

DYNAMIC CARTS

STUDY GUIDE

INTRODUCTION

Dynamics carts are used in studies of many different principles of physics including energy, forces, speed, velocity, acceleration, momentum, inertia and Newton's Laws of motion. **Energy** is defined as the ability to do work. There are many types of energy including mechanical, electrical, sound, heat, light and chemical energy. **Kinetic energy** is the energy of movement and **potential energy** is the energy of position or structure. Energy can be **transferred** from one object to another and **transformed** from one type of energy to another. When two objects collide, such as your dynamic carts, kinetic energy can be transferred from one cart to another and transformed to sound and heat.

A **force** is defined as a push or a pull. Forces are classified as either **contact** or **action-at-a-distance** forces. Pushing a lawn mower is an example of a contact force (two objects actually touching each other) whereas gravity is an example of a force that acts on an object at some distance from the object. **Friction** is a special kind of contact force that occurs when two objects rub against each other. The heavier an object is, the greater the frictional force that holds it in place.

When **unbalanced forces** act on an object, a change of **motion** occurs. This is part of **Newton's First Law of Motion** which says, "Every body remains in a state of rest or uniform motion in a straight line unless acted upon by an external force." For example, if you push a toy car, the force of your hand pushing the car is stronger than the force of friction that acts to hold it in place and the car moves. If there are no unbalanced forces acting on an object at rest, it will tend to remain at rest; if it is in motion, it will tend to remain in motion. Related to this law is the concept of **inertia**, which is a property of matter that causes it to resist changes in its state of motion.

Motion is a change in position of an object. The distance of movement per time interval is referred to as **speed**. **Velocity** takes into account the speed of an object but also the direction it travels. Velocity can change over time as well; objects increase or decrease in speed or change direction of movement. This change in the rate of velocity over time is called **acceleration**. A car that is turning, one that is braking and one that is speeding up are all accelerating because their velocity is changing over time.

Newton's Second Law of Motion states, "The force required to accelerate an object is proportional to the mass of the object and the acceleration given

it." It states that the value of an unbalanced force (F) is equal to its mass (m) times acceleration (a).

$$F = m \times a$$

Stated another way, the acceleration is directly related to the unbalanced force: the stronger the force, the greater the acceleration. The acceleration is inversely related to the mass: the greater the mass, the less the acceleration.

Newton's Third Law of Motion states that "For every action there is an equal and opposite reaction." For example, the jet engines of a plane push air very quickly out the back of the plane. The air pushes back on the plane with the same force and the plane moves forward very quickly. This law is also called the **action-reaction principle**.

Momentum is defined as the product of an object's mass and its velocity. Newton called this the "quantity of motion" of an object. For example, a large truck traveling at 60 mph has a greater momentum than a small car traveling at the same speed. Their velocity is the same but because the truck has a greater mass, its momentum is also greater. Similarly, a small bullet fired from a gun doesn't have much mass but because its speed is so great, it has a greater momentum than a heavier object moving slowly (such as a chair pushed slowly across a room).

The momentum of an object remains constant unless its velocity or mass changes. The momentum of several objects in a system is equal to the sum of the momenta of these objects. The **Conservation of Momentum Law** states that the total momentum of a system is conserved as momentum is transferred from one object to another. The momentum lost by one object is gained by the other object. The application of this principle will be demonstrated in the following experiments.

Your dynamic carts are useful for studies of the physical principles listed above because they are designed to minimize any frictional forces between the cart and the wheels and they are also designed to travel in relatively straight lines. They can be weighted with various masses to see the effect of extra mass on velocity, momentum and acceleration. We have included several experiments in your kit instructions, but there are many other possibilities to explore beyond those given here. These activities will reinforce the scientific skills of observation, quantifying and predicting.

