12505 Air Track

Student Name:______________________________

PURPOSE

- To provide a low-friction, one-dimensional surface on which students can predict, observe and record a variety of mechanical concepts.

SAFETY

Please observe the following safety concerns:

- *An instructor should be present when this apparatus is in use.*
- To prevent electrical shock, do not use an air track that is broken or has exposed electrical wiring or components.
- Keep hands, arms, and faces off of the air track while it is in use.
- Keep the area around the air track clear.
- If the gliders move too quickly, they may fly off the track. Stand to one side of the air track and be prepared to catch any gliders that may fly off of the track.
- When using pulleys and masses, stand clear of any area where masses may fall. Use a rubber mat to protect the floor and the masses from breaking.
- Wear appropriate eye protection while using this apparatus.

ASSEMBLY

Banana plugs are attached to all bumpers and magnets in this set. To attach these bumpers to the gliders, push the banana clips that are attached to the bumpers into the holes that are located at either end of the gliders.

The included mounting screws are used to attach the coiled springs to the gliders (8-32 x 1 $^1/_4$") and to the air track (10-24 x 4"). To attach the screws to the air track, simply screw them into the holes located at either end of the air track. To attach the screws to the large glider, screw them into the hole located at the top of the glider.

To attach the included pulley to the air track, use the small screw that is included with the pulley assembly. Make sure that the screw is fastened tightly to the pulley, and that the pulley wheel spins parallel to the air track.

TIME REQUIREMENTS

The air track and gliders arrive assembled, and the individual pieces that supplement the gliders can be attached to the gliders quickly. The full apparatus should require five to ten minutes for complete setup. The experiments listed in this instruction manual should require no more than 30 minutes apiece.

INTRODUCTION

Every movement in our world is met with some amount of resistance (air resistance, fluid friction, sliding friction, etc.). Forces such as friction and air resistance are known as *non-conservative forces*, because they dissipate kinetic energy of motion. Observations can be made, and measurements can still be taken, in the presence of these 'limiting' forces. However, for accurate observations and descriptions of motion in our world, the effects of these non-conservative forces must be accurately included in analyzing the motion. This can add to the complexity of describing and analyzing results.

Experiments conducted in the International Space Station or other spacecraft have the advantage of a low gravity, low friction environment. Most of us are not able to travel to a space station to conduct experiments, and those conditions are not easily recreated on the surface of the Earth. However, the air track can allow motion with extremely low friction, providing much easier observations and results that are more easily understood. For many purposes, when experimenting with the air track, the effects of friction become negligible.

CONCEPTS

Equations of Motion.

A cornerstone of classical mechanics are the four *equations of motion*. These equations are simple descriptions of motion in relation to different variables, and are all derived from the equation for displacement as a function of time

$$x = ½at^2 + v_0t + x_0$$

where 'x' is a total displacement, 't' is the time interval in which the motion occurs, 'a' is the acceleration of the object, and 'v_0' and 'x_0' are the initial velocity and the initial displacement of the object, respectively. Displacements are measured relative to a certain reference point.

The four equations of motion are:

$$(1)\ v_f = v_0 + a(\Delta t)$$
$$(2)\ x = ½(v_0 + v_f)(\Delta t)$$
$$(3)\ x = ½a(\Delta t)^2 + v_i(\Delta t)$$
$$(4)\ v_f^2 = v_0^2 + 2ax$$

where 'v_f' and 'v_0' are initial and final velocities of an object, 'a' is the acceleration of that object, 'x' is the displacement through which the object moves, and 'Δt' is the time interval in which the object moves. These four equations are the most common ways to mathematically describe motion.

Newton's Laws of Motion.

To move an object, one must exert a force on it. Mathematically, forces are described by the equation

$$\Sigma F = ma$$

where 'ΣF' is the net force on a particular object, 'm' is the mass of that object, and 'a' is the acceleration caused by the force. Force and acceleration are both vectors, and both point in the same direction.

Newton's Laws of Motion briefly describe the nature of forces:

- Newton's 1st Law (Inertia): Unless acted upon by a net force, an object will remain at rest or at constant velocity.
- Newton's 2nd Law ($\Sigma F = ma$): The acceleration of an object is directly proportional to the net force on that object, and inversely proportional to the mass of the object.
- Newton's 3rd Law (Reciprocity): When one object exerts a force on a second object, the second object will exert an equal and opposite force on the first object.

Hooke's Law.

Hooke's Law, which applies to spring-like objects, states that the amount of force required to stretch or compress a spring or other object over a certain displacement is directly proportional to that displacement. Mathematically, this force is described as

$$F = -kx$$

where 'F' is the force involved in distorting the object, 'k' is the spring constant of the object (measured in Newtons per meter), and 'x' is the net displacement of the object, measured from its equilibrium point. A negative sign exists in this equation to show that the direction of the force is always opposite the direction of the displacement of the object.

