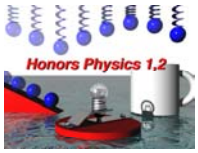


Impulse and Momentum
Impulse

CONCEPT EXPLORATION

In this unit you will be exploring the idea of impulse and momentum. You probably have a sense of what is meant by momentum since this is a part of our everyday vocabulary. Do you have any momentum right now?

Engagement Questions

1. What has the most momentum, a skateboard rolling down the sidewalk or a parked car? Explain your answer.

2. What has the most inertia, a skateboard rolling down the sidewalk or a parked car? Explain your answer.

3. Explain how momentum is different from inertia.

4. What has the most momentum, a sailboat moving at 5 m/s or an aircraft carrier moving at 5 m/s? Explain your answer.

5. What seems to be the important components of the momentum of an object?

6. Is there direction to the momentum of an object? Is momentum a vector or a scalar quantity?

7. Evaluate the following student statements. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

Student A

"In order to have momentum an object has to be moving. Also, the momentum of an object must be in the direction that the object is moving. Since velocity tells you what direction an object is moving, velocity must be an important part of momentum."

Student B

"Since a bigger object has more momentum than a smaller object traveling at the same speed, the weight of an object must be a part of the momentum of the object."

The momentum of an object has two parts, mass and velocity. **Momentum** is defined as the mass-velocity product for an object. The symbol that we use for momentum is the lower-case letter "p". The momentum equation therefore is:

p = mv

The Challenge

You will investigate how to change the momentum of an object.

Your Ideas about the Challenge

8. What is the momentum of your lab cart as it remains at rest on the table? Explain your answer.

9. What would you have to do to your lab cart to change its momentum?

10. Evaluate the following student statement about the questions that you just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

"Anything with zero velocity would have zero momentum. To give something that isn't moving some momentum you would have to apply a force to it."

At each lab station you will find the following:
A computer with an interface, a motion detector, and a lab cart with a mass attached to the top.

Your teacher will place a velocity-time graph on your computer display.

The Investigation

a. Place the lab cart on the table top approximately 50 cm away from the motion detector.
b. Make sure that there is at least one meter of area in the direction that the lab cart will be pushed.
c. Turn on the graphing program.
d. Push on the lab cart so that it moves away from the motion detector with a constant velocity after you release it.
e. Stop the lab cart after it has traveled approximately 1 meter.
e. Push on the lab cart with a stronger push so that it moves away from the motion detector with a constant velocity.
f. Stop the lab cart and stop the graphing program.

11. Which push gave the lab cart a greater velocity, the first push or the stronger push?

12. Which push gave the lab cart a greater momentum, the first push or the stronger push? Explain how you know.

13. Is the relationship between force and change in momentum a direct relationship or an inverse relationship? Explain how you know.

The Investigation (continued)

a. Place the lab cart on the table top approximately 50 cm away from the motion detector.
b. Make sure that there is at least one meter of area in the direction that the lab cart will be pushed.
c. Turn on the graphing program.
d. Give the lab cart a quick push so that it moves away from the motion detector with a constant velocity of 0.5m/s after you release it. You may have to try this several times to get a speed close to 0.5 m/s.
e. Give the lab cart a push for a longer period of time so that it again moves with a constant velocity of 0.5 m/s after you release it.
f. Turn off the graphing program.

14. Describe the difference between the size of the forces that you had to exert on the lab cart in each case in order to give the cart the same velocity. Did you push with the same amount of force for the longer-time period to give your lab cart the same velocity?

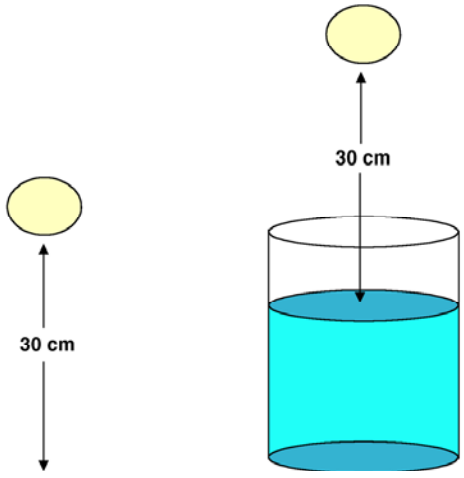
15. Did either force result in a greater change in momentum for the cart? Explain your answer.

16. Describe in terms of the amount of force and time that you used for the two different ways that you produced the same change in momentum for the lab cart.

