Honors Physics
Unit 5: Work & Energy

Slides

Work & Power

Work

- Occurs when a force is applied over a displacement
- Measured in *Joules* (J)
  - 1 J = 1 $kg \cdot m^2/s^2$ = 1 N·m
- Is a scalar

Work Equation

$$W = F_{\parallel} \cdot d$$

W = work
$F_{\parallel}$ = component of force parallel to displacement
d = displacement

Work Equation

$$W = Fd\cos\theta$$

W = work
F = force
d = displacement
θ = angle between force and displacement

Work – Three Cases

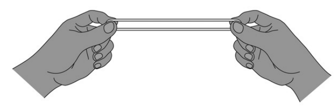
Three cases:

1. Force & displacement in same direction → positive work
   - $\theta = 0°$ → $\cos 0° = 1$
2. Force & displacement in opposite directions → negative work
   - $\theta = 180°$ → $\cos 180° = -1$
3. Force & displacement are perpendicular → zero work
   - $\theta = 90°$ → $\cos 90° = 0$

Types of Work

- "Mechanical" work
  - Examples: pushing a shopping cart, lifting a textbook

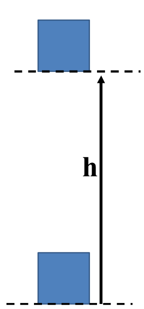
- Work against resistance
  - Examples: stretching a rubber band, pulling a bow

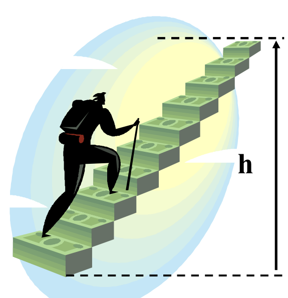


- Work to deform (change shape)
  - Examples: squeezing a stress ball, bending a piece of metal

Work Against Gravity

- Lift an object upward against the downward force of gravity.
- Move objects to a higher position.
- Height is the vertical displacement in the up or down direction.

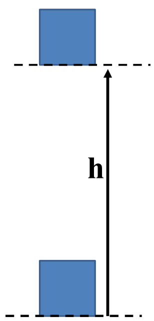


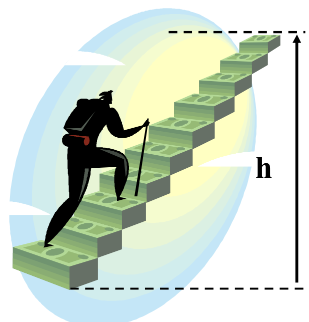


Work Against Gravity

$$W = m \cdot g \cdot h$$

W = Work (J)
m = mass (kg)
g = 9.81 (m/s^2)
h = height (m)





Power

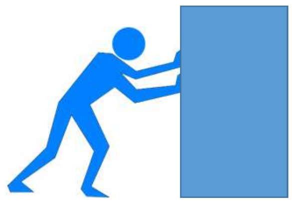
- Measure of how quickly work is done
  - More work over a shorter time = more power
- Unit
  - 1 Joule/sec (J/s) = 1 Watt (W)
  - In some situations, we also use the unit *horsepower*

$$P = \frac{W}{t}$$

P = power (Watts)
W = work done (Joules)
t = time (seconds)

Calculate Work and Power

A man pushes a box 25.0 meters across the floor in 5.0 seconds. He pushes with net 30 N of force. (Assume no friction).



- Calculate the work performed. **750 J**
- Calculate the power. **150 W**

A man pulls a wagon with a net force of 40 N in a straight-line distance of 30 m for 1 minute. (Assume no friction).

- Calculate the work performed. **1200 J**
- Calculate the power. **20 W**

Energy

What is energy?