Static Equilibrium.

Suppose we have a cart resting on an inclined plane. If we let go of the cart, it will roll down the inclined plane, with either a constant velocity or a constant acceleration.

If the cart rolls down the inclined plane with a constant velocity, or stays in place, then the net force on the cart is zero. This is one example of *static equilibrium*: all of the forces acting on the cart (weight as a result of gravity, friction due to contact between the plane and the cart, and the normal force that the plane exerts on the cart in reaction to gravity) sum to zero. However, if the cart rolls down the ramp with a constant acceleration, static equilibrium is broken: the forces acting on the cart do not sum to zero.

Work and Energy.

A net force on an object does work on that object. Mathematically, that work is described by the formula

$$W = F\ d\cos\theta$$

where 'W' is the net work done on the object, 'F' is the net force on the object, 'd' is the displacement through which the object moves, and 'θ' (Greek letter 'theta') is the angle between the force and the displacement.

Using the equations of motion from linear kinematics, the work-energy theorem can be derived. The work-energy theorem states that any work done on an object will translate to either a change in its kinetic energy, or a change in its potential energy. Mathematically, this theorem is written as

$$W = \Delta KE = -\Delta PE$$

where 'ΔKE' is change in kinetic energy, and 'ΔPE' is change in potential energy. These energies are defined as

$$KE = \tfrac{1}{2}mv^2$$
$$PE = mgh$$

where 'm' is the mass of a particular object, 'v' is the speed/velocity of the object, 'g' is the acceleration due to gravity (9.8 m/s^2 locally), and 'h' is the height of the object, in relation to a set reference frame.

Conservation of Linear Momentum.

The linear momentum of an object in motion is given by the formula

$$p = mv$$

where 'p' is the linear momentum of the object, 'm' is the mass of the object, and 'v' is the velocity of the object. Momentum and velocity are both vectors pointing in the same direction.

In all collisions, the sum of the momenta of two objects after they collide is equal to the sum of their momenta before they collide. In an *elastic* collision, the kinetic energy of the objects is the same before and after the collision; kinetic energy is conserved. In an *inelastic* collision, kinetic energy is not conserved; some kinetic energy is lost to friction and heating during the collision. In an explosive event, kinetic energy (from spring potential energy, chemical energy, etc.) increases, although total momentum remains unchanged. For example, when a gun is fired, both the gun and bullet have increased kinetic energy, but their equal and opposite momenta sum to zero.

Conservation of momentum can be mathematically described by the following equation:

$$(m_1v_1)_i + (m_2v_2)_i = (m_1v_1)_f + (m_2v_2)_f$$

where terms on the left side are the initial momenta of two objects in the collision, and terms on the right side are the final momenta of those objects. In an elastic collision, kinetic energy is also conserved:

$$\tfrac{1}{2}m_1v_{1i}^2 + \tfrac{1}{2}m_2v_{2i}^2 = \tfrac{1}{2}m_1v_{1f}^2 + \tfrac{1}{2}m_2v_{2f}^2$$

where the terms on the left side of the equation are the initial kinetic energies of the objects in the collision, and the terms on the right side of the equation are the final kinetic energies of the objects in the collision. From these two equations, the velocities of the objects after the collision can be found:

$$v_{1f} = [(m_1 - m_2)/(m_1 + m_2)]v_{1i} + [2m_2/(m_1 + m_2)]v_{2i}$$
$$v_{2f} = [2m_1/(m_1 + m_2)]v_{1i} + [(m_2 – m_1)/(m_1 + m_2)]v_{2i}$$

Conservation of Mechanical Energy.

Conservation of mechanical energy is an important concept that can be studied with an inclined plane. This concept simply states that on Earth, an object will have a certain potential energy, and when given the opportunity, that potential energy will change to kinetic energy. For example, if you drop a ball off of a building, the ball has a certain potential energy atop that building, as well as a potential energy at the ground. The ball also has a kinetic energy just before it hits the ground, and had no kinetic energy when you dropped it; the change in the kinetic energy of the ball is equal to the change in its potential energy. This translation from potential to kinetic energy, or vice versa, is conservation of mechanical energy.

Mathematically, conservation of energy can be expressed with the following formula:

$$PE_i - PE_f = KE_f - KE_i$$

where PE_i and KE_i are the initial potential and kinetic energies of an object, and PE_f and KE_f are the final potential and kinetic energies of the object. This formula can be again changed:

$$KE_i + PE_i = KE_f + PE_f.$$

This mathematical manipulation shows that on Earth, under the influence of only gravitational forces, the sum of kinetic and potential energies for an object is the same at all instances of its motion.

Simple Harmonic Motion.

