Physics 2A
Chapter 10: Energy and Work

"It is good to have an end to journey toward; but it is the journey that matters, in the end."
Ursula K. Le Guin

"*Nobody made a greater mistake than he who did nothing because he could only do a little*."
Edmund Burke

Reading: pages 289 - 315 (skip section 10.7)

Outline:

⇒ work done by a constant force
⇒ energy
    types of energy
    energy transformations
    work-energy equation
    law of conservation of energy
⇒ kinetic energy
⇒ potential energy
    gravitational potential energy
    elastic potential energy
⇒ thermal energy
⇒ using the law of conservation of energy
    conservation of mechanical energy

Problem Solving

You should know how to calculate the work done by a force if the force is constant: $W = Fd\cos\theta$. In this equation, θ is the angle between the force and the displacement. The work done by a force can be positive, negative, or zero depending upon the value of θ.

The work-energy theorem tells us that the total work W done on a system is equal to the change in energy of the system. That is, $W = \Delta E$ where:

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \ldots$$

In this equation, $K = ½ mv^2$ is kinetic energy, $U_g = mgy$ is gravitational potential energy, $U_s = ½ kx^2$ is elastic potential energy, E_{th} is thermal energy, and E_{chem} is chemical energy. If the system is isolated so that no work is done on the system, then $W = 0$ and

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} + \Delta E_{chem} + \ldots = 0.$$

This is called the law of conservation of energy.

In any system where friction is present, the thermal energy of the system will increase. The increase in thermal energy when kinetic friction is present is given by $\Delta E_{th} = f_k \Delta x$.

For most ordinary systems that we will study, the forms of energy that are typically transformed are kinetic energy, gravitational and elastic potential energies, and thermal energy. We can then write the law of conservation of energy as:

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{th} = 0.$$

Another way of writing conservation of energy is:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{th} = K_i + (U_g)_i + (U_s)_i.$$

If friction can be neglected so that $\Delta E_{th} = 0$, then this equation becomes:

$$K_f + (U_g)_f + (U_s)_f = K_i + (U_g)_i + (U_s)_i.$$

This is called conservation of mechanical energy, where mechanical energy is defined as the sum of the kinetic and potential energies of a system.

Questions and Example Problems from Chapter 10

Question 1
Give a specific example of a system with the energy transformations shown below:

a) $W \rightarrow K$

b) $K \rightarrow U$

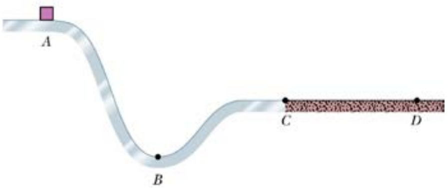
c) $U \rightarrow \Delta E_{th}$

d) $W \rightarrow U$

e) $W \rightarrow \Delta E_{th}$

f) $K \rightarrow \Delta E_{th}$

Question 2
In the figure below, a block slides from A to C along a frictionless ramp, and then it passes through horizontal region CD, where a frictional force acts on it. Is the block's kinetic energy increasing, decreasing, or constant in (a) region AB, (b) region BC, and (c) region CD? (d) Is the block's mechanical energy increasing, decreasing, or constant in those regions?



SUMMARY

The goals of Chapter 10 are to introduce the concept of energy and to learn a new problem-solving strategy based on conservation of energy.

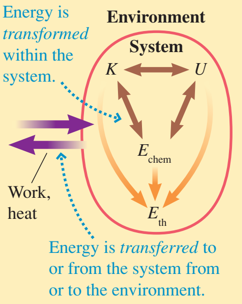
GENERAL PRINCIPLES

Basic Energy Model

Within a system, energy can be **transformed** between various forms.

Energy can be **transferred** into or out of a system in two basic ways:

- **Work:** The transfer of energy by mechanical forces.
- **Heat:** The nonmechanical transfer of energy from a hotter to a colder object.



Energy is *transformed* within the system.

Energy is *transferred* to or from the system from or to the environment.

Conservation of Energy

When work W is done on a system, the system's total energy changes by the amount of work done. In mathematical form, this is the **work-energy equation:**

$$\Delta E = \Delta K + \Delta U_g + \Delta U_s + \Delta E_{\text{th}} + \Delta E_{\text{chem}} + \cdots = W$$

A system is **isolated** when no energy is transferred into or out of the system. This means the work is zero, giving the **law of conservation of energy:**

$$\Delta K + \Delta U_g + \Delta U_s + \Delta E_{\text{th}} + \Delta E_{\text{chem}} + \cdots = 0$$

Solving Energy Conservation Problems

PREPARE Choose your system so that it's isolated. Draw a before-and-after visual overview.

SOLVE

- If the system is isolated and there's no friction, then mechanical energy is conserved:

$$K_f + (U_g)_f + (U_s)_f = K_i + (U_g)_i + (U_s)_i$$

- If the system is isolated but there's friction present, then the total energy is conserved:

$$K_f + (U_g)_f + (U_s)_f + \Delta E_{\text{th}} = K_i + (U_g)_i + (U_s)_i$$

ASSESS Kinetic energy is always positive, as is the change in thermal energy.

IMPORTANT CONCEPTS

Kinetic energy is an energy of motion:

$$K = \underbrace{\tfrac{1}{2}mv^2}_{\text{Translational}} + \underbrace{\tfrac{1}{2}I\omega^2}_{\text{Rotational}}$$

Potential energy is energy stored in a system of interacting objects.

