Chapter 9 Homework
Due: 9:00am on Monday, October 19, 2009
Note: To understand how points are awarded, read your instructor's Grading Policy.

Impulse on a Baseball

Learning Goal: To understand the relationship between force, impulse, and momentum.

The effect of a net force \( \sum F \) acting on an object is related both to the force and to the total time the force acts on the object. The physical quantity impulse \( \vec{J} \) is a measure of both these effects. For a constant net force, the impulse is given by

\[
\vec{J} = \vec{F} \Delta t.
\]

The impulse is a vector pointing in the same direction as the force vector. The units of \( \vec{J} \) are \( \text{N} \cdot \text{s} \) or \( \text{kg} \cdot \text{m/s} \).

Recall that when a net force acts on an object, the object will accelerate, causing a change in its velocity. Hence the object's momentum \( \Delta \vec{p} = m \Delta \vec{v} \) will also change. The impulse-momentum theorem describes the effect that an impulse has on an object's motion:

\[
\Delta \vec{p} = \vec{J} = \vec{F} \Delta t.
\]

So the change in momentum of an object equals the net impulse, that is, the net force multiplied by the time over which the force acts. A given change in momentum can result from a large force over a short time or a smaller force over a longer time.

In Parts A, B, C consider the following situation. In a baseball game the batter swings and gets a good solid hit. His swing applies a force of 12,000 N to the ball for a time of \( 0.7 \times 10^{-5} \) s.

Part A
Assuming that this force is constant, what is the magnitude \( J \) of the impulse on the ball?

Enter your answer numerically in newton seconds.

**ANSWER:**

\[ J = 8.40 \text{ N} \cdot \text{s} \]

Correct

We often visualize the impulse by drawing a graph of force versus time. For a constant net force such as that used in the previous part, the graph will look like the one shown in the figure.

![Graph of force versus time](image)

Part B

The net force versus time graph has a rectangular shape. Often in physics geometric properties of graphs have physical meaning.

**ANSWER:**

For this graph, the **area** of the rectangle corresponds to the impulse.

The assumption of a constant net force is idealized to make the problem easier to solve. A real force, especially in a case like the one presented in Parts A and B, where a large force is applied for a short time, is not likely to be constant.

A more realistic graph of the force that the swinging bat applies to the baseball will show the force building up to a maximum value as the bat comes into full contact with the ball. Then as the ball loses contact with the bat, the graph will show the force decaying to zero. It will look like the graph in the figure.

![Graph of force versus time](image)

Part C
If both the graph representing the constant net force and the graph representing the variable net force represent the same impulse acting on the baseball, which geometric properties must the two graphs have in common?

**ANSWER:**

- Maximum force
- Area
- Slope
When the net force varies over time, as in the case of the real net force acting on the baseball, you can simplify the problem by finding the average net force $\vec{F}_{\text{avg}}$ acting on the baseball during time $\Delta t$. This average net force is treated as a constant force that acts on the ball for time $\Delta t$. The impulse on the ball can then be found as $J = \vec{F}_{\text{avg}} \Delta t$.

Graphically, this method states that the impulse of the baseball can be represented by either the area under the net force versus time curve or the area under the average net force versus time curve. These areas are represented in the figure as the areas shaded in red and blue respectively.

The impulse of an object is also related to its change in momentum. Once the impulse is known, it can be used to find the change in momentum, or if either the initial or final momentum is known, the other momentum can be found. Keep in mind that $J = \Delta \vec{m}$ (or $J = \Delta v \cdot \Delta t$). Because both impulse and momentum are vectors, it is essential to account for the direction of each vector, even in a one-dimensional problem.

**Part D**

Assume that a pitcher throws a baseball so that it travels in a straight line parallel to the ground. The batter then hits the ball so it goes directly back to the pitcher along the same straight line. Define the direction the pitcher originally throws the ball as the $+x$ direction.

**ANSWER:**

The impulse on the ball caused by the bat will be in the $-x$ direction.

**Part E**

Now assume that the pitcher in Part D throws a 0.145-kg baseball parallel to the ground with a speed of 32 m/s in the $+x$ direction. The batter then hits the ball so it goes directly back to the pitcher along the same straight line. What is the ball’s velocity just after leaving the bat if the bat applies an impulse of $-8.4 \text{ N} \cdot \text{s}$ to the baseball?

**Enter your answer numerically in meters per second.**

**ANSWER:**

$-25.9 \text{ m/s}$

The negative sign in the answer indicates that after the bat hits the ball, the ball travels in the opposite direction to that defined to be positive.

**Conceptual Question 9.1**

**Part A**

Rank in order, from largest to smallest, the momenta $\vec{p}_1$ to $\vec{p}_4$ of the objects in the figure.

**Rank from largest to smallest. To rank items as equivalent, overlap them.**

**ANSWER:**

...
Part A
Find the magnitude $p_i$ of the total initial momentum of the two-block system.

Hint A.1 How to approach the problem

Express your answer numerically.