Simple harmonic motion, or SHM, is the periodic oscillatory (back-and-forth) motion of *simple harmonic oscillators*. Systems that undergo simple harmonic motion include pendulums, gliders attached to springs, molecules in a solid, diatomic molecules, and other oscillating systems.

A simple harmonic oscillator experiences a net force which causes its oscillatory motion. For example, the force that causes the oscillation of a pendulum is the gravitational force that the Earth exerts on the pendulum; of course, the pendulum must be displaced from its equilibrium point for oscillation to occur. In the absence of friction and air resistance, the pendulum will oscillate continuously.

For an explanation of the physics behind Procedure G and H, which involves simple harmonic motion, consult the Appendix. The mathematical explanation of these two situations involves knowledge of differential equations, and is intended for a college-level intermediate mechanics class or laboratory.

PROCEDURE A (ACCELERATION DUE TO A CONSTANT FORCE)

A photogate, or an ultrasonic motion detector with appropriate data collecting software, is recommended for this experiment. If using a photogate, attach the included picket fence to the top of the glider in this experiment. If using an ultrasonic motion detector, attach a small paper sail (or another appropriate target) to the glider, in order to take accurate data with the motion detector.

Attach the large bumpers to the large glider for this experiment. Use a pan balance or spring scale to determine the mass of the glider. Screw one of the mounting screws into the hole drilled into the top of the glider. Attach the pulley assembly to the end of the air track, making sure that the end of the air track is suspended over the floor. Obtain a piece of string that is just long enough to stretch from the air track to the pulley (about 1.8 meters), and tie a loop at each end.

Before beginning this experiment, be sure to only record data while the hanging mass is in motion. (When the mass hits the floor, there is no longer a net force on the system due to the hanging mass!)

Before turning the air supply on, place the large glider at the end opposite to the pulley assembly. Attach a mounting screw to the glider by screwing it into the hole in the top of the glider. Place the string over the mounting screw, and attach a small mass (10 grams or so) to the other end of the string.

Q1. Draw a free-body diagram for the mass on the string and the glider. From these two free-body diagrams, calculate the acceleration of the system.

Turn on any data collection equipment and prepare it for use. Once the data collection equipment is ready, hold the glider steady. While the glider is steady, make sure that the string is correctly fed through the pulley and that the pulley is correctly aligned to the air track. Turn on the air supply and let go of the glider.

Q2. Use the data you just collected to determine the acceleration of the glider/hanging mass system. How do your results compare to your calculations?

Record your results, and repeat this procedure for 5 or 6 trials.

Q3. How can you account for the error in your experiment?

Repeat this experiment using different masses. Draw free-body diagrams and perform calculations for each individual mass you use.

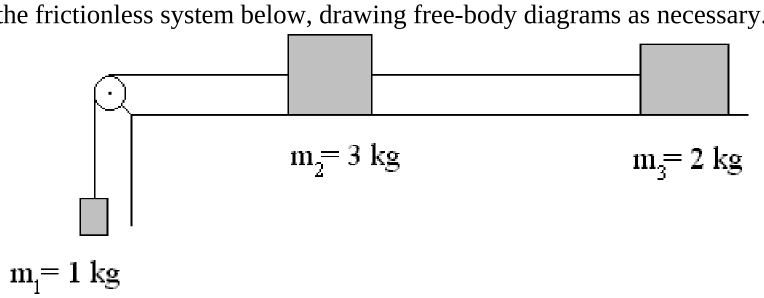
ASSESSMENT A

1. Revisit the free-body diagrams of the individual components of the system that you drew in Q1. Using those free-body diagrams, draw a free-body diagram for the system as a whole.

2. What forces are in the individual free-body diagrams that aren't in the free-body diagram of the system? Why are they missing?

3. How would your results changed if you used a string with a significant mass (i.e. a thick string or cord)?

4. Calculate the acceleration of the frictionless system below, drawing free-body diagrams as necessary.



PROCEDURE B (ACCELERATION DUE TO AN INCLINE, PART I)

Elevate the air track to an arbitrary angle by adjusting the screws on the front foot of the air track, or by propping books under the front foot of the air track. Affix a small bumper to the front and back of the large glider. Measure the angle at which the air track is inclined with a protractor. Use a pan balance or spring scale to measure the mass of the glider with its bumpers.

Q1. Draw a free-body diagram of the glider at the top of the air track. Leave out friction and air resistance.

Q2. Using the force vectors from your free-body diagram and trigonometry, calculate the acceleration of the glider on the air track.

While the air supply is off, rest the glider at the top of the air track, against its uppermost edge. Measure the position of the edge of the glider that is closest to the top of the air track; this will be the *initial position* of the glider. Move the glider to the bottom of the air track, and measure its position at the bottom at the exact same edge of the glider; this will be the *final position* of the glider. Determine the displacement through which the glider moves.

