1. In #__ on RS III you wrote that "whenever A pushes on B, then B pushes back on A with an ________ but opposite force". Some authors call this "Newton's Third Law of Motion", although it says nothing about motion. We'll call it "Newton's Obvious Principle of Interaction".
   a. On what page was it discovered? __ -Have we ever found any exceptions to this rule? ___
   b. Do all interactions involve equal and opposite pairs of forces? _______ (If not, please explain.)
   c. Does the interaction principle apply in collisions? ___
   d. If the forces involved in a collision do occur in equal and opposite pairs then the impulses delivered by those forces must also be ______ and _______, as recorded in #__ on RS __.
   * e. What must we conclude (from 1d) about the two momentum changes caused by a collision?

2. Observe what happens when a moving lab cart (with mass "M_1") slams into the rear end of a stationary cart (with mass "M_2") which is not held in place. *Please use those given symbols in 2abc.* Try using spring bumpers and also using soft bumpers made of modelling clay. Also try making the masses unequal. If the two carts bounce apart then the collision is said to be "elastic" or partially elastic. If they stick together it's an "inelastic" collision.
   a. The second cart's final velocity ("V_{2f}") is always greater than the first cart's initial velocity ("V_{1i}") *only* if M_1 is _______ than _____ and the collision is ___________ic. (Use the given symbols.)
   b. The collision causes the first cart to reverse the direction of its velocity if ____ > _____ and the collision is _____________ic.
   c. Under what condition will the two final velocities always be *equal?* _________

* 3. If the interaction principle is valid, how must the total momentum of a pair of objects before they interact compare with the total momentum of the pair after the interaction? On page 43 the answer to that question was called the "Momentum Conservation Principle", recorded in #___ on RS IV.
   a. Please write the momentum conservation principle as a complete statement, in English.
   b. Write it again in *algebraic language*. Define your symbols for mass and velocity as in #2, 4a & 5.
   c. Copies of this discovery are recorded for future reference in #__ on RS IV *and* in #__ on RS V.

4. Imagine a one-kilogram hammer striking a three-kilogram brick held in a person's hand. The collision is inelastic and the hammer velocity is about 3 m/sec just before impact. Use the clues below to determine how fast the broken pieces move just after impact.
   a. Choose symbols, as we did in #2 & 3: Let "__" and "__" represent the masses of the________ and________, respectively. Let "__" and "__" represent the initial and final velocities.
   b. According to #9 on RS V, the total momentum before impact = ______ _________ after impact. Using the symbols defined above, it says: (___)(___) = (___ + ____)(__) -Does #3 agree? __
   c. Solve eq. 4b for the unknown final velocity. *Use parentheses where needed:* __ = ____________
   d. Insert the given numbers and calculate the unknown: __ = ________________ = _____ ______ (As usual, the only numbers that you need to write are the *given* ones and the *answer*.)

5. Choose *one* of the six types of rear-end collision in #2 for this investigation: "I choose to investigate an ___lastic collision with M_2 (the target mass) ______ ___ M_1, as in part __ of #2. The wheels on my cart had ______ friction." (some, no) Make sketches showing the expected shapes of the graphs listed below for *your* type of collision. Show the coasting motions before *and* after impact. Use the *same* time scale for each graph. Indicate the time when the collision occurs on the axis of each graph, and try *not* to contradict #2. (Clue: A *sudden* impact must cause a _______ change in momentum.) These predictions can be tested with sonic rangers.
   a. Sketch the expected graph of momentum vs. time for the first cart.
   b. Sketch the expected graph of momentum vs. time for the second cart.
   c. *USING #2 & 3,* sketch a graph of *total* momentum vs. time.

* 6. A 2000-pound car moving north at 45 mph collides with a 3000-pound car moving east. The resulting junk pile sticks together and slides in a direction 37 degrees north from east. Use the momentum conservation principle to deduce the original speed of the heavier car. Start with a vector diagram; save the arithmetic for last. As in 4d, the *only* numbers needed in your explanation are the *given* numbers and the *final answer*. If you need a calculator you are doing it the hard way.

