UNITED SCIENTIFIC SUPPLIES, INC.

OPERATING INSTRUCTIONS AND ACTIVITY GUIDE

Dynamics Carts

DNCART2

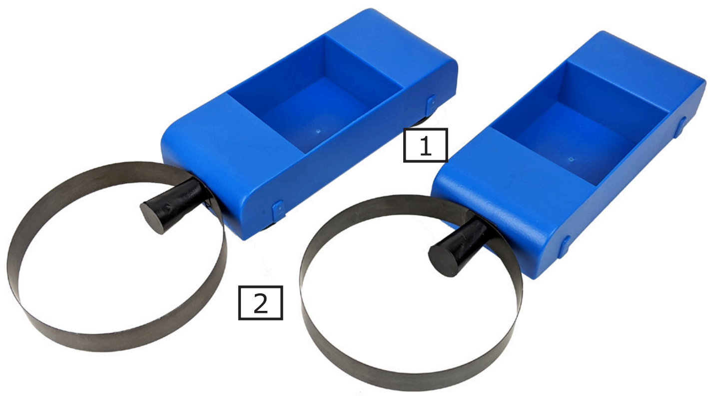


Figure 1

DESCRIPTION

The dynamics carts allow you to investigate experiments in conservation of elastic collisions, velocity, acceleration and momentum. The set contains two plastic carts, each with a steel bumper and a rubber stopper. Each cart also has a recessed compartment to place in additional weights, available separately.

IDENTIFICATION OF COMPONENTS

1. Hall's Cart
2. Steel spring bumpers/rubber bumpers

NGSS STANDARDS

Elementary	Middle School	High School
3-PS2 Motion and Stability: Forces and Interactions • 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object. 4-PS3 Energy • 4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide	MS-PS2 Motion and Stability: Forces and Interactions • MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. • • MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.	HS-PS2 Motion and Stability: Forces and Interactions • •HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

SUGGESTED ACTIVITIES

1. Force and Acceleration
2. Conservation of Momentum

ADDITIONAL MATERIALS REQUIRED

1. Meter stick or tape measure
2. Protractor
3. Ramp (at least 50 cm long)
4. Slotted masses or hooked weights
5. Stopwatch
6. Scale

PRE LAB ASSEMBLY

When investigating collisions, use the rubber stopper to secure the steel bumper to the front of the cart.

Figure 2

With the set screw attached, connect either the rubber stopper, or the rubber stopper and steel bumper as needed.

BACKGROUND

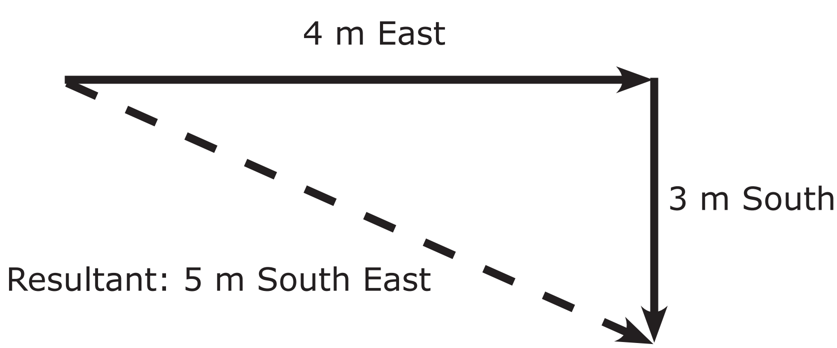
Vectors and Scalars

Displacement refers to a change in an object's position. There are two quantities that are important to know in defining an object's displacement: the magnitude and direction. If a cart moves 4 meters east, its displacement is very different than moving 3 meters south. Items which have this combination of a magnitude and direction are called *vectors*.

