- **Theme Music:** Java Jazz

  Universal Law

- **Cartoon:** Jef Mallett

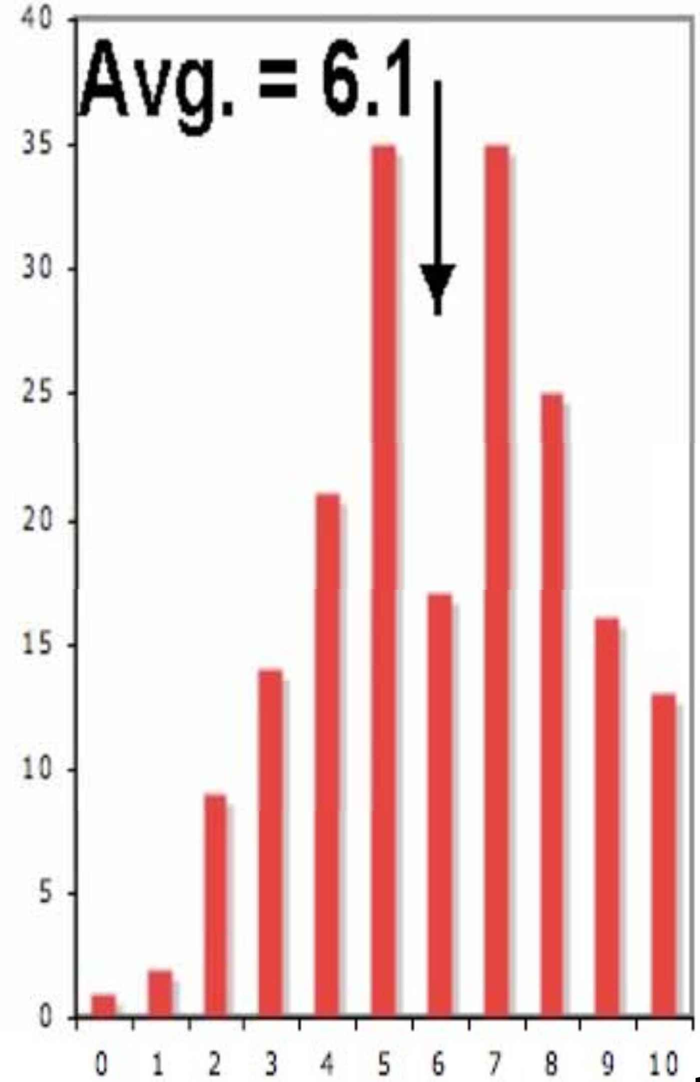
  Frazz

Outline

- Go over Quiz 6
- Recap: Work–Energy Theorem
- Potential Energy:
  - Gravity
  - Springs
- Conservative and Non-conservative forces
  - Friction
- Dimensions and units of energy
- Power

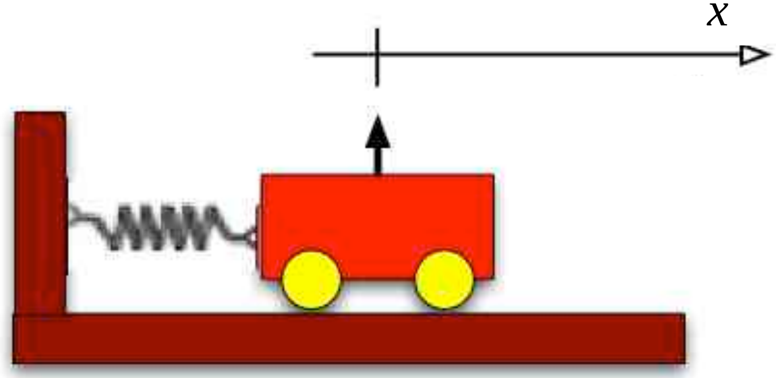
Quiz 6

	6.1	6.2	6.3	6.4
a	23%	1%	82%	46%
b	4%	5%	18%	13%
c	41%	9%	0%	36%
d	64%	11%		5%
e	39%	74%		
f	2%			



Example: Springs

- Consider our work-energy result for a particular case: the only unbalanced force is a restoring force from a spring.



$$\Delta(\tfrac{1}{2}mv^2) = \vec{F}^{net} \cdot \Delta\vec{r}$$
$$= -kx\Delta x$$

If x is changing over the interval what x should we use?

$$= -k\langle x\rangle\Delta x = -k\left(\frac{x_i + x_f}{2}\right)\left(x_f - x_i\right) = -\tfrac{1}{2}k\left(x_f^2 - x_i^2\right)$$
$$= -\Delta\left(\tfrac{1}{2}kx^2\right)$$

Potential Energy: Springs

- Since the work term also looks like a change, we can bring it to the left and get a *conservation law*.