Q3. Why is it important to choose one side of the glider when performing your measurements?

Return the glider to the top of the air track. Turn on the air supply. Using the Equations of Motion in the Concepts section, determine the acceleration of the glider as it moves down the air track. Repeat this procedure for several different angles.

Q4. What assumptions do you make about the initial velocity of this system?

Q5. Were the results you obtained in this experiment correct? How can you account for any error in this experiment?

Repeat this experiment for several different angles. For best results, use angles of 15 degrees or less.

ASSESSMENT B

1. If the air track were inclined to an angle of 90 degrees, what acceleration would the glider experience?

2. If the air track lays flat, how would the glider accelerate?

3. Based on questions 1 and 2, the free-body diagrams that you drew during the experiment, and your experimental results, write a mathematical rule that relates the acceleration of the glider to the angle at which the air track is inclined.

PROCEDURE C (ACCELERATION DUE TO AN INCLINE, PART II)

Use a large glider with two small bumpers for this experiment, and incline the air track at the same angle as you did at the beginning of Procedure B. Set up your photogates or your sonic motion detector, and prepare them for use.

Before recording any data, turn on the air supply. Give the glider a quick push up the air track. If you are using photogates to record data, make sure that your pushes in this experiment clear all of the photogates that you use.

Q1. Does the glider move with a constant velocity or a constant acceleration? How can you tell?

Q2. Draw a free-body diagram of the glider at some point on the air track (neglect friction and air resistance). Would this free-body diagram look any different if the glider is at any other point on the air track?

With the air supply running, turn on the photogates or the sonic motion detector. Give the glider a quick push up the air track as you did previously. Record your results.

Q3. Does the data you took confirm your answer to Q1?

Q4. Is your data consistent with the free-body diagram you drew in Q2?

Repeat this experiment several times, while changing the following variables:

- Mass of the glider
- Speed at which the glider is initially released
- Angle at which the air track is inclined

Q5. Does a change any of these variables affect the results of your experiment? Explain why or why not.

ASSESSMENT C

1. When the glider is moving up the inclined air track, eventually, it will slow to a stop near the top of the air track and head back down. Does the acceleration stay constant throughout the glider's motion?

2. If the air track were inclined to 90 degrees, what acceleration would the glider experience?

3. If the air track is laid parallel to the tabletop, what acceleration would the glider experience?

4. Based on questions 2 and 3 and your experimental results, write a mathematical rule that relates the acceleration of the glider to the angle at which the air track is inclined.

5. Does the acceleration of the glider down the air track depend on the mass of the glider? Explain why or why not.

PROCEDURE D (ACCELERATION DUE TO AN INCLINE, PART III)

Use a large glider with two small bumpers for this experiment, and incline the air track at the same angle as you did in Procedure C. Set up your photogates or your sonic motion detector, and prepare them for use. If using photogates, set a photogate at the bottom of the air track, in order to measure the speed of the glider at the bottom of the air track. Measure the height of the glider at the top and bottom of the air track.

Q1. Find the potential energy of the glider at the top of the inclined air track and the bottom of the inclined air track. What coordinate system should you use for these measurements?

Q2. Using the Conservation of Mechanical Energy formulas in the Concepts section, calculate the speed of the glider at the bottom of the ramp. What do you assume about the speed of the glider at the top of the ramp?

Place the glider at the top of the inclined air track. Prepare your sonic motion detector or photogate for data collection, and turn on the air supply.

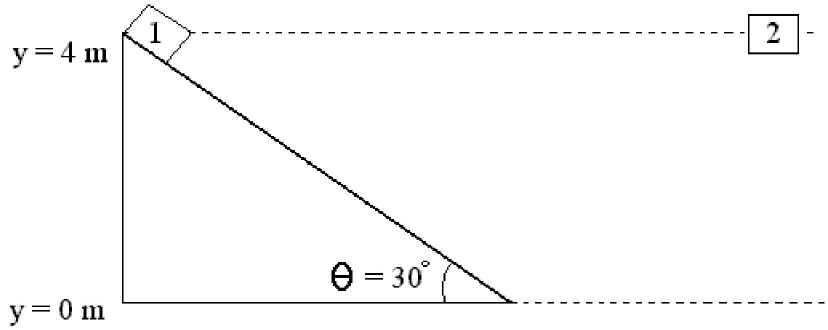
Q3. From your data, find the speed of the glider at the bottom of the ramp. How does your data compare to your initial calculations?

Conduct five or six data runs where the mass of the glider steadily increases for each run. Find the speed at the bottom of the ramp after each run.

Q4. Does the mass of the glider matter in your calculations for the speed at the bottom of the track?

