14300 Dynamics Carts w/o Hoops

Teachers Instructions

- *Required Accessories*
  - (2) Table stops (wooden bars)
  - (4) C-Clamps
  - (2) Recording Timers (#15210 or #15215)
  - (5) Bricks or Books (or other identical objects for use as masses)
  - (1) Meter Stick
  - (1) Pan Balance
  - (1) Table Clamp Pulley (#33020)
  - Modeling Clay
  - Masking Tape
  - Screwdriver
  - Thread
  - Assorted Weights
- *Optional Accessories*
  - Accelerometer (#10-100)
  - Spirit Level
  - Ultrasonic Motion Detector
  - Spring Scale
  - (2) Two pair of spring Hoops, (#10-4300ACC)

PURPOSE

- To investigate the vector nature of forces and conservation of momentum.

TIME REQUIREMENT

- Procedure A should be completed in about 30-40 minutes.
- Procedure B should be completed in about 45-60 minutes.
- Procedure Each procedure should require no more than 10 minutes for initial setup time.
- C should be completed in about 30-40 minutes.
- Procedure D should be completed in about 45-60 minutes.
- Individual times may vary based on time necessary for questions, discussion, or addressing student concerns.

STANDARDS

The student will show evidence of the following criteria from the National Science Education Standards (NSES) for grades 5-12:

- Grades 5-12 (Content Standard A):
  - **Abilities necessary to do scientific inquiry.**
    (*The student uses this apparatus to conduct scientific inquiry about motions and forces; addressed in Procedures A, B, C, and D.*)
  - **Understandings about scientific inquiry.**
    (*The student uses this apparatus to understand the process by which the nature of forces is studied; addressed in Procedures A, B, C, and D.)*

- Grades 5-8 (Content Standard B):
  - **Motions and Forces.** The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.
    (*Addressed in Procedures A, B, C, and D; the student uses this apparatus to observe and measure motion.)*
  - **Motions and Forces.** An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
    (*Addressed in Procedures A, B, C, and D; the student uses rubber bands, masses and pulleys, or other equipment to exert forces on this apparatus in order to observe Newton's Laws of Motion.*)

- Grades 9-12 (Content Standard B):
  - **Motions and Forces.** Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship F = ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.
    (*Addressed in Procedures A, B, C, and D; the student uses rubber bands, masses and pulleys, or other equipment to exert forces on this apparatus, in order to observe Newton's Laws of Motion.*)

- Grades 9-12 (Content Standard B):
  - **Conservation of Energy and the Increase In Disorder.** The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
    (*Addressed in Procedures B and D. Students use this apparatus to explore kinetic and potential energy, and the transfer of energy between carts.*)

  - **Conservation of Energy and the Increase In Disorder.** All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
    (*Addressed in Procedures B and D. Students use this apparatus to explore kinetic and potential energy.*)

For more specific standards, consult science education standards for your state, province, or nation.

SAFETY AND STORAGE SUGGESTIONS

Inform your students of the following safety concerns:

- The exploder mechanism will arrive in cocked position. Handle with care. Place the cart on a table before releasing the exploder mechanism, and keep hands and face away from the piston.
- While performing this experiment, be sure to stop moving carts before they reach the edge of the table. Stand clear of any area where carts could fall. Carts may break if they fall from a table.
- While rubber bands are inherently harmless, do not use rubber bands as projectiles or as projectile launchers.
- Fasten metal bumpers securely to carts. While inherently harmless, do not use bumpers as weapons.
- Do not leave carts on the floor, where they may present a slipping hazard.
- Wear appropriate eye protection when using this apparatus.

Store this apparatus in a supply closet or other isolated location, preferably on a shelf. Be sure not to leave carts on the floor where they may present a slipping hazard.

ASSEMBLY

- *Carts.* Both carts are previously assembled; the steel bumpers must be attached to the screws at the front of the cart. Use a screwdriver to loosen and tighten screws.

- *Recording Timer.* Consult instruction manual for assembly advice.

INTRODUCTION

Sir Isaac Newton (1643-1727), an English scientist and mathematician, laid the groundwork for nearly three centuries of work in physics. With his three laws of motion and a description of celestial and terrestrial movement, Newton provided a framework for the process of inquiry in physics. Newton's Laws of Motion provide an important insight into forces, mechanics and gravitation (just to name a few subjects!) and are still pertinent to physics nearly 300 years later.

CONCEPTS

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 (**ΣF = 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.

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 remain at total of zero.

