Mechanics
Conservation of Energy

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Last time

- concept of potential energy
- conservative and nonconservative forces
- potential energy definition
- some kinds of potential energy
- potential energy diagrams

Overview

- isolated and nonisolated systems
- mechanical energy
- conservation of mechanical energy
- general conservation of energy
- how to solve energy problems

Conservation of Energy

When a quantity maintains a fixed value in physics, we say that quantity is *conserved*.

In many systems, the total amount of energy is fixed, so we can use this principle, the **conservation of energy**, to solve problems.

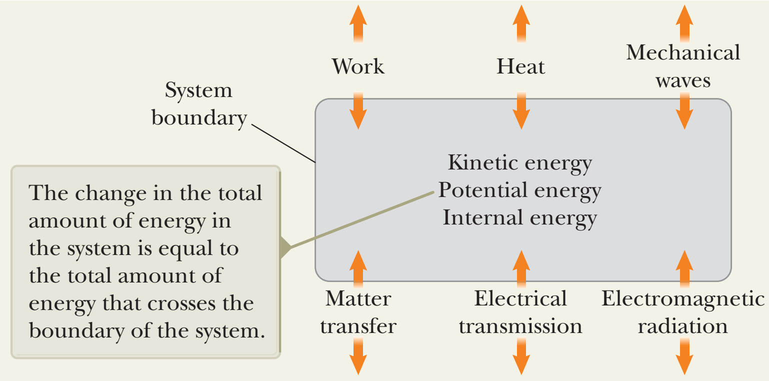
Isolated and Nonisolated Systems

Isolated systems do **not** exchange energy with the environment.

Nonisolated systems do. Non-isolated systems can lose energy to the environment or gain energy from it.

Note: in these energy lectures, I mean the system is isolated or not with respect to *energy* specifically.

Nonisolated Systems



[1]Figures from Serway & Jewett.

Mechanical Energy

The *mechanical energy* of a system is the energy that can be used to do work.

It is defined as the sum of the system's kinetic and potential energy:

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The mechanical energy of a system can change under two circumstances:

- nonconservative forces act on the system decreasing the mechanical energy
- other external forces act that may add energy to the system or reduce it (applied forces)

Conservation of Mechanical Energy

If the system is isolated: no friction, no air resistance, no external applied work, then the mechanical energy is conserved:

$$\Delta E_{\text{mech}} = \Delta K + \Delta U = 0$$

Energy can change from kinetic to potential or vice versa, but the total mechanical energy is constant.

Isolated System: Mechanical Energy Conservation

A rock is dropped from rest a height h.

By considering energy, find an expression for how fast it is moving just before it hits the ground.

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System: rock + Earth

Let point i be the moment it is dropped; f be just before it strikes the ground. Let $y = 0$ be the ground level.

$$\begin{aligned}
\Delta K + \Delta U &= 0 \\
(K_f - \cancelto{0}{K_i}) + (\cancelto{0}{U_f} - U_i) &= 0 \\
K_f &= U_i \\
\frac{1}{2}mv^2 