to see if it is written clearly.

1. When an object is coasting to a stop on a uniform, level surface its acceleration is ____tive.
   a. Sketch a speed-time graph to illustrate the coasting motion. (See #10 on RS II or #3 on p. 48.)
   b. Does the object's acceleration change while it is coasting? ____
   c. The coasting object's graph of friction force vs time is a ____________al line.
   d. In #3 on page 48 you were asked about the motion of an object influenced by a steady force. The motion of a coasting object ___ (is, isn't) a good example, because....

2. A small amount of rolling friction may have acted to retard the motion of your cart on page 48.
   a. List the variables which that force must depend upon. (Use #15-18 on RS III.)
   b. Were any of those variables changed during your experiment? ___ (* If so, please explain.)
   c. Does the friction depend upon the propelling force? ___ If so, please sketch the graph which describes that relation, and say what page that discovery comes from.
   d. Was the friction force the same for each run? ___ If not, did it change very much? ___ (Explain.)
   * e. Was the friction force the same for each team? (Please explain *without* contradicting 2a.)

3. Can the graph of acceleration vs propelling force go through the origin if friction is significant? ____

* 4. Did your graph on page 48 show any evidence of friction? *Explain and illustrate your evidence.*

5. The **"total force"** acting on an object is defined as the *vector sum of all the forces acting on it.*
   a. Has this important definition been recorded on RS V? ____ -Is it also on RS III? ____
   * b. Describe a graph of the cart's *acceleration* vs. the *total force* acting on the cart.
   * c. Using 5b above with 7b on RS I, write a *general* conclusion describing how the acceleration of *any* object must depend on the forces acting on it. Write your statement so that it is *always* true.
   * d. Explain how the *direction* of an object's acceleration can be predicted by using information about the forces which act on it. (Copy from page 31, 32, 33, 34R, 40, 48, or #4 on RS III.)
   e. Copies of these conclusions (5b & 5c) are being saved in #_____ on RS V.

* 6. Using SI units exclusively, give the mass of your vehicle and the slope of your "A vs. TF" graph. Keep a copy of that information for future reference. *Show* how that slope is calculated, and *show* how the ranges or uncertainties of the mass and slope were estimated. Don't forget the units.

7. Here's a routine proportion problem involving force and acceleration. "When a frictionless cart is pulled along a horizontal surface with a 2.0-pound force, it accelerates at 4.2 ft/sec^2. How much force is needed to make it accelerate at 8.0 ft/sec^2?" *A solution is outlined below:*
   a. According to 2b on RS V, that acceleration is proportional to the _____ _____ acting on the _____.
   b. Using 7e on RS I, we conclude that the acceleration ratio is equal to the ______ ratio.
   c. Write that equation using *symbols*, not numbers: ____ = ______
   d. Solve that equation for the unknown force: ____ = ______
   e. Plug in the given data. (Notice that the acceleration units needn't be written because they cancel.)

TF_2 = (____ ___)(____ ÷ ____) = 3.81 lb.

8. Both accelerations given in #7 were measured by allowing the cart to accelerate along a 12.0-foot track, starting from rest. Let's use the given data to see how the time intervals must compare.
   a. A relation between acceleration and time interval is in #6 on RS II. Solving it for "a", we find that the acceleration is *proportional to the ___ power of time interval if the ________ is unchanged.*
   b. Using #17d on RS II, we conclude that the acceleration ratio (a_2/a_1) is equal to _________. (Insert a formula involving the first and second time intervals.)
   c. Solve equation 8b for the longer time interval.
   d. Show (by plugging in the given data) that the longer interval is about 1.38 times the shorter one.

9. If the accelerations in #7 each had two-percent uncertainties and the given force had a one-percent uncertainty, how much uncertainty must the time ratio in 8d have? _____ -How about the **TF_2** value in 7e? _____ Please use #25 on RS II and #13 on RS IV to *explain* your answers.

