Unit 1: Momentum & Impulse

Impulse and Change in Momentum

Momentum is a vector quantity. It is the product of a body's mass and its velocity.

$\vec{p} = m\vec{v}$ Units: kg·m/s

Impulse is a vector quantity. It is defined as the application of a net force on an object over a period of time.

Impulse $= \vec{F}_{net} \cdot \Delta t$ Units: N·s

This **impulse-momentum equation** states that an impulse on an object causes a change in its momentum (i.e. $m\,\Delta v$) :

Impulse $= \vec{F}\,\Delta t = m\,\Delta\vec{v}$ or $\vec{F}\,\Delta t = \Delta\vec{p}$

The impulse-momentum equation well explains the concept of **cushioning**.

Based on $F = \dfrac{\Delta p}{\Delta t}$, we see that $F \propto \dfrac{1}{\Delta t}$ (inverse relationship)

A cushion will change an object's momentum over a longer period of time, and thus, this will decrease the force on the object.

Note: Impulse (change in momentum) remains constant and unaffected.

Ex. A 16.0 kg object hits the ground with a downward velocity of 62.64 km/h. If it experiences an impulse from the ground of 500 Ns upwards, determine its final momentum.

1. A ball is thrown at 10 m/s towards various barriers. In which case does the ball experience the greatest impulse?

   A. The ball hits a wall and rebounds at 2.0 m/s.
   B. The ball hits a wall and rebounds at 7.0 m/s.
   C. The ball hits a wall, sticks to it and stops moving.
   D. The ball breaks a window and continues moving at 10 m/s in the original direction.

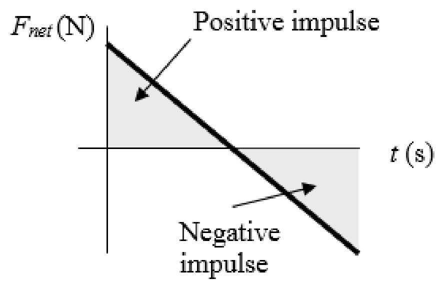
2. A rock climber falls and is saved from injuries by a climbing rope that is slightly elastic. The importance of the elasticity of the climbing rope can be understood in terms of impulse because elasticity results in

   A. decreased force during an increased time interval
   B. increased force during an increased time interval
   C. decreased force during a decreased time interval
   D. increased force during a decreased time interval

Impulse for a Changing Net Force

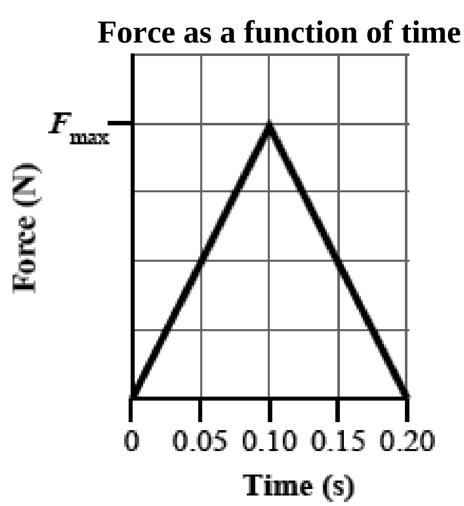
If the net force on an object is changing (usually shown on a *F* - *t* graph), then:

Impulse = Area between the line and the *t*-axis



This graph shows the relationship between the force on a 0.801 kg football and the time a kicker's foot is in contact with the ball.

As a result of the kick, the football, which was initially at rest, has a final speed of 28.5 m/s.



NR. 3 The magnitude of the maximum force, F_{max}, exerted on the ball during the kicking process, expressed in scientific notation, is $\boldsymbol{a}.\boldsymbol{b} \times 10^{c}$ N.

The values of ***a***, ***b***, and ***c*** are _____ , _____ , and _____.

Law of Conservation of Momentum

Momentum is conserved for collisions and explosions only if the system is **isolated**.

