DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

TSOKOS LESSON 2-4
MOMENTUM AND IMPULSE

Essential Idea:

- Conservation of momentum is an example of a law that is never violated.

Nature Of Science:

- The concept of momentum and the principle of momentum conservation can be used to analyze and predict the outcome of a wide range of physical interactions, from macroscopic motion to microscopic collisions.

International-Mindedness:

- Automobile passive safety standards have been adopted across the globe based on research conducted in many countries.

Theory Of Knowledge:

- Do conservation laws restrict or enable further development in physics?

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Understandings:

- Newton's second law expressed in terms of rate of change of momentum
- Impulse and force–time graphs
- Conservation of linear momentum
- Elastic collisions, inelastic collisions and explosions

Applications And Skills:

- Applying conservation of momentum in simple isolated systems including (but not limited to) collisions, explosions, or water jets
- Using Newton's second law quantitatively and qualitatively in cases where mass is not constant

Applications And Skills:

- Sketching and interpreting force–time graphs
- Determining impulse in various contexts including (but not limited to) car safety and sports
- Qualitatively and quantitatively comparing situations involving elastic collisions, inelastic collisions and explosions

Guidance:

- Students should be aware that $F = ma$ is the equivalent of $F = \frac{\Delta p}{\Delta t}$ only when mass is constant
- *Solving simultaneous equations involving conservation of momentum and energy in collisions will not be required*

Guidance:

- Calculations relating to collisions and explosions will be restricted to one-dimensional situations
- A comparison between energy involved in inelastic collisions (in which kinetic energy is not conserved) and the conservation of (total) energy should be made

Data Booklet Reference:

$$p = mv$$

$$F = \frac{\Delta p}{\Delta t}$$

$$E_K = \frac{p^2}{2m}$$

$$\text{Im}\,pulse = F\Delta t = \Delta p$$

Utilization:

- Jet engines and rockets

Aims:

- Aim 3: conservation laws in science disciplines have played a major role in outlining the limits within which scientific theories are developed

Aims:

- Aim 6: experiments could include (but are not limited to): analysis of collisions with respect to energy transfer; impulse investigations to determine velocity, force, time, or mass; determination of amount of transformed energy in inelastic collisions

Aims:

- Aim 7: technology has allowed for more accurate and precise measurements of force and momentum, including video analysis of real-life collisions and modeling/simulations of molecular collisions

Introductory Video

Concept of Momentum

- Momentum is a product of the mass and the velocity of an object

$$\vec{p} = m\vec{v}$$

- Momentum is a vector quantity whose direction is the same as the velocity
- Unit of momentum is

$$(kg)(m/s) = kg \bullet m/s$$

- But is often referred to as N·s

$$(kg \bullet m/s^2)(s) = kg \bullet m/s$$

Newton's Second Law

- The average net force on a body equals the ***rate of change*** of a body's momentum

$$\vec{F}_{net} = m\vec{a}$$

$$\vec{F}_{net} = m\frac{\Delta\vec{v}}{\Delta t}$$

$$\vec{F}_{net} = m\frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

$$\vec{F}_{net} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}$$

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$$

Example 1

$$\vec{p} = m\vec{v}$$

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$$

- A 0.100 kg ball moving left to right at 5 m/s bounces off a vertical wall with no change in speed. If the collision lasted for 0.1 s, what force did the wall exert on the ball?
  A. 0 N
  B. 5 N
  C. 10 N
  D. -10 N
  E. Cannot be determined from the information

Example 1

- A 0.100 kg ball moving left to right at 5 m/s bounces off a vertical wall with no change in speed. If the collision lasted for 0.1 s, what force did the wall exert on the ball?
  A. .
  B. .
  C. .
  D. -10 N
  E. .