PROCEDURE A (BRIEF DESCRIPTION)

This procedure is ideal for grades 5-12.

Students will examine the qualitative nature of forces acting on a cart, using rubber bands to exert forces on a cart in different situations. A recording timer will be used to give students a visual representation of the consequence of forces. Students will observe collisions between carts with metal bumpers to make conclusions about conservation of momentum in a collision.

ANSWERS (PROCEDURE A)

(1) Changes in Velocity with a Constant Force.

Q1. Do sources of 'friction' exist in this experiment? Explain.

While the friction due to contact between the table and the cart is the primary force acting on the cart, a small amount of friction should occur due to the recording timer. Air resistance can also be considered a 'frictional' force. Both of these forces can be neglected in this experiment.

(2 and 3) Dependence of Acceleration on Force and Mass.

Q2. Are your results for experiments (2) and (3) consistent with Newton's 2nd Law? Explain.

These two experiments should demonstrate that force is inversely proportional to mass, and directly proportional to acceleration, as stated by Newton's 2nd Law. In the first experiment, students should notice that acceleration increases with the number of rubber bands used. In the second experiment, students should notice that acceleration due to a constant force decreases with the addition of mass.

(4) Force Acting at an Angle.

Q3. How does the acceleration of the cart due to a force at an angle differ from the acceleration due to a force exerted parallel to the long axis of the cart?

Force is a vector, and in this particular experiment, only the component of the force which acts parallel to the long axis of the cart has any effect. As the force from the rubber band is directed at an increasing angle to the long axis of the cart, the magnitude of the acceleration should approach zero as the force becomes perpendicular to the long axis of the cart.

Q4. Is there an angle that will yield maximum acceleration? Minimum acceleration? Explain.

'Maximum' acceleration occurs when the force from the rubber band is directed parallel to the long axis of the cart (or, at an angle of zero degrees). 'Minimum' acceleration occurs when the force is directed at an angle of 90 degrees to the long axis of the cart.

ANSWERS (ASSESSMENT A)

(1) Changes in Velocity with a Constant Force.

What do you notice about the acceleration of the cart in this experiment?

As the cart travels down the table, the dots on the ticker tape produced by the recording timer are closer together. From this data, one can conclude that the cart experiences a decreasing velocity from contact with the table.

Based on the frictional acceleration you calculated in this experiment, what force would you have to exert on the cart in order to move it at a constant velocity?

If there is a frictional acceleration $a_{friction}$, which is opposite the direction of the motion, then the force due to that acceleration is $\Sigma F_{friction} = ma_{friction}$. The force needed to move the cart at a constant velocity is an equal and opposite force, or $\Sigma F_{move} = -ma_{friction}$.

(2) Dependence of Acceleration on Force.

Explain how you would find the average force exerted by each rubber band.

First, obtain a calculation for the average acceleration of the cart. Then calculate the net force exerted on the cart by all rubber bands, and divide by the number of rubber bands used.

(3) Dependence of Acceleration on Mass.

How does the acceleration of the cart change as you add mass?

The acceleration of the cart should decrease as you add mass, as acceleration and mass are inversely proportional.

What if you doubled the force exerted by the rubber band(s) in this experiment? How would your data change?

If you double the force exerted by the rubber bands and exert that force on the same mass, acceleration should double.

PROCEDURE B (BRIEF DESCRIPTION)

This procedure is ideal for grades 5-12.

Using both carts, students will qualitatively analyze conservation of momentum by examining some elastic collisions (collisions involving both carts and the optional spring bumpers) and inelastic collisions (collisions where both carts stick together after the collision).

ANSWERS (PROCEDURE B) {Possible with optional hoops}

(1) Elastic Collisions.

Q1. How do the carts exert forces on one another? Explain.

The carts exert forces on each other when in contact during a collision, as stated by Newton's 3rd Law. For example, when two carts in motion collide, each cart exerts a force on the other, and those forces reverse their movement.

Q2. Predict the motion of the two carts during and after the collision, and justify your prediction.

For this question, allow students to make and test their own predictions about the behavior of the cart. If both carts are in motion and collide 'head-on', the carts should remain in contact with one another for a brief moment, and the force that each cart exerts on the other should result in an acceleration that reverses their direction.

Q3. Observe the behavior of both carts during and after the collision. Was your prediction correct?

See answer to Q2.

(2) Inelastic Collisions.

Q4. Predict the motion of the two carts during and after the collision, and justify your prediction.