ASSEMBLY AND GENERAL OPERATION

Your dynamic carts assembly includes the following items:

Dynamic carts, 2	Metal bands, 2
Spring	Screws, 2
Piston	Rubber bands, 10
Metal cylinder	Instructions

In addition to these items, you will also need

a large level table or board with 2 wooden bumpers or blocks clamped to either end
a watch with a second hand
weights (like small bricks or bags of sand)

1. Attach the spring to the piston by slipping the end loop of the spring through the two holes in the end of the piston to make a secure attachment. Make certain you do not stretch the spring out of shape in the process. (If the spring is already attached to the piston, skip this step and go on to step 2.)
2. One cart has a metal cylinder down its length with a screw that secures it. Unscrew the screw from the cylinder and insert the spring (attached to the piston) into the cylinder with a twisting motion until the loop of the spring is visible through the free end. Make sure the slots in the piston attached to the spring are facing up toward the top of the cart.
3. Slowly screw down the screw through the cart, the metal cylinder and the loop of the spring. You may need to reposition the spring so that the screw passes through the loop.
4. The slots of the piston should be facing the top of the cart, and the screw should be securing the metal spring and the metal cylinder. Try pulling the piston a few times to make sure the spring is secure and is free to move.
5. To operate the piston, push it back into the cylinder until the metal slot clicks into place and the wooden peg pops up. There are two slots or possible positions for the piston, one for softer collisions and one for harder collisions. To release the piston, push down on the wooden peg. **(Use caution when operating the piston and keep your face away from this area at all times. The release force of the piston is quite strong and the piston could cause bruises or injury to the eyes if used improperly! Do not let small children operate this instrument.)**
6. To attach the metal bands for use as bumpers, curve the metal band to form a loop with the holes in the ends of the band aligned. Place the holes of the band over the hole in the end of the dynamics cart. Screw down the bands to the hole. (Both carts have holes to attach the metal bumpers.)

7. For all the experiments, make certain that the table you are using is as level as possible. Set a cart on the table at different spots and see if it rolls in one direction or if it remains stationary. Even a slight slope to the table can lead to errors in the experimental results.
8. When moving the carts and causing various collisions, make certain the carts are aligned in a straight line, perpendicular to the ends of the table.
9. For all the experiments, you will need a barrier of some type at either end of the table. We suggest clamping pieces of wood to the ends using c-clamps. You can use heavy objects like a stack of books or weighted boxes but these will take up room on the table, leaving less space for the motion of the carts. The barriers need to be firmly fixed and not moved when impacted by the carts.
10. For experiments involving the piston, we recommend using the softer collision setting first and then using the harder collision if you wish to repeat the set of experiments with a different force.
11. All of the following experiments involve careful observation of the motion of the carts. In particular, pay close attention to their speed and direction before, during, and immediately after impact.

CONSERVATION OF MOMENTUM (A)

Experiment 1

The problem statements you will answer with this experiment are: **"What affect does an explosive force from a piston have on the velocity of two opposing carts at rest? How does increasing the mass of one of the carts change this affect on velocities?"**

1. Push the piston in to the first slot and set this cart against the other cart, so that they are facing each other, with the piston touching the other cart. Measure from the wooden barriers to the carts on either end so that the carts are equal distances from the barriers.
2. Check again to make sure the piston of the first cart is in contact with the front of the second cart and then release the spring.
3. Record the time elapsed in seconds from the release of the piston to when the carts hit the barrier. Repeat the procedure 2-3 times and use the average of the time values to record in Table 1. Also record the average distance each cart traveled, from their starting point to the barrier. **Do both carts impact the barriers at the same time?**

4. Repeat these steps again, this time adding a 1-kilogram (kg) weight to the cart without a piston. You can use a weight of another size but the experiment works best if you know the mass of the weight.
5. Record the time for the carts to hit the barrier and the distance traveled again in Table 1.
Which cart impacts the barrier first?
6. Repeat the procedure again, increasing the mass on one cart to 2 kg and then 3 kg. When the weights increase, the heavier cart might not make it to the barrier before it stops. In this case, the distance traveled for the weighted cart (from the starting point until it stops) would need to be measured each time.
7. Record your results. Velocity is distance traveled over time. **Calculate the velocities for the carts from your data.**
8. Try to determine a relationship between mass, velocity and transfer of momentum. **How does adding mass affect the velocity and momentum?**

You should see that when both carts are empty, the explosion of the piston causes both carts to impact the barrier at the same time. The potential energy in the coiled spring of the piston converts to kinetic energy, the piston “explodes” and hits the opposing cart. This cart pushes with an equal and opposite reaction on the other cart. The two carts now have kinetic energy and velocity; they are moving in a certain direction over time. Since both carts have a mass and velocity, they also have momentum. Remember that momentum is a product of an object’s mass and velocity. The momentum in the cart system is conserved and both carts travel at the same speed in opposite directions as they have approximately the same mass.

