* 1. How can we predict the *direction* of the sliding friction force exerted on an object by the surface on which it slides? Answer this question with a brief *opening statement* that is *always true*. Copy it into #14 on RS III. (See #8 on page 37, or #1 on page 38.) *Also use these clues:*
  a. A sliding friction force can act on a coasting object even when there is *no* propelling force.
  b. A force is exerted **on** something, **by** something. Whenever you mention a force you must tell what it is exerted *by* and what it is exerted *on*. Those objects are not vectors; they have *no direction.*
  c. If you mention a motion or velocity you must *name* the object which is moving and tell what *other* object the motion is relative to. *Use nouns, not pronouns.*

2. Whenever a static *or* sliding friction force is exerted on an object by a surface, the angle between that force and the surface must be __ degrees, as in the diagrams on pages 36R & 39.

* 3. Copy the definition of "sliding friction coefficient" from RS III. Then rearrange that equation to show how it can be used to predict the strength of a sliding friction force, as in #8 on page 39.

* 4. Copy the definition of "static friction coefficient" from RS III. (It's the slope of a graph.) Please underline the key word. (It was in *italics* when I gave you the definition on page 39.)

5. For a given pair of surfaces are the static and sliding friction coefficients variables? ___
  -If they are, please list the *other* variables which they depend on. (See 15 & 17 on RS III.)

6. A 14-kilogram crate resting on a level floor can be moved by a 25-newton horizontal force.
  a. Now a second crate, identical to the first, is placed on top of the first. Exactly how does that affect the normal force? _____ --the friction coefficient? _______ --the friction force? _____
  b. How much friction is there between the pair of sliding crates and the floor? _____ ___
  c. Show how you use the *given data* to calculate the friction coefficient. _______________ = _______
  d. Does 6a contradict #5? ___ -Does 6b contradict 6a? ___

7. Draw an object resting on a slightly tilted board. Starting at the center of the object, draw and *label* a *long* arrow representing the gravitational force on that object. (Use #8 & #12 on RS III.)
  a. Does friction help the object slide down the board? __ -Does it oppose the sliding motion?__
  b. Draw and label another arrow representing the friction force exerted on the object by the board.
  c. Does 7b contradict 7a? ____ -Does 7b contradict #2? ____ (If so, you get no credit.)
  d. Draw and label a *third* arrow describing the normal force exerted on the object by the board. Remember that the board is *slightly* tilted. The word "normal" *tells* you the direction of this force.
  e. The object is not sliding and the board is not moving. Using #3 on RS III, we conclude that the acceleration of the object is ___ and therefore the *sum* of the three forces acting on the object is ___.
  f. Draw and label the vector sum of those forces *without* altering their directions. *Use 7e.*
  g. Explain how you know that the diagram in 7f is a right triangle.
  h. The "inclination angle" is the angle between the board and the horizontal. In this example the angle is much ____ than 45 degrees. (greater, less) Do *both* diagrams (7b & 7f) show that fact?___
  i. The angle between the _________ force and the _______ force in 7f equals the inclination angle.
  j. The product of normal force and the static friction coefficient is called ________ ______ _______. *Copy it from #4 without changing the underlined word.* -Does that product have units? ___
  * k. Is the friction force in this example necessarily equal to that product? Use 7j to explain your answer.

8. Now the inclination angle in #7 is gradually increased, but not enough to make the object slide down. Draw a new diagram like 7f but with a slightly larger tilt angle. (The _____ward force is unchanged.)
  a. The new diagram shows that the friction force is ___creased, and the normal force is ___creased
  b. The ratio of the friction force to the normal force is ___creased. Does 8a agree? ____
  c. Is the friction coefficient affected? _____ -Does this agree with #5? ___ -with 6a? ___
  If not, explain which answer is wrong and why it hasn't it been corrected.
  d. There is a name for the *maximum possible value* of the ratio in 8b: Copy it from #4: _________ _________ __________ Does the ratio have units? ___ -Does 8d agree with #3-6 above? ___
  e. What happens if the tilt angle is increased more after that maximum has been reached? ____

9. Suppose you know all of the forces acting on an object. How can you use that information to predict the direction of the object's acceleration? (See #4 on RS III or #7 on page 37.)