For this question, allow students to make and test their own predictions about the behavior of the cart. If both carts are in motion and collide 'head-on', the carts should remain in contact with one another after the inelastic collision, stuck together by the modeling clay which absorbed the kinetic energy. If the two carts each had momentum of the same value, but in opposite directions, the total momentum was zero, and the carts should be motionless after the collision.

Q5. Observe the behavior of both carts during and after the collision. Was your prediction correct?

See answer to Q4.

Q6. Are your results in this section consistent with Newton's 3rd Law? How can you tell?

Each of the results in this section should be consistent with Newton's 3rd Law. The carts should exert equal and opposite forces on each other when they are in contact during a collision.

ANSWERS (ASSESSMENT B)

Estimate the total momentum of the two-cart system before and after the collision in (1). Is momentum conserved in this experiment? Explain.

The total momentum before the collision should be the sum of the product of mass and velocity for both carts. The momentum should have a net magnitude and direction; if the sum of the momenta after the collision is equal to the sum of the momenta before the collision, then the total momentum is conserved. Your students should be able to see that this appears to be true by estimating the speeds and approximating the momenta in each experiment.

Estimate the total momentum of the two-cart system before and after the collision in (2). Is momentum conserved in this experiment? Explain.

The total momentum of the two-cart system before and after the collision should be the sum of the product of mass and velocity for both carts, just as in (1). In this experiment, however, the carts will stick together after they collide. The sum of the momenta of both carts is the same, but the behavior of the two-cart system once both carts have collided will be different in this case. For example, if two identical carts are moving toward one another at the exact same speed in the *elastic* case, the carts will collide, bounce off of one another, and move at the same speed and in the opposite direction after they collide.

In the *inelastic* case, however, if both carts have identical mass and velocity before the collision, they will come to a complete stop when they collide and stick, because the equal (and opposite) momentum vectors for both carts will add to zero.

PROCEDURE C (BRIEF DESCRIPTION)

This procedure is ideal for grades 9-12.

Students will use the carts in conjunction with weights and a recording timer to make quantitative observations about the nature of forces. With the data from the recording timer, students will physically measure displacements and calculate velocity and acceleration measurements. From these calculations, students can make conclusions about the nature of forces.

To examine conservation of momentum, students will use the exploder cart to create a collision. These carts will be attached to ticker tapes to record their movement. From this data, students can measure the velocity and calculate the momentum of each cart, and make conclusions regarding the conservation of momentum in this experiment.

ANSWERS (PROCEDURE C)

(1) Determining the Effect of Friction.

Q1. Does an external force act on the cart? Explain your answer.

External frictional forces (due to the surface and the ticker tape) act on the cart in this experiment. A cart simply rolling on the surface should eventually roll to a stop under the influence of these forces.

Q2. Are your observations consistent with Newton's 1st Law? Explain.

When net force on the cart is zero, your students should be able to move the cart with constant speed. If no net force is exerted on the cart, then the cart does not experience a change in speed. These results are consistent with Newton's 1st Law.

(2) Dependence of Acceleration on Force.

Q3. How does acceleration change as the force on the cart increases?

As force increases, acceleration should increase proportionally.

Q4. Do the hanging masses and the cart have the same acceleration?

Because the cart, string, and hanging masses are all connected and act as a system, all three objects should have the same acceleration.

(3) Dependence of Acceleration on Mass.

Q5. How does acceleration change as the mass of the cart increases?

As mass increases, acceleration should decrease.

Q6. Are your results for these experiments consistent with Newton's 2nd Law? Explain.

Both of these results are consistent with Newton's 2nd Law: force, mass, and acceleration are related in proportion to one another.

ANSWERS (ASSESSMENT C)

(1) Determining the Effect of Friction.

Does the cart have an acceleration in this experiment?

Yes, the cart should have a negative acceleration due to friction in this experiment. This negative acceleration is a result of a frictional force that is equal to the product of the mass of the cart and the frictional acceleration.

If so, what force would you have to exert on the cart in order to move it at a constant velocity? Specify magnitude and direction.

The force should be equal in magnitude to the frictional force exerted on the cart by the surface, and opposite in direction. Net forces on the cart will sum to zero, and the cart can either be at rest or moving at a constant velocity in this case.

(2) Dependence of Acceleration on Force.

How would you calculate the amount of force provided by the hanging weights in this experiment?

The entire system should have the same acceleration, so the amount of force provided by the hanging weights, minus any frictional forces, is equal to the product of their acceleration multiplied by the mass of the entire system.

(3) Dependence of Acceleration on Mass.