Answer: $p_i = 183 \text{ kg} \cdot \text{m/s}$

Correct

Part B
Find $v_f$, the magnitude of the final velocity of the two-block system.

Hint B.1 How to approach the problem

Express your answer numerically.

Answer: $v_f = 2.82 \text{ m/s}$

Correct

Problem 9.17
A 300 g bird flying along at 15 m/s sees a 10 g insect heading straight toward it with a speed of 30 m/s (as measured by an observer on the ground, not by the bird). The bird opens its mouth wide and enjoys a nice lunch.

Part A
What is the bird's speed immediately after swallowing?

Answer: $4.84 \text{ m/s}$

Correct

Momentum in an Explosion
A giant "egg" explodes as part of a fireworks display. The egg is at rest before the explosion, and after the explosion, it breaks into two pieces, with the masses indicated in the diagram, traveling in opposite directions.

Part A
What is the momentum $p_{A,i}$ of piece A before the explosion?

Hint A.1 Initial momentum

Express your answer numerically in kilogram meters per second.

Answer: $p_{A,i} = 0 \text{ kg} \cdot \text{m/s}$

Correct

Similarly, piece B has zero momentum before the collision. The total momentum of the "egg," the sum of the two individual momenta, is also zero.

Part B
During the explosion, is the force of piece A on piece B greater than, less than, or equal to the force of piece B on piece A?

Hint B.1 Forces in an explosion

Hint not displayed
Part C
The momentum of piece B is measured to be 500 kg \cdot m/s after the explosion. Find the momentum $p_{A,f}$ of piece A after the explosion.

Hint C.1 Conservation of momentum

Enter your answer numerically in kilogram meters per second.

**ANSWER:**

$p_{A,f} = -500$ kg \cdot m/s

Catching a Ball on Ice

Olaf is standing on a sheet of ice that covers the football stadium parking lot in Buffalo, New York; there is negligible friction between his feet and the ice. A friend throws Olaf a ball of mass 0.400 kg that is traveling horizontally at 11.7 m/s. Olaf's mass is 69.2 kg.

Part A

If Olaf catches the ball, with what speed $v_f$ do Olaf and the ball move afterward?

Hint A.1 How to approach the problem

Hint A.2 Find the ball's initial momentum

Express your answer numerically in centimeters per second.

**ANSWER:**

$v_f = 6.72$ cm/s

Part B

If the ball hits Olaf and bounces off his chest horizontally at 7.40 m/s in the opposite direction, what is his speed $v_f$ after the collision?

Hint B.1 How to approach the problem

Hint B.2 Find the ball's final momentum

Express your answer numerically in centimeters per second.

**ANSWER:**

$v_f = 11.0$ cm/s

Colliding Cars

In this problem we will consider the collision of two cars initially moving at right angles. We assume that after the collision the cars stick together and travel off as a single unit. The collision is therefore completely inelastic.

Two cars of masses $m_1$ and $m_2$ collide at an intersection. Before the collision, car 1 was traveling eastward at a speed of $v_{1,i}$ and car 2 was traveling northward at a speed of $v_{2,i}$. After the collision, the two cars stick together and travel off in the direction shown.
First, find the magnitude of \( \vec{v}' \), that is, the speed \( v' \) of the two-car unit after the collision.

Express \( v' \) in terms of \( m_1, m_2, \) and the cars' initial speeds \( v_1 \) and \( v_2 \).

\[
v' = \sqrt{\frac{(m_1v_1)^2 + (m_2v_2)^2}{(m_1 + m_2)}}
\]

Part B

Find the tangent of the angle \( \theta \).

Express your answer in terms of the momenta of the two cars, \( p_1 \) and \( p_2 \).

\[
\tan(\theta) = \frac{p_1}{p_2}
\]

Part C

Suppose that after the collision, \( \tan(\theta) = 1 \); in other words, \( \theta = 45^\circ \). This means that before the collision:

- The magnitudes of the momenta of the cars were equal.
- The masses of the cars were equal.
- The velocities of the cars were equal.

Conservation of Momentum in Two Dimensions Ranking Task

Part A

The figures below show bird's-eye views of six automobile crashes an instant before they occur. The automobiles have different masses and incoming velocities as shown. After impact, the automobiles remain joined together and skid to rest in the direction shown by \( \theta_{final} \). Rank these crashes according to the angle \( \theta \), measured counterclockwise as shown, at which the wreckage initially skids.

Problem 9.39

A firecracker in a coconut blows the coconut into three pieces. Two pieces of equal mass fly off south and west, perpendicular to each other, at 20 m/s. The third piece has twice the mass as the other two.

Part A

What is the speed of the third piece?

Express your answer using two significant figures.

\[
14 \text{ m/s}
\]

Part B

What is the direction of the third piece? Give the direction as an angle east of north.

Express your answer using two significant figures.

\[
\theta = 45^\circ \text{ east of north}
\]
Your score on this assignment is 99.3%. 
You received 59.59 out of a possible total of 60 points.