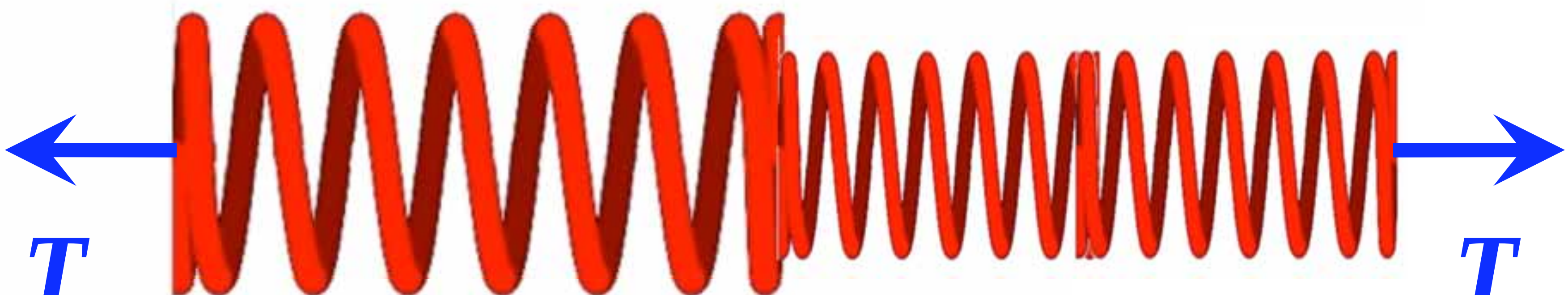
- **Theme Music: Aimee Mann**
  Momentum
- **Cartoon: Pat Brady**
  Rose is Rose

Outline

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

Springs

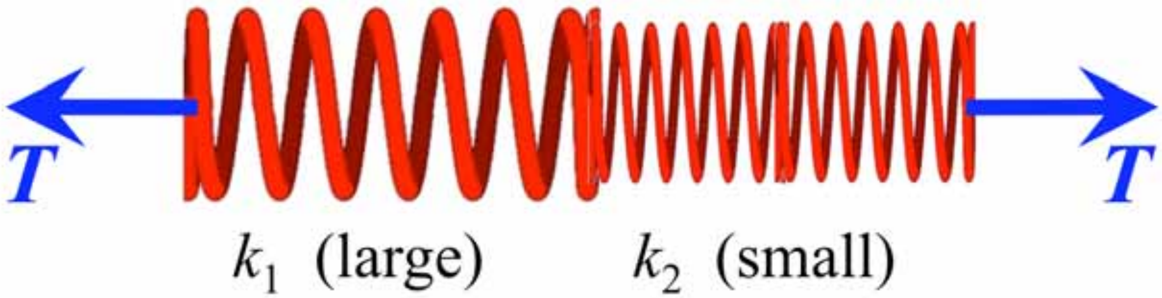
- How much does each spring stretch?
- What are the forces the springs exert on each other?
- How do you know?



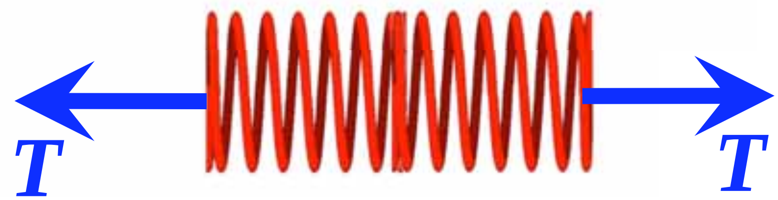
T ***T***

k_1 (large) k_2 (small)

What's the effective spring constant?



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



$$T = k_1 \Delta s_1$$

$$T = k_2 \Delta s_2$$

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

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

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

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.

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.

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

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

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

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

The Impulse-Momentum Theorem

- Newton 2 $\vec{a} = \vec{F}^{net} / m$
- Put in definition of *a* $\dfrac{\Delta\vec{v}}{\Delta t} = \dfrac{\vec{F}^{net}}{m}$
- Multiply up by Δt $m\Delta\vec{v} = \vec{F}^{net}\Delta t$
- Define Impulse $\vec{I}^{net} = \vec{F}^{net}\Delta t$
- Combine to get Impulse-Momentum Theorem

$$\Delta\vec{p} = \vec{I}^{net}$$

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:

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

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

Momentum Conservation: 2

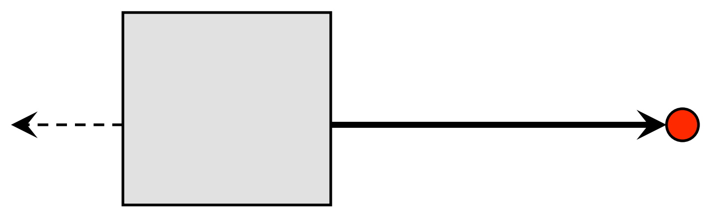
- So: If two objects interact with each other in such a way that the <u>external</u> forces on the pair cancel, then momentum is conserved.

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

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

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!