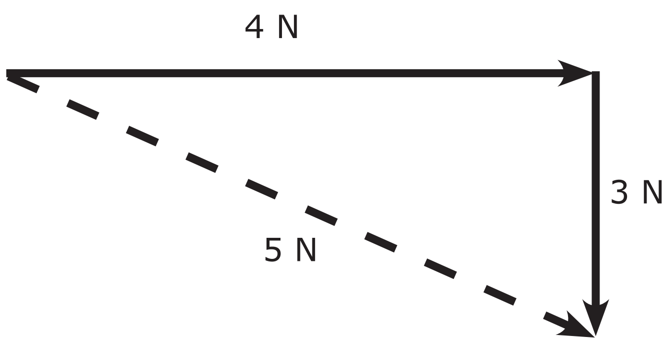
A *scalar* quantity only has a magnitude, or number. Examples for each are:

4 m is a distance = scalar
4 m east is displacement = vector

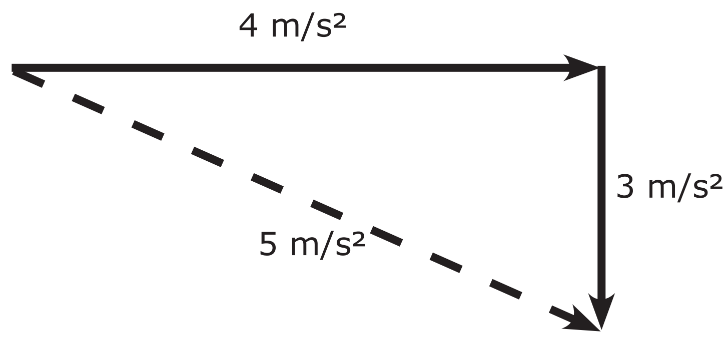
Vector quantities can be added together to yield the final resultant vector. If you combine the two previously mentioned displacements, you obtain a resultant displacement of 5 m south east.



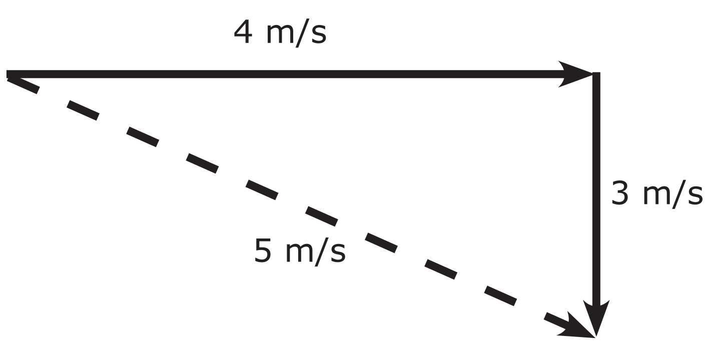
This combining of vectors can also be done for force, velocity and acceleration.



Force



Acceleration



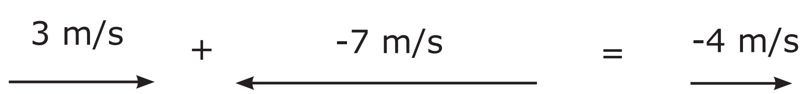
Velocity

One important distinction to keep in mind is the difference between velocity and speed. Velocity has a magnitude and a direction (vector), while speed is simply a magnitude (scalar). The speedometer of your car registers your speed, but at no time gives you a direction.

Frame of Reference

Since vectors have direction as an integral part of their attributes, it is necessary to discuss a frame of reference. Typically the Cartesian graph is used for assigning positive and negative values to a vector. The two vectors below can be combined to yield a resultant of 1 N to the right.

This can also be applied to velocity



Force and Acceleration

Newton's Second law expresses that the velocity of an object will change when an external force is applied. This external force can cause the object to accelerate, such as the force provided by an car engine. The external force can also cause the object to decelerate, such as friction or by hitting another object.

Since force is a vector, the direction in which the force is acting on the object is very important. A negative acceleration will be caused by a negative force, a force that is acting against the original motion of the mass.

The relationship between the force (F) on a mass (m) and acceleration(a) is represented by:

$$F = ma$$

The cart below will accelerate to the right because the falling mass will exert a force due to its weight. The larger the falling mass, the faster the cart will accelerate. Similarly the larger the mass of the cart, the larger the force that is required to cause it to accelerate at a certain rate.

