You need only turn in asterisked Additional Problems in class. Remember to show your work in detail for those problems. Complete the online problems using the WebAssign system.

**Online Problems**

**Chapter 9** – Problems 34, 38, 42  
**Chapter 10** – Problems 3, 12, 16, 27

A. In elastic rectilinear collisions of bodies with equal masses, it is readily observed that (1) when the bodies approach each other with equal and opposite velocities, they rebound with equal and opposite velocities (i.e., they exchange their initial velocities); and (2) when the first body is moving toward the right while the second body is stationary, the first body stops still and the second body moves off with the same velocity as the first (i.e., the bodies again exchange their initial velocities). Christian Huygens, a contemporary of Newton, raised an insightful question about these two observations: Are these simply two unconnected and independent phenomena, or is there a deeper order in nature that connects them to some common law or principle?

We start as Huygens did with the observation that “equal hard bodies” (meaning perfectly elastic bodies of equal mass) approaching each other with equal and opposite velocities rebound with velocities unchanged in magnitude as illustrated in the following figure. Our frame of reference is denoted by O. The two bodies, A and B, moving parallel to the x-axis with velocities \( v_{A1} \) and \( v_{B1} \) undergo a rectilinear collision. Not only is this starting point consistent with observations but it is also consistent with our deep sense of symmetry in natural phenomena. It is this sense of symmetry, for example, that leads us to expect identical objects placed at equal distances from the pivot point of a seesaw to balance each other. We would be surprised at any other outcome and be very certain that the two objects were not identical if they failed to balance.

We next ask the question: What would happen if body B is initially stationary, and an identical body A approaches with velocity \( v_{A1} \) in the same reference frame O as shown in the next figure. Huygens proceeded to address this question through the clever device of viewing the second collision from another frame of reference O’, which made the second collision identical in character with the first one. He chose O’ to move to the right at uniform velocity \( v_o = v_{A1}/2 \) relative to frame O as shown in the next figure.

a) Argue in your own words that if we take the velocity \( v_o \) of frame O’ relative to O to be \( v_o = v_{A1}/2 \), the two objects, viewed from O’, will appear to be approaching each other at equal and opposite velocities of magnitude \( v_o = v_{A1}/2 \). Use the kinematic concept of relative velocity addition. **continued on back**
b) Still from the point of view of O': The two bodies will now rebound with equal and opposite velocities, also of magnitude $v_{A1}/2$. Enter these after-collision velocities in O’ on the figure, with appropriate symbols.

c) Now view these after-collision velocities from the original frame O. Show that from the point of view of O, body A will have zero velocity while body B will be moving to the right with velocity $v_{A1}$.

d) Argue in your own words that this analysis shows the two seemingly different types of collision to be intimately related and to be governed by some common underlying order in nature. (This common order turns out to be conservation of momentum, regardless of frame of reference.)

B.* A circular object starts from rest at position $\theta = 0.0$ rad at clock reading $t = 0.0$ s. At clock reading $t = 5.0$ s it is observed to be at position $\theta = +40.0$ rad and to have an instantaneous velocity of $\omega = +11.0$ rad/s. Examine the interconnections of the given data carefully.

a) Was the acceleration of the object uniform or nonuniform? Explain your reasoning.

b) Sketch the shape of the velocity versus clock reading graph that is implied by the data. Is the graph straight or curved? If it is curved, is it concave upward or downward?

C. Suppose that in our laboratory frame of reference $O_L$ a flat, relatively massive steel wall moves to the right (in the $x$-direction) with uniform velocity of magnitude $v_W$. The wall is perpendicular to the $x$-axis. A small steel ball moves toward the right with a larger velocity $v_B$, catches up with the wall and undergoes a perfectly elastic collision, bouncing back toward the left.

a) What is the initial velocity of the ball in the frame of reference $O_P$ of the steel plate? With what velocity will the ball rebound in this frame of reference? What will be the final velocity of the ball in frame $O_L$? Explain your reasoning.

b) Suppose now that the wall moves toward the left with uniform velocity $v_W$ as the ball still moves toward the right. What will be the final velocity of the ball in frame $O_L$ after the rebound? Explain your reasoning following a sequence similar to that in part (a).

c) In each of the two preceding cases what happens to the kinetic energy of the ball in frame $O_L$. Does it increase, decrease, or remain unchanged? Explain your reasoning. If the kinetic energy of the ball changes, where does any decrease go and where does any increase come from?

d) A piston, confining a gas in a cylinder is moving at uniform velocity either inward (compressing the gas) or outward (expanding the gas). In light of your analysis in part (c), describe what must be happening on average to the kinetic energies of molecules of gas that rebound from the piston as the gas is compressed and as it is expanded.

e) In the situations visualized in part (d) take the system under consideration to be the gas. Explain where the predicted kinetic energy changes go or come from. In other words, what happens regarding work being done by the piston on the gas or by the gas on the piston?