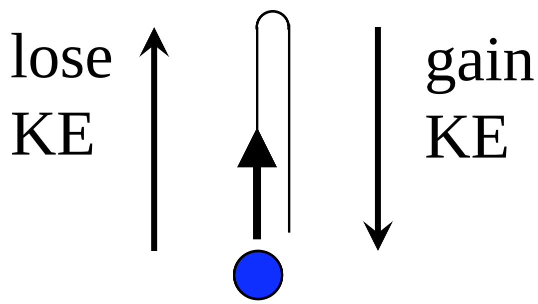
$$\Delta(\tfrac{1}{2}mv^2 + \tfrac{1}{2}kx^2) = 0$$

$$U_s = \tfrac{1}{2}kx^2$$

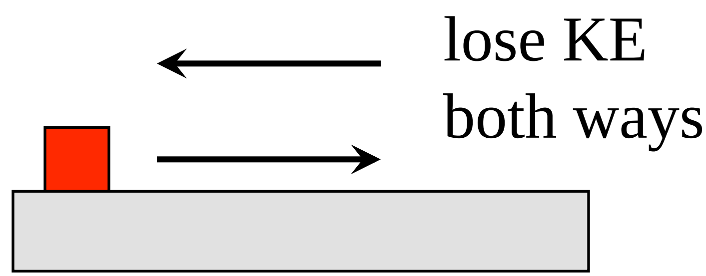
- We interpret the quantity $\tfrac{1}{2}kx^2$ as a new kind of energy — *spring potential energy*.

Conservative forces

- Forces (like gravity or springs) are conservative if when the force takes KE away, you can get it back when you go back to where you started.
- If the kinetic energy that a force takes away can't be restored by going back to where you started it is called non-conservative.
- Compare gravity and friction:



Gravity: Conservative



Friction: Non-Conservative

The Work-Energy Theorem

- For some forces, "conservative" forces, calculating the work they do is especially easy ***because it only depends on where you start and where you end***

$$\Delta(\frac{1}{2}mv^2) = \vec{F}_{all}^{net} \cdot \Delta\vec{r}$$

$$\Delta(\frac{1}{2}mv^2) = \vec{F}_{cons}^{net} \cdot \Delta\vec{r} + \vec{F}_{non-c}^{net} \cdot \Delta\vec{r}$$

Work-Energy Theorem

- So we can express the work done by a conservative force as a change in potential energy

$$\Delta(\frac{1}{2}mv^2) = \vec{F}^{net}_{cons} \cdot \Delta\vec{r} + \vec{F}^{net}_{non-c} \cdot \Delta\vec{r}$$

$$\Delta(\frac{1}{2}mv^2) = \quad -\Delta U \quad + \vec{F}^{net}_{non-c} \cdot \Delta\vec{r}$$

$$\Delta(\tfrac{1}{2}mv^2 + U) = \vec{F}^{net}_{non-C} \cdot \Delta\vec{r}$$

- U is called the <u>total potential energy</u> (so far, from gravity and/or springs), $KE + U$ is called the <u>total mechanical energy</u>.

Non-conservative forces/situations

- Friction / drag
  - Three kinds of forces drain ME: friction (indep. of v), viscosity (prop. to v), drag (prop. to v^2)
- Breaking / crushing
  - Normal forces are typically springy and conservative.
  - If an object is deformed too much, the structure can change (break) and drain ME.
- Chemical reactions
  - Chemical structure is another kind of potential energy that can be stored. It can create or drain ME.