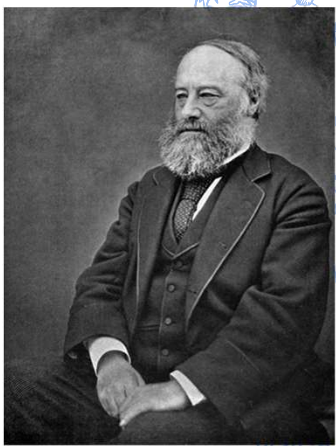
A quantity in the universe, called **energy**, that has different forms and can change between those forms, but the total amount never changes

For example:
- Kinetic (motion)
- Potential (position)
- Internal
- Electromagnetic
- and others...

Units of Energy

Energy is measured in **joules (J)**

$$1 \text{ joule} = 1 \text{ J} = 1 \text{ kg·m}^2/\text{s}^2$$



James Prescott Joule

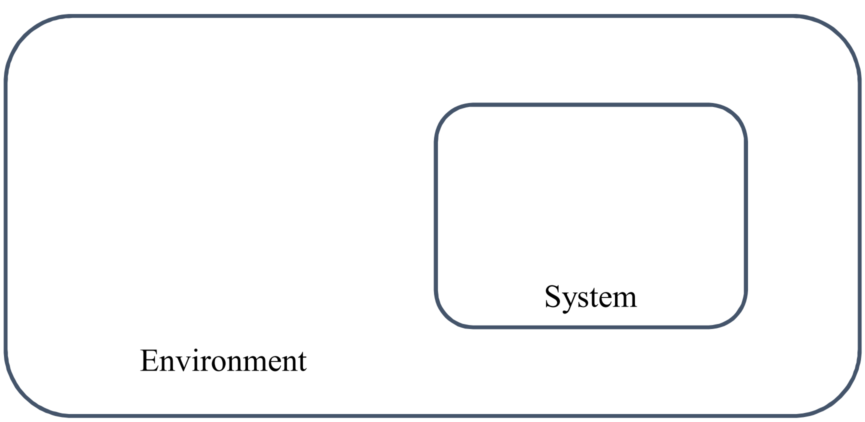
Systems

- System: some portion of the Universe you are focusing on
- Environment: everything in the Universe that is *not* the system

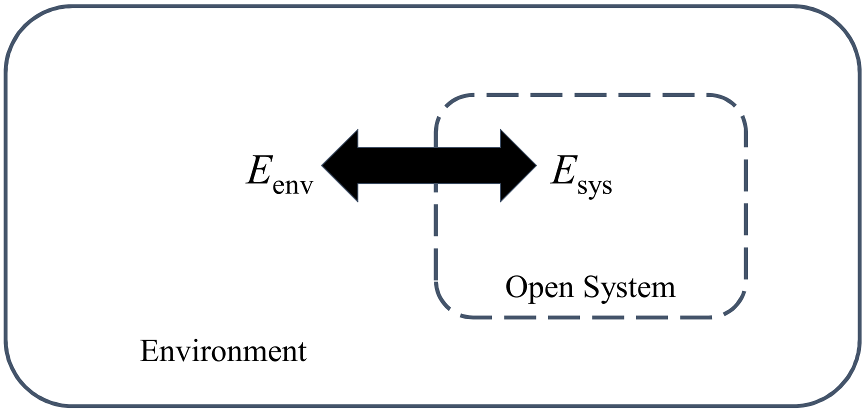
- Open system: energy can be transferred between the system and the environment

- Closed system: energy cannot be transferred between the system and the environment
  - Also called an isolated system