* 7. Particle A has a mass of 2.0×10^{-14} kg and an initial velocity of 4.0×10^5 m/s eastward. After hitting particle B, the new velocity of A is 2.0×10^5 m/s, 30 degrees east from north. B was at rest before impact. In what direction does B move just after the collision? *Explain and illustrate.*

1. Let ___ and ___ represent the masses of two objects which are in contact. Since no outside forces act on them they remain motionless until an explosion between them drives them apart with equal and opposite impulses. Let ___ and ___ represent the two velocities just after the explosion.
   a. What does the momentum conservation law predict about this interaction?. *Use the symbols defined above.* This equation says that the two final velocities have ______ directions. (identical, opposite)
   * b. Solve for the unknown velocity ratio. (Don't contradict 1a.) Explain how that prediction was tested.

2. A cart with perfectly frictionless wheel bearings was coasting on a horizontal surface. A brick with zero forward velocity was dropped a short distance onto the moving cart. *Neither mass changed.*
   a. Forward momentum was transferred *suddenly* from the ______ to the ______.
   b. Sketch a speed-time graph showing how the cart's motion is affected when the brick lands.

3. Now the brick is ground into powder and poured *gradually* through a stationary funnel onto a very long coasting cart. The wheels are still frictionless and no powder is spilled from the cart.
   a. In this case (unlike 2a) momentum is transferred ________ly from the _______ to the ______.
   b. Does the cart's mass change? ____ -Does the brick's mass change? ___
   * c. Without contradicting 3a or 3b, describe and illustrate how the motion of this cart differs from 2b.
   * d. Can the graph in 3c be linear? -Can it cross the time axis? *Please explain and illustrate.*

4. Now the same cart is coasting along the same surface, carrying a heavy load of sand. The cart begins to leak. Sand trickles out and is left lying on the surface. Is mass still conserved?______
   a. Does the cart's forward momentum change? ___ *If so, describe the cause.*
   b. Does the sand's forward momentum change? ___ *If so, describe the cause.*
   c. Does the cart's velocity change? ___ --Does this contradict 4a? ___
   d. Do your answers agree with the mass conservation law? ___ --with Newton's first law? ___

5. A long, horizontal plastic pipe is clamped rigidly at one end. The other end is plugged. A small hole has been drilled in the pipe near the plugged end. Water enters the clamped end under high pressure, and squirts downward from the hole into a bucket. The pipe is slightly flexible, like a diving board.
   a. Suppose the water flow rate is increased: Do you expect the plugged end to respond by moving to a new equilibrium position? ___ -Will it move up, down, or sideways? ___
   b. On page 50 what name was given to the force which bends the pipe in 5a? (See RS V.) __________
   c. In #10 on RS V there is a formula predicting the strength of that force: **F =** ______ *Check units!*
   d. According to 5b, that ____ward force acts on the __________.

6. Pinoccio's nose resembled a broomstick growing straight out from his face with a steady speed "Sp":
   a. How far does its tip move from his face during a time interval "Δt"? ΔL = _____
   b. How can the added nasal volume be calculated from that change in length and the radius? ΔV = ___
   c. Show how equation 6b can be used to calculate the speed of the water emerging from the pipe in #5.
   * d. What measurements could you easily make that would enable you to predict the thrust of the water rocket by using 5c & 6c? Describe how you would make the measurements, how you would convert units wherever necessary, and how you would use the results to predict the thrust in SI units.
   * e. Describe and illustrate a procedure for *measuring* that force to *test* the prediction in 6d.

7. Imagine a car moving at constant speed "S", through a bunch of air molecules:
   a. It will hit the molecules in the region directly ahead of it. The cross-sectional area of that region is the car's "frontal area", represented by "A". The length of that region can be found by multiplying ___ by the the travel time, "ΔT". Using the given symbols, the volume of the region must be _____.
   b. Let "__" represent the air density. Using the symbols already chosen, show how the mass of the air in the region can be determined from its density and volume: **Mass =** _______.
   c. Every time the car hits an air molecule it changes the molecule's velocity from about zero (on the average) to roughly ___. Use that fact with 7b to create a formula for the impulse delivered to the air by the car during that time interval. *Use only the symbols chosen above.* **Impulse =** ______
   d. Do the units check in 7c? ___ What variables do you expect the drag force exerted on the car by the air to depend upon?________ *Choose from the symbols defined above.*
   e. According to the definition of "impulse" you can determine the force which the car exerts on the air by __________ing the impulse formula (in 7c) by ____. The resulting equation (simplified) says "**Drag Force =** _______". (saved in # __ on RS ___) -Does that result agree with 7d? ____
   f. What SI units do you get when you insert numerical data into this formula? ________

