Pre-Lab 9:

Due: 12/6

Print your full LAST name: ________________________________

Print your full first name: ________________________________

Print your Lab TA’s name: ________________________________

What is your Lab TA’s box # (located outside of Wngr 234)? ______

Print your Lab SECTION # here: --------------------

Sign your name (full signature): ____________________________

Print today’s date: ____________________________
Pre-Lab 9:

1. Two objects have the same linear momentum.
   (a) Do their velocities necessarily have the same direction? Explain your reasoning.
   (b) Do their velocities necessarily have the same magnitude? Explain your reasoning.

2. You are a passenger on a jetliner that is flying at a constant velocity. You get up from your seat and walk toward the front of the plane. As a result, your forward momentum increases. What (if anything) happens to the forward momentum of the plane? Explain your reasoning.

3. A collision occurs between three moving billiard balls in such a way so that there are no outside influences acting on the three-ball system. Is the momentum of each ball conserved during the collision? If so, explain your reasoning. If not, what quantity is conserved?

4. When land ice on Antarctica melts and flows into the sea, eventually it circulates and therefore distributes uniformly over the earth’s oceans. As a result, does the earth’s rotational speed increase, decrease or remain unaffected? (And how does change the length of one day?)

5. Cart A (mass = 1.50 kg), traveling on a horizontal frictionless track at a velocity of 0.240 m/s, makes a head-on collision with cart B (mass = 2.50 kg), which is initially at rest. After the collision, cart B has a velocity of 0.180 m/s. What is the velocity of cart A?
6. Look at the diagram below. Carts A and B can roll freely and without friction on the level track. Cart B has twice the mass of Cart A. Suppose that Cart A is moving at a velocity \( v_A \) when it collides with Cart B (initially at rest). After the collision, Cart A is moving at one-third of its original speed but in the opposite direction.

(a) What is the relationship between the final velocities of the two carts? Justify your answer, using the Conservation of Linear Momentum to write an appropriate equation, then rearranging it to make your point. Show all your work here.

(b) How should you position Cart B prior to the collision so that your prediction about the carts’ two final velocities will be verified if the two carts each hit an end bumper at the same time after the collision? To figure this out, you’ll must account for the lengths of the carts and the track. Work the problem without numbers, using \( l_A \), \( l_B \) and \( l_T \) for the respective lengths. Label any/all positions and lengths you need to in order to solve the problem.

Now mark your recommended point of impact (use a ruler) on this sketch, using your algebraic result from above.

![Diagram of carts on a track]

\( l_T \)

Note: The above problem is a model for the derivations and calculations you’ll need to do in the lab itself. Indeed, except for the actual numbers you’ll be able to obtain for the lengths of the carts and track, the above problem is identical to the situation on page 5. So you should keep a copy of this page to help you with the lab.

In fact, you’ll save yourself a lot of lab time (and it’s a long lab if you don’t prepare in advance) by completing most of pages 5-8 before you get to lab. Get all the equations worked out so that all you need to do is measure the carts and the track, plug in the numbers to make your predictions, and do the test runs. The lab will go much more quickly then—you’ll finish in two hours or less, so you won’t need to return during Week 6 to complete it. (Those who don’t prepare in advance this way will need more than two hours to do the whole lab.)
Lab 9:

Linear and Angular Momentum

**Purpose of the lab:** To get acquainted with the phenomena of linear and angular momentum, particularly situations modeling collisions or explosions, where momentum is conserved because all net forces are internal to the system.

**Note:** This is an in-lab exercise. (There is also a Pre-Lab 5 set of exercises, due at the start of your Lab 5 session.) However, parts of this lab have some derivations and calculations that you should do before you come to lab (see in particular question 6 in the Pre-Lab). Otherwise you won’t finish this lab in one session.

**Materials needed:** A calculator may be handy. Extra paper may be needed and provided—take plenty of room on these pages and others to answer the questions and draw any needed diagrams.

**Directions:** There are 5 stations set up around the lab room, each with one or more momentum demonstrations. In most cases, you will need to prepare your data sheets and derivations before doing the experiment/demonstration (which don’t take very long).

**Cautions:** Note: Several of these stations use air tracks or other low-friction tracks to approximate ideal, frictionless conditions. These tracks have been carefully leveled—please don’t bump them or the tables they’re sitting on! Also, please be careful of the air hoses supplying the tracks (and pardon the noise of the vacuum).

At the stations involving the rotating chair: If you are sitting in the chair, be careful not to hit observers around you! (And observers: Please give the chair and occupant enough room to rotate freely—even with his/her arms and legs outstretched!) For the experiment with the bicycle wheel: Be sure to wear the gloves and avoid getting your fingers caught in the spokes—just brake the outside of the wheel with the gloved palm of your hand!
Station A: “Stand-Still” Collision

In this demonstration, Cart A will be moving at some velocity $v_A$ when it collides with Cart B (initially at rest). After the collision, Cart B will have some velocity, $v_B$, and Cart A will be at rest. The two carts have equal masses.

QA1: Assuming ideal, frictionless conditions (no outside influences acting on either cart, except by the other cart), what would you guess about the starting and ending velocities of the two carts in this scenario?

QA2: Justify your answer via the Conservation of Linear Momentum: Write an appropriate equation and rearrange it to make your point.
Station B: Double-Take

In this demonstration, Cart A will be moving at some velocity $v_{Ai}$ when it collides with Cart B (which is initially at rest). After the collision, Cart A will be moving at one-third of its original speed but in the opposite direction. Cart B has twice the mass of Cart A.