Systems

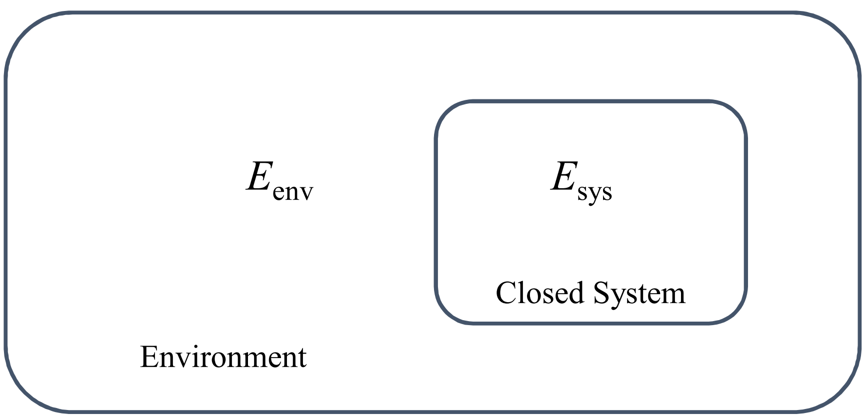


Open System



$E_{sys} + E_{env}$ = constant

Closed System



E_{sys} = constant $\Rightarrow$ $\Delta E_{sys} = 0$

Conservation of Energy

- Energy is neither created nor destroyed, but it can change into different forms
- Total amount of energy in the Universe does not change
- In a closed system, the total amount of energy does not change
- In an open system, the amount of energy entering the system equals the amount of energy leaving the environment, and vice versa

Kinetic Energy

Energy associated with motion

$$KE = \frac{1}{2}mv^2$$

m = mass of object (kg)

v = velocity or speed of object (m/s)

Transfer of Energy

How do we transfer energy into or out of a system?

Energy Transfers

There are different types of energy transfers. Two that we will study are:

1. Work!
   - Work is a transfer of energy
2. Waves
   - Waves transfer energy, we'll learn more about this next unit

Work as a Transfer of Energy

When I do positive (+) work on a system:

- Energy is transferred from the environment into the system
- E_{sys} increases

When I do negative (-) work on a system:

- Energy is transferred from the system into the environment
- E_{sys} decreases

Work-Kinetic Energy Theorem

When work is done on a system and the only change in the system is the speed, then the amount of net work done equals the change in the KE of the system.

$$W_{net} = \Delta KE = KE_f - KE_i$$

Note:

- Positive work increases KE (energy transferred *into* system)
- Negative work decreases KE (energy transferred *out* of the system)

Lifting a Bowling Ball

System: the bowling ball

When I lift the bowling ball, I do positive work on the system, meaning I transfer energy into the system. If I transferred energy into the system, why did the KE of the system not increase?

Lifting a Bowling Ball

System: the bowling ball + the Earth

When I lift the bowling ball, I do positive work on the system, meaning I transfer energy into the system. If I transferred energy into the system, where did that energy go if the KE of the system did not increase?

It was converted into **potential energy**!

(Gravitational PE, specifically)

Potential Energy

- Energy associated with position
- Two types:
  - Gravitational PE (GPE)
  - Elastic PE (EPE)
- Can think of as storing energy to later do some work
  - "Potential" energy because it has the potential to do work
- Measured in units of Joules

Gravitational Potential Energy (GPE)

- Energy associated with the height of an object above a zero level (usually the ground)

$$GPE = mgh$$

GPE = gravitational PE (J)
m = mass of object (kg)
g = 9.81
h = height (m)

Gravitational Potential Energy (GPE)

NOTE: GPE is only present if the Earth is considered to be part of the system

- In that case, the gravitational force is not doing work on the system since it is an internal force

Elastic Potential Energy (EPE)

- Energy associated with stretching an object (like a spring or rubber band)

$$EPE = \frac{1}{2}kx^2$$

EPE = elastic potential energy (J)
k = spring constant (how stiff the spring is) (N/m)
x = distance spring is stretched or compressed (m)

Mechanical Energy

Mechanical Energy

The sum of the kinetic energy and potential energy of an object is referred to as **mechanical energy**:

$$ME = KE + GPE + EPE$$

ME = mechanical energy

KE = kinetic energy

GPE = gravitational potential energy

EPE = elastic potential energy

Conservation of Mechanical Energy

In a **closed system** with **no friction**, the mechanical energy of a system is conserved. Its value does not change.