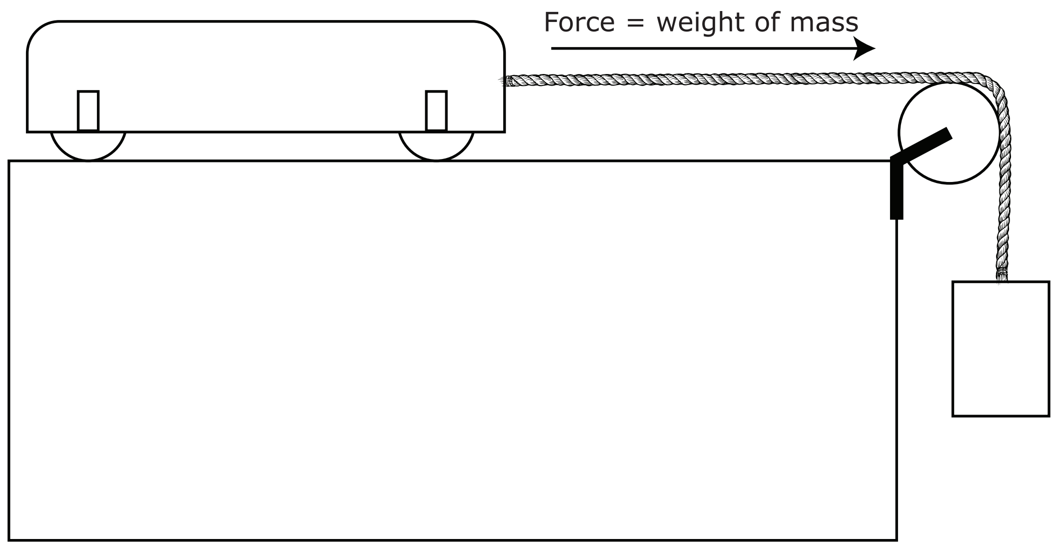


Figure 3

A force (F) will cause a change in velocity (a) and likewise, a change in velocity (a) will cause a force (F).

When a cart is on a ramp, the force causing it to move is due to gravity. In order to determine the force pulling the cart down the ramp due to gravity, you need to determine the *component* of the weight down the ramp.

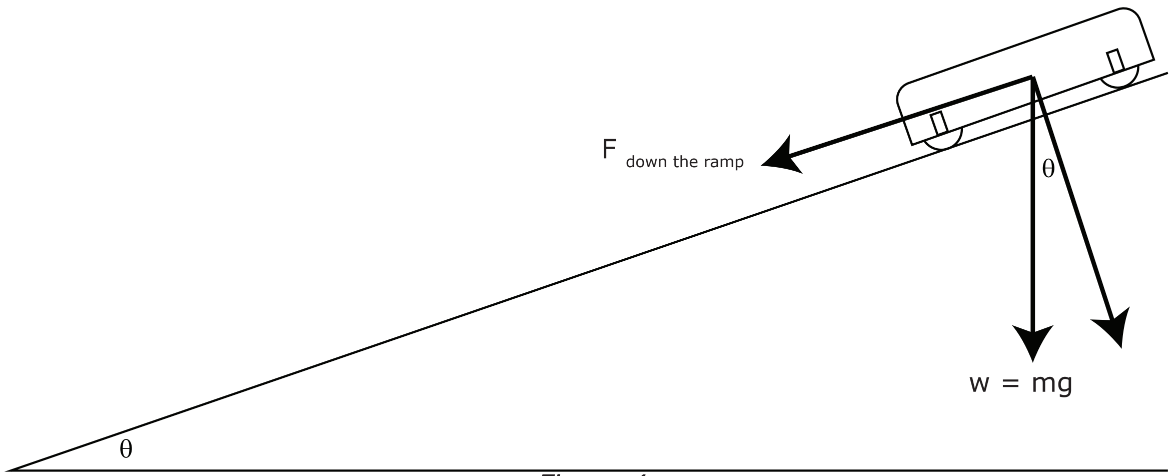


Figure 4

The formula for determining the force of the cart pulling it down the ramp is:

$$F_{\text{down the ramp}} = (mg)\sin\theta$$

θ = angle of the ramp

m = mass of the cart

g = acceleration due to gravity

With this formula, you can determine the force causing the cart to move down the ramp. $F_{\text{down the ramp}}$ Substituting this force into Newton's Second law, we obtain the combined equation:

$$F = ma$$
$$F_{\text{down the ramp}} = ma$$
$$(mg)\sin\theta = ma$$

Simplifying the equation further yields an acceleration that is only dependent upon the angle of the ramp and gravity.