$$\vec{p} = m\vec{v}$$

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{\Delta t}$$

$$\vec{F}_{net} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}$$

$$\vec{F}_{net} = \frac{-0.5 - 0.5}{0.1}$$

$$\vec{F}_{net} = \frac{-1.0}{0.1}$$

$$\vec{F}_{net} = -10N$$

Impulse

$$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t}$$

- The desire to do something without thinking, usually based on emotion
- If Δt is large, then F_{net} represents average force on the body
- If Δt is infinitely small, then F_{net} represents instantaneous force on the body and,

$$\Delta \vec{p} = \vec{F}_{net} \Delta t$$

is called the impulse of the force

Impulse

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- Impulse is the area under the curve of a force-time graph and equals the ***total*** momentum change

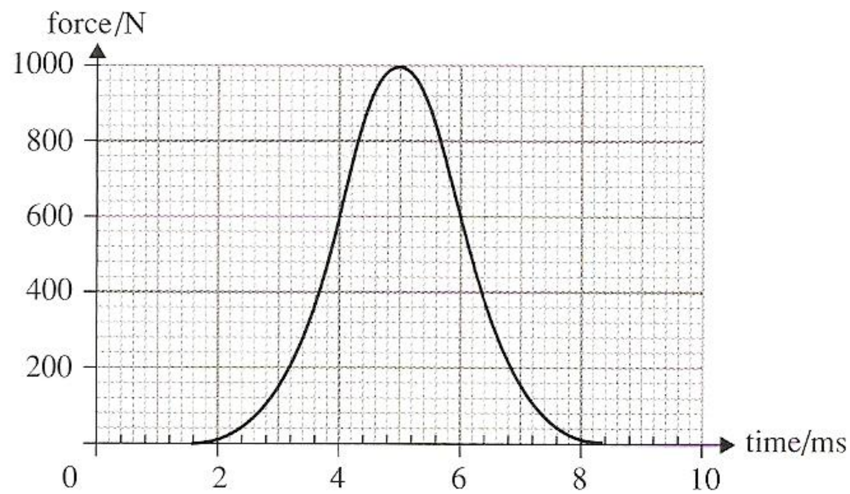
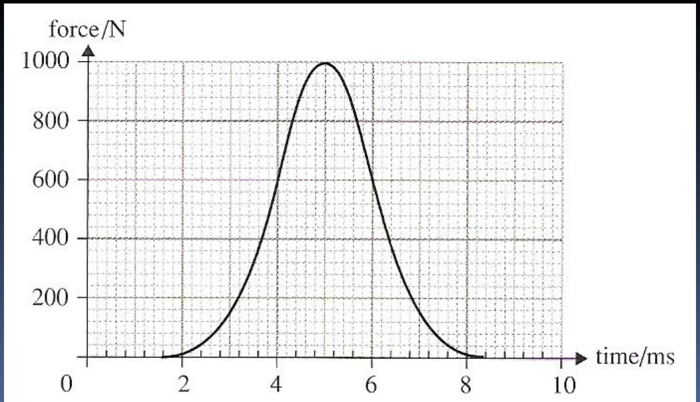


Figure 6.5 The area under the force–time graph gives the total momentum change of the body the force acts upon.

Impulse

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

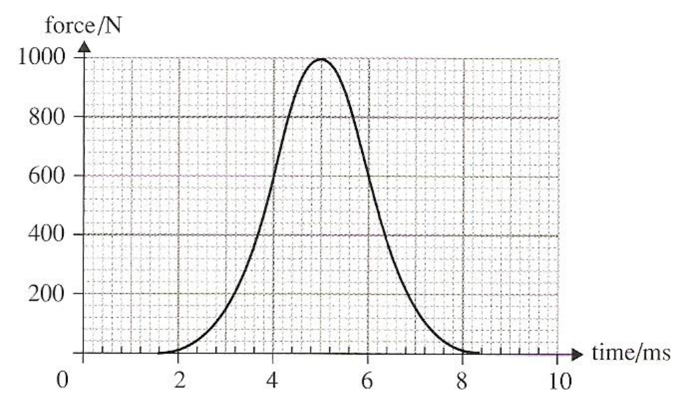
- Q. I push a box with one hand, then with two hands. Can I do this with the same impulse each time?