$$ME_i = ME_f$$

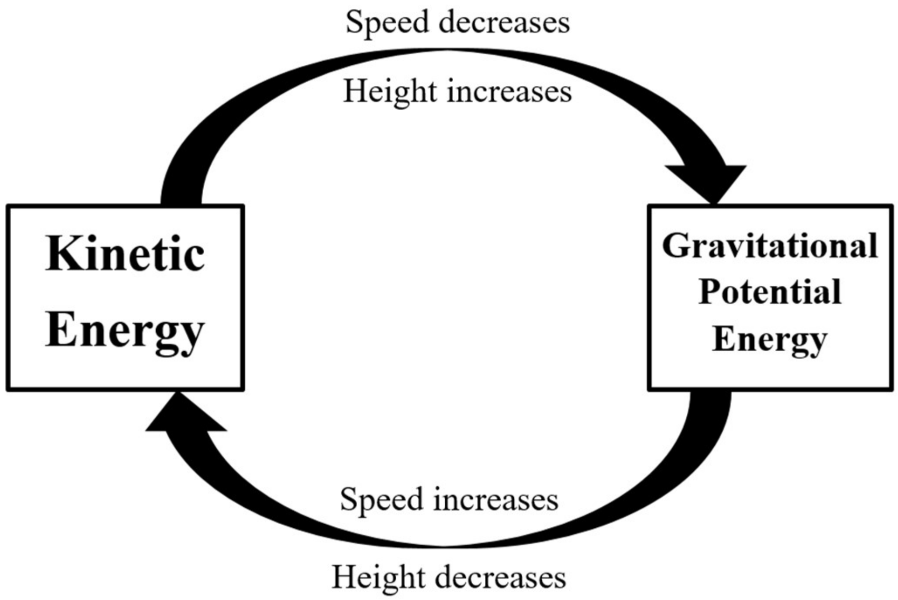
As the object moves up and down, speeds up and slows down, the energy will transform between KE and PE, with the total amount not changing.

