

## CH01-4 Momentum

## Force and momentum

A constant force acts on a fan cart. If we double the mass of the cart (with the same force acting on the cart), has half the acceleration.

Clearly the force on a cart changes the velocity of the cart. However, the rate that the velocity changes depends on the mass of the cart. Both mass and the velocity of the cart are important.

## Momentum

The momentum of a particle has the same direction as its velocity. However, it depends linearly on the particle's rest mass. It also depends on gamma.

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

where

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{|\vec{v}|}{c}\right)^2}}$$

## Approximate momentum

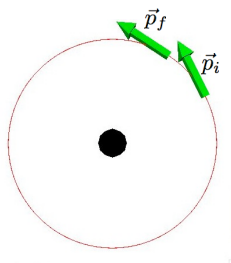
$$\vec{p} \approx m \vec{v} \quad \text{if speed much less than } c$$

What speeds are considered "much less than  $c$ "?

## A force on an object causes a change in momentum

$$\Delta \vec{p} = \vec{p}_f - \vec{p}_i$$

The classical model of Hydrogen is the Bohr model where the electron orbits the proton. What is the change in momentum of the electron during the interval shown?



## Rate of Change of Momentum

$$\frac{\Delta \vec{p}}{\Delta t}$$

## Example

In your 600-kg car, you are traveling in a straight line with a constant speed of 40 m/s in the +x direction when you hit your brakes, and in a time interval of 3.0 sec you slow to 25 m/s. What is your change in momentum during this time interval? What is the rate of change of your momentum?

## Example

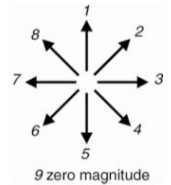
A 0.05-kg toy airplane tied to a string flies in a circle. At one clock reading, its velocity is  $\langle -1.2, 0.8, 0 \rangle$  m/s. At a later clock reading, its velocity is  $\langle -1.2, -0.8, 0 \rangle$  m/s. What is the airplane's change in momentum during this time interval?

## Example

Suppose that a 0.005-kg superball is dropped from a height of 5 m. The ball is moving downward at a speed of 10 m/s just before hitting the floor. After hitting the floor, it bounces upward at a speed of 7 m/s. What is its change in momentum?

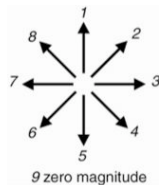
## Poll

A tennis ball is moving horizontally at a speed of 30 m/s in the -x direction when it is struck by a tennis racket and leaves the racket horizontally in the +x direction at a speed of 30 m/s. What is the direction of the change in momentum of the tennis ball or is it zero?



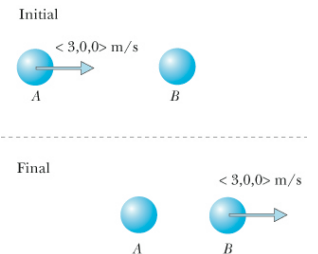
## Poll

During a dismount, a gymnast is moving in the downward direction when her toes first touch the mat. As a result of interacting with the mat, she slows to a stop in short time interval. While slowing down due to the collision with the mat, what direction is her change in momentum?



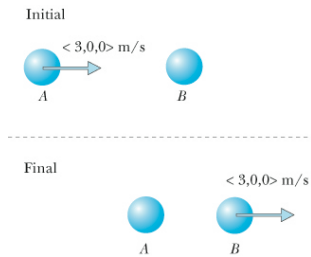
## System and Surroundings

If Ball A is the System, what is the change in momentum of the System?



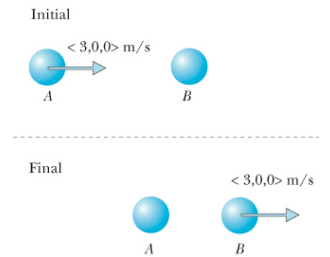
## System and Surroundings

If Ball B is the System, what is the change in momentum of the System?



## System and Surroundings

If Balls A and B together are the System, what is the change in momentum of the System?



## The Momentum Principle

Newton's second law

A fundamental principle

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

- cause-effect relationship
- change in momentum is in same direction as net force
- applies to each component of momentum
- net force is due to interactions of the system with the surroundings
- time interval is the duration of the interaction
- product of net force times the time interval is called *impulse*
- if no interaction, momentum of the system is constant

## VPython Spaceship

If the spaceship speeds up while moving to the right, what direction is the net force on the spaceship?

If the spaceship slows down while moving to the right, what direction is the net force on the spaceship?

## VPython Spaceship

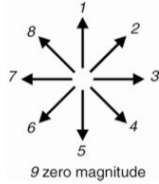
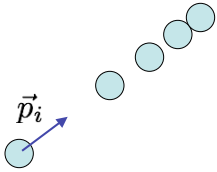
If the spaceship speeds up while moving to the left, what direction is the net force on the spaceship?

If the spaceship slows down while moving to the left, what direction is the net force on the spaceship?

## 1-D: Force and speed

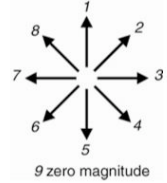
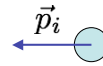
## Poll

For the object moving as shown below, what direction is the net force on the object?



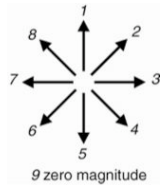
## Poll

A football player is running in the direction shown when he collides with another player and comes to a stop. What is the direction of the net force on the (first) player during the collision?



## Poll

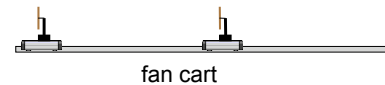
Suppose that a 0.005-kg superball is dropped from a height of 5 m. The ball is moving downward at a speed of 10 m/s just before hitting the floor. After hitting the floor, it bounces upward at a speed of 7 m/s. What is the direction of the net force on the ball during the collision with the floor?



## Momentum Update

If you know the initial momentum and the change in momentum of the system (impulse), then you can calculate the final momentum.

$$\vec{p}_f = \vec{p}_i + \Delta\vec{p}$$



## Approximations

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

Exactly correct for constant net force!  
...only approximately correct for a small time interval.

As the time interval gets smaller, the approximation becomes increasingly accurate.

$$\Delta\vec{p} = \int_{t_i}^{t_f} \vec{F}_{net} dt$$

## Predicting momentum (and velocity) for a constant net force

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