- All objects involved in the collision / explosion must be included.
- There is no net external force ($F_{net} = 0$) on the entire system throughout the motion
  So, when you consider the entire system, all forces must cancel!

Conservation of momentum states that the total momentum of a system remains constant.

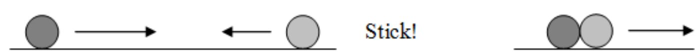
i.e. $\vec{p}_{Ti} = \vec{p}_{Tf}$

There are three interactions you should be familiar with:

#1. Collision: Hit and bounce

$$\vec{p}_{1i} + \vec{p}_{2i} = \vec{p}_{1f} + \vec{p}_{2f}$$
$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

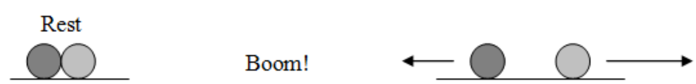
#2. Collision: Objects stick to each other



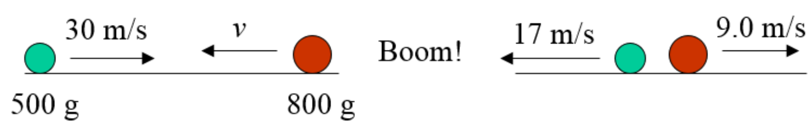
$$\vec{p}_{1i} + \vec{p}_{2i} = \vec{p}_{12f}$$
$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = (m_1 + m_2)\vec{v}_f$$

#3. Explosion (Recoil): An object (initially at rest) explodes into two pieces.

$$0 = \vec{p}_{1f} + \vec{p}_{2f}$$
$$0 = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$



Ex. Determine the initial velocity of the 800 g ball.



Elastic Collisions

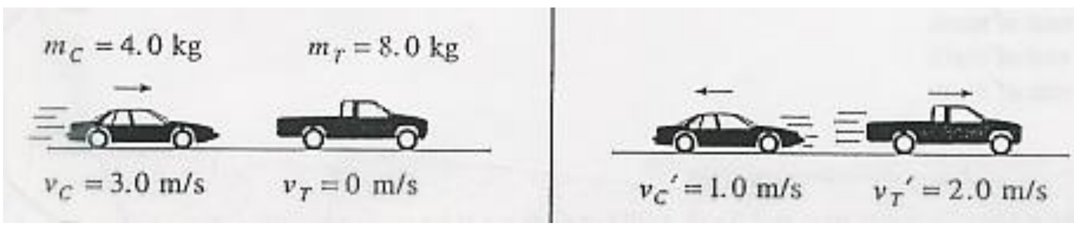
Elastic collisions are those where both momentum and kinetic energy are conserved.

$$\vec{p}_{Ti} = \vec{p}_{Tf} \qquad \text{and} \qquad Ek_{Ti} = Ek_{Tf}$$

Note: A collision is considered **inelastic** when momentum is conserved, but kinetic energy is not conserved (energy is lost due to heat / sound).

Use the following information to answer the next question.

A 4.0 kg toy car, moving East at 3.0 m/s, collides with an 8.0 kg toy truck that is initially at rest. After the collision, the car is moving West at 1.0 m/s, while the truck is moving East at 2.0 m/s.



7. Which of the following is true?

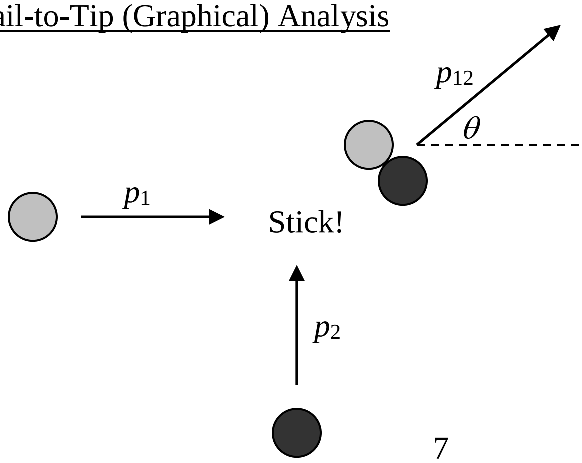
   A. Momentum is not conserved, and the collision is not elastic.
   B. Momentum is conserved, and the collision is not elastic.
   C. Momentum is not conserved, and the collision is elastic.
   D. Momentum is conserved, and the collision is elastic.