Conservation of Mechanical Energy

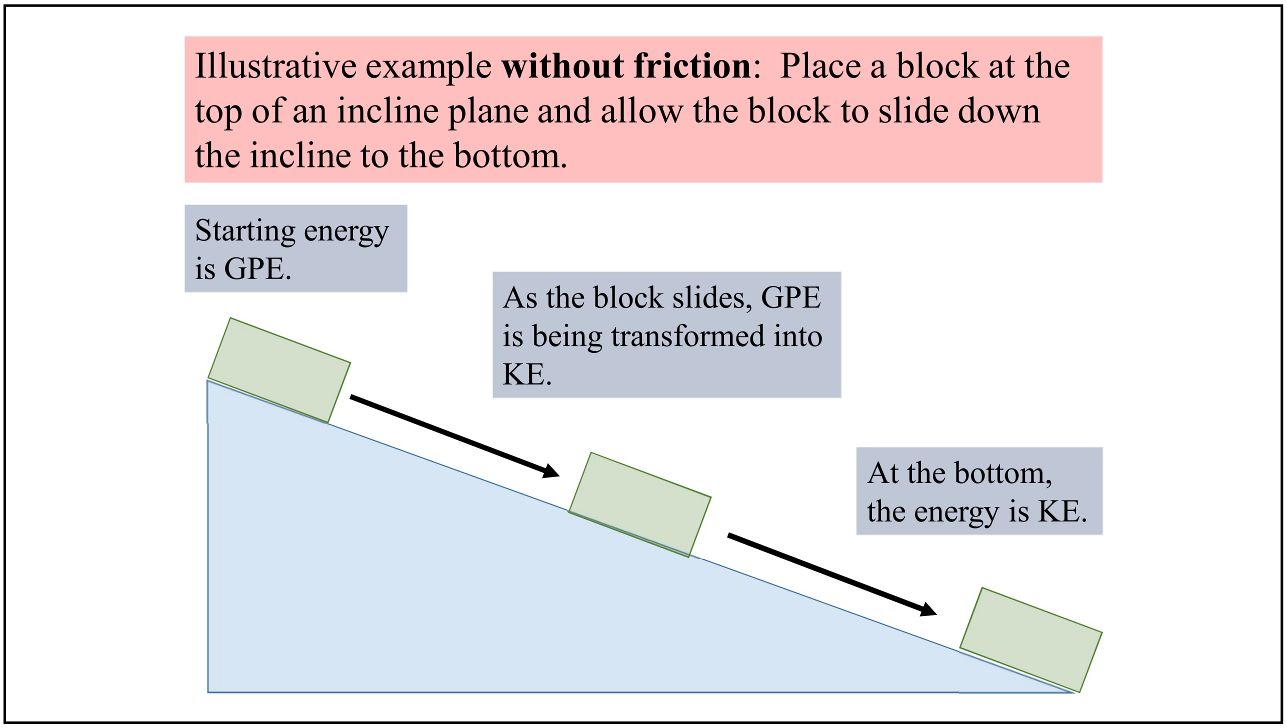
$$ME_i = ME_f$$

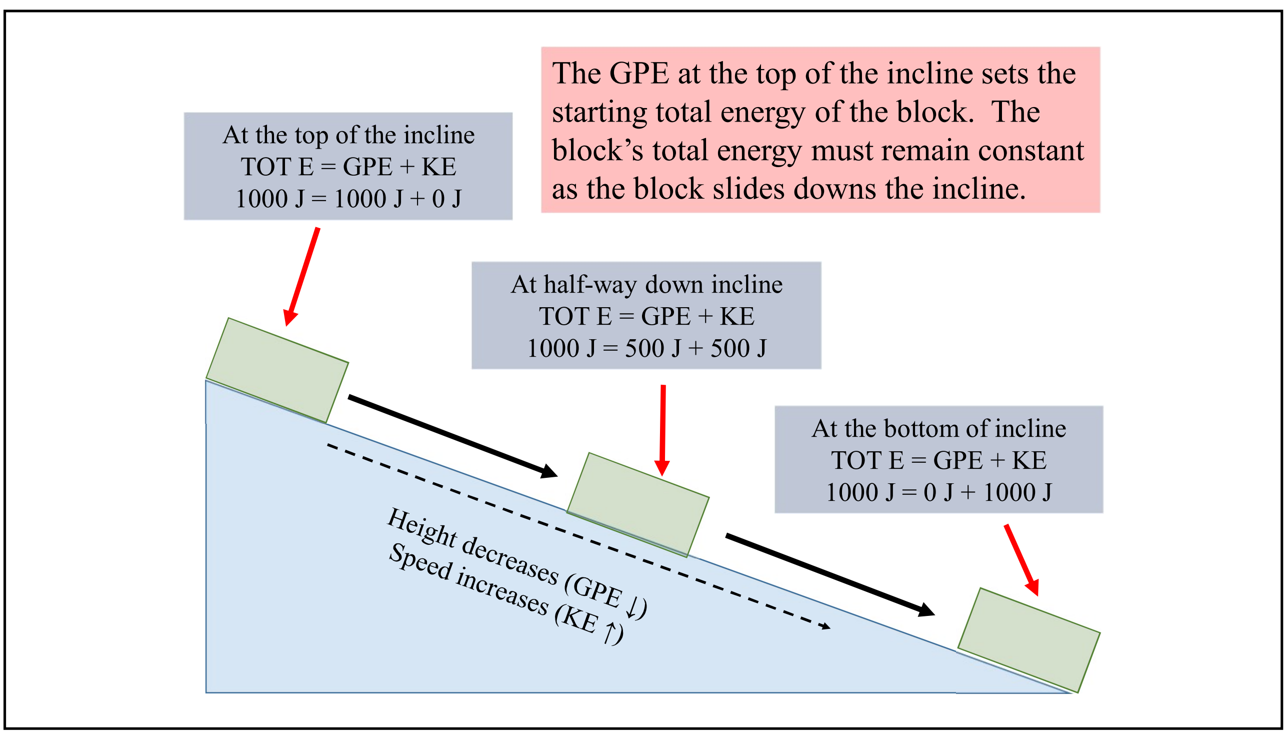
$$KE_i + GPE_i + EPE_i = KE_f + GPE_f + EPE_f$$

