Lecture 17: Potential Energy

Warm-Up Activity

Question?

(A) Answer?

A Deeper Model for Interactions

- Quantities
  - Energy E
  - Work $W = \int_{r_i}^{r_f} \vec{F} \cdot d\vec{r}$
  - Kinetic Energy $K = \frac{1}{2}mv^2$
- Laws
  - Work-energy theorem $W_{\text{net,ext}} = \Delta E_{\text{total}}$

Potential Energy

- Potential energy is present when there is an *internal* interaction between objects within a system.
- How do we figure out how much potential energy something has?
  - We can look at the work that the internal interaction would have done if it were external.
- For special kinds of internal forces (called *conservative* forces):

$$\Delta U = -W_{\text{internal}}$$

Questions	System 1: Tennis Ball	System 2: Tennis Ball + Earth
External forces?	Gravity	None
$W_{\text{net,ext}}$	$+mgh$	0
ΔE_{total}	$+mgh$	0
What kinds of E are there and how have they changed?	Kinetic energy increases.	Kinetic energy increases. Potential energy decreases.

L17-1: Gravitational Potential Energy

You drop a tennis ball (mass m) off the top of a tall building (height h).

Questions	System 1: Tennis Ball	System 2: Tennis Ball + Earth
External forces?		
$W_{\text{net,ext}}$		
ΔE_{total}		
What kinds of E are there and how have they changed?		

Gravitational Potential Energy

When a mass m in a system changes its height by an amount Δh:

(A) If we don't include the Earth in the system, then the Earth does work on the system equal to

$$W_g = -mg\Delta h.$$

This changes the total energy of the system.

(B) If we include the Earth in the system, then the potential energy of the system changes by an amount

$$\Delta U_g = mg\Delta h.$$

This does not change the total energy of the system.

Other Kinds of Energy
In PH 212, you will work with rotational kinetic energy and the energy carried by different types of waves, and in PH 213, you will work with electric potential energy.

There are other kinds of energy. To name just a few, you might deal with chemical energy in some situations, or perhaps you could think about the energy stored in pressurized gas (thermodynamics will teach you a lot about how changes in pressure and volume will affect the temperature of a gas).

A Deeper Model for Interactions

- Quantities
  - Energy E
  - Work $W = \int_{r_i}^{r_f} \vec{F} \cdot d\vec{r}$
  - Kinetic Energy $K = \frac{1}{2}mv^2$
  - Potential Energy $U =$ depends on interaction
    You have to tell everyone where zero PE is!
    - Gravity $U_g = mgy$
    - Spring $U_{sp} = \frac{1}{2}kx^2$
- Laws
  - Work-energy theorem $W_{\text{net,ext}} = \Delta E_{\text{total}}$

(B) 600 J

The displacement is squared ($U_{sp} = \frac{1}{2}kx^2$), so it doesn't matter if it is positive or negative. The same amount of stretch or compression stores the same amount of energy.

L17-2: Stretch vs. Compression

- A spring's potential energy is 0 J at $x = 0$ (equilibrium).
- When you stretch the spring to the right ($x = +3$ cm), the spring's potential energy is 600 J.
- What is the spring's potential energy when you compress the spring to the left ($x = -3cm$)?

(A) 1200 J

(B) 600 J

(C) 0 J

(D) -600 J

(E) -1200 J

(D) -600 J

If you can change to a lower height, you can always decrease gravitational potential energy. There is always more energy to access, even if you start at zero. The choice of zero is arbitrary; the change in potential energy is what matters.

L17-3: Second Floor vs. Basement

- An object's gravitational potential energy with the Earth is 0 J on the **first floor**.
- On the **second floor**, 3 meters above the first floor, the gravitational potential energy is 600 J.
- What is the gravitational potential energy when the object is in the basement (3 meters underground)?

(A) 1200 J

(B) 600 J

(C) 0 J

(D) -600 J

(E) -1200 J

Solving Problems with Energy

- The energy of a system depends on:
  - *where* each object is located (potential),
  - *how fast* each object is moving (kinetic).
- The **change** in a system's energy is often easy to calculate.

L17-4: Down a Waterslide

- You (mass m) slide down a frictionless waterslide (height h) that makes an angle θ.
- How fast are you moving at the bottom of the waterslide?
  - What system do you want to choose?
  - What kinds of energy do we have?

System

Your system should be you and the Earth. If the Earth is outside of our system, then gravity does work on you. We can solve the problem this way, but that is not the method of conservation of energy. By putting you and the Earth in the system, there is no work done, and you and the Earth share gravitational potential energy.

It can be very helpful to organize our energies into a table. Each row is a different point in time, and each column is a type of energy in the system, written as a symbolic equation. The right column is the total energy, each entry of which is obtained by summing all of the different energy equations in that row.

	K	U_g	E_{total}
Initial	0	mgh	mgh
Final	$\frac{1}{2}mv^2$	0	$\frac{1}{2}mv^2$

The work energy theorem tells us that

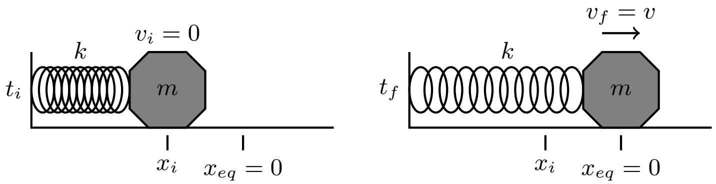
$$\begin{aligned} \Delta E &= W_{\text{net,ext}} \\ E_f - E_i &= 0 \\ E_f &= E_i. \end{aligned}$$

As such, if we know there is no work done between two times in our table, we can set the total energy entries of those rows equal to each other. In particular:

$$\begin{aligned} \frac{1}{2}mv^2 &= mgh \\ v &= \sqrt{2gh}. \end{aligned}$$

Note that the angle of the waterslide doesn't matter! The change in height is important, but how exactly we get from the top to the bottom doesn't matter. This is an aspect of gravity being a conservative force.

System
The system should be the spring and the rock. This makes the spring force internal, so we can use spring potential energy instead of work done by the spring.



	K	U_{sp}	E_{total}
t_i	0	$\frac{1}{2}kx_i^2$	$\frac{1}{2}kx_i^2$
t_f	$\frac{1}{2}mv^2$	0	$\frac{1}{2}mv^2$

There is no external work being done on this system, so $\Delta E_{\text{total}} = 0$ by the work-energy theorem. As such, the total energy is conserved, and $E_f = E_i$:

$$\begin{aligned}\frac{1}{2}mv^2 &= \frac{1}{2}kx_i^2 \\ v^2 &= \frac{k}{m}x_i^2 \\ v &= x_i\sqrt{\frac{k}{m}}.\end{aligned}$$

L17-5: Rock with a Spring

- A rock (mass m) is compressing a horizontal spring with constant k by an amount x_i.
- If you release the rock from rest, how fast is the rock moving when the spring returns to equilibrium?
  - What system do you want to choose?
  - What kinds of energy do we have?
  - Draw a diagram to help!
  - Find the speed of the rock.

Solving Problems with Energy

- The **change** in a system's energy is often easy to calculate.
  - Choose a system.
  - Identify all forms of energy.
  - Draw energy bar diagrams.
    - A simple, descriptive before-and-after sketch is also good for setting up the problem.
    - An energy bar diagram helps you translate from the positions and velocities of the objects into what you expect the energies to be doing over time.
  - Identify each energy symbolically.
    - Organize them in a table!

Main Ideas

- We can solve physics problems from an *energy approach* instead of from a *force approach*.

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