Physics 1021

Spring 2012, Ch 9a

Momentum (Chapter 9)

New Topic

Momentum

Momentum is "inertia" of motion  "Quantity of motion"

Inertia depends on mass

Easy to start | Hard to start

Momentum depends on mass and velocity

Easy to stop (m, v) | Hard to stop (M, v)

Easy to stop (m, v) | Hard to stop (m, V)

momentum = mass × velocity

Linear Momentum

- Momentum ***p*** is defined as: $p = m v$

  ⇒ ***p*** is a vector since ***v*** is a vector

  ⇒ units of momentum are ***kg*m/s***

- How is force related to momentum?
  - use Newton's 2nd Law: *force* is related to the *change of momentum*

$$\Sigma F = ma = m\frac{\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t} = \frac{dp}{dt} \Rightarrow \Sigma F = \frac{dp}{dt}$$

Impulse

New Topic

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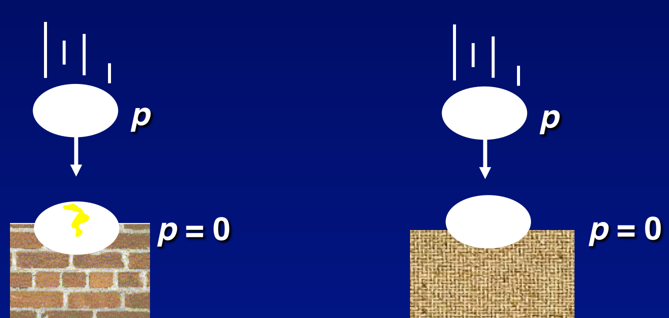
$$Impulse = F\Delta t = \Delta p$$

Impulse = change in momentum !

Why is it better to have padding?



$$F \; \Delta t \quad = \quad \Delta p \quad = \quad F \; \Delta t$$

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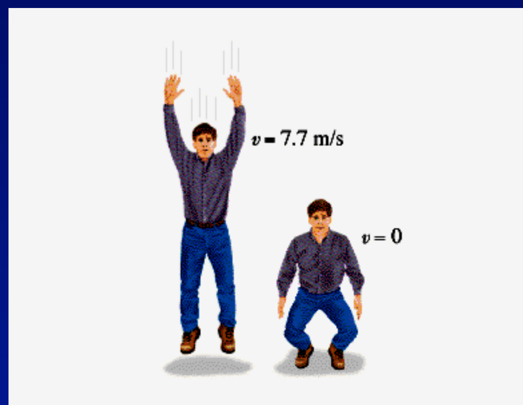
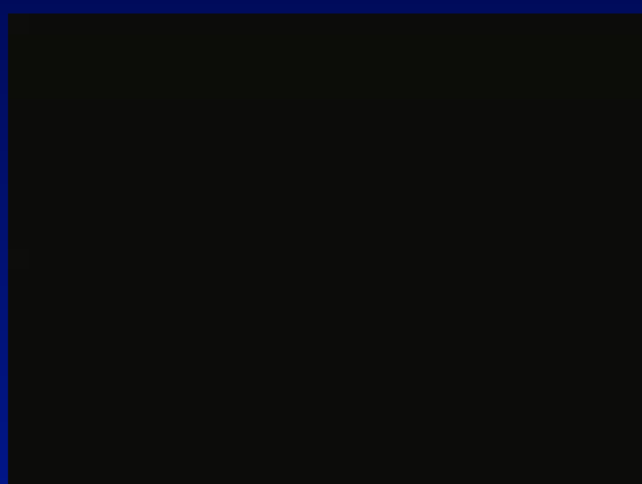
- **Would you rather land with your legs bending or stiff?**
  - You will still have the same impulse (Δp) in each case
  - But by bending, you extend the interaction time Δt
  - So the average force F_{av} is less if you bend your legs!



Crash Test



Introduction to impulse

- Why impulse instead of force?
  - Time-dependent force that is difficult to model
  - But well-defined initial and final states
  - Examples:
    - » Meteor strikes earth
    - » Bat hits base ball

Impulse and Momentum

Momentum is the product of a particle's mass and velocity, has units of kg m/s, and is given by

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

The *impulse* upon a particle is defined as

$$\textbf{impulse} = J_x = \int_{t_i}^{t_f} F_x(t)\, dt$$
$$= \text{area under the } F_x(t) \text{ curve between } t_i \text{ and } t_f$$

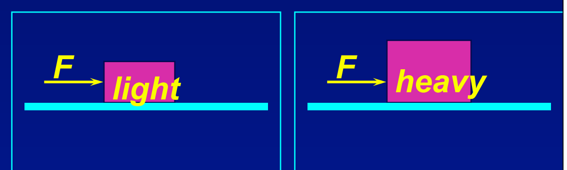
Impulse has units of N s, but you should be able to show that N s are equivalent to kg m/s. The **impulse-momentum theorem** is

$$\Delta p_x = J_x \qquad \text{(impulse-momentum theorem)}$$

ConcepTest 9.1 Two Boxes I

Two boxes, one heavier than the other, are initially at rest on a horizontal frictionless surface. The same constant force F acts on each one for one second. Which box has more momentum after the force acts ?

1) the heavier one
2) the lighter one
3) both the same



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ConcepTest 9.1 Two Boxes I

Two boxes, one heavier than the other, are initially at rest on a horizontal frictionless surface. The same constant force *F* acts on each one for exactly *1 second*. Which box has more momentum after the force acts ?