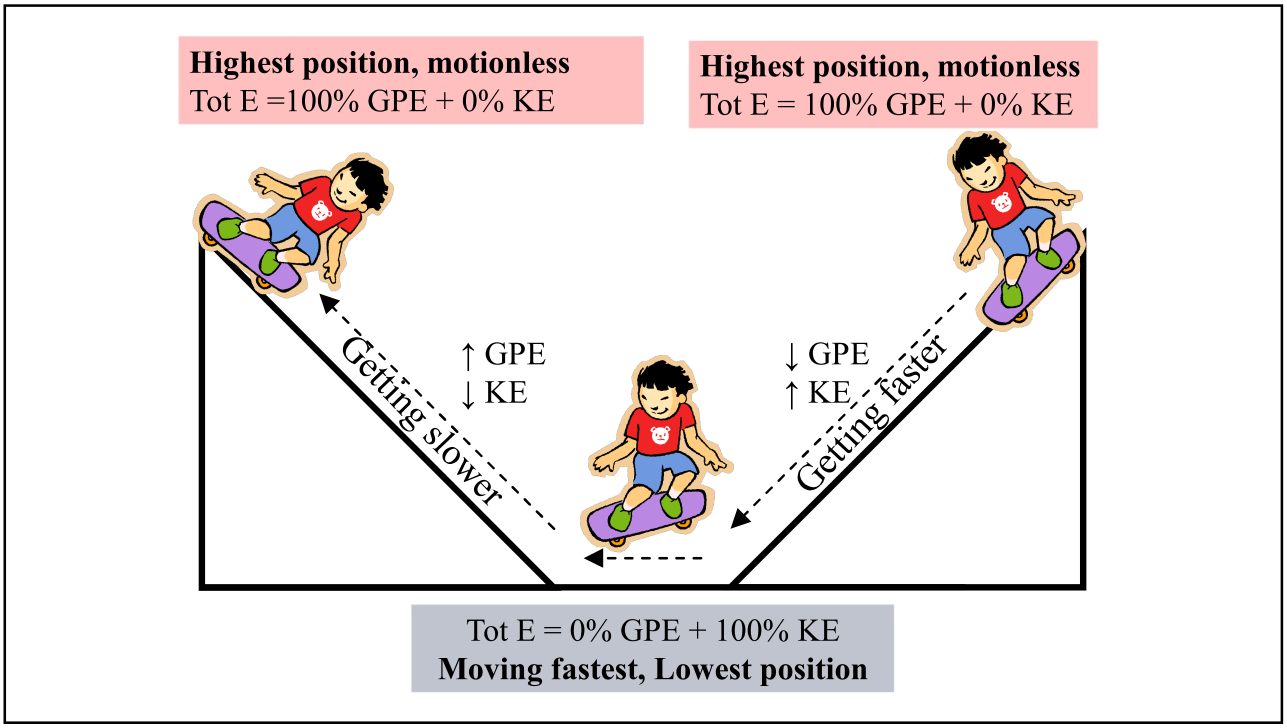
$$\frac{1}{2}mv_i^2 + mgh_i + \frac{1}{2}kx_i^2 = \frac{1}{2}mv_f^2 + mgh_f + \frac{1}{2}kx_f^2$$