	Amount of time required to produce the same change in momentum
Small Force	
Large Force	

Check your work with your teacher ☐

Your teacher will select a student volunteer to drop two different eggs from a height of 30 cm. The following questions relate to the demonstration that you will see.



In each case the egg was allowed to drop for a distance of 30 cm before it began to stop moving.

17. Was the broken egg going faster, slower, or the same speed when it first hit the counter top, compared to the speed of the unbroken egg when it reached the surface of the water? How do you know this?

The speed mentioned in the previous question would be the **initial velocity (v_0)** for the two eggs as they began to stop.

18. What was the final velocity for both eggs after they stopped moving?

This velocity would be the **final velocity (v)** for the two eggs as they completely stopped moving.

19. How did the change in velocity compare for the two eggs? Were they the same size or did one of the eggs have a larger change in velocity ($v - v_0$)? Explain how you know.

20. How did the change in momentum compare for the two eggs? Were they the same or did one of the eggs have a larger change in momentum ($mv - mv_0$)? Assume that the eggs had the same mass (m).

21. Which egg changed its momentum in a shorter period of time? Explain how you know.

22. Which egg must have experienced the greater force? How do you know this?

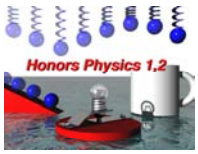
23. Summarize the relationship between force and time for objects with the same mass that experience the same change in momentum. Hint; when you have a given change in momentum for an object is the force applied to the object increased or decreased when you decrease the amount of time?

24. Evaluate the following student statements about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.

Student A
"I would rather punch a pillow than a brick with my fist since the time of collision with the pillow would be greater."

Student B
"That's whack, if the change in velocity for your fist is the same, whether you punch a pillow or a brick, then the change in velocity, which is the same as acceleration, must be the same size according to Newton's 2nd law. That would make the size of the force the same. It would hurt just as much."

Check your work with your teacher ☐



Impulse and Momentum
Impulse

CONCEPT DEVELOPMENT

During the exploration activity you determined that both the force exerted on an object as well as the length of time during which the force was exerted, produced a change in the object's momentum. **Impulse** is defined as the product of a net force and the time during which this force acts on an object. Impulse (I) = Ft, or simply I = Ft.
What would happen to you if one of your "friends" exerted an impulse on your body?

Engagement Activity and Questions

Stand about 2 meters away from your partner. Gently toss a bocce ball back and forth trying to give it the same speed each time. When you catch the ball, try stopping it as quickly as possible with your hands and then try stopping it over a longer period of time by moving your hands with the ball as you catch it.

1. When did you sense the greater force on your hands, when you tried to stop the bocce ball quickly or when you tried to stop it slowly? Explain how the length of time during which you changed the momentum of the bocce ball influenced the size of the resulting force on your hands.

The Challenge

You will determine the relationship between the impulse exerted on a body and the change in momentum experienced by this body as a result of the impulse.

Your ideas about the challenge

2. Would you experience a big change in momentum is a big impulse was exerted on your body? Explain your answer.

3. Identify the net force that would make the system, pictured below, change its momentum.

At each lab station you will find the following:

A computer with an interface, a motion detector, a lab cart, a length of string, a pulley, an electronic balance and a hanging mass.

The Investigation

a. Find the mass of your entire system using the electronic balance. The system includes the cart, string, and hanging mass. Record this quantity (m) expressed in kilograms in the data table that follows.
b. Hold the lab cart, in place, approximately 80 cm away from the pulley at the edge of the table.
c. A string should be attached to one end of the lab cart and then pass over a pulley at the end of the lab station.
d. A 20 g mass should be attached to the end of the string hanging over the pulley.
e. The motion detector should be approximately 0.5 m behind the lab cart facing in the direction the lab cart will begin to move once it is released.
f. Start the graphing program.
g. Release the lab cart from rest.
h. Stop the lab cart before it strikes the pulley and stop the graphing program.
i. From the velocity-time graph on your computer display determine the magnitude of the velocity at 0.5 seconds and at 1 second. Record these values in the data table that follows.

Data Tables

Mass of your System (kg)

Time (s)	Velocity (m/s)
0.5	
1	

4. Calculate the momentum of the system at 0.5 s and at 1 s. Be sure to label your answers with appropriate units.

$p_{0.5} = mv_{0.5} =$

$p_1 = mv_1 =$

5. Find the change in momentum (Δp) for your system between 0.5 s and 1 s. Be sure to label your answers with appropriate units.

