Today's Concepts:

a) Energy and Friction
b) Potential Energy and Force
Unit 9: Prelecture Feedback

• Block sliding down the ramp checkpoint.
• Macroscopic work
• Connection between force and potential energy.
• Please keep going through problems like the homework
Energy and Friction

• Last time: Mechanical Energy (K+U) is a constant of the motion for conservative forces.

• Today: Change in mechanical energy is equal to work done by nonconservative forces.
Last Time:

Generalize mechanical energy conservation to conservative systems including springs:

\[
\frac{1}{2} kx_i^2 + mgh_i + \frac{1}{2} mv_i^2 = \frac{1}{2} kx_f^2 + mgh_f + \frac{1}{2} mv_f^2
\]

Spring P.E.  K.E.  Gravitational P.E.
Energy and Friction

- Last time: Mechanical Energy (K+U) is a constant of the motion for conservative forces.
- Today: Change in mechanical energy is equal to work done by nonconservative forces.
Macroscopic Work done by Friction

Work-Kinetic Energy Theorem

\[ \Delta K = W_{Net} \]
\[ -\frac{1}{2} m v_o^2 = -\mu_k m g D \]

Macroscopic Work done by Friction

\[ f_k = \mu_k N \]

\[ D = \frac{v_o^2}{2 \mu_k g} \]

\[ v_f = 0 \]
Macroscopic Work:

\[ W = \int_{a}^{b} \mathbf{F} \cdot d\mathbf{l} \]

Applied to big (i.e. macroscopic) objects rather than point particles (picky detail)

We call it “macroscopic” to distinguish it from “microscopic”.
Work-Kinetic Energy Theorem

\[ \Delta K = W_{Net} \]

\[ -\frac{1}{2} m v_o^2 = -\mu_k m g D \]
“Heat” is just the kinetic energy of the atoms!
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This is how the conservative “fundamental forces” (gravity, electromagnetism...) give rise to nonconservative macroscopic forces.
Example: A block of mass 12 kg has an initial velocity of 1.0 m/s to the right as it slides across the floor with a coefficient of kinetic friction $\mu_k = 0.45$. How far does it travel before coming to rest? Solve via:

a) 2\textsuperscript{nd} law and kinematics equations

b) Work-energy theorem
Conservative and Nonconservative Forces

\[ \Delta K = W_{tot} = W_{gravity} + W_{friction} \]

\[ 0 = W_{gravity} + W_{friction} \]

\[ 0 = mgH + W_{friction} \]

must be negative
A block of mass $m$, initially held at rest on a frictionless ramp a vertical distance $H$ above the floor, slides down the ramp and onto a floor where friction causes it to stop a distance $r$ from the bottom of the ramp. The coefficient of kinetic friction between the box and the floor is $\mu_k$.

What is the macroscopic work done on the block by friction during this process?

A) $mgH$  
B) $-mgH$  
C) $\mu_k mgD$  
D) 0
What is the macroscopic work done on the block by friction during this process?

A) $mgH$  
B) $-mgH$  
C) $\mu_k mgD$  
D) 0

B) All of the potential energy goes to kinetic as it slides down the ramp, then the friction does negative work to slow the box to stop.

C) Since the floor has friction, the work done by the block by friction is the normal force times the coefficient of kinetic friction times the distance.
A block of mass $m$, initially held at rest on a frictionless ramp a vertical distance $H$ above the floor, slides down the ramp and onto a floor where friction causes it to stop a distance $D$ from the bottom of the ramp. The coefficient of kinetic friction between the box and the floor is $\mu_k$. What is the total macroscopic work done on the block by all forces during this process?

A) $mgH$  
B) $-mgH$  
C) $\mu_k mgD$  
D) 0

\[ \Delta K = W_{tot} \]
**CheckPoint**

What is the total macroscopic work done on the block by all forces during this process?