Impulse

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

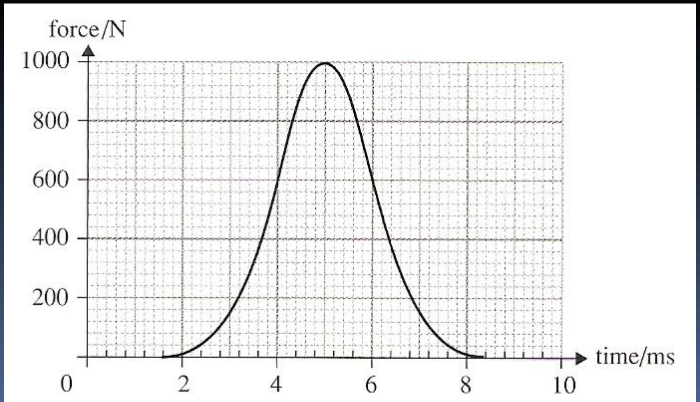
- Q. I push a box with one hand, then with two hands. Can I do this with the same impulse each time?
- A. Yes. The push with two hands will involve a larger force, but if done over a shorter period of time it will have the same impulse as with one hand.



Impulse

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- Q. What impact will this have (pun intended) on a car accident with or without an airbag?

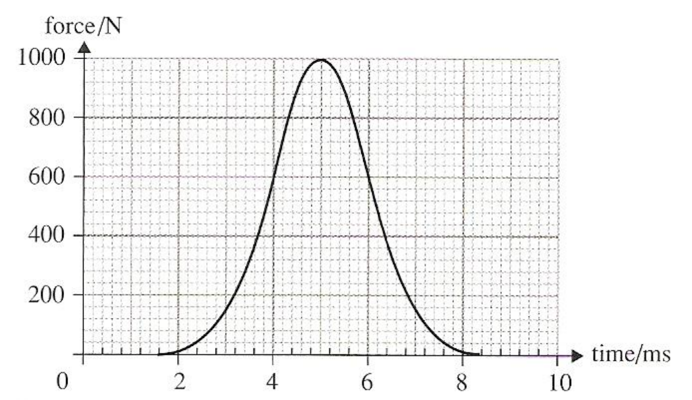


Impulse

$$\Delta\vec{p} = \vec{F}_{net}\Delta t$$

- Q. What impact will this have (pun intended) on a car accident with or without an airbag?
- A. Without an airbag, the force is applied over a short period of time as the driver hits the steering wheel. With an airbag, the momentum changes over a longer period of time so the net force is reduced.

$$\frac{\Delta\vec{p}}{\Delta t} = \vec{F}_{net}$$



Conservation of Momentum

Conservation of Momentum

- The total momentum of a system is defined as the ***vector sum*** of the individual momenta

$$P_{total} = m_1\vec{v}_1 + m_2\vec{v}_2$$

- When no external forces act on a system, the total momentum of the system stays the same

$$m_{1i}\vec{v}_{1i} + m_{2i}\vec{v}_{2i} = m_{1f}\vec{v}_{1f} + m_{2f}\vec{v}_{2f}$$

Conservation of Momentum

- If a car runs into a wall and the wall doesn't move, how is momentum conserved?
- If I jump off a chair and land on the ground, how is momentum conserved?

$$m_{1i}\vec{v}_{1i} + m_{2i}\vec{v}_{2i} = m_{1f}\vec{v}_{1f} + m_{2f}\vec{v}_{2f}$$

Where does momentum go?

