Phy 211: General Physics I

Chapter 8: Potential Energy & Conservation of Energy

Lecture Notes

Work & Potential Energy

- Potential Energy (U) is the energy associated with the configuration of a system, such as:
  - The position of an object
  - The deformation of a spring
- Potential Energy is a calculated quantity that represents the stored energy within the system (associated with a force) that has the potential to perform work.
- Forms of Potential Energy:
  - Gravitational PE (U_{grav}): The potential for gravitational force to perform work due to an object's elevation, defined as:

$$U_{grav} = mgy$$

  - Elastic PE ($U_{elastic}$): The potential for elastic force to perform work due to a spring's deformation, defined as:

$$U_{elastic} = \tfrac{1}{2}kx^2$$

Conservative vs. Nonconservative Forces

Conservative Forces:

1. When the configuration of a system is altered, a force performs work (W_1). Reversing the configuration of the system results in the force performing work (W_2). The force is conservative if: $W_1 = -W_2$
2. A force that performs work independent of the path taken.
3. A force in which the net work it performs around a closed path is always zero or:

$$W_{net} = 0\text{ J} \text{ \{for closed path\}}$$

Examples:

Gravitational force (F_g), Elastic force (F_{spring}), and Electric force (F_E)

Nonconservative Forces:

1. The work performed by the force depends on the path taken
2. When the configuration of a system is altered then reversed, the net work performed by the force is not zero: $W_{net} \neq 0\text{ J}$ {for closed path}
3. Work performed results in energy transformed to thermal energy

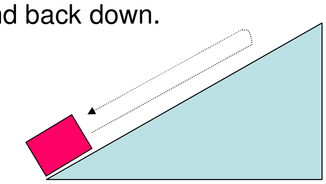
Examples:

Air Drag (F_{Drag}) and Kinetic friction ($f_{kinetic}$)

Sliding on an Incline

Example: *No friction (conservative force)*

A 1 kg object (v_o=5 m/s) travels up a 30° incline and back down.



1. The W_{net} performed by F_g (up):

$$W_{up} = \tfrac{1}{2}(1\text{ kg})\left[\left(0\tfrac{m}{s}\right)^2 - \left(5\tfrac{m}{s}\right)^2\right] = -12.5\text{ J}$$

2. The W_{net} performed by F_g (down):

$$W_{down} = \tfrac{1}{2}(1\text{ kg})\left[\left(-5\tfrac{m}{s}\right)^2 - \left(0\tfrac{m}{s}\right)^2\right] = 12.5\text{ J}$$

3. The total W_{net} performed: $W_{net\text{ by }F_g} = -12.5\text{ J} + 12.5\text{ J} = 0\text{ J}$

Example: With Kinetic Friction (nonconservative force)

A 1 kg object (v_o=5 m/s) travels up a 30° incline and back down against a 1.7 N kinetic friction force. *Note: Block will not travel up as far as previous example.*

The W_{up} performed by f_k (up):

$$W_{f\text{ up}} = \vec{f}_k \cdot \Delta\vec{r} = (-1.70\text{ N})(1.89\text{ m}) = -3.21\text{ J}$$

The W_{down} performed by f_k (down):

$$W_{f\text{ down}} = \vec{f}_k \cdot \Delta\vec{r} = (1.70\text{ N})(-1.89\text{ m}) = -3.21\text{ J}$$

The total W_{net} performed:

$$W_{net\text{ by }f} = W_{f\text{ up}} + W_{f\text{ down}} = -3.21\text{ J} - 3.21\text{ J} = -6.42\text{ J}$$

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Defining or Identifying a System

- A system is a defined object (or group of objects) that are considered distinct from the rest of its environment
- For a defined system:
  1. all forces associated strictly with objects within the defined system are deemed internal forces
     - Internal forces do not transfer energy into/out of the system when performing work within the system

     Example: The attractive forces that hold the atoms of a ball together. These forces are ignored when applying Newton's 2^{nd} Law to the ball.
  2. all forces exerted from outside the defined system are deemed external forces
     - External forces transfer energy into/out of the system when performing work on a system

     Example: The gravitational force that performs work on a falling object (the system) increases the ball system's (kinetic) energy.

     Note: When the ball **and** the earth are together defined as the system, the work performed by the gravitational force on the ball does NOT transfer energy into the system.
- The appropriate of a system determines when a force is considered internal or external & can go a long way toward simplifying the analysis of a physics problem
- The total energy associated with a defined system:

$$E_{system} = U + K + E_{thermal} + E_{Internal}$$

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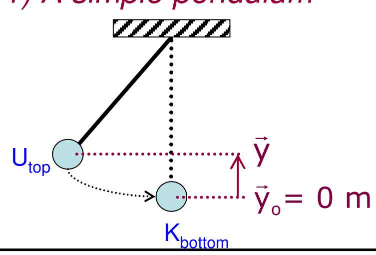
Conservation of Mechanical Energy

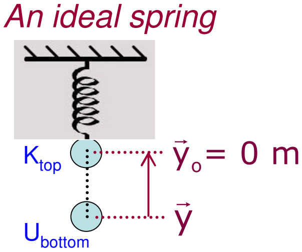
- In mechanical systems where only **conservative internal** forces are present, the total mechanical energy of the system is conserved.