Two-Dimensional Interactions

The Law of Conservation of Momentum also applies to **two dimensional interactions**. Since momentum is a vector quantity that is conserved during interactions, we use a **vector diagram** to solve two dimensional problems.

There are two situations you need to be familiar with:

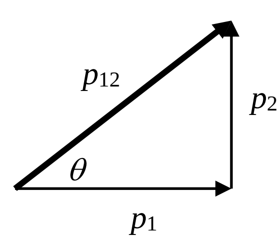
1. Tail-to-Tip (Graphical) Analysis



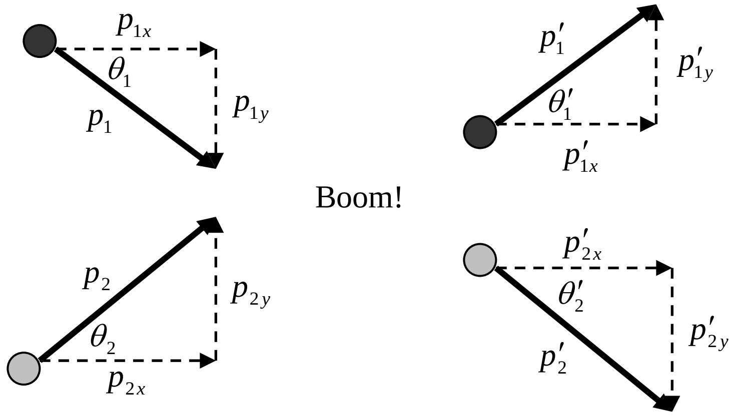
Conservation of momentum

$$\vec{p}_{Ti} = \vec{p}_{Tf}$$

$$\vec{p}_1 + \vec{p}_2 = \vec{p}_{12}$$



2. Components Analysis



Conservation of momentum (x)

$$\vec{p}_{Tx} = \vec{p}_{Tx}'$$

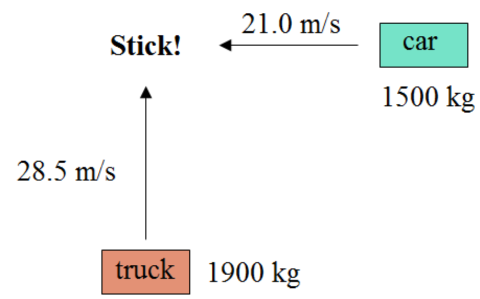
$$\vec{p}_{1x} + \vec{p}_{2x} = \vec{p}_{1x}' + \vec{p}_{2x}'$$

Conservation of momentum (y)

$$\vec{p}_{Ty} = \vec{p}_{Ty}'$$

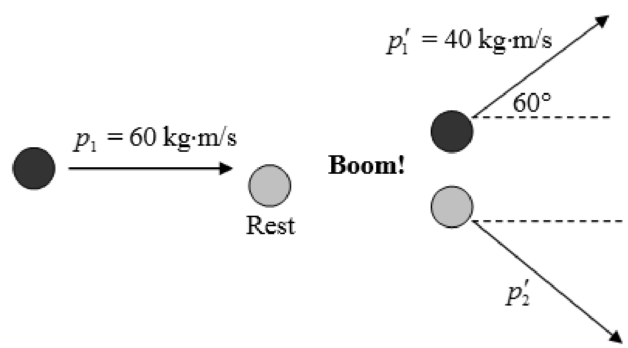
$$\vec{p}_{1y} + \vec{p}_{2y} = \vec{p}_{1y}' + \vec{p}_{2y}'$$

Ex. Sketch the vector triangle that would determine their velocity after the collision.