When one cart is weighted, its velocity decreases and the other cart’s velocity increases. As more and more weights are added, the weighted cart’s velocity decreases more and the other cart’s velocity increases more. The weighted cart decreases in velocity because, as you add masses to it, it still has the same initial force that gives it motion (the explosion). Since this same force has to move a larger mass that has more inertia, the cart moves more slowly. Also, because this cart has increased in mass, its momentum increases. With its greater momentum, it pushes on the other cart with a greater force. Since the lighter cart has not changed in mass, the greater momentum it receives is translated into a greater velocity.

CONSERVATION OF MOMENTUM (B)

Experiment 2

The problem statements you will answer in this experiment are: **What affect does an explosive force from a piston have on the velocities of two opposing carts at rest if the piston is not in contact with the 2nd cart? Does this affect on the velocities change if the mass of one of the carts increases?**

1. Repeat the entire procedure given above for experiment 1 but do not let the piston be in contact with the 2nd cart before release. Let the piston be some distance from the 2nd cart before release but still contacting the 2nd cart after release.
2. **What happens to the velocities of the carts after the collision as compared to when the piston is in contact with the 2nd cart before release?**

The velocities and therefore momentum of the carts will be less because the energy of the spring and piston when it contacts the cart is less. The piston’s greatest kinetic energy and velocity is when it is first released. By the time it reaches the end of the spring release, the energy and velocity decrease appreciably and the piston strikes the cart with less force. The carts’ velocities decrease as a result.

COLLISION OF 2 CARTS: 1 AT REST

Experiment 3

Problem statements: **If a moving object collides with another object that is at rest, what will the resultant velocities of the two objects be? Are the resultant velocities affected if one object’s mass increases?**

1. Attach the metal bumpers to the carts as described in “Assembly.”
2. With one cart at rest, roll the other cart into the resting cart so that the bumpers collide.
3. Repeat this procedure 2-3 times and take the average value for time elapsed to record in Table 1 (the time from the point of collision to when the cart hits the wooden barrier). Try to use the same force each time when pushing the carts. Also record the average distance between the starting position of the resting cart to where it collides with the barrier. **What happens to the resting cart? What happens to the rolling cart?**
4. Repeat the above steps, with a 1 kg weight on the resting cart, using the same force to push the moving cart. Repeat again using 2 and 3 kg weights on the resting cart. Record your results. Remember that the weights will slow one cart down and it might stop before the barrier.

Measure the distance traveled from the starting point to where the cart stops.

- Repeat #4, putting the weights on the moving cart this time, and record the results.
- Determine the velocities of the carts from your data. **How does adding weights affect the velocity of the moving cart? Of the resting cart?**

When the two carts have no weights and the moving cart (A) collides with the resting cart (B), cart A stops and cart B moves on with approximately the same velocity that A had before the collision.

When cart A is weighted with 1, 2, and 3 kg weights, its inertia increases and it no longer completely stops after the collision but continues rolling in the same direction, only more slowly. Cart B is sent off at a greater velocity than when cart A did not have weights. When cart B is weighted, it has a greater inertia and moves more slowly after the collision, while cart A rebounds in the opposite direction. Momentum of the system is conserved in both cases, with the lighter cart's velocity being greater after impact due to its mass being less than the cart which has weights.