Two Dimensional Collisions

- Momentum is a vector quantity and is conserved as a vector quantity
- When bodies collide at an angle, momentum is conserved in the resolved x- and y-axes

Two Dimensional Collisions

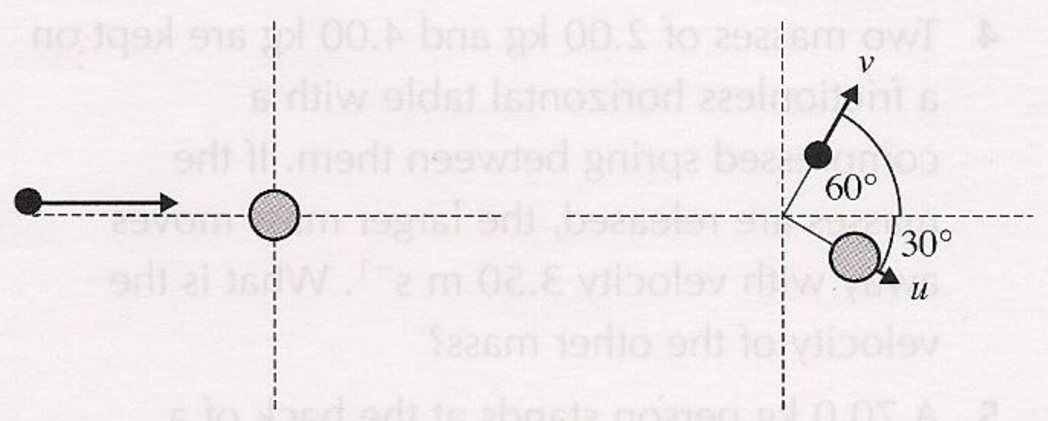


Figure 6.16.

- Consider a collision of the above two masses
- The smaller is 4.0kg moving at 12m/s
- The larger is 12.0kg at rest
- After the collision, the smaller deflects at a 60 degree angle above the horizontal
- The larger deflects 30 degrees below the horizontal

Two Dimensional Collisions

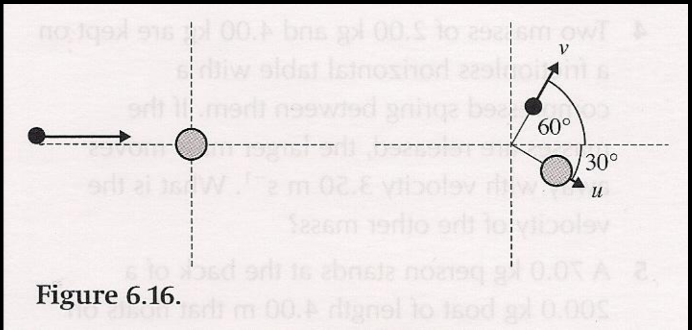


Figure 6.16.

$$x-axis$$

$$P_{i_x} = m_{1i}\vec{v}_{1i} + m_{2i}\vec{v}_{2i}$$

$$P_{i_x} = (4)(12) + 0 = 48$$

$$P_{f_x} = \left(m_{1f}\vec{v}_{1f}\right)\cos 60 + \left(m_{2f}\vec{v}_{2f}\right)\cos 30$$

$$P_{f_x} = 4\vec{v}_{1f}\cos 60 + 12\vec{v}_{2f}\cos 30 = 48$$

- m_{1i} = 4.0kg
- v_{1i} = 12m/s
- m_{2i} = 12.0kg
- v_{2i} = 0

Two Dimensional Collisions

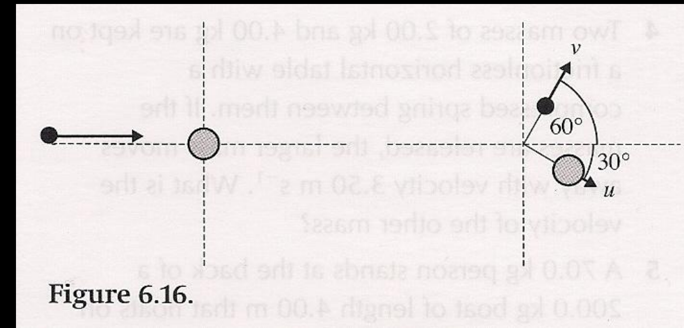


Figure 6.16.