Components Analysis

Ex. For the collision shown, determine the magnitude of p_2'.



Curve-Straightening and Graphical Analysis

Example. In a circular motion experiment, the period of rotation (T) is varied and the resulting centripetal acceleration (a_c) is measured. All other variables are held constant.

$$a_c T^2 = 4\pi^2 r$$

where r is the radius of the circle.

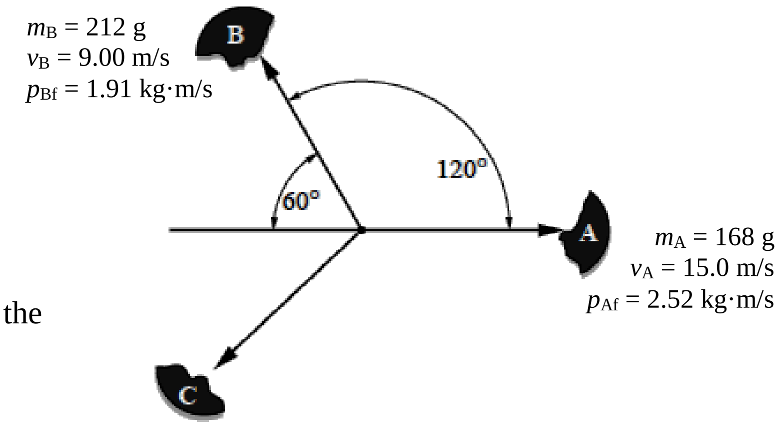
- Sketch the straightened curve.

- Explain how to determine the radius using the significance of the slope.

8. A 2.0 kg puck traveling due east at 2.5 m/s collides with a 1.0 kg puck traveling due south at 3.0 m/s. They stick together on impact. The resultant direction of the combined pucks is

   A. 31º S of E
   B. 40º S of E
   C. 50º S of E
   D. 59º S of E

9. A glass ornament of mass 575 g sitting on a table is subjected to a resonant frequency of 440 Hz. The ornament breaks into three pieces that travel horizontally across the frictionless tabletop. Fragment **A** has a mass of 168 g and fragment **B** has a mass of 212 g.



The magnitude of the momentum of the third piece of glass, fragment C, is

A. 5.19 kg·m/s
B. 3.85 kg·m/s
C. 2.28 kg·m/s
D. 0.610 kg·m/s

10. In a circular motion experiment, a mass is swung in a circle with a constant radius *r*. The period of rotation (*T*) is varied and the resulting orbital speed (*v*) is measured. The known equation relating the variables would be $vT = 2\pi r$.
For the straightened relationship, which of the following determines the radius from the significance of the slope?

A. $r = 2\pi \cdot slope$

B. $r = \dfrac{1}{2\pi \cdot slope}$

C. $r = \dfrac{2\pi}{slope}$

D. $r = \dfrac{slope}{2\pi}$

Unit 2: Forces and Fields

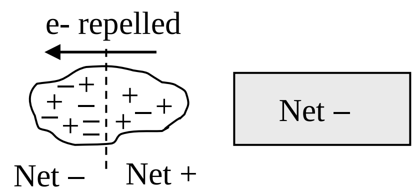
The **Fundamental Law of Electric Charges** states that:

- There are two types of charges: positive (deficit of e-) and negative (excess of e-)
- Like charges repel each other
- Opposite charges attract each other

Law of Conservation of Charges: Electric charge can neither be created nor destroyed but may be transferred.

Induced Separation of Charge (Charged object attracting a neutral object)

When a net negative object (for example) is brought near (without touching) the neutral object, the electrons are repelled (due to like charges). This induces a separation of charge within the neutral object. Since an opposite charge is induced in the closest region, they attract.



Matter can become electrically charged through three different processes:

1. Charging by friction (gain equal but opposite charges)

   When two objects (typically insulators) are rubbed together, friction creates heat energy. The material with a stronger hold on electrons will strip electrons off the other material. This gives the objects equal but opposite charges.