How does the acceleration of the cart change as you add mass to the cart?

The acceleration of the cart should decrease as you add mass to the cart.

What if you doubled the amount of mass hanging from the thread in this experiment? How would your data change?

If you doubled the amount of mass hanging from the thread, your acceleration would increase by a factor of two if there were no friction in this experiment.

PROCEDURE D (BRIEF DESCRIPTION)

This procedure is ideal for grades 9-12.

Using two recording timers, two dynamics carts, masses, spring bumpers and modeling clay, students will conduct a quantitative analysis of several different elastic and inelastic collisions. Students will use ticker tape data and find the mass of each cart in order to determine the momenta of the two-cart system before and after each collision.

ANSWERS (PROCEDURE D)

Q1. What factors, aside from friction between the cart and the table, could influence your results in this experiment?

The ticker tapes fed through the recording timers will have some small influence. Also, the 'explosion' from the cart piston is not perfect: some energy is lost to sound, and the spring does not perfectly transfer energy to the piston when the piston is released. In the other collisions, some energy may also be lost to the deformation of the spring bumpers and the modeling clay.

Q2. How does the momentum of Cart A before the collision compare to its momentum after the collision?

The momentum of Cart A before the collision is greater than its momentum after the collision, when the cart is not moving.

Q3. How does the momentum of Cart B before the collision compare to its momentum after the collision?

The momentum of Cart B before the collision (when the cart is not moving) is less than its momentum after the collision.

Q4. What happened to the momentum of Cart A after its collision with Cart B in the collision described above? Explain in terms of the forces on each cart.

In this collision, the momentum from Cart A seems to be 'transferred' to Cart B. Newton's 3rd Law is in effect here: because both carts have the same mass, and each cart exerts an equal and opposite force on the other, both carts will experience equal and opposite accelerations as well. This will bring Cart A to a stop while sending Cart B away with the same momentum.

Q5. How does the momentum of Cart A before the collision compare to its momentum after the collision?

In this collision, the momentum of Cart A before the collision is greater than its momentum after the collision (the cart is moving more slowly after the collision than before the collision).

Q6. How does the momentum of Cart B before the collision compare to its momentum after the collision?

In this collision, the momentum of Cart B before the collision is less than its momentum after the collision (the cart is moving faster after the collision than before the collision.

Q7. Why did Cart A continue moving, instead of coming to a stop as it did in the previous collision? Explain in terms of the forces on each cart.

The effect of Newton's 3rd Law are still seen here, but the effect is different due to the change in mass: while both carts still exert equal and opposite forces on the other, the cart with greater mass will experience less acceleration than the cart with less mass. Therefore, Cart B will not put up the force necessary to slow Cart A to a stop.

Q8. How does the momentum of Cart A before the collision compare to its momentum after the collision?

In this collision, Cart A will have more momentum before the collision than after the collision, because it is moving more slowly after the collision.

Q9. How does the momentum of Cart B before the collision compare to its momentum after the collision?

In this collision, Cart B will have more momentum after the collision than before the collision, because it is moving faster after the collision.

Q10. What happens to Cart A after its collision with Cart B?

After the collision, Cart A sticks to Cart B, and they move as a system. Cart A slows down when it collides with Cart B, and Cart B accelerates so that it moves at the same velocity as Cart A.

Q11. Explain why Carts A and B are moving more slowly after they collide than Cart A moved before the collision.

When both carts collide and stick, they exert forces on one another, according to Newton's 3rd Law. The force exerted on Cart A by Cart B will slow Cart A down, but will not bring it to a stop. The force exerted on Cart B by Cart A will cause Cart B to accelerate, and since both carts are stuck together and move as a system, both carts will move with the same velocity.

Q12. Cart A is heavier than Cart B in this experiment. What do you think would happen during the collision if they had the same mass? Test to see if your prediction is correct.

If Cart A and Cart B had the same mass, the carts will stick together and, due to the equal and opposite forces they exert on one another, they will both come to a stop as they collide.

Q13. Consider the possibility of performing these experiments in a near-weightless environment (such as the International Space Station). How would this environment change the results of the experiment?

On Earth, frictional effects will detract from this experiment: friction due to the weight of the carts will take away some momentum and some kinetic energy during collisions, and drag from the recording timers will have some small effect. However, at the International Space Station, no friction due to the weight of the carts exists; the carts will therefore continue in a constant velocity (constant speed in a straight line) unless acted upon by a net force. During an elastic collision in this environment, momentum and kinetic energy are both conserved.