$$x - axis$$

$$P_{f_x} = 4\vec{v}_{1f}\cos 60 + 12\vec{v}_{2f}\cos 30 = 48$$

$$y - axis$$

$$P_{i_y} = 0$$

$$P_{f_y} = \left(m_{1f}\vec{v}_{1f}\right)\sin 60 + \left(m_{2f}\vec{v}_{2f}\right)\sin 30$$

$$P_{f_y} = 4\vec{v}_{1f}\sin 60 + 12\vec{v}_{2f}\sin 30 = 0$$

- m_{1i} = 4.0kg
- v_{1i} = 12m/s
- m_{2i} = 12.0kg
- v_{2i} = 0

Two Dimensional Collisions

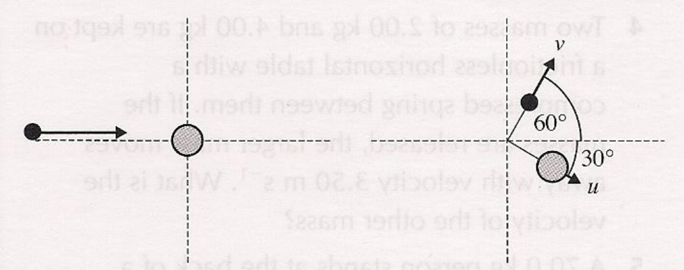


Figure 6.16.

$$x - axis$$

$$P_{f_x} = 4\vec{v}_{1f}\cos 60 + 12\vec{v}_{2f}\cos 30 = 48$$

$$y - axis$$

$$P_{f_y} = 4\vec{v}_{1f}\sin 60 + 12\vec{v}_{2f}\sin 30 = 0$$

- m_{1i} = 4.0kg
- v_{1i} = 12m/s
- m_{2i} = 12.0kg
- v_{2i} = 0

Solve equations simultaneously

Kinetic Energy and Momentum

- Momentum is ***always*** conserved in ***all*** collisions
- Kinetic energy is ***only*** conserved in ***tooootaly elastic*** collisions
  - This because in a perfectly elastic collision, no energy is lost to heat, sound or outside objects
  - When two objects stick together after a collision, the collision is said to be ***tooooooooootaly inelastic*** (or plastic)

Rocket Equation

- M = mass of rocket + fuel (m)
- δv = change in velocity
- δm = change in mass of fuel
- u = velocity of the exhaust gases
- After time δt, the mass of the exhaust is δm, the mass of the rocket is $M - \delta m$, the speed of the rocket is $v + \delta v$, and the speed of the exhaust is $u - (v + \delta v)$

Rocket Equation

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- u = velocity of the exhaust gases
- After time δt, the mass of the exhaust is δm, the mass of the rocket is M - δm, the speed of the rocket is v + δv, and the speed of the exhaust is u – (v + δv)

$$Mv = (M - \delta m)(v + \delta v) - \delta m(u - v - \delta v)$$

$$Mv = Mv + M\delta v - \delta m\delta v - \delta m\delta v - \delta mu + \delta mv + \delta m\delta v$$

$$0 = M\delta v - \delta mu$$

Rocket Equation

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- δv = change in velocity
- δm = change in mass of fuel
- u = velocity of the exhaust gases
- After time δt, the mass of the exhaust is δm, the mass of the rocket is M - δm, the speed of the rocket is v + δv, and the speed of the exhaust is u – (v + δv)

$$0 = M\delta v - \delta m u$$

$$M\delta v = \delta m u$$

$$M\frac{dv}{dt} = \frac{dm}{dt}u$$

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QUESTIONÈSi

Homework

Pg. 109-110, #72-83