Potential Energy (Ch 8)

- Potential energy is the energy associated with the configuration of a system of objects that exert forces on each other
  - This can be used only with conservative forces
  - When conservative forces act within an isolated system, the kinetic energy gained (or lost) by the system as its members change their relative positions is balanced by an equal loss (or gain) in potential energy.
  - This is Conservation of Mechanical Energy

Types of Potential Energy

- There are many forms of potential energy, including:
  - Gravitational
  - Electromagnetic
  - Chemical
  - Nuclear
- One form of energy in a system can be converted into another

System Example

- This system consists of Earth and a book
  - Do work on the system by lifting the book through \( \Delta y \)
  - The work done is \( mgy_b - mgy_a \)

Potential Energy

- The energy storage mechanism is called potential energy
- A potential energy can only be associated with specific types of forces
- Potential energy is always associated with a system of two or more interacting objects
**Gravitational Potential Energy**

- Gravitational Potential Energy is associated with an object at a given distance above Earth’s surface.
- Assume the object is in equilibrium and moving at constant velocity.
- The work done on the object is done by $F_{\text{app}}$ and the upward displacement is $\Delta r = \Delta y \hat{j}$.

**Gravitational Potential Energy, cont**

- $W = (F_{\text{grav}} \cdot \Delta r)$
- $W = (mg \hat{j} \cdot [(y_b - y_a) \hat{j}])$
- $W = mgy_b - mgy_a$
- The quantity $mg\Delta y$ is identified as the gravitational potential energy, $U_g$
  - $U_g = mg\Delta y$
  - Units are joules (J)

**Conservation of Mechanical Energy**

- The mechanical energy of a system is the algebraic sum of the kinetic and potential energies in the system.
- $E_{\text{mech}} = K + U$
- The statement of Conservation of Mechanical Energy for an isolated system is
  \[ K_i + U_i = K_f + U_f \]

**Conservation of Mechanical Energy, example**

- Look at the work done by the book as it falls from some height to a lower height.
- $W_{\text{on book}} = \Delta K_{\text{book}}$
- Also, $W = mg\Delta y = mgy_a - mgy_b$
- So, $\Delta K = -\Delta U_g$
Elastic Potential Energy

- *Elastic Potential Energy* is associated with a spring.
- The force the spring exerts (on a block, for example) is $F_s = -kx$.
- The work done by an external applied force on a spring-block system is
  - $W = \frac{1}{2} kx^2 - \frac{1}{2} kx^2$.

Elastic Potential Energy, cont

- This expression is the elastic potential energy: $U_s = \frac{1}{2} kx^2$.
- The elastic potential energy can be thought of as the energy stored in the deformed spring.
- The stored potential energy can be converted into kinetic energy.

Elastic Potential Energy, final

- The elastic potential energy stored in a spring is zero whenever the spring is not deformed ($U = 0$ when $x = 0$).
- The energy is stored in the spring only when the spring is stretched or compressed.
- The elastic potential energy is a maximum when the spring has reached its maximum extension or compression.
- The elastic potential energy is always positive.
  - $x^2$ will always be positive.

Problem-Solving Strategy

- If the mechanical energy of the system is conserved, write the total energy as
  - $E_i = K_i + U_i$ for the initial configuration.
  - $E_f = K_f + U_f$ for the final configuration.
- Since mechanical energy is conserved, $E_i = E_f$ and you can solve for the unknown quantity.
- If friction is present, then
  - $E_f = K_f + U_f + W_f$ (work done by friction).
Conservation of Energy, Example 1 (Drop a Ball)

- Initial conditions:
  - $E = K_i + U_i = mgh$
  - The ball is dropped, so $K_i = 0$
  - The potential energy is zero at the ground level
  - Conservation rules applied at some point $y$ above the ground gives
    - $\frac{1}{2}mv_f^2 + mgy = mgh$

Conservation of Energy, Example 2 (Pendulum)

- As the pendulum swings, there is a continuous change between potential and kinetic energies
- At $A$, the energy is potential
- At $B$, all of the potential energy at $A$ is transformed into kinetic energy
  - Let zero potential energy be at $B$
- At $C$, the kinetic energy has been transformed back into potential energy

Conservative Forces

- The work done by a conservative force on a particle moving between any two points is independent of the path taken by the particle
- The work done by a conservative force on a particle moving through any closed path is zero
  - A closed path is one in which the beginning and ending points are the same

Conservative Forces, cont

- Examples of conservative forces:
  - Gravity
  - Spring force
- We can associate a potential energy for a system with any conservative force acting between members of the system
  - This can be done only for conservative forces
  - In general: $W_C = -\Delta U$
Nonconservative Forces

- A nonconservative force does not satisfy the conditions of conservative forces
- Nonconservative forces acting in a system cause a change in the mechanical energy of the system

Nonconservative Forces, cont

- The work done against friction is greater along the red path than along the blue path
- Because the work done depends on the path, friction is a nonconservative force

Conservative Forces and Potential Energy

- The conservative force is related to the potential energy function through
  \[ F_x = -\frac{dU}{dx} \]
- The x component of a conservative force acting on an object within a system equals the negative of the potential energy of the system with respect to x

Conservative Forces and Potential Energy – Check

- Look at the case of a deformed spring
  \[ F_x = -\frac{dU}{dx} = -\frac{d}{dx}\left(\frac{1}{2}kx^2\right) = -kx \]