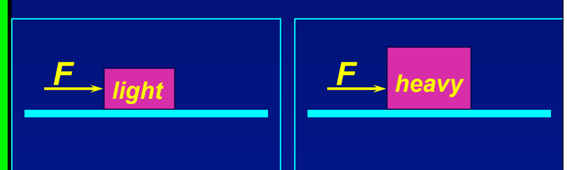
1) the heavier one
2) the lighter one
3) both the same

We know: $F_{av} = \frac{\Delta p}{\Delta t}$

so impulse $\Delta p = F_{av} \Delta t$

In this case F and Δt are the *same* for both boxes !

Both boxes will have the *same final momentum*.

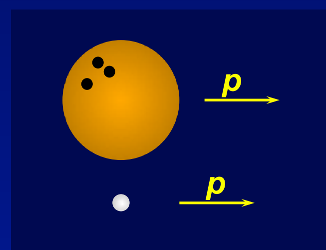


Follow-up: Which box has a larger velocity after the force acts?

ConcepTest 9.2 Going Bowling I

A bowling ball and a ping-pong ball are rolling towards you with the same momentum. If you exert the same force to stop each one, which takes a longer time to bring to rest?

1) the bowling ball
2) same time for both
3) the ping-pong ball
4) impossible to say



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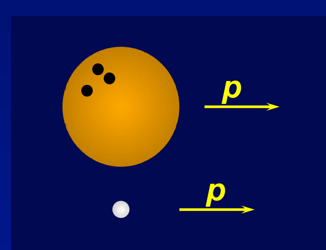
1) the bowling ball
2) same time for both
3) the ping-pong ball
4) impossible to say

We know: $F_{av} = \frac{\Delta p}{\Delta t}$ so $\Delta p = F_{av} \Delta t$

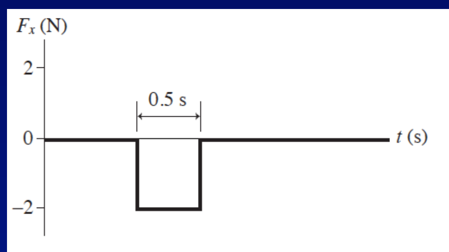
Here, F and Δp are the *same* for both balls!

It will take the *same amount of time* to stop them.



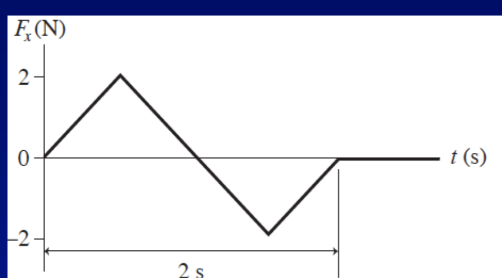
Example 1

- A 2 kg object is moving to the right (+x) with a speed of 1 m/s. What is its speed after applying the impulse pictured below?



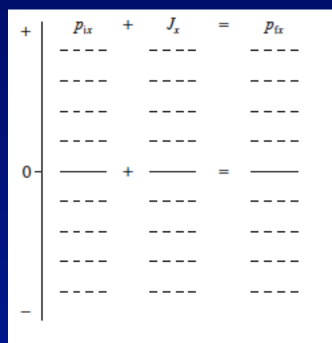
Ponderable 1

- A 2 kg object is moving to the ***left*** (-x) with a speed of 1 m/s. What is its speed after 1s of applying the impulse pictured below? After 2 s?



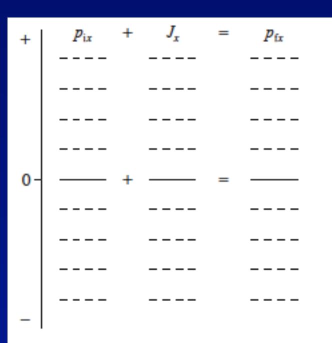
Example 2

- A clay ball is thrown at the ceiling and sticks there. Considering only the momentum immediately before and after the collision, draw momentum – impulse diagram for the collision.



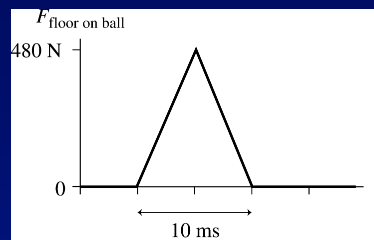
Ponderable 2

- A bouncy ball is thrown at the ceiling and bounces right back. Considering only the momentum immediately before and after the collision, draw momentum – impulse diagram for the collision. Does the bouncy ball or the clay ball exert more force on the ceiling?



Example 3

- A 200 g rubber ball is released from a height of 2.0 m. It falls to the floor, bounces, and rebounds. The force of the floor on the ball is shown in the figure. How high does the ball rebound?



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Ponderable 3

- A particle of mass m is at rest at t=0. It is momentum for t>0 is given by $p_x=6t^2$ kgm/s. Find an expression for the force as a function of time.

PHYS 1021: Chap. 9, Pg 20

Tangible – measure the impulse

Every group should get a tennis ball and drop it from a height of 1 m. Determine the impulsive force imparted to the ball by the floor. Try this on carpet and on a hard surface (table top or in the hall). Discuss the difference in the impulsive force between the hard and soft landing cases.