1. A 3.5-newton forward force is used to drag a block at a steady 0.50 m/sec. After 2.0 seconds, the forward force is suddenly increased to 5.2 N. The force is maintained at that new value for 3.0 sec.
   a. Sketch graphs of forward force vs time and friction force vs time. (Use #4 on RS III.)
   b. Sketch the block's speed-time graph. (You tried this in #9 on page 38. Also see 15 - 17 on RS III.)

2. An object is placed on a horizontal surface. Mr. A pulls on it with a force of 9.0 pounds, 37 degrees east from north. At the same time, Mr. B pulls on it with a force of 12.0 lb., 37 degrees south from east. Starting from rest, the object accelerates uniformly as long as the forces act on it.
   a. Describe the direction of the acceleration and show how that answer is obtained. (Use p. 35R.)
   b. Describe the direction of the friction force acting on the object while it's accelerating. (#14 on RS III)
   c. Is the friction force *less* than 15 lb., *equal* to 15 lb., or *greater* than 15 lb.? ________ _______

3. A one-ounce magnet sticks to the front of a refrigerator. A 17-ounce force is required to pull it off the door. When a two-ounce keychain is hung on it the magnet slides down at a steady rate.
   a. Sketch a diagram indicating the directions of the forces acting on the sliding magnet. Label each one.
   b. How much normal force and how much friction are exerted by the door on the sliding magnet?
   c. Determine the friction coefficient for this pair of surfaces, and show how you do it.
   d. What was the total force acting on the magnet before the keychain was hung on it? ____ ____
   e. Is static friction always equal to static coefficient times normal force? ___ (See #13 on RS III.)
   f. Can the static friction ever exceed that product? ___

4. Imagine a sack of fertilizer being dragged across a level floor with a friction coefficient of 0.45.
   a. Draw two arrows tail-to-head representing the friction force and the normal force acting on the sack. Make them long enough for ±1% precision. (See #12 on RS III.) Make sure that they have the length ratio given above. Also be sure to make the angle between them agree with the given information.
   b. Now suppose the direction of pull is 60 degrees up from horizontal. Use that information to complete the vector diagram. Remember to label all four sides of the diagram.
   c. The "friction" arrow must be 0.45 times as long as the __________ arrow.
      The arrow representing the gravitational force on the sack is ____ cm. long.
      The arrow representing the pulling force described in part b is ___ cm long.
   * d. If the sack weighs 228 pounds, how strong must the pulling force be?
   * e. Consider some different directions of pull, other than 60 degrees up from horizontal. Find one for which the force required to drag the sack is less than the one found in 4d. Explain your logic.
   f. When you change the direction of pull (as in 4e) does that alter the gravitational force on the sack? __

* 5. Support a meter stick horizontally on two fingers. Slowly bring your fingers together. Do it several times, with starting points chosen randomly. Notice the final location of your fingers on the stick.
   a. What is the total force on the stick when one finger is sliding and the other isn't?
   b. Fingers can't see. How do the fingers decide which one will slide and which one will not?
   c. Use 5a and 5b to predict the final location (meeting point) if one of the fingers is replaced with a pen.
   d. Try it. If your prediction is incorrect, find out why.

6. Imagine pulling a heavily loaded wagon. The wheel bearings are nearly frictionless and the ground is perfectly level but still a lot of effort is required to keep the wagon moving. The retarding force which you must overcome is called "rolling friction".
   a. Do you expect the rolling friction to be greater on hard pavement, or on sand?
   b. Do you expect the rolling friction to be greater with soft rubber tires, or with hard ones?
   c. Do you want the tires of your automobile or bicyle to have a lot of rolling friction in normal use?

7. Suppose we coat the pavement with ice to reduce static and sliding friction:
   a. Will that affect the rolling friction significantly? ___ -If so, will it be increased, or decreased? __
   b. Explain why that *is* or is *not* a good thing to do to our highways.

* 8. Railroad trains almost never use rubber tires, and automobiles almost never use steel tires. Why not?
   If your answer to 7b or 8 involves friction, please specify which kind you are referring to.

* 9. You did experiments to find the answers to the questions about static and sliding friction on pages 38 & 39. What *similar questions* about *rolling* friction would require experiments?