COLLISION OF 2 CARTS: MOVING IN OPPOSITE DIRECTIONS

Experiment 4

Problem statements: **If two objects moving in opposite directions collide, what will their resultant velocities be? How will increasing the mass of one of the objects affect the resultant velocities?**

- Measure the midway point from the wooden barriers to the center of the table.
- With the metal bumpers attached, roll the two carts into each other with the same speed so that their bumpers collide. Make the carts collide at the midway point between the barriers.
- Repeat this procedure 2-3 times and record the average time from the point of impact that it takes the carts to hit the wooden barrier. Also record the average distance the carts traveled from their collision point to the barriers.
- Load one of the carts with a 1 kg weight and roll the carts into each other with the same speed. Record time and distance as described above.
- Add more weights (2 kg and 3 kg) to the loaded cart and repeat.
- Determine the velocities of the carts from your data. **What relationship do you see between mass and velocity?**

When both carts collide and neither is weighted, they rebound with equal velocities. When one cart is weighted, the heavier cart rebounds more slowly

while the lighter cart rebounds at a higher speed than previously. **Can you explain how this demonstrates the conservation of momentum?**

FORCE AND ACCELERATION STUDY

Experiment 5

Problem statements: **What is the relationship between the force on an object and the resultant acceleration of the object? For a given force, how does increasing the mass of the object affect its acceleration?**

- Hook one rubber band around the front plate of one of the carts. Hold the cart against one of the wooden barriers and stretch the rubber bands in front of the cart the same distance (two people work best, one to hold the cart and one person to stretch the rubber band).
- Release the cart, and as it travels toward the rubber band, lift the band slightly so the cart does not run over it. The important point is to not let the band retard the speed of the cart; but don't pull up on the cart or interfere with its motion with the band after release.
- Repeat the procedure 2-3 times and record in Table 2 the average time elapsed from the point of release until the cart reaches the wooden barrier. Also record the average distance from the starting point of the cart to the barrier.
- Repeat this procedure ,successively adding more weights to the cart (1 kg, 2 kg and 3 kg). Record your results and determine the velocity of the cart.
- Determine the acceleration of the cart (a) by dividing the change in velocity (Δv) over the time elapsed (t). For example, if an unweighted cart with a force of one rubber band went from a velocity of zero to 1 meter per second in 2 seconds then the acceleration would be the change in velocity (1 m/s final velocity – 0 m/s initial velocity) divided by the time elapsed (2 seconds) or
$$a = \Delta v / t = (1 \text{ m/s} - 0 \text{ m/s}) / 2 \text{ s} = 0.5 \text{ m/s}^2$$
- How does adding weights affect the cart's velocity and acceleration?**
- Remove the weights and repeat this procedure, adding a second rubber band to one of the carts and recording your results. How does increasing the force affect the acceleration of the cart?
- Successively add 1, 2, and 3 kg weights to the cart with 2 rubber bands, repeat the procedure and record the results.
- Continue on, using three rubber bands with one cart and so on up to 10, with and without weights.

How does the increased force of additional rubber bands affect the acceleration of the carts? To see this relationship, plot the data on a graph with the number of rubber bands (force) on the x-axis and acceleration on the y-axis.

Force is directly proportional to mass and mass is inversely proportional to acceleration, as we saw earlier in Newton's 2nd law ($F = m \times a$). Your results should show that adding force to the cart by adding rubber bands causes that cart to hit the barrier sooner. Its velocity and therefore acceleration increases. Adding mass to the cart causes it to take more time to hit the barrier. Its velocity and therefore acceleration have decreased.

TEACHING TIPS FOR YOUNG CHILDREN

Begin the topic of momentum by defining a force as a pull or a push. Ask your child to describe different pushes and pulls that they do or see every day (a person pulling a cart, a bulldozer pushing dirt, gravity pulling a feather to earth). The child should be able to see that all movement is a result of a force. Use a small paper clip and ask the child to think of various forces that they could use to move the paper clip. They could use a magnet (magnetic force), drop the paper clip (gravity), push or pull the paper clip with their fingers or blow on it with air from their mouth (contact forces).

Explain that magnetic forces and gravity are examples of forces that act at a distance. We can't see these forces, but they are real—we can see their effects. We can't see God either, but we do see His effects. There are many parts of God's creation that are real but are also invisible. Can you think of other examples?

