Announcements

- WebWorK due on Wednesday
- I'm working on grading the tests, but it may be later in the week. Or I may be able to post scores but not hand them back to talk about them.
- Grade reports will be updated as soon as I have the tests scored.
- Polling: `rembold-class.ddns.net`

Review Question

An oxygen molecule (O_2) is traveling at 60% the speed of light. If an oxygen molecule has a mass of 5.313×10^{-23} g, what is the total energy of the molecule?

A) 860 pJ

B) 4.78 nJ

C) 5.98 nJ

D) 106 µJ

Transferring Energy

- We know by the Energy Principle that our change in energy will be equal to how much energy enters or leaves the system
- Need a way to describe how energy is entering or leaving the system
- How can we change energy?
    - A force! $\Delta\vec{\mathbf{p}} = \vec{\mathbf{F}}_{net}\Delta t$!
    - Seeing what else is a bit more subtle. Consider

$$\begin{aligned}
E &= mc^2 + \frac{p^2}{2m} \\
\Delta E &= 0 + \Delta\left(\frac{p^2}{2m}\right) \\
&= \frac{1}{2m}\Delta(p^2) = \frac{1}{2m}2p\Delta p \\
&= \frac{p}{m}F_{net}\Delta t = F_{net}v_{avg}\Delta t \\
&= F_{net}\Delta r
\end{aligned}$$

Work Basics

- Current form has no direction attached to it, but forces and positions are vectors
- Only really want forces in direction of motion
  - We know forces $\perp$ to the motion only change the direction!
- Returning to dot products!

Work by Constant Force

The work done by a constant force is defined as

$$W = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{r}}$$

- Hence the work is:
  - positive if force has component in same direction as displacement
  - negative if force has component in the opposite direction as displacement
  - zero if force has no component in the direction of displacement

Summarizing

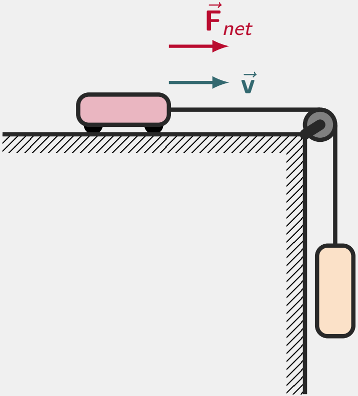
- We are looking at situations where the mass is not changing, so that there is no change in the rest energy
  - Only options for energy at the moment are rest energy or kinetic energy, so:

$$\Rightarrow \Delta E = \Delta K$$

- The changes in ΔK come from external forces moving masses in the system

$$\Delta K = W_{net} = \vec{\mathbf{F}}_{net} \cdot \Delta\vec{\mathbf{r}} = \underbrace{\vec{\mathbf{F}}_1 \cdot \Delta\vec{\mathbf{r}}}_{W_1} + \underbrace{\vec{\mathbf{F}}_2 \cdot \Delta\vec{\mathbf{r}}}_{W_2} + \cdots$$

Work it to the Right



- Does K increase or decrease?
- Sign of ΔK?
- Forces acting on cart?
- For each, sign of Work?
- Sign of W_{net}?
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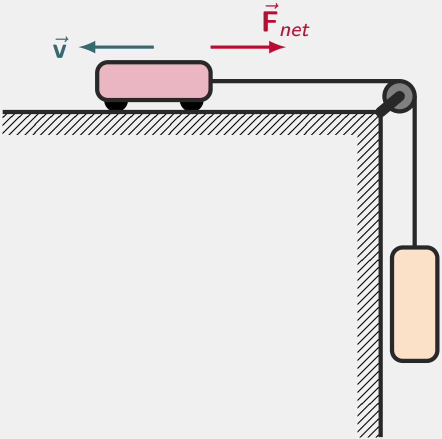
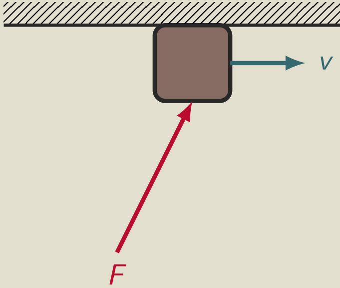


Example: On the Dot

I'm pushing a box with a force of $F = \langle 3, 6, 0 \rangle$ N. Unfortunately, the box is against a wall, such that it only moves 10 m to the right in the time I'm pushing it. How much work did I do? If there was no friction, how fast is the box moving?



Understanding Check!

A crane lowers a steel girder into place. The girder moves with constant speed. Consider the work W_g done by gravity and the work W_T done by the tension in the cable. Which of the following is true if upwards is the positive direction?

A) W_g and W_T are both positive

B) W_g is positive and W_T is negative

C) W_g is negative and W_T is positive

D) W_g and W_T are both 0

Being a More General Worker

- Suppose we don't have a constant force
  - Break up $\Delta\vec{\mathbf{r}}$ into small chunks in which the force is mostly constant
  - Add up all those contributions
- Taking the small chunks to get really tiny, we end up with an integral!

$$W = \int_{\vec{\mathbf{r}}_i}^{\vec{\mathbf{r}}_f} \vec{\mathbf{F}} \cdot \mathrm{d}\vec{\mathbf{r}}$$

- Integrals should make you think "Area under curve"
  - This is just the area under the force vs distance curve!
  - Comparable to how the impulse ($\Delta\vec{\mathbf{p}}$) was the area under the force vs time curve!

Stretchy Energy

Suppose you have a spring with a spring constant of $5\,\mathrm{N/m}$ (comparable to the springs you've used in lab). How much energy would it take to stretch such a spring from it's equilibrium point to $5\,\mathrm{m}$ stretched?

Putting it all Together

- Our goal with work was to quantify the energy entering or leaving a system
- We can now write the Energy Principle as

$$\Delta E_{sys} = W_{surr} + \text{ other inputs}$$

or, in a more iterative manner:

$$E_{sys,f} = E_{sys,i} + W_{surr} + \text{ other inputs}$$

- These are generally going to be the major methods you use to approach Energy Principle problems

Example: Ball Throwing

I throw a ball such that I apply a force of $\langle 10, 0, 0 \rangle$ N during which the ball travels a distance of 40 cm in the x-direction. What is the speed of the 800 g ball when it leaves my hand?

Example: Such a Hero

A $10\,000\,\text{kg}$ semi-truck is rolling slowly across level ground ($v = 1\,\text{m/s}$) toward a small group of playing children. Throwing on your superhero cape, you rush to the front of the semi and begin pushing against it. Due to the size of the semi, you are forced to push upwards at an angle of $45°$. If the children are playing $3\,\text{m}$ away, how hard must you push to stop the semi in time?

Practice Time!

Suppose you have a 10 kg wooden box that you are pushing across a rough level floor. The floor has a coefficient of kinetic friction of 0.7 and a coefficient of static friction of 0.8 with the box. You push the box with a force equal to $\langle 100, -20, 0 \rangle$ N and want to move it 20 m across the floor in the positive x-direction. Afterwards you hope to lift the box at a constant velocity straight up to a height of 2 m.

- First things first. Show that you can indeed move the box.
- How much work do you do on the box pushing it across the floor?
- How much work does friction do on the box as it moves across the floor?
- What is the speed of the box after the 20 m?
- How much work do you do on the box lifting it?