QB1: Assuming ideal, frictionless conditions (no outside influences acting on either cart, except by the other cart), what is the relationship between the final velocities of the two carts in this scenario? Justify your answer by using the Conservation of Linear Momentum: Write an appropriate equation and rearrange it to make your point.

QB2: How should you position Cart B prior to the collision so that your prediction will be verified if the two carts hit the end bumpers at the same time after their collision? To decide this, first measure the lengths of the actual carts and track.

\[ l_A = \text{___________} \quad l_B = \text{___________} \quad l_T = \text{___________} \]

Now calculate the necessary point of impact for their collision so that they reach the track’s end bumpers simultaneously afterwards—mark this point of impact on the sketch below.

![Diagram of the carts and track](image)

Now try it on the actual track....
Station C: Triple Trip

In this demonstration, Cart A will be moving at some velocity $v_A$ when it collides with Cart B (initially at rest). After the collision, Cart A will be moving at one-half of its original speed and in the opposite direction. Cart B has three times the mass of Cart A.

**QC1:** Assuming ideal, frictionless conditions (i.e. no outside influences acting on either cart, except by the other cart), what is the relationship between the final velocities of the two carts in this scenario? Justify your answer by using the Conservation of Linear Momentum: Write an appropriate equation and rearrange it to make your point.

**QC2:** How should you position Cart B prior to the collision so that your prediction will be verified if the two carts hit the end bumpers *at the same time after their collision*? To decide this, first measure the lengths of the actual carts and track (show your measurements here).

$$l_A = \underline{\hspace{2cm}} \quad l_B = \underline{\hspace{2cm}} \quad l_T = \underline{\hspace{2cm}}$$

Now calculate the necessary point of the impact for their collision so that they reach the bumpers simultaneously afterwards—mark this point of impact on the sketch below.

![Sketch of carts and track](image)

Now try it on the actual track….

**QC3:** *How else could you visually verify a correct prediction* in this particular case—just by watching the carts after they collide (indeed, starting from any impact point on the track)?
Station D: Various Minor Explosions

In this demonstration, you’ll place two carts together on a low-friction (assume: no-friction) track, with a spring-loaded plunger set on one of them. When the spring is released, it pushes the two carts apart. You will try three different combinations of mass on the carts. The idea in each case will be to predict the relationship between their velocities as they move apart after the explosion, using what you know about the Conservation of Linear Momentum (and you may assume there are no outside influences on the carts).

To verify your predictions, you must set the point of the explosion so that afterwards the two carts hit the opposite bumpers in the track at the same time. To decide this, you will need to know the lengths of the actual carts and track (show your measurements here):

\[ l_A = \quad l_B = \quad l_T = \]

(bumper) \hspace{1cm} \hspace{1cm} \hspace{1cm} (bumper)

\[ l_T \]

**QD1:** For two carts of equal mass, predict the correct point of explosion (so that the carts hit bumpers simultaneously afterward). Show your work here—then try it....

**QD2:** If one cart’s mass is twice as much as the other’s, predict the correct point of explosion (so that the carts hit bumpers simultaneously afterward). Show your work here—then try it....

**QD3:** If one cart’s mass is three times as much as the other’s, predict the correct point of explosion (so that the carts hit bumpers simultaneously afterward). Show your work here—then try it....
Station E: Give Me a Brake!

QE1: Most of us have seen a figure skater whose big spinning finale at the end of her routine makes her into a veritable blur. At first, she’s spinning at some reasonable rate, but then—with nobody giving her any kind of push to faster, she’s able to increase her rate of rotation a LOT. *How does she do that?* Answer by using the Conservation of Angular Momentum: Write an appropriate equation and rearrange it to make your point.

Now (either you or someone from your group—someone who is not prone to motion sickness) climb aboard the chair. Take one of the weights in each hand and hold out your hands and also extend your legs straight out. Have everyone else back up to give you some room, and then have one person give you a *(gentle)* turn—not very fast!

Go around a couple of times, then draw your arms and legs in.... Now extend them out again.... (When you’ve had enough, ask someone to stop the chair.)

Now, let another volunteer from the group—someone with good arm strength—put on the gloves and sit in the chair. This time he/she should remain basically still as someone gives him a gentle spin *clockwise*, as viewed from above. Then someone else should hold the bicycle wheel so that its axis is vertical and someone should give it a strong spin—get it going pretty good—also *clockwise*, as viewed from above. Now, without changing the orientation of that axis, carefully give the spinning wheel to the person rotating in the chair. Then that person should hold the bottom axis in one hand and use the other (gloved) hand to brush against the *outside* of the spinning wheel (don’t catch any fingers in the spokes!), until the wheel is at rest against the glove. Notice what happens. And then notice what happens if that person gives the stopped bike wheel a good spin (try each direction) to get it started again.

Stop the chair and repeat the experiment, but in the second trial, give the bike wheel a *counter-clockwise* spin before handing it to the spinner chairperson.

QE2: What happens in each case as the person spinning in the chair stops the bike wheel against his/her glove? What happens when he/she gives it a spin to get it going again?

QE3: When the chairperson stops the bike wheel, this is a *collision of two rotating objects*. At first, each is rotating independently. Afterwards, the two objects are rotating together. When the chairperson re-spins the bike wheel, this is an *explosion of two rotating objects*. Explain these observations using the Conservation of Angular Momentum: Write appropriate equations and rearrange them to make your points.