<u>ANSWERS (ASSESSMENT D)</u>

What were your results for the total momentum of each two-cart system before and after the collision? Is momentum conserved in all of these experiments? Explain.

Individual results will vary from student to student, but students should find, based on their results, that momentum is conserved in all events detailed in this experiment. In the 'explosion' event, students will see that the exploder cart will move in the opposite direction of the other cart. Since both carts have relatively the same mass, each will move with the same speed, in opposite directions, as a result of the explosion. This result should also be indicated by ticker tape data.

In the first collision event (involving both carts with no additional masses and bumpers attached) student data should indicate that the cart which is moving at first 'transfers' its momentum to the second cart. Afterwards, data should indicate that the first cart comes to a stop, and the second cart moves with the same momentum as the first cart.

In the second collision event (involving both carts, one with additional mass, bumpers attached to both carts), students should see that the cart with the additional mass (which is the first to move) will continue to move after the collision with less speed, but that the first cart (with less mass, and initially at rest) moves more quickly than the first cart.

In the third collision event, the first cart (either with or without an additional mass) collides and sticks to the second cart. After the collision occurs, the two-cart system should have less overall velocity than before the collision. Kinetic energy is not conserved in this inelastic event; momentum, however, is still conserved.

How would the behavior of both carts in the first elastic collision experiment change if the cart in motion were twice as heavy as the cart at rest? Would momentum still be conserved? (Hint: think about the forces involved in the collision.)

Before any mass is added, the two carts are of relatively equal mass. In this elastic collision, when the first cart, which moves with a particular velocity, collides with the second stationary cart, it will stop and 'transfer' its momentum to the second cart, which will then move at the same velocity at which the first cart moved.

If the first cart's mass is doubled, and still collides with the second cart, the first cart will exert a force on the stationary second cart, 'transferring' momentum as a result of the collision (Newton's 3rd Law). The stationary (lighter) cart also exerts a force on the moving cart; that force will slow the cart down, but will not stop the cart. Instead, the first cart will 'follow' the second cart. However, Newton's 3rd Law still holds: each cart exerts an equal and opposite force on the other cart. Also, mass and acceleration are proportional according to Newton's 2nd Law. Therefore, momentum in this experiment will also be conserved.

For each of the two-cart events, calculate the total kinetic energy of the carts before and after each event.(Remember that kinetic energy is not a vector quantity, so kinetic energy is a positive value regardless of the direction of motion of the carts.) What happens to the total kinetic energy during each event? Is kinetic energy conserved in any of the events?

Student calculations for the kinetic energy of each cart during each collision will vary based on measurements. Before the explosion event, the total kinetic energy of the two carts is zero. After the explosion event, however, both carts are moving away from each other with the same speed. This gives them each the same kinetic energy. In this collision, students will find that while momentum may be conserved, kinetic energy is not.

Before the first elastic collision involving carts with bumpers, Cart A moves toward Cart B, which is stationary. After the collision, Cart B should have the same momentum and kinetic energy that Cart A had before the collision. Students will find that momentum and kinetic energy are conserved in this experiment.
In the second elastic collision involving carts with bumpers, Cart A has an additional mass, and Cart B remains unchanged. After the collision, Cart B should have a momentum and kinetic energy that Cart A gives as a result of the collision, but Cart A will 'follow' Cart B with a reduced momentum and kinetic energy. Students will find that momentum and kinetic energy are conserved in this experiment.

In the inelastic collision, Cart A moves toward Cart B and both carts stick together. The two cart system should move with lesser speed than Cart A had before the collision. While momentum is conserved in this experiment, students should find that kinetic energy is not conserved.

SUGGESTIONS FOR ADDITIONAL EXPERIMENTS

The steel bumpers can be used to conduct investigations of elastic collisions between two carts in a variety of different situations. Collisions between similar and dissimilar masses can also be examined. An ultrasonic motion probe can be used to gather quantitative data. An accelerometer (# 10-100) can also be used to determine the magnitude and direction of a constant acceleration. This piece of equipment can be used in these experiments, as well as on an inclined plane.

As discussed in the answers for Q13 in Procedure D, friction has a noticeable effect on the Dynamics Carts in these experiments. While it is not practical to avoid these limitations by moving the experiment to the International Space Station, an air track (#12500 or #12505) can create experiments where effects due to friction are negligible. Using an air track and gliders, along with a photogate or some form of acoustic data collection, demonstrations of conservation of momentum, conservation of kinetic energy in an elastic collision, and other concepts can be made more clearly.