1. Suppose the Jolly Green Giant picks up an automobile and playfully pushes the front in. When he is finished he has done a ____tive amount of work damaging the car.
   a. The same job could have been done on the car by crashing it into a tree. How is the work done damaging the car ("damage work") related to the car's loss of kinetic energy in that case? ______
   b. This damage work is _____tive. How is the loss in KE related to the *change* in KE? _________

2. Suppose a 2200-pound car gets caved in 80 cm. when it hits a stone wall at 28 mph. Show that the average force exerted on the car by the wall during the collision is roughly 10^5 N. (Use #1 on RS II.)

3. Imagine a car with mass "m" crashing into a parked car with mass "Rm". Just after impact the two cars may be locked together, but both must still be moving because momentum is conserved.
   a. Is this collision "elastic"? ___ Is it "inelastic"? ____ The final KE is ____ than the original KE, so the damage work is ______tive in this collision. Does 1b agree with this answer? ___
   b. Write an equation relating the amount of damage work to the initial and final kinetic energies. Remember to check signs carefully. (You'll get no credit if 3b contradicts 3a.) _____ = _______

4. Show how the momentum conservation principle is used to predict the velocity of the wreckage immediately after the collision in terms of the original velocity and mass ratio "R". (See #6 on p. 55 or 6c on p. 63 or #9 on RS V.) Remember to define your symbols clearly. ___________

5. Calculate the ratio of the kinetic energy after collision to the kinetic energy before, in each of the following collisions: (a) a car hitting a wall, as in #2. (b) a car hitting a parked car, as in #6.

* 6. If the velocity after the collision can be predicted, as in #4, then the loss of kinetic energy (damage work) can also be predicted. Use #3b and #4 to show how the amount of damage can be calculated from the original KE and the mass *ratio*. Simplify your result and sketch a graph of D vs R.

7. Show that when a moving car crashes into an identical parked car the damage inflicted on the first car is only one fourth as much as it would be if it smashed into a huge boulder with the same speed.

8. Suppose you observe a set of inelastic collisions between moving objects and stationary objects. They always stick together after the collision.
   a. Using #4, sketch a graph showing how the kinetic energy ratio in #5 (KE_f/KE_o) must depend on the mass ratio for the kind of collision described in #3 and #5. Remember to define your symbols and to explain how you figured out its shape. *Guesses earn no credit.*
   b. Let E_2 represent the final KE of the target. Show how E_2/E_o depends on R.

9. When a baseball player's head is struck by a fast-moving ball the coach and teammates know immediately whether or not an ambulance will be required by observing how the ball bounces off the head. How and why must the extent of the injury depend on the elasticity of the collision?

10. In 1980 an amusing series of letters appeared in **Consumer Reports** in response to an article about damage in the April issue. Read the letters and explain why you agree or disagree with them.

Letter 1: *"...You showed a picture of a car that hit a hard barrier at 35 mph. That is equivalent, you said, to two cars of the same size and weight meeting head-on, each at 35 mph. The most basic course in physics tells us differently. When two cars hit head-on, there must be a sum of the two velocities. Thus, the speed for the two cars colliding at 35 mph would be the equivalent of 70 mph."* (R.C.P.)

Letter 2: *"It's true that the combined speed on impact in such a crash would be 70 mph. But each car would absorb half of the energy of the crash. That's the same as one car hitting a solid barrier at 35 mph, in which case the one car would take all the punishment."* (from C.R.)

Letter 3: *"Your reply to R.C.P.'s letter... makes me wonder where you learned physics. It certainly does make a difference whether a car hits a fixed barrier at 35 mph, or whether two cars, each travelling at 35 mph, hit head-on. In the latter case, the force on each car will be twice as much as in the former case. Try it if you aren't convinced."* (from D.W., Syracuse, N.Y.)

1. Find two identical objects such as marbles, superballs, billiard balls, or ball bearings which are round, hard, and elastic. With one of them initially stationary, see what happens when they collide.
   a. Measure the angles between the original velocity and the two final velocities. If you like, you may use data from the coin-collision experiment on page 44b. Please illustrate these measurements.
   b. Choose symbols: Let "__" represent the velocity of the first object just before the collision, let "__" represent the velocity of the first object just *after* collision, let "__" represent the velocity of the second (target) object just after the collision. Also let "__" represent the mass of one object.
   c. Use those symbols to write a vector equation relating the three momentums.
   d. Construct an accurate vector diagram to illustrate that equation. (See #12 on RS III.) Use the actual measured angles, and remember to label the vectors.
   e. The largest angle in the triangle is the one between the arrow labelled __ and the arrow labelled ___. Let the symbol "θ" represent that angle. In 1d that angle was θ = ____ degrees. *Does 1a agree?* ___
   f. Use that symbol with the ones defined above to write the law of cosines for this triangle.
   g. To make that equation tell us something about KE we must divide both sides by ___. *Do it now.*
   h. Equation 1g tells us that the kinetic energy just after the collision is ____ than the KE just before the collision, because θ is ____ than ___ degrees. (less, greater) In a more elastic collision between identical objects θ would be ________ (smaller, greater) but it would not be _____ than __ degrees.
   i. Which term in equation 1g represents the loss in KE produced by the collision? (Copy it.) _____ -Does it have the right units? ___ *If not, find your mistake and correct it.*
   * j. What kind of coin comes closest to conserving kinetic energy in collisions with its own kind? Describe experimental evidence (using 1h) to support your answer.

2. In "one-dimensional" collisions (like the ones on pages 65 and 42) the angle between the two final momentums can only be ___ or ___ degrees.
   a. Does this contradict 1h? ___
   * b. Does that mean that kinetic energy can never be conserved in such collisions? Explain by writing a clarified version of 1h on the back of this paper. *Write it carefully so that it is always true.*
   c. Write an equation which describes how the total kinetic energy before a one-dimensional *elastic* collision is related to the total KE after the collision. Let the masses be equal, and let the target be stationary before impact. Remember to define your symbols.
   d. Use the momentum conservation law to eliminate one of the unknown final velocities from the energy equation that you wrote for 2c. (See #4 on page 65 or 6c on page 63.) *Simplify the result.*
   e. If you said in 2b that kinetic energy can never be conserved in such a collision then prove that equation 2d has no solutions.

3. A "**Collision Parameter**" is defined as the distance between the center of the target and an extended line representing the path of the moving object before collision. In effect, the collision parameter tells how far off-center the collision is. *Please draw and label a diagram to illustrate that definition.*
   a. In #2 the collision parameter was ____. In terms of the two radii of the two colliding objects, what is the largest possible value that you can give to the collision parameter without missing the target? ("Radii" is the plural of "radius".) *The two radii are not necessarily equal.*
   b. When moving spheres or disks collide they usually begin to spin. If the collision parameter is small and we increase it slightly, the amount of spin produced by the collision will ___crease.
   c. Sketch a graph in quadrants 1 & 2 to show roughly how you expect the amount of spin given to the objects by the collision to depend on the collision parameter. *Try not to contradict 3a or 3b.*
   d. Does a spinning object have some sort of energy that a non-spinning object does not have? ___ How might this cause the *apparent* elasticity of the collision to depend on the collision parameter? (Sketch another graph.) *Try not to contadict 3c. Label the point mentioned in 3a on both graphs.*
   e. Is it possible for the total KE just after impact to be zero? ___ Do your sketched graphs agree? __
   f. How does the final KE compare with the original KE when the collision parameter is greater than the sum of the two radii? ______ -Do your graphs agree with that fact? ___ *Fix them if necessary.*