October 15, 2010   Physics 121   Prof. E. F. Redish

■ **Theme Music: Aimee Mann**
   Momentum
■ **Cartoon: Pat Brady**
   Rose is Rose

Copyright © 1998 United Feature Syndicate, Inc.
Redistribution in whole or in part prohibited
10/15/10   Physics 121   **1**

Outline

■ Properties of Forces
  – Examples
■ Momentum
  – definition
  – the Impulse-Momentum Theorem
  – Momentum conservation

10/15/10   Physics 121   **2**

Springs

■ How much does each spring stretch?
■ What are the forces the springs exert on each other?
■ How do you know?

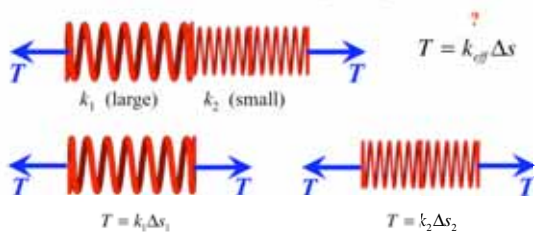*T*   *T*

k_1 (large) k_2 (small)

10/15/10   Physics 121   **3**

What's the effective spring constant?

$$T = k_{eff}\Delta s$$

k_1 (large) k_2 (small)

$$T = k_1\Delta s_1$$ $$T = k_2\Delta s_2$$

$$\Delta s = \Delta s_1 + \Delta s_2$$

$$\frac{T}{k_{eff}} = \frac{T}{k_1} + \frac{T}{k_2}$$

$$\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2}$$

10/15/10   4

Reconciling an intuition

■ Many people have the sense that
   when you throw an object into the air,
   "the force of the hand" stays with it
   as it moves up.

■ We now know (from N0) once the object
   has left your hand it only pays attention
   to one force – its weight.

■ But there is a way we can refine
   the "force of the hand" intuition
   to reconcile it with the physics we have learned.

10/15/10   Physics 121   12

Recapping Momentum:
What a "hit" gives an object

■ Let's go back to our original formulation of
   Newton's second law with the bowling ball
   and the hammer and separate what we "give
   to the object" on one side and "what the
   object receives from a hit" on the other.

$$\blacksquare \vec{} = \vec{F}\Delta t = m\Delta\vec{v}$$

■ So when we "hit" an object we change its
   value of "mv". This is just N2 in "delta"
   form.

10/15/10   Physics 121   13

Momentum: Definition

■ We define <u>momentum</u>:

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

■ This is a way of defining "the amount of motion" an object has.

■ Our "delta" form of N2 becomes

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

which we can rewrite as

$$\vec{F}^{net} = \frac{\Delta(m\vec{v})}{\Delta t} = \frac{\Delta\vec{p}}{\Delta t}$$

10/15/10   Physics 121   **14**

The Impulse-Momentum Theorem

■ Newton 2 $\vec{a} = \vec{F}^{net}/m$

■ Put in definition of a $\frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{F}^{net}}{m}$

■ Multiply up by Δt $m\Delta\vec{v} = \vec{F}^{net}\Delta t$

■ Define Impulse $\vec{\mathcal{J}}^{net} = \vec{F}^{net}\Delta t$

■ Combine to get Impulse-Momentum Theorem $$\Delta\vec{p} = \vec{\mathcal{J}}^{net}$$

10/15/10   Physics 121   **15**

Momentum Conservation: 1

■ Consider a system of two objects, A and B, interacting with each other and with other ("external") objects. By the IMT

$$m_A\,\Delta\vec{v}_A = (\vec{F}_A^{ext} + \vec{F}_{B\to A})\Delta t$$

$$m_B\,\Delta\vec{v}_B = (\vec{F}_B^{ext} + \vec{F}_{A\to B})\Delta t$$

■ Adding:

$$m_A\,\Delta\vec{v}_A + m_B\,\Delta\vec{v}_B = \left[\vec{F}_A^{ext} + \vec{F}_B^{ext} + \left(\vec{F}_{A\to B} + \vec{F}_{B\to A}\right)\right]\Delta t$$

$$\Delta\left(m_A\vec{v}_A + m_B\vec{v}_B\right) = \vec{F}^{ext}\Delta t$$

10/15/10   Physics 121   **16**

Momentum Conservation: 2

■ So: If two objects interact with each other in such a way that the external forces on the pair cancel, then momentum is conserved.

$$\Delta\left(m_A \vec{v}_A + m_B \vec{v}_B\right) = 0$$

$$m_A \vec{v}_A^i + m_B \vec{v}_B^i = m_A \vec{v}_A^f + m_B \vec{v}_B^f$$

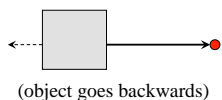10/15/10   17

Example: Recoil

■ When an object at rest emits a part of itself, in order to conserve momentum, it must go back in the opposite direction.

■ What forces are responsible for this motion?

(object goes backwards)   **Do it!**

10/15/10   Physics 121   18