$$W_{nc} = 0 \Rightarrow E_{system} = U + K = constant$$

- Energy within the system may transform from one type of mechanical energy to another. When this occurs: $\Delta E_{system} = 0\ J \Rightarrow \Delta U = -\Delta K$

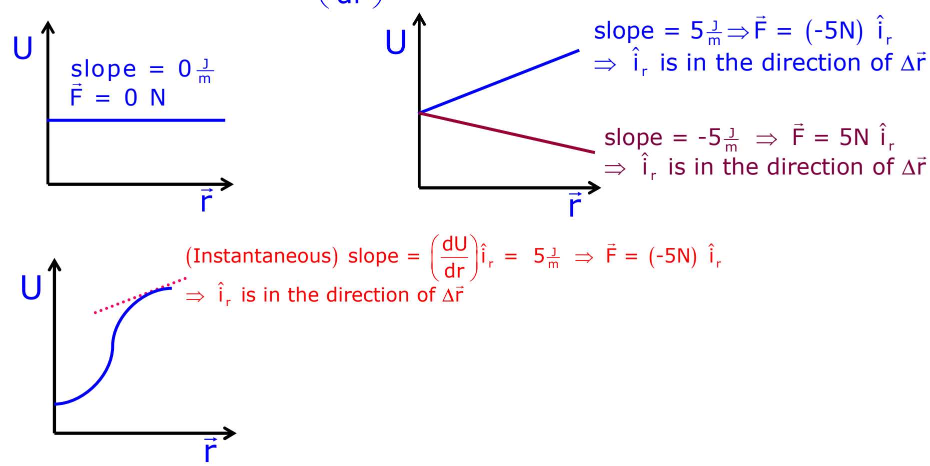
Example: *1) A simple pendulum* *2) An ideal spring*





Interpreting a Potential Energy Graph

- A potential graph is plot of U vs r for a system
  - The slope of the graph defined the force exerted along the graph $\text{slope} = \left(\frac{dU}{dr}\right)\hat{i}_r = -\vec{F}$



Work Done on a System by External Forces

- For a defined system, ***external forces*** are forces that are not defined within the system yet perform work upon the system
- External forces transfer energy into or out of a system: $W_{Ext} = W_{Ext}^{con} + W_{Ext}^{NC} = \Delta E_{system}$

$$W_{Ext} = \Delta U + \Delta K + \Delta E_{Internal} + \Delta E_{thermal}$$

  - <u>Conservative</u> external forces alter the U and K (a.k.a. the mechanical energy) of a system:

$$W_{Ext}^{con} = \Delta E_{system} = \Delta U + \Delta K$$

  - <u>Nonconservative</u> external forces may alter the mechanical energy (U, K) as well as the non-mechanical energy ($E_{internal}$ and/or $E_{thermal}$) of a system:

$$W_{Ext}^{NC} = \Delta E_{system} = \Delta U + \Delta K + \Delta E_{Internal} + \Delta E_{thermal}$$

Conservation of Energy

- In general, the total energy associated with a system of objects represents the complete state of the system:

$$E_{Tot} = U + K + E_{Internal} + E_{thermal}$$

- Work represents the transfer of energy into/out of a system:

$$W = \Delta E_{system} = \Delta U + \Delta K + \Delta E_{Internal} + \Delta E_{thermal}$$

- For an isolated system, the total energy within a system remains a constant value:

$$E_{system} = U + K + E_{Internal} + E_{thermal} = \text{constant}$$

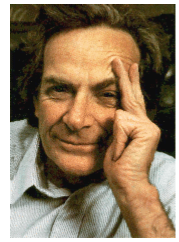
or, for any 2 moments:

$$E_{system} = U_1 + K_1 + E_{Internal\ 1} + E_{thermal\ 1} = U_2 + K_2 + E_{Internal\ 2} + E_{thermal\ 2}$$

Deeper Thoughts on Cons. of Energy

- Physicists have identified by experiment 3 fundamental conservation laws associated with isolated systems:
  1. *Conservation of Energy*
  2. *Conservation of Mass*
  3. *Conservation of Electric Charge*
- Treated as accepted "facts", these laws have allowed for experimental predictions that would not have been foreseen otherwise:
  1. Conservation of Energy led to the discovery of the neutrino during neutron decay within the atomic nucleus
  2. Conservation of Mass is fundamental in the prediction of new substance formed during chemical processes
  3. Conservation of Electric Charge predicts the formation of neutrons do to the collision of protons with electrons, a process called Electron Capture.
- Considered as accepted "facts", these laws have allowed for experimental predictions that would not have been foreseen otherwise.

Feynman on Energy



Richard Feynman (1918-1988)

"*There is a fact, or if you wish, a law, governing natural phenomena that are known to date. There is no known exception to this law - it is exact so far we know. The law is called conservation of energy [it states that there is a certain quantity, which we call energy that does not change in manifold changes which nature undergoes]. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number, and when we finish watching nature go through her tricks and calculate the number again, it is the same...*"