1. An object rests on a smooth, level floor. A steady forward force causes the object to accelerate.
   a. Show how we can use the given mass and acceleration to calculate the *total* force on the object..
   b. Show how we can use the given forward force and the total force in 1a to calculate the backward (friction) force on the object. (Both 1a and 1b should be answered with *formulas*.)
   c. The object's mass is 1.55 kg. The forward force was 3.4 N. Its acceleration was 1.14 m/s^2. Use #2 on RS V to calculate the new acceleration after the forward force suddenly stops acting.
   d. How is the friction force affected if we double the original forward force on the object? _______
   e. Predict the new acceleration in 1d. *Show* how your prediction is made.

* 2. Estimate (in range form) the strength of the drag force that you feel exerted on your hand by the air when you stick your hand out the window of a rapidly moving vehicle. (Is it more than the weight of a banana? --of a brick?) Also note the speedometer reading and show how the frontal area of your hand is estimated. Use that information with #11 on RS V and #1 on RS II to estimate the density of air as a range with SI units. *Explain your estimates. Remember to check units.*

3. For any object falling through air there is a special falling speed at which the upward drag force completely cancels the downward gravitational force. That speed is the object's "terminal velocity".
   a. How much acceleration must the object have when falling at terminal velocity? _____
   b. The drag force acting on the object is very ______ just after release because its velocity is very small. At the beginning of its speed-time graph the slope must be ___ ____. (number with units)
   c. As the falling speed gradually increases, the drag force must ________ly __crease.
   d. The *total* force on the object gradually __creases, so the slope of the speed-time graph ___creases.
   e. Sketch the object's speed-time graph without contradicting 3a-3d.
   f. Sketch the object's displacement-time graph and its acceleration-time graph. (Use 3b.)

* 4. Prove that in SI units the gravitational field strength at any location must be equal to the gravitational acceleration. (Use Newton's second law and the short definition of a "newton" on RS V.)

5. Imagine a 130-pound person in a spacecraft far from any planet or star, accelerating at 9.8 m/sec^2. She steps onto a scale to weigh herself, just as she would at home.
   a. According to the scale her apparent weight is ____ lb, exerted on _______ by the _______.
   b. There are no windows in this craft. Is there any way for the person to tell the difference between the "artificial" gravity which seems to hold her down against the scale in the space ship and the real gravity she would experience on the earth? ____ (If so, please explain.)
   * c. Suppose the acceleration of some other spacecraft is known. How can you use that information to predict the strength and direction of the artificial gravity in that accelerating frame of reference?

* 6. In #8 on p. 47 we found that if pulleys and a suspended weight are used to propel a cart then the forward force on the cart ___creases somewhat at the moment of release even if the wheels and pulleys are frictionless. Explain why that sudden change is unavoidable. (Use 4a on p. 50.)

7. News reports of rocket launchings often used to mention the weight of the rocket before takeoff, the thrust of the engines, and the fuel burning rate (i.e. the number of pounds of fuel and oxidizer consumed per minute). First choose symbols to represent the given and known quantities: Let "g" represent _________ _______ ________ as usual, so the initial weight = (__)g _____ward. Let "____" represent the upward thrust, let "___" represent the constant burning rate, and let "__" represent time from the start. Upward vectors are _____tive. Use *only* those symbols, in 7a-7f:
   a. Neglecting air drag, the total force acting on it as it lifts off = ______ (Be careful with signs.)
   b. The initial acceleration = _____
   c. The remaining mass after burning fuel for some time = _____. The acceleration at that time = ____
   d. Sketch the accceleration vs time graph described in 7d. (Use common sense.)
   e. Sketch the corresponding speed-time graph. (Think about whether the graphs are linear and whether or not they go through the origin. Don't hesitate to correct obvious mistakes.)

8. Suppose 90% of a rocket's initial mass is fuel and oxidizer, and its initial acceleration is 1.5 g. (g = 9.8 m/s^2.) How much acceleration will the rocket have just before it runs out of fuel? Without gravity this problem is trivial. With uniform gravity acting on the rocket it is only a bit more complicated. *Explain it both ways if you can, using 7d. Try not to contradict 7e.*