$\Delta p = p - p_0 = p_1 - p_{0.5} =$

6. Calculate the weight of the 20 g mass (0.02 kg). Be sure to label your answer with appropriate units.

$F_g = (0.02\ kg) \cdot g = (0.02\ kg) \cdot (9.8\ m/s^2) =$

7. Calculate the impulse that made your system change its momentum.

$I = Ft = F \cdot (0.5s) =$

8. How did the size of the impulse (I) compare to the size of the change in momentum (Δp) for your system? Were they close in size or was one quantity a lot bigger than the other one?

Check your work with your teacher.

The relationship between impulse and momentum is shown by the impulse equation. The impulse equation is simply another form of Newton's 2nd law.

Newton's 2nd law can be written in equation form as you see to the right

$$F_{net} = ma$$

In the unit on kinematics you found that acceleration is defined as the rate of change of velocity. This can be written in equation form.

$$a = \frac{\Delta v}{t} = \frac{v - v_0}{t}$$

If you substitute the second expression for acceleration into Newton's 2nd law and just consider the case where there is a single unbalanced force acting on a body you get the equation you see to the right.

$$F = m\left(\frac{v - v_0}{t}\right)$$

Using algebra to rearrange the terms you get the equation you see to the right.

$$Ft = m(v - v_0)$$

Finally distributing the mass through the change in velocity, on the right side, you get one form of the impulse equation.

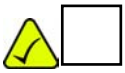
$$Ft = mv - mv_0$$

On the left side of the final equation you have the product of F · t, which is the impulse part of the impulse equation. If an unbalanced force (F) is exerted on a given mass (m) for a period of time (t), the mass experiences an **impulse**.

On the right side of the impulse equation you have the product m · v (final momentum) minus the product m · v_0 (initial momentum). The difference between final momentum and initial momentum is the **change in momentum** (Δp).

The impulse equation states that the magnitude and direction of an impulse on a body of mass m is equal to the magnitude and direction of the change in momentum produced by that impulse.

9. Show that impulse units (N · s) are equivalent to momentum units (kg · m/s). Hint; what is the unit breakdown for a Newton?

Check your work with your teacher. 

One way of expressing the impulse equation is in the form that you saw at the end of the derivation on this page:

$$\mathbf{Ft = mv - mv_0}$$

In this next investigation you will be using the impulse equation in another form in order to observe one application of this equation.

The Challenge

You will determine the magnitude of the impulse and the change in momentum for a lab cart that bounces off of a horizontal surface.

Your ideas about the challenge

A ball is dropped from a height so that it strikes the floor with a speed of 5 m/s. It then leaves the floor with a speed of 4 m/s as it bounces off of the floor.

dropped

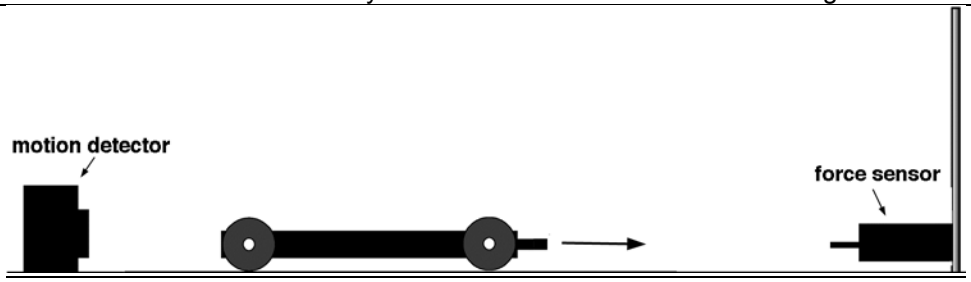
10. What must have been the change in velocity ($\Delta v = v - v_0$) for this ball during the time that it hit the table?

Check your work with your teacher.

At each lab station you will find the following:
A computer with an interface, a motion detector, a force sensor, an electronic balance, and a lab cart with a bumper
Your teacher will make sure that there is both a velocity-time graph and a force-time graph on your computer display.

The Investigation

a. The lab cart should be placed so that the bumper end of the cart faces the force sensor approximately 40 cm away.
b. The motion sensor should be approximately 40 cm behind the lab cart facing in the direction that the cart will move when it is pushed towards the force sensor.
c. Turn the graphing program on.
d. Gently push the lab cart towards the force sensor so that it bounces off of the sensor and reverses direction.
e. Stop the graphing program.
f. Take note of the velocity of the cart before and after it hit the force sensor. Record these values in the data section that follows. Be sure to use the correct sign for each velocity.
g. Record the maximum force registered by the force sensor. Record this in the data section.
h. Record the initial time of contact as well as the final time of contact in the data section.
i. Use the electronic balance to find the mass of your lab cart. Record this value in kilolgrams in the data section.