Define momentum in terms of size and speed; big, fast objects have more momentum than small, slow object. Have the child slap the palm of his own hand slowly with a small object like a plastic cup, then slap it quickly. He feels in his receiving hand the difference of momentum or force of the two speeds for the same object. Explain that the first time, the cup is traveling slowly and has less momentum or force than the second time. Then, have the child slap his palm again with the same cup at a slow speed. Give the child a much heavier cup and have them slap their palm again at the same speed. Explain that the larger cup has the same speed as the smaller, but its momentum is greater because it weighs more.

Let the children watch the collision experiments given above. They will be able to absorb quite a bit of the "common sense" of momentum without necessarily knowing the reasons for its occurrence. Ask them what forces they see as the carts move and collide together. Ask them which cart has the

greater momentum as you experiment with different speeds and weights on the cart.

Tell the child about friction. Explain that this is a force that results when two substances rub against one another. There is a frictional force between your shoe and the ground, between a wheel and the road, between a table and a cup you slide over it. This force slows down the carts; otherwise they would keep moving indefinitely. Ask the child to think what would happen if there was no friction. Would they be able to walk? Drive? Ride a bike?

There are many applications that young children can make of their studies of motion and momentum to the world around them. Use their toys, home, and environment to help them investigate further the forces and movement of objects.

FURTHER STUDY

Although many of the differences in velocities and impact times of the above experiments can be estimated and general trends observed, high school level work should include more exact measurements of time and speed. We recommend purchasing a recording timer to exactly measure the distances traveled by the carts and the elapsed time. Graph the data and determine the velocities and accelerations of the carts for the various experiments.

You can use the dynamics carts with inclined planes to study the force of gravity and the mechanical advantages for inclined planes as well as the amount of work done by inclined planes. Additional items that would be helpful are an inclined plane, a spring scale, a recording timer and a physics textbook for appropriate equations.

Ask your child how the principles of momentum that they have observed are utilized in the world around them. For example, many forms of martial arts utilize the principles of conservation and transfer of momentum. In some self-defense maneuvers, the momentum of large person is redirected by changing their motion (a flip, throw or block) instead of being completely transferred to their opponent as would happen by receiving a blow. Can you think of other ways this principle could be applied advantageously?

Explain that the topics of this investigation are very broad; forces, momentum, speed, and the other concepts are all describing the way matter and energy behave. These phenomena are predictable; they follow certain mathematical relationships of direct or indirect proportionality. The movement of objects can be predicted and described based on these relationships, if the investigator applies the equations properly. What does this predictability and orderliness of the physical principle of motion reveal about the nature of God?

TABLE 1.

Experiment	Velocity of Carts (d = distance traveled after impact, t = time elapsed) (v = velocity = d/t)											
	No weights			1kg			2 kg			3 kg		
	d	t	v	d	t	v	d	t	v	d	t	v
#1. Piston contacting 2nd cart												
Cart 1												
Cart 2												
#2. Piston not contacting 2nd cart												
Cart 1												
Cart 2												
#3. 1st cart collides with 2nd cart at rest												
Trial 1: weight on resting cart												
Cart 1												
Cart 2												
Trial 2: weight on moving cart												
Cart 1	n/a	n/a	n/a									
Cart 2	n/a	n/a	n/a									
#4. Carts collide with same velocity												
Cart 1												
Cart 2												

TABLE 2.

Force & Acceleration Experiment	Velocity of Carts (d = distance traveled after impact, t = time elapsed) (v = velocity = d/t, a = acceleration = v/t)															
	No weights				1kg				2 kg				3 kg			
	d	t	v	a	d	t	v	a	d	t	v	a	d	t	v	a
Trial 1: no rubber bands																
Trial 2: 1 rubber band																
Trial 3: 2 rubber bands																
Trial 4: 3 rubber bands																
Trial 5: 4 rubber bands																
Trial 6: 5 rubber bands																
Trial 7: 6 rubber bands																
Trial 8: 7 rubber bands																
Trial 9: 8 rubber bands																
Trial 10: 9 rubber bands																
Trial 11: 10 rubber bands																