Q5. From the speed of the glider at the end of the air track and the length of the air track, calculate the acceleration of the glider. Does your result match the results of Procedures B and C?

ASSESSMENT D



1. Suppose you have two objects: object 1, which has a mass of 1 kilogram, slides down a frictionless ramp that is inclined at 30 degrees above the horizontal. The ramp rises to 4 meters above the horizontal. Object 2 has a mass of 2 kilograms, and is allowed to fall from a height of 4 meters. Neglect air resistance.

a. What is the speed of object 1 when it gets to the bottom of the ramp?

b. What is the speed of object 2 just before it hits the ground?

c. How long does it take object 1 to reach the bottom of the ramp?

d. How long does it take object 2 to reach the ground?

PROCEDURE E (ELASTIC COLLISIONS: QUALITATIVE ANALYSIS)

(1) Same Speed, Same Mass.

To create this collision event, use two gliders of the same mass (preferably, the 15 centimeter gliders). Attach the magnetic bumpers to the gliders, using the small spring bumpers to protect the gliders against impact on the airtrack stops.

Q1. Predict the motion of each glider after a 'head-on' collision occurs, where the gliders move toward each other with the same speed.

Use the Hand Held Glider Launcher to start both gliders at the same velocity by quickly pulling away the launcher when both gliders are moving at a suitable velocity. One glider should bounce back and head toward the other glider with the same speed.

Q2. Describe the behavior of the two gliders after the collision. Was your prediction correct?

Q3. Is the collision you observed consistent with Newton's 3rd Law? Explain.

(2) One Glider Stationary, Same Mass.

Repeat the instructions for creating the event in part (1); for this event, keep one of the gliders stationary, and allow the other glider move across the air track with a different speed, but still collide 'head-on'.

Q4. Predict the motion of the gliders after this collision occurs.

Q5. Test your prediction, and describe the behavior of the two gliders after the collision. Was your prediction correct?

Q6. Is the collision you observed consistent with Newton's 3rd Law? Explain.

(3) Same Speed, Different Mass.

Repeat the instructions for creating the event in part (1); for this event, one glider is more massive than the other glider, and both gliders still collide 'head-on'.

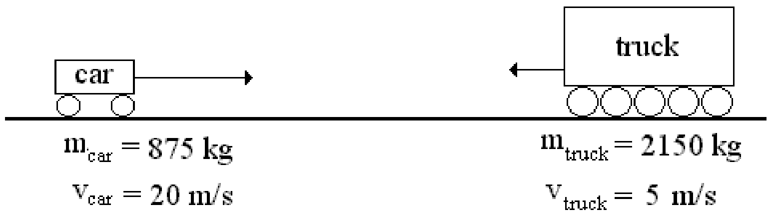
Q7. Predict the motion of the gliders after this collision occurs.

Q8. Test your prediction, and describe the behavior of the two gliders after the collision. Was your prediction correct?

Q9. Is the collision you observed consistent with Newton's 3rd Law? Explain.

ASSESSMENT E

1. Suppose a small car (m = 875 kg) collides head-on with a large truck (m = 2150 kg), and the collision between the two vehicles is completely elastic. The car moves at 20 m/s toward the truck before the collision, and the truck moves at 5 m/s towards the car before the collision. A picture of the situation is below. (Let vectors pointing to the right be positive for this question.)



a. Find the initial momentum of the system.

b. Find the velocities of both vehicles in this system after they collide.

c. Check your calculations to make sure that momentum in this system is conserved.

PROCEDURE F (ELASTIC COLLISIONS: QUANTITATIVE ANALYSIS)

For this experiment, you will use three gliders (two large gliders, one small glider) affixed with small bumpers, and photogates or a sonic motion detector. Attach the spring bumpers to the ends of the gliders that will impact the stops on the airtrack. Attach the magnet bumpers to the gliders such that they will provide an elastic collision. Record the positions and velocities of the carts from the moment they are released until one of the carts hits the stop at the end of the air track. In some collisions, the carts rebound backwards from the way they were originally moving. Pay very close attention to determining correct velocities before and after the collisions.

(1) Same Speed, Same Mass.

To create this collision event, use two gliders of the same mass (preferably, the 15 centimeter gliders). Attach the small bumpers to the gliders in this experiment. Be sure that your photogates or your motion detector are on and ready to begin collecting data.

Q1. Predict the motion of each glider after a 'head-on' collision occurs, where the gliders move toward each other with the same speed.

Use the Hand Held Glider Launcher to start both gliders at the same velocity by quickly pulling away the Launcher when both gliders are moving at a suitable velocity. One glider should bounce back and head toward the other glider with the same speed. Record the velocities of the two carts before and after the collision.

Q2. Describe the behavior of the two gliders after the collision. Was your prediction correct?