- A) $mgH$
- B) $-mgH$
- C) $\mu_k mgD$
- D) 0

D) total work is equal to the change in kinetic energy. Since the box starts and ends at rest, the change in kinetic energy is zero.

\[
\Delta K = W_{tot}
\]
### Potential Energy vs. Force

The force $F(x)$ is given by:

$$F(x) = -\frac{dU(x)}{dx}$$

<table>
<thead>
<tr>
<th>P.E. Function $U$</th>
<th>Force $\vec{F}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity (Near Earth)</td>
<td>$mgh + U_o$</td>
</tr>
<tr>
<td>Gravity (General Expression)</td>
<td>$-G\frac{m_1m_2}{r} + U_o$</td>
</tr>
<tr>
<td>Spring</td>
<td>$\frac{1}{2}kx^2 + U_o$</td>
</tr>
</tbody>
</table>
Suppose the potential energy of some object $U$ as a function of $x$ looks like the plot shown below.

Where is the force on the object biggest in the $-x$ direction?

A) (a)  B) (b)  C) (c)  D) (d)
**Checkpoint**

Suppose the potential energy of some object $U$ as a function of $x$ looks like the plot shown below.

Where is the force on the object biggest in the $-x$ direction?

**A)** (a)  **B)** (b)  **C)** (c)  **D)** (d)

$$F(x) = -\frac{dU(x)}{dx}$$
Flashcard Question

Suppose the potential energy of some object $U$ as a function of $x$ looks like the plot shown below.

Where is the force on the object zero?

A) (a)  B) (b)  C) (c)  D) (d)

$$F(x) = -\frac{dU(x)}{dx}$$
Suppose the potential energy of some object $U$ as a function of $x$ looks like the plot shown below.

Where is the force on the object in the $+x$ direction?

A) To the left of (b)  B) To the right of (b)  C) Nowhere

\[ F(x) = -\frac{dU(x)}{dx} \]
A mass $m = 16$ kg is pulled along a horizontal floor with NO friction for a distance $d = 7.9$ m. Then the mass is pulled up an incline that makes an angle $\theta = 35^\circ$ with the horizontal and has a coefficient of kinetic friction $\mu_k = 0.44$. The entire time the massless rope used to pull the block is pulled parallel to the incline at an angle of $\theta = 35^\circ$ (thus on the incline it is parallel to the surface) and has a tension $T = 79$ N.

- What is work done by tension before the incline?
- What is the speed of the block before the incline?
- What is the work done by friction after traveling up the incline?
- What is the work done by gravity after traveling up the incline?
- How far does the block travel before coming to rest?
You plan to take a trip to the moon. Since you do not have a traditional spaceship with rockets, you will need to leave the earth with enough speed to make it to the moon. Some information that will help during this problem:

\[ m_{\text{earth}} = 5.9742 \times 10^{24} \text{ kg} \]
\[ r_{\text{earth}} = 6.3781 \times 10^6 \text{ m} \]
\[ m_{\text{moon}} = 7.36 \times 10^{22} \text{ kg} \]
\[ r_{\text{moon}} = 1.7374 \times 10^6 \text{ m} \]
\[ d_{\text{earth to moon}} = 3.844 \times 10^8 \text{ m (center to center)} \]
\[ G = 6.67428 \times 10^{-11} \text{ N\cdot m}^2/\text{kg}^2 \]

• How far will you get with some initial speed?
• If you have the minimum speed 11,068 m/s required, what is your speed when you reach the moon?
• Which effects minimum speed? \( m_{\text{earth}} \), \( r_{\text{earth}} \), \( m_{\text{ship}} \)?
HW Example:
Potential Energy in Earth-Moon System

\[ U = -\frac{G M_E m}{r} \]

\[ F = -\frac{dU}{dr} = -\frac{G M_E m}{r^2} \]
HW Example:
*Potential Energy in Earth-Moon System*

\[ U = -\frac{G M_E m}{r} - \frac{G M_M m}{(d - r)} \]

\[ F = -\frac{dU}{dr} = -\frac{G M_E m}{r^2} + \frac{G M_M m}{(d - r)^2} \]