Data Tables

First (initial) velocity (m/s)	Second (final) velocity (m/s)

Maximum Force (N)

Initial time of contact (s)	Final time of contact (s)

Mass of cart (kg)

11. Explain why one of your velocities is positive while the other velocity is negative. What does the sign associated with the velocity indicate?

12. Calculate the change in velocity for your bouncing cart. Be sure to retain the sign values you received from your computer display. Label the values with appropriate units.

$\Delta v = v - v_0 =$

13. Why did your change in velocity turn out to be a negative value? What was the direction for your change in velocity?

14. Calculate the change in momentum for your cart by multiplying the mass by the change in velocity (Δv). Be sure to use the appropriate units.

$m\Delta v$ =

15. Calculate the time that the cart was in contact with the force sensor.

final time - initial time = $t - t_0$ =

16. Calculate the force by using the impulse equation ($Ft = m\Delta v$) solved for force. Be sure to use the appropriate units.

$$F = \frac{m\Delta v}{t}$$

17. How did the force that you calculated above compare to the maximum force that you received from the force sensor during the time that the cart struck the force sensor? How do you explain this?

18. Evaluate the following student statement about the investigation you performed. Identify ideas that are consistent with your observations and others that are not consistent with your observations.
"The size of the force changed during the time that the cart collided with the force sensor. The value that we calculated must be some sort of average force."

Check your work with your teacher.

Impulse and Momentum
Impulse

CONCEPT REFINEMENT

Review

The impulse that an object experiences is the product of the unbalanced force and the time during which this force acts on the object ($I = Ft$). The magnitude and direction of the impulse is equal to the magnitude and direction of the change in momentum that the object experiences ($I = \Delta p$).

The impulse equation can be expressed and utilized in a number of different ways. Below is an expansion of the impulse equation.

1. For each indicated part identify the name of the physics concept by writing the name on the line provided. One of these is done for you as an example.

Check your work with your teacher.

A 2000 kg truck moving at 10 m/s crashes into a brick wall so that it stops after a short period of time.

2. Calculate the initial momentum for this truck before the crash. Assume that the truck was traveling in the positive direction before the crash.

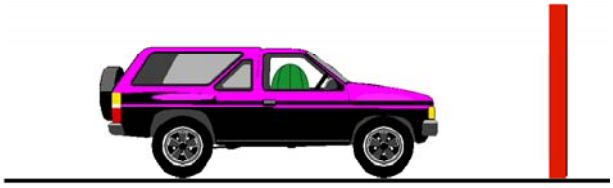
3. Calculate the final momentum for this truck after the crash.

4. Calculate the change in momentum that took place during the crash.

5. Explain why the change in momentum is a negative quantity.

6. Calculate the force on the truck if it is given that the crash occurred in a period of time of 0.01 s.

Two 5 kg watermelons are sitting in the front seat of this truck during the crash. Both watermelons have a final velocity of zero after the crash.



One of the watermelons is restrained by a seat belt and it also hits an airbag so that it stops in a period of time of 0.1s.

7. Calculate the average force that this watermelon experienced while it stopped moving.

The other watermelon stopped in a period of time of 0.001 s, since it was stopped by the dash board of the truck.

8. Calculate the average force that this other watermelon experienced while it stopped moving.

9. How many 500 N students would it take to equal the forces on each of these watermelons?

seat belt and airbag watermelon: _____

dash board watermelon: _____

Check your work with your teacher ☐

A baseball traveling at 30 m/s approaches a batter. The batter hits the ball so that it reverses direction at a speed of 40 m/s.

10. Calculate the change in velocity for this baseball.

11. Calculate the change in momentum for this baseball if it is given that the baseball has a mass of 0.1 kg.

12. What was the magnitude and direction for the impulse that the ball experienced during the contact with the bat?

13. The bat exerts a force of 15,000 N on the baseball. How long was the bat in contact with the ball?

14. What force did the ball exert on the bat? Explain how you know this.

15. What impulse did the bat experience during the contact with the ball?

16. Calculate the change in velocity for the bat given that it had a mass of 1.5 kg.

Check your work with your teacher ☐