Q3. Is the collision you observed consistent with Newton's 3rd Law? Explain.

Q4. Calculate the momentum of each glider before and after the collision. What do you notice about the total momentum of the system before and after the collision?

Q5. Calculate the kinetic energy of each glider before and after the collision. What do you notice about the total kinetic energy before and after the collision? (Remember: energy is a scalar!)

(2) One Glider Stationary, Same Mass.

Repeat the instructions for creating the event in part (1); for this event, keep one of the gliders stationary, and allow the other glider move across the air track with a different speed, but still collide 'head-on' with the other glider. Make a prediction (before the collision) about how the gliders will move after they collide, and then create the collision. Record the velocities of both gliders before and after the collision.

Q6. Describe the behavior of the two gliders after the collision. Was your prediction correct?

Q7. Is the collision you observed consistent with Newton's 3rd Law? Explain.

Q8. Calculate the momentum of each glider before and after the collision. What do you notice about the total momentum of the system before and after the collision?

Q9. Calculate the kinetic energy of each glider before and after the collision. What do you notice about the total kinetic energy of the system before and after the collision?

(3) One Glider Stationary, Different Mass.

Repeat the instructions for creating the event in part (1); for this event, one glider is more massive than the other. Keep the more massive glider stationary, and allow the lighter glider move across the air track with and collide 'head-on' with the more massive glider. Make a prediction (before the collision) about how the gliders will move after they collide, and then create the collision. Record the velocities of both gliders before and after the collision.

Q10. Describe the behavior of the two gliders after the collision. Was your prediction correct?

Q11. Is the collision you observed consistent with Newton's 3rd Law? Explain.

Q12. Calculate the momentum of each glider before and after the collision. What do you notice about the total momentum of the system before and after the collision?

Q13. Calculate the kinetic energy of each glider before and after the collision. What do you notice about the total kinetic energy of the system before and after the collision?

After analyzing the collision, create a collision where the lighter glider is stationary and the more massive glider is in motion and collides with the lighter glider 'head-on'. Make a prediction (before the collision) about how the gliders will move after they collide, and then create the collision. Record the velocities of both gliders before and after the collision.

Q14. Describe the behavior of the two gliders after the collision. Was your prediction correct? How is this collision different from the last collision you studied?

Q15. Is the collision you observed consistent with Newton's 3rd Law? Explain.

Q16. Calculate the momentum of each glider before and after the collision. What do you notice about the total momentum of the system before and after the collision?

Q17. Calculate the kinetic energy of each glider before and after the collision. What do you notice about the total kinetic energy of the system before and after the collision?

<u>(4) Same Speed, Different Mass.</u>

Repeat the instructions for creating the event in part (1); for this event, one glider is more massive than the other glider, and both gliders still collide 'head-on'. Make a prediction (before this collision) about how the gliders will move after they collide, and **then create the collision.** Record the velocities of both gliders before and after the collision. Record the velocities of the gliders before and after the collision.

Q18. Describe the behavior of the two gliders after the collision. Was your prediction correct?

Q19. Is the collision you observed consistent with Newton's 3rd Law? Explain.

Q20. Calculate the momentum of each glider before and after the collision. What do you notice about the total momentum of the system before and after the collision?

Q21. Calculate the kinetic energy of each glider before and after the collision. What do you notice about the total kinetic energy of the system before and after the collision?

PROCEDURE G (INELASTIC COLLISIONS: QUALITATIVE ANALYSIS)

For this procedure, attach the inelastic bumper(banana plugs) to the glider where the gliders will collide. Attach small bumpers to the opposite sides of the glider.

(1) Same Mass, Same Speed.

Use two identical 15 centimeter gliders to conduct this section of the experiment. Set these gliders up as described above.

Q1. Predict the motion of each glider after a 'head-on' collision occurs with this setup, where the gliders move toward each other with the same speed and stick together.

Use the Hand Held Glider Launcher to start both gliders at the same velocity, by quickly pulling away the launcher when both gliders are moving at a suitable velocity. One glider should bounce back and head toward the other glider with the same speed.

Q2. Describe the motion of the gliders after the collision. Was your prediction correct?

Q3. Is momentum conserved in this experiment? How can you tell?

(2) One Glider In Motion, One Glider Stationary, Same Mass.

Use the setup described in (1) for this experiment.

Q4. Predict the motion of each glider after a 'head-on' collision occurs with this setup, where one glider moves toward a stationary glider, and both gliders stick together after they collide.

While the air supply is off, set the less massive glider in the middle of the track. This glider should remain still for this experiment. Place the more massive glider beside the first, and turn the air supply on. Give the glider a quick push in the opposite direction. The glider should bounce back and head toward the stationary glider.

Q5. Describe the motion of the gliders after the collision. Was your prediction correct?