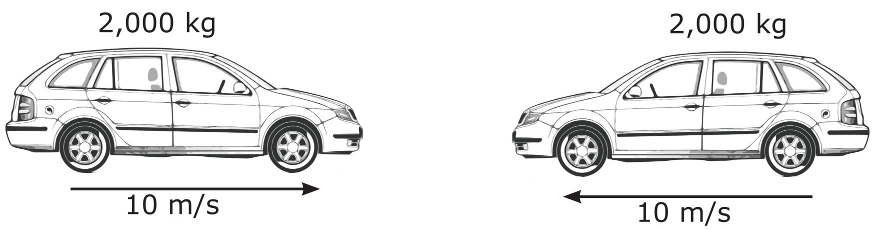
$$a = (g)\sin\theta$$

Conservation of Momentum/Impulse

If an object is moving at a constant velocity, it is said to have *momentum*. The momentum (p) of an object depends on the mass (m) of the object and its velocity (v) and is expressed by the equation:

$$p = mv$$

Since momentum depends on velocity, it is also a vector; so the direction an object is moving is important. The both objects below have the same magnitude of momentum but their directions are opposite in direction.



$p = mv$
$= (2{,}000\ \text{kg})(10\ \text{m/s})$
$= 20{,}000\ \text{kg m/s}$

$p = mv$
$= (2{,}000\ \text{kg})(-10\ \text{m/s})$
$= -20{,}000\ \text{kg m/s}$

If these two collide, the concept of conservation of momentum states that the total change in momentum must be zero. When objects collide, there will be a change in velocity and therefore a change in momentum.

In order for the change in momentum to be conserved, we need to look at the momentum of each object before and after the collision.

Using the above example where the cars are equal and opposite, we can identify the in momentum for each car.

Before the collision = After the collision

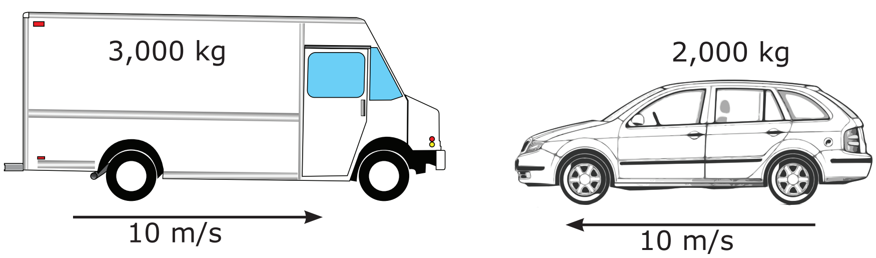
$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$$

$$(2{,}000\text{kg})(10\ \text{m/s}) + (2{,}000\text{kg})(-10\ \text{m/s}) = (2{,}000\text{kg})(0\ \text{m/s}) + (2{,}000\text{kg})(0\text{m/s})$$

$$0 = 0$$

So after the collision, both cars are stationary. Momentum has been conserved, but velocity has changed.

Using this idea of conservation of momentum, we can also predict the velocity of objects in a collision. If we use the same scenario but switch the one car with a heavy truck, the result will be very different. Now the goal is to find how fast the small car will be traveling after the collision, if the truck comes to rest.



Before the collision = After the collision

$$m_1v_1 + m_2v_2 = m_1v'_1 + m_2v'_2$$

$$(3{,}000\text{kg})(10\ \text{m/s}) + (2{,}000\text{kg})(-10\ \text{m/s}) = (3{,}000\text{kg})0 + (2{,}000\text{kg})(x\ \text{m/s})$$

$$30{,}000\ \text{kg m/s} + 20{,}000\ \text{kg m/s} = 2{,}000\text{kg}\ (x)$$

$$x = 25\ \text{m/s}$$

The "+" indicates that the final velocity is in the positive direction. The car moves back much faster than it arrived.