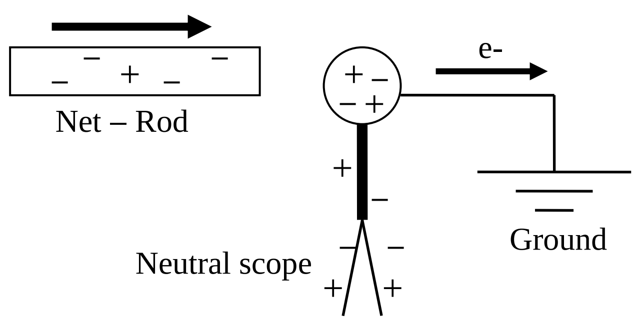
2. Charging by conduction (gains same charge)

   When a negatively charged rod (for example) is touched to a neutral conducting object, some of the excess electrons on the rod (repelled by neighbouring electrons), move over to the object. Thus, both objects gain a negative charge.

   Note: If the two metal objects are identical (in mass and volume), then they will gain equal charges.

3. Charging by induction (gains opposite charge)

   When a net negative rod (for example) is brought near (without touching) a grounded electroscope, electrons are repelled (due to like charges) and travel into the ground. If the ground is then removed (while the negative rod is still close), then the scope gains a positive charge.



RTD EXAM PREP

Physics 30

Practice Questions

"I'm warning you, Perkins – your flagrant disregard for the laws of physics will not be tolerated!"

NR. 1 In a vehicle safety test, a 1 580 kg truck travelling at 60.0 km/h collides with a concrete barrier and comes to a complete stop in 0.120 s. The magnitude of the change in the momentum of the truck, expressed in scientific notation, is __________ $\times 10^{w}$ kg·m/s.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

2. A small rubber ball moving at high speed strikes a stationary cart. As a result of the collision, the rubber ball rebounds and the cart rolls forward. Which object experienced the greater magnitude of impulse?

   A. The cart
   B. The rubber ball
   C. Both experienced the same magnitude of impulse
   D. It depends on whether the collision was elastic or inelastic

3. *The risk of a motorist becoming fatally injured in a vehicle collision is reduced when an airbag or a seatbelt is used because the airbag or seatbelt __i__ change in momentum by ___ii__ the stopping force the motorist experiences.*

   The statement above is completed by the information in row

Row	*i*	*ii*
A.	achieves the same	decreasing
B.	achieves the same	increasing
C.	decreases the	decreasing
D.	increases the	increasing

NR. 4 A 1 000 kg vehicle moving westward at 15.0 m/s is subjected to a 10 000 N·s impulse to the north. The magnitude of the final momentum of the vehicle, expressed in scientific notation is $\boldsymbol{a.bc} \times 10^{d}$ kg·m/s.

The values of ***a***, ***b***, ***c***, and ***d*** are _____ , _____ , _____ , and _____.

NR. 5 A 0.150 kg ball moving at 40.0 m/s is struck by a bat. The bat reverses the ball's direction and gives it a speed of 50.0 m/s. The average force the bat applies to the ball if they are in contact for 6.00 ms, expressed in scientific notation is $\boldsymbol{a.bc} \times 10^{d}$ N.

The values of ***a***, ***b***, ***c***, and ***d*** are _____ , _____ , _____ , and _____.

SOLUTIONS

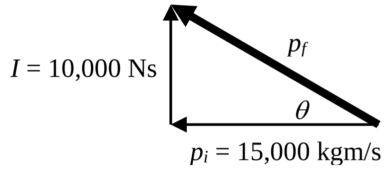
1. **2.63** $\Delta\vec{p} = m\Delta\vec{v} = m(\vec{v}_f - \vec{v}_i)$ = 1580 kg (0 – 16.67 m/s) = –2.63 × 10^4 kg·m/s

2. **C** Based on Newton's 3rd Law, the forces (and thus, impulses) are equal but opposite.