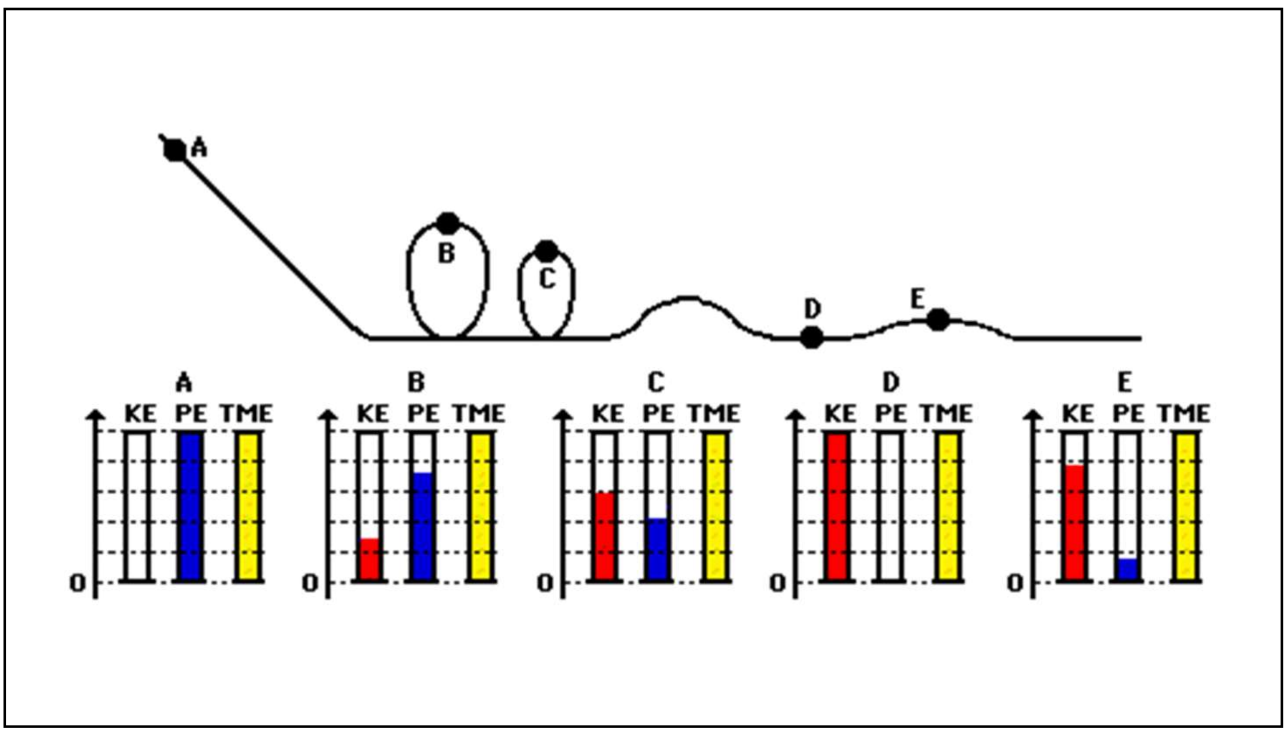


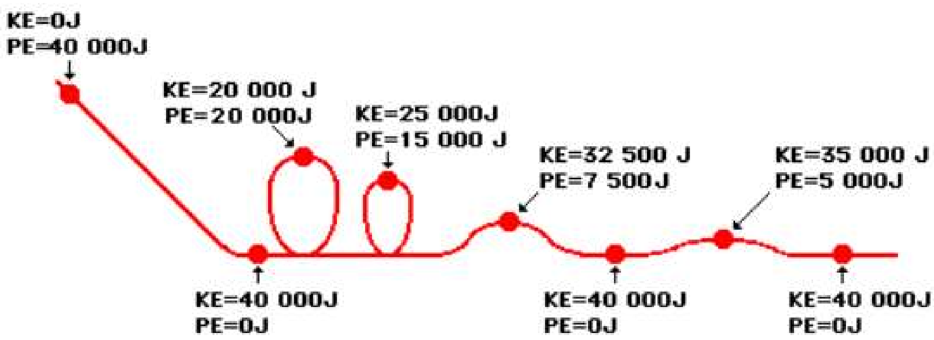
Analyzing Motion Using Conservation of Mechanical Energy


Illustrative example **without friction**: Place a block at the top of an incline plane and allow the block to slide down the incline to the bottom.
Starting energy is GPE.
As the block slides, GPE is being transformed into KE.
At the bottom, the energy is KE.