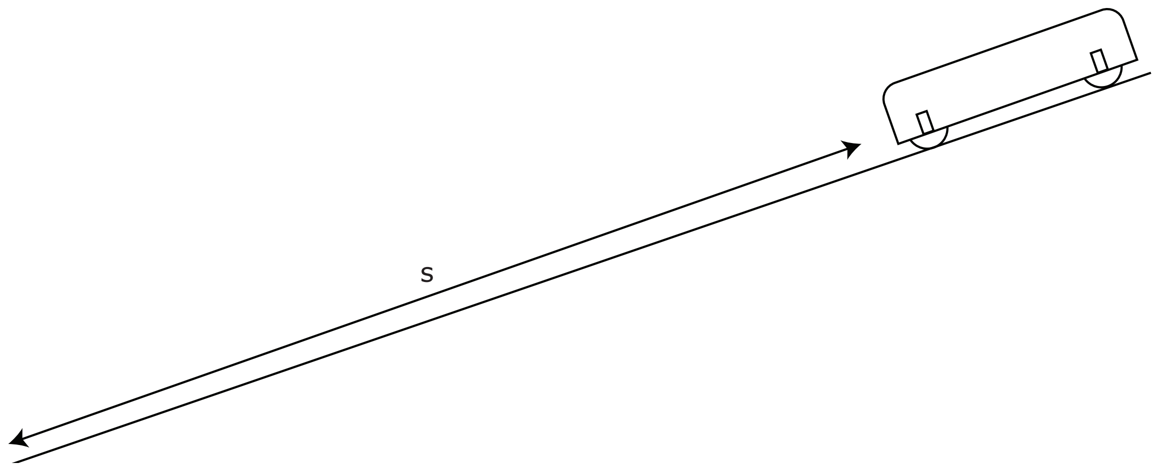
The conservation of momentum presented here does not take into account the energy lost to non-conservative forces like friction.

THE DEMONSTRATIONS

1: Acceleration down a ramp

Materials Included: One dynamics cart
Materials Needed: Ramp, stopwatch, ruler, protractor, masses.

For this experiment, you are going to calculate the acceleration of two different cart masses down a ramp, and use this to determine the force exerted on the cart.



- Set up a ramp that is at least 50 cm long.
- Measure the angle of the ramp:__________
- Measure the length of the ramp that the cart will travel, call this distance "s".
- Start a stopwatch when the cart is released and stop the stopwatch as the cart reaches the end of the measured track. Record this time and call it "t".
- Calculate the cart's acceleration, a, using the formula: $a = 2s/t^2$

Place a mass in the cart and repeat the steps above. Calculate the acceleration for this new trial.

Since the mass of the cart varies, the force pulling the cart down the ramp will also vary. In order to determine the force pulling the cart down the ramp due to gravity, you need to determine the component of the weight down the ramp.

The formula for determining the force of the cart pulling it down the ramp is:

$$F_{\text{down the ramp}} = (mg)\sin\theta$$

With this formula, you can determine the force causing the cart to move down the ramp. $F_{\text{down the ramp}}$ Substituting this force into Newton's Second law, we obtain the combined equation:

$$F = ma$$

$$F_{\text{down the ramp}} = ma$$

$$(mg)\sin\theta = ma$$

Simplifying the equation further yields an acceleration that is only dependent upon the angle of the ramp and gravity.

$$a = (g)\sin\theta$$

Use this formula to determine the theoretical acceleration of the cart down the ramp at the given angle.

Analysis

1. How do the two different techniques for determining the acceleration down the ramp compare?

2. Determining the velocity at the end of the ramp.

Based on the distance the cart traveled "s" and the acceleration "a", use the formula below to determine the velocity of the car at the end of the ramp. Note that since the cart starts from rest, the initial velocity is zero.