3. **A** An airbag has no effect on impulse (change in momentum). Instead, it increases the time of collision, thus decreasing the force (inverse relationship between F and t).

4. **1804** $\vec{I} = \Delta\vec{p} = \vec{p}_f - \vec{p}_i$ $\vec{p}_f = \vec{p}_i + \vec{I}$

$p_f = \sqrt{10{,}000^2 + 15{,}000^2}$ = 1.80 × 10^4 kg·m/s



5. **2253** (Ref: Away from bat +) $\vec{F}\Delta t = m\Delta\vec{v} = m(\vec{v}_f - \vec{v}_i)$

$\vec{F} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t} = \frac{0.150\,kg[(50m/s) - (-40m/s)]}{6 \times 10^{-3}s}$ = 2.25 × 10^3 N

6. **C** Since force is constant, $\vec{F}\Delta t = m\Delta\vec{v}$ $\Delta\vec{v} = \frac{\vec{F}\Delta t}{m} = \frac{(8.0\,N)(1.0\,s)}{5.0\,kg}$ = 1.6 m/s

$\Delta\vec{v} = \vec{v}_f - \vec{v}_i$ $\vec{v}_f = \Delta\vec{v} + \vec{v}_i$ = 1.6 m/s + 3.0 m/s = 4.6 m/s

7. **A** $\vec{I}$ = total area = (8.0 N) (1.0 s) + 0.5 (8.0 N) (0.5 s) = 8 Ns + 2 Ns = 10 N·s

8. **13.0** (East +, West –) Cons of Momentum $\vec{p}_T = \vec{p}'_T$ $m_1\vec{v}_1 = m_1\vec{v}'_1 + m_2\vec{v}'_2$

(1.2) (40) = (1.2) (–25) + 6 v v = 13 m/s East

9. **4431** (Up +, Down –) Cons of Momentum $\vec{p}_T = \vec{p}'_T$ $0 = m_1\vec{v}'_1 + m_2\vec{v}'_2$

0 = (0.002) (841) + 3.80 v v = –4.43 × 10^{-1} m/s

10. **9.09** Cons of Momentum $\vec{p}_T = \vec{p}'_T$ $m_1\vec{v}_1 = (m_1 + m_2)v'$

(1.00 × 10^4) (2) = (2.20 × 10^4) v v = 9.09 × 10^{-1} m/s

11. **A** In a collision, momentum is conserved. Since this collision will definitely create heat and sound, it is not elastic (i.e. total kinetic energy is not conserved).

12. **8.41** Before the collision: p_{car} = 29,400 kgm/s x = 29,400 kgm/s ; y = 0
After: x_{1f} = 20,000 cos 20° = 18,794 kgm/s ; y_{1f} = 20,000 sin20° = 6840 kgm/s

$\vec{p}_{Tx} = \vec{p}'_{Tx}$ 29,400 = 18,794 + x_{2f} x_{2f} = 10,606 kgm/s

$\vec{p}_{Ty} = \vec{p}'_{Ty}$ 0 = 6840 + y_{2f} y_{2f} = –6840 kgm/s

$p = \sqrt{10606^2 + 6840^2}$ = 12,621 kgm/s ; $v = \frac{p}{m} = \frac{12621}{1500}$ = 8.41 m/s

13. **A** Cons of Momentum $\vec{p}_T = \vec{p}'_T$ $0 = m_1\vec{v}'_1 + m_2\vec{v}'_2$

0 = (3) (15) + (110 + 20 – 3) v v = –0.35 m/s

14. **C** Before the collision, the y-component of the momentum is zero.
After: p_{1f} = (18.8) (0.14) = 2.632 kgm/s ; y_{1f} = 2.632 sin 67° = 2.4228 kgm/s
The total momentum after the collision must also be zero, so the y-components are equal but opposite. Thus, y_{2f} = –2.4228 kgm/s