The GPE at the top of the incline sets the starting total energy of the block. The block's total energy must remain constant as the block slides downs the incline.
At the top of the incline
TOT E = GPE + KE
1000 J = 1000 J + 0 J
At half-way down incline
TOT E = GPE + KE
1000 J = 500 J + 500 J
At the bottom of incline
TOT E = GPE + KE
1000 J = 0 J + 1000 J
Height decreases (GPE ↓)
Speed increases (KE ↑)


Highest position, motionless
Tot E =100% GPE + 0% KE
Highest position, motionless
Tot E = 100% GPE + 0% KE
↑ GPE
↓ KE
↓ GPE
↑ KE
Getting slower
Getting faster
Tot E = 0% GPE + 100% KE
Moving fastest, Lowest position


A
B
C
D
E
KE PE TME
0



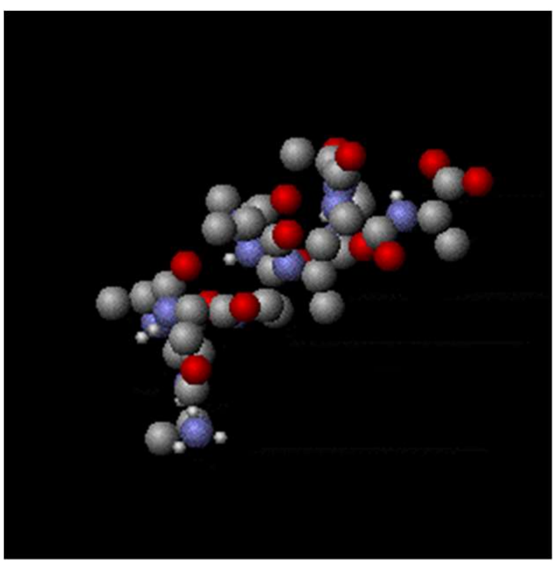
Internal Energy

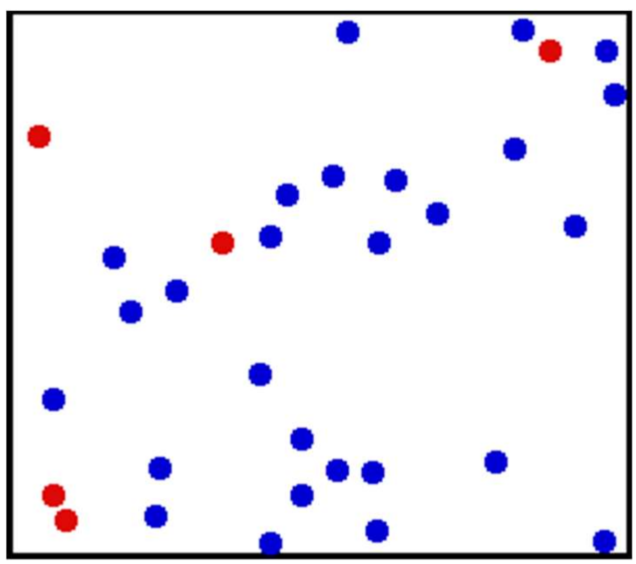
What does friction do to mechanical energy?

Mechanical energy: Potential energy and kinetic energy of the ***whole object***

- Based on the mass of the object
- Based on how fast the object moves
- Based on the object's position

Internal energy: the total energy contained within an object due to the kinetic energy and potential energy of the ***molecules*** that make up the object





Forms of Energy Included in Internal Energy

- **Chemical energy** stored in the chemical bonds holding the atoms together in a molecule.
- **Attraction energy (potential)** between molecules (London forces, electrostatic, or hydrogen bonding). Energy holding molecules together.
- **Kinetic energy** of molecules (translational, rotational, or vibrational)—how fast the molecules move (influences temperature)

Friction Increases Internal Energy

Friction in a system converts mechanical energy into internal energy

When there is friction, mechanical energy is **NOT** conserved

- Mechanical energy decreases
- Internal energy increases

Note: *Total* energy (mechanical + internal) does not change