A~~n~~ Mechanical Energy Conservation Theorem

- Suppose our system has both gravity and spring forces
  - The only force that changes the object's speed is gravity.
  - Other forces (normal forces) can change direction.
  - Friction must be negligible.
- Using this can be tricky. Typically,
  - Springs act in one part of the problem, gravity in another. One must focus on the physics to decide what is appropriate.

$$\Delta(\tfrac{1}{2}mv^2 + mgh + \tfrac{1}{2}kx^2) = 0$$

$$\tfrac{1}{2}mv_i^2 + mgh_i + \tfrac{1}{2}kx_i^2 = \tfrac{1}{2}mv_f^2 + mgh_f + \tfrac{1}{2}kx_f^2$$

Using the Work-Energy Theorem

- The work-energy theorem is most useful when you want to find how a position and velocity are related but you don't need to know "when" (anything about times).
- To use the WETh you need to
  - choose your objects
  - decide what forces act on them (FBD!)
  - use PEs for conservative forces
  - calculate work for non-conservative forces.

Dimensions and Units of Energy

- $[1/2\ mv^2] = M\text{-}(L/T)^2 = ML^2/T^2$
- $1\ kg\text{-}m^2/s^2 = 1\ N\text{-}m = 1$ Joule
- Other units of energy are common (and will be discussed later)
  - Calorie
  - eV (electron Volt)
  - erg ($=1\ g\text{-}cm^2/s^2$)

Power

- An interesting question about work and energy is the rate at which energy is changed or work is done. This is called *power*.

$$\text{Power} = \frac{\text{Energy change}}{\text{time to make the change}}$$

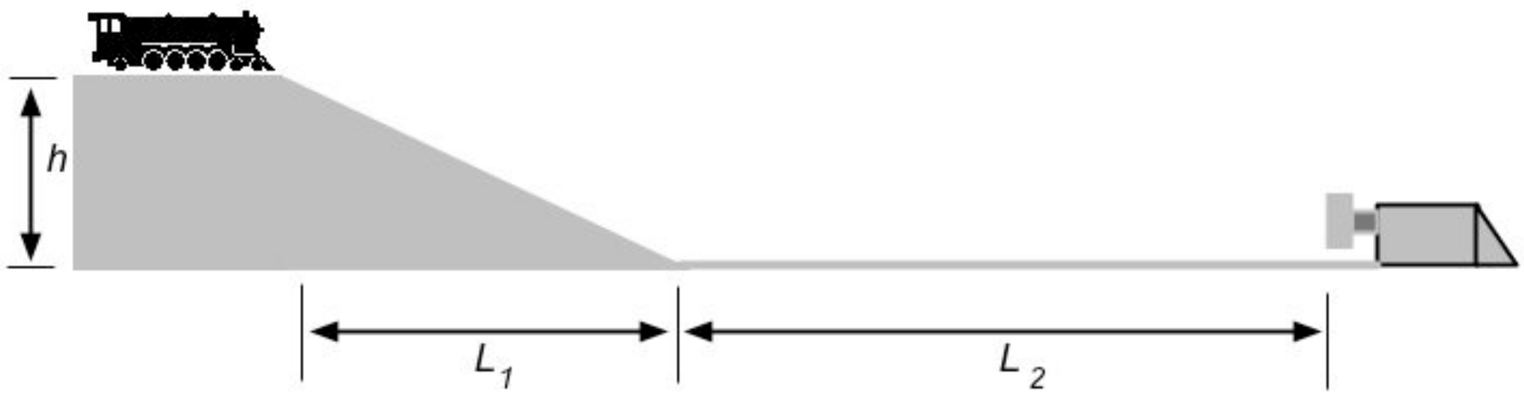
$$= \frac{\Delta W}{\Delta t} = \vec{F}^{\,net} \cdot \frac{\Delta \vec{r}}{\Delta t} = \vec{F}^{\,net} \cdot \vec{v} \quad \text{(for mechanical work)}$$

- Unit of power

1 Joule/sec = 1 Watt

Stopping a train

A toy train of mass *m* comes off a hill traveling at a velocity v_0, rolls down an incline of height *h*, rolls a short distance on a straight track, and strikes a bumper containing a spring of spring constant *k*. The distances are as indicated on the figure below. The train is just rolling, not powered.



(a) Assuming that friction and the rotational energy of the wheels can be ignored, describe the changes in the forms of energy of the system starting with the instant the train begins down the hill until it comes to a stop at the bumper.

(b) What is the speed of the train, *v*, when it is on the straight piece of track? Express your answer in terms of the symbols given above.