Q6. Is momentum conserved in this experiment? How can you tell?

Create another collision with the less massive glider in motion and the more massive glider at rest, and answer questions 4-6 for this collision as well.

(3) Different Mass, Same Speed.

Use one large glider and one small glider for this experiment; set these gliders up in the same manner that is described for two large gliders in (1).

Q7. Predict the motion of each glider after a 'head-on' collision occurs with this setup, where the gliders move toward each other with the same speed and stick together.

Use the Hand Held Glider Launcher to start both gliders at the same velocity, as described in (1). One glider should bounce back against the end of the air track and head toward the second glider at the same speed.

Q8. Describe the motion of the gliders after the collision. Were your predictions correct?

Q9. Is momentum conserved in this experiment? How can you tell?

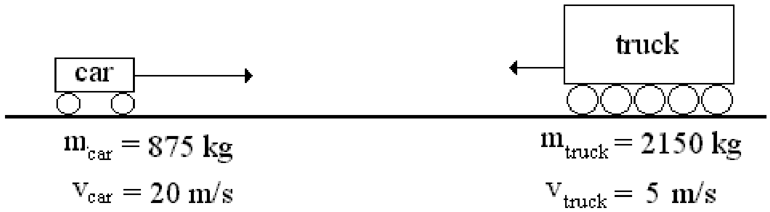
Variations.

Use the gliders, the inelastic bumper, and masses to recreate different variations of inelastic collisions. If you choose to explore different variations of inelastic collisions, answer the following questions for each collision:

- What was the individual momentum of the two gliders before their collision?
- What was the result of their collision?
- Is momentum conserved in this collision?

ASSESSMENT G

1. Suppose the same small car (m = 875 kg) collides head-on again with a large truck (m = 2150 kg). This time, the collision between the two vehicles is completely *inelastic*. The car moves at 20 m/s toward the truck before the collision, and the truck moves at 5 m/s towards the car before the collision. A picture of the situation is below. (Let vectors pointing to the right be positive for this question.)



a. Find the initial momentum of the system.

b. Find the final velocity of the system.

c. Check your calculations to make sure that momentum in this system is conserved.

PROCEDURE H (INELASTIC COLLISIONS: QUANTITATIVE ANALYSIS)

For this experiment, you will use three gliders (two large gliders, one small glider) affixed with small bumpers, an inelastic bumper (banana plug), and photogates or sonic motion detectors. Attach the inelastic bumper to the ends of carts that will be involved in each collision in this experiment. Have small elastic bumpers on the ends of the carts that will collide with the ends of the air track. Record the positions and velocities of the carts from the moment they are released until one of the carts hits the stop at the end of the track.

(1) Same Mass, Same Speed.

Use two identical gliders (preferably, two 15 centimeter gliders) to conduct this section of the experiment. Set these gliders up as described above; be sure that your photogates or sonic motion detectors are on and ready to collect data.

Use the Hand Held Glider Launcher to start both gliders at the same velocity, by quickly pulling away the launcher when both gliders are moving at a suitable velocity. One glider should bounce back and head toward the other glider with the same speed. Before creating this collision, predict the motion of the system of gliders after the collision.

Q1. Describe the motion of the gliders after the collision. Was your prediction correct?

Q2. Calculate the momentum of each glider before the collision, and the momentum of the system after the collision. Is momentum conserved in this experiment? How can you tell?

Q3. Calculate the kinetic energy of each glider before the collision, and the kinetic energy of the system after the collision. Is kinetic energy conserved in this experiment?

(2) One Glider In Motion, One Glider Stationary, Same Mass.

Use the setup described in (1) for this experiment.

While the air supply is off, set the less massive glider in the middle of the track. This glider should remain still for this experiment. Place the more massive glider beside the first, and turn the air supply on. Before creating this collision, predict the motion of the system of gliders after the collision. Give the glider a quick push in the opposite direction. The glider should bounce back and head toward the stationary glider.

Q4. Describe the motion of the gliders after the collision. Was your prediction correct?

Q5. Calculate the momentum of each glider before the collision, and the momentum of the system after the collision. Is momentum conserved in this experiment? How can you tell?

Q6. Calculate the kinetic energy of each glider before the collision, and the kinetic energy of the system after the collision. Is kinetic energy conserved in this experiment?

Create another collision with the less massive glider in motion and the more massive glider at rest. Before creating this collision, predict the motion of the gliders before and after the collision.

(3) Different Mass, Same Speed.

Use one large glider and one small glider for this experiment; set these gliders up in the same manner that is described for two large gliders in (1).

Use the Hand Held Glider Launcher to start both gliders at the same velocity, as described in (1). One glider should bounce back against the end of the air track and head toward the second glider at the same speed. Before creating this collision, predict the motion of the system of gliders after the collision.