- **Gravitational potential energy:** $U_g = mgy$
- **Elastic potential energy:** $U_s = \frac{1}{2}kx^2$

Mechanical energy is the sum of a system's kinetic and potential energies:

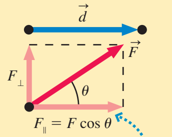
$$\text{Mechanical energy} = K + U = K + U_g + U_s$$

Thermal energy is the sum of the microscopic kinetic and potential energies of all the molecules in an object. The hotter an object, the more thermal energy it has. When kinetic (sliding) friction is present, the increase in the thermal energy is $\Delta E_{\text{th}} = f_k \Delta x$.

Work is the process by which energy is transferred to or from a system by the application of mechanical forces.

If a particle moves through a displacement $\vec{d}$ while acted upon by a constant force $\vec{F}$, the force does work

$$W = F_\| d = Fd\cos\theta$$



Only the component of the force parallel to the displacement does work.

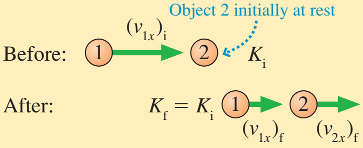
APPLICATIONS

Perfectly elastic collisions

Both mechanical energy and momentum are conserved.

$$(v_{1x})_f = \frac{m_1 - m_2}{m_1 + m_2}(v_{1x})_i$$

$$(v_{2x})_f = \frac{2m_1}{m_1 + m_2}(v_{1x})_i$$



Power is the rate at which energy is transformed . . .

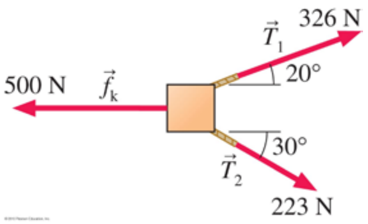
$$P = \frac{\Delta E \xleftarrow{} \text{Amount of energy transformed}}{\Delta t \xleftarrow{} \text{Time required to transform it}}$$

. . . or at which work is done.

$$P = \frac{W \xleftarrow{} \text{Amount of work done}}{\Delta t \xleftarrow{} \text{Time required to do work}}$$

Question 3
Sandy and Chris stand on the edge of a cliff and throw identical mass rocks at the same speed. Sandy throws her rock horizontally while Chris throws his upward at an angle of 45° to the horizontal. Are the rocks moving at the same speed when they hit the ground, or is one moving faster than the other? If one is moving faster, which one? Explain

Problem 1
The two ropes shown in the bird' s-eye view of the figure below are used to drag a crate exactly 3.0 m across the floor. How much work is done by each of the ropes on the crate?



Problem 2
To pull a 50 kg crate across a horizontal floor at a constant velocity, a worker applies a force directed 20^{o} above the horizontal. A 25.0 N frictional force opposes the motion of the crate. As the crate moves 3.0 m, what is the work done on the crate by (a) the worker's force, (b) the kinetic frictional force, (c) the gravitational force on the crate, and (d) the normal force?

Problem 3

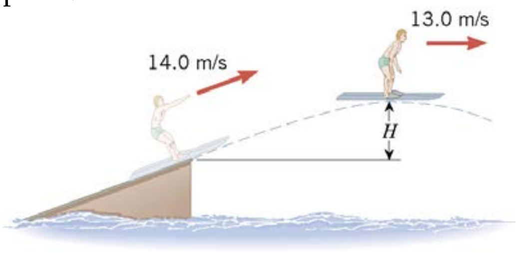
A 20.0 g plastic ball is moving to the right at 30.0 m/ s. How much work must be done on the ball to cause it to move to the right at 10.0 m/s?

Problem 4

A fireman of mass 80 kg slides down a pole. When he reaches the bottom, 4.2 m below his starting point, his speed is 2.2 m/s. By how much has thermal energy increased during his slide?

Problem 5

A water-skier lets go of the tow rope upon leaving the end of a jump ramp at a speed of 14.0 m/s. As the drawing indicates, the skier has a speed of 13.0 m/s at the highest point of the jump. Ignoring air resistance, determine the skier's height H above the *top of the ramp* at the highest point.



Problem 6

What minimum speed does a 100.0 g puck need to make it to the top of a frictionless ramp that is 3.00 m long and inclined at 20.0°?

Problem 7

As a 15,000 kg jet lands on an aircraft carrier, its tail hook snags a cable to slow it down. The cable is attached to a spring with spring constant 60,000 N/m. If the spring stretches 30.0 m to stop the plane, what was the plane's landing speed?

Problem 8
A slingshot fires a pebble from the top of a building at a speed of 14.0 m/s. The building is 31.0 m tall. Ignoring air resistance, find the speed with which the pebble strikes the ground when the pebble is fired (a) horizontally, (b) vertically straight up, and (c) vertically straight down.

Problem 9
A boy reaches out if a window and tosses a ball straight up with speed of 10.0 m/s. The ball is 20.0 m above the ground as he releases it. Use conservation of energy to find (a) the ball's maximum height above the ground and (b) the speed of impact on the ground.

Problem 10
A pitcher throws a 0.140 kg baseball, and it approached the bat at a speed of 40.0 m/s. The bat does W = 70.0 J of work on the ball in hitting it. Ignoring air resistance, determine the speed of the ball after the ball leaves the bat and is 25.0 m above the point of impact.

Problem 11
A car accelerates uniformly from rest to 20.0 m/s in 5.6 s along a level stretch of road. Ignoring friction, determine the average power required to accelerate the car if (a) the weight of the car is 9.0×10^3 N, and (b) the weight of the car is 1.4×10^4 N.