1. Think about the motion of a block sliding to a stop on a level surface:
   a. A ______ward force called "_________" causes its velocity to ___crease while it slides.
   b. Does the strength of that force decrease while the block is sliding? ___
   -Does it increase? ____ Does it remain constant? ___ (See #15 on RS III.)
   c. That force causes the brick to slow down with a ________ acceleration. (constant, changing)
   d. Sketch the expected speed-time graph. Then check to see if page 23 agrees with your sketch.
   e. The slope of the graph in 1d is _____tive, indicating that the block's forward velocity and its acceleration had __________ directions. (similar, opposite) Does 4b on RS III agree? ___

2. Now the same block slides with the same initial speed to a full stop on a different level surface with a friction coefficient only 2/3 as great. Sketch the new speed-time graph near the old one.
   a. Calculate the ratio of the new friction force to the old one. _______
   b. What is the ratio of the new acceleration to the old one? ________
   c. The graphs show that the new sliding distance is ________ than the old one. (See #2 on RS II.)
   * d. Show how the ratio of the new sliding distance to the old one is calculated. Don't contradict 2c.

3. The force needed to drag a brick at constant velocity across a level table top is 5.0 newtons. The same force accelerates the same brick at 2.0 m/sec^2 when it's on a *frictionless* level surface.
   a. Whenever the *total force* acting on it is 5.0 N this brick always __________s at ____ ____.
   b. How strong was the friction force exerted by the *table top* on the brick? ____ ___
   c. Now suppose the original propelling force is doubled when the brick is on the the *table*: The new *total force* on the brick must be ___ ___, so the new *acceleration* must be _____ ____.
   d. Does 3c contradict 3a? ___
   * e. Explain what will happen in 3c if the propelling force is tripled instead of doubled. *Use 3b!*

4. A rocket weighs 150,000 lb on earth. It lifts off with an acceleration of 9.8 m/sec^2.
   a. Calculate the apparent weight of a 150-lb. person in the rocket during the launch. ____ ____
   b. If air drag can be ignored, then only *two forces* act on the rocket during liftoff: The propelling force (called "thrust") is ___ward, and the the ___________al force is downward.
   c. Which of those forces must be the stronger one? _________
   d. If it fell freely, the rocket would accelerate downward at ______ m/s^2.
   e. **WITHOUT** converting units, we can conclude (as in 3a) that this particular rocket always accelerates at _____ ______ whenever the total force acting on it is __________ _____.
   * f. **WITHOUT** converting units, show how you calculate this rocket engine's thrust. (It's best to convert units *only when necessary*.)
   * g. Explain why doubling the thrust found in 4f will *triple* this rocket's acceleration. (A sketched graph of acceleration vs. thrust will make the reason obvious.)

5. Hang some object like a shoe from a string. Release the string and watch the object fall.
   a. Does gravity still act on the object while it is falling? __
   b. How much tension does the string have while the object is falling freely?______

6. Let "m" represent the mass of the object hanging from the string in #5.
   a. When it is *not* accelerating, the total force on the object is ____. Does #3 on RS III agree? ___
   b. Use #3 on RS III or the 3rd pulley principle to create a formula for the string tension in 6a.

7. Suppose the string goes over a pulley and that the object has a downward acceleration:
   a. Is the total force on the object still the same as in #6? ______
   b. Has the gravitational force on the object changed? ____
   c. The string tension has __creased. Does 5b agree? ___ Does #5 on RS III agree? ___

8. In the space at the right, sketch the graph of string tension vs acceleration described in 5, 6, and 7. *You'll need this on page 51. Let downward vectors be considered positive.*

* 9. **Extra Credit:** Create an equation describing the graph in #8 and explain how you know that it is correct. Remember to define your symbols. The equation must contain a symbol representing the slope of the graph. Be sure to get its sign and units right. Also explain what that slope depends on, and how its value can be predicted.