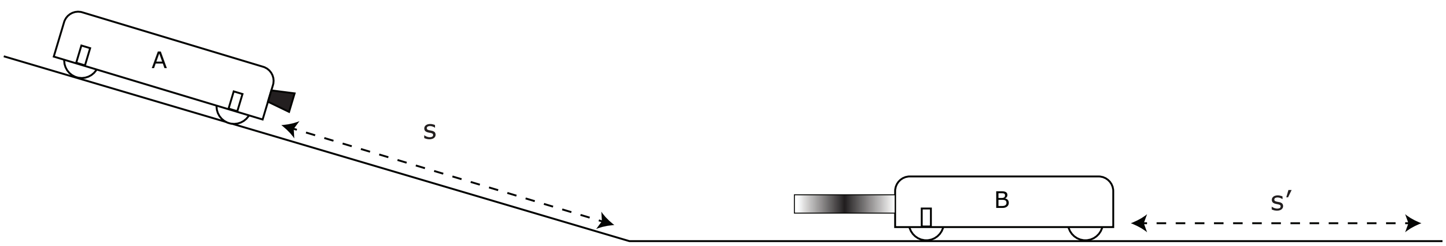
$$v_f^2 - v_i^2 = 2as$$

2: Conservation of Momentum

Materials Included: Two dynamics cart with bumpers
Materials Needed: Stopwatch (2), ruler, masses, protractor

When two carts collide there will be a conservation of momentum. Momentum depends on the objects velocity and mass, p = mv. While the mass is easy to determine, the velocity is a little more difficult. It requires measuring distance traveled and time. To investigate the conservation of momentum we will look at it in terms of observation (qualitative) and actual measurements (qualitative).

A. Qualitative



- Set up the ramp to the same angle as in the first activity. Make the position of Cart A on the ramp and the distance “s” the same as in the first activity.
- Cart A should only have the rubber stopper while Cart B has the steel bumper.
- Make sure Cart B is far enough away from the end of the ramp - a distance at least equal to the length of Cart A.
- Record the mass of both carts.
- Release Cart A and measure the distance that the collision causes cart B to move backwards, s’. Record this distance as s’.
- Repeat this process for three more trials with the flowing criteria:

  Trial 2: place a mass in Cart A.

  Trial 3: Place the same mass in both carts

  Trial 4: Place a mass in Cart B only

Trial	Cart A mass (kg)	Cart B mass (kg)	Distance Cart B moves: s’ (m)
1			
2			
3			
4			

B. Quantitative

In order to investigate the conservation of momentum in more detail, we will need to determine the velocity of each cart. To help eliminate the affects of friction, do not use the carts alone. Place a small mass in each, anywhere from 20 grams to 200 grams.

You will need two stopwatches, one for each cart.

Measurements needed for Cart A: Time from rest to colliding with Cart B (t)

Distance traveled down the ramp (s)

Formulas needed:

$$a = 2s/t^2$$

$$v_f^2 = 2as$$

Measurements needed for Cart B: Time from the collision from Cart A until it comes to rest (t)

Distance traveled s'

Formulas needed:

$$v = 2s'/t$$

- Set up the ramp to the same angle as in the first activity. Make the position of Cart A on the ramp and the distance "s" the same as in the first activity.
- Cart A should only have the rubber stopper while Cart B has the steel bumper.
- Record the mass on both carts.
- Release Cart A, measure the time (t) for the cart to impact the other cart and the distance traveled(s).
- When Cart B starts to move, start the stopwatch and time how long it takes for the cart to come to rest (t). Measure and record the distance it travels (s').

- Calculate the velocity and momentum for each cart.
- Repeat this process for three more trials with the following criteria:
  - Trial 2: place a different mass in Cart A.
  - Trial 3: Place the same mass in both carts
  - Trial 4: Place a different mass in Cart B only

Trial	Cart A mass (kg)	Cart A velocity (m/s)	Cart A Momentum	Cart B mass (kg)	Cart B Velocity (m/s)	Cart B Momentum
1						
2						
3						
4						

Analysis

1. How did the momentum of the two carts compare with each other?

2. As the mass on each cart was bigger, did the momentums become similar to each other or farther apart? What factor do you think caused this pattern?

MAINTENANCE

Store the dynamics carts in a large enough container so that the spring bumpers are not bent.