Q7. Describe the motion of the gliders after the collision. Were your predictions correct?

Q8. Calculate the momentum of each glider before the collision, and the momentum of the system after the collision. Is momentum conserved in this experiment? How can you tell?

Q9. Calculate the kinetic energy of each glider before the collision, and the kinetic energy of the system after the collision. Is kinetic energy conserved in this experiment?

Variations.

Use the gliders, the inelastic bumper, and masses to recreate different variations of inelastic collisions. If you choose to explore different variations of inelastic collisions, answer the following questions for each collision:

- What was the individual momentum of the two gliders before their collision?
- What was the result of their collision?
- Is momentum conserved in this collision?

PROCEDURE I (HARMONIC MOTION)

Before conducting this experiment, measure the following:

- Mass of small glider with one mounting screw and one small bumper
- Spring constant of the coil spring

Attach a mounting screw to one end of the air track. Place the small glider (with mounting screw and small bumper) on the air track, use a coil spring to attach the glider to the mounting screw. Before turning on the air track, be sure that it is level, and rest the glider at the end of the air track, so that the spring is not stretched from equilibrium. Displace the glider about 20 centimeters from equilibrium, hold the glider in place.

Q1. Keep a hold of the glider, and with your free hand, draw a free-body diagram for the glider while it is initially displaced from equilibrium. What is the direction of the net force on the glider?

Now, move the glider so that it is displaced 10 centimeters from equilibrium, and hold it in place.

Q2. Keep a hold of the glider, and with your free hand, draw a free-body diagram for the glider at this point. Is the magnitude of the net force on the glider greater than, equal to, or less than the magnitude of the net force on the glider in Q1? How can you tell?

Move the glider to its equilibrium point, and hold it in place.

Q3. Does the spring exert any force on the glider?

Q4. Draw a free-body diagram for the glider at this point.

Once again, move the glider so that it is displaced 15 centimeters from equilibrium, and hold it in place. Then, return it to 30 centimeters from equilibrium.

Q5. How does the net force on the glider change as it moves toward, and away from, equilibrium?

Turn on the air supply, and once again, move the glider so that it is displaced 20 centimeters from equilibrium. Let go of the glider, and observe and describe its movement. Use a photogate or a sonic motion detector to record the motion of the glider.

Q6. Is the motion of the glider on the air track consistent with the free-body diagrams you drew in Q1, Q2, and Q4? What do you notice about the direction of the net force on the glider in comparison to the velocity of the glider at any given point? (Hint: think of the first part of this procedure as 'snapshots' of the motion of the glider.)

Allow the glider to oscillate again by displacing it from equilibrium and letting go. Now, use a stopwatch to time five or six periods of the oscillation of the glider. From your results, find the period of oscillation for this system. Change gliders (from the small to the large glider) and find the period of oscillation for the system.

Q7. How did the period of the oscillation change as the mass changed? Explain your observation in terms of the force exerted on the glider by the spring at any given time during the glider's motion.

PROCEDURE J (HARMONIC MOTION: DETERMINING THE MASS OF A GLIDER IN AN OSCILLATING SYSTEM)

(Note: Mathematical analysis of this experiment may be difficult for an Honors or AP high school physics class, because the mathematics required for such an analysis is generally not introduced in high school mathematics classes; however, it can be done conceptually by Honors or AP high school physics students. For an in-depth mathematical analysis of this experiment, see the Appendix.)

Use a large glider with no bumpers attached for this experiment. Be sure that the air track is level, and determine the spring constant of the two coil springs by hanging one of the springs from a ring stand or ceiling support. Measure the length of the spring at equilibrium (while no mass hangs from it). After you have measured the length of the spring at equilibrium, hang a 20 gram mass on the spring and measure the length of spring. Find the difference between the two displacements, and use Hooke's law to find the spring constant. (See Hooke's Law in the Concepts section.)

Place a mounting screw into the hole in the top of the glider, and place one mounting screw on each end of the air track. Attach both springs to the glider, and attach one spring to each mounting screw at either end of the air track. Turn on the air supply and find the point on the air track where the glider remains at rest.

Q1. What is the net force on the glider at this point?

Q2. What would the net force on the glider be if you displaced it 40 centimeters from equilibrium, in either direction?

Displace the glider 40 centimeters from equilibrium and hold it in place. Let the glider go, and using a stopwatch, time five or six oscillations, and determine the average period of the oscillation.

Q3. Using the formula for the period of this oscillating system in the Appendix, calculate the mass of the glider. Use a balance to determine the mass of the glider; how does your calculation for the mass of the glider compare the mass of the glider as determined by a balance?

Q4. Use the mass of the glider, as determined by the balance, to calculate the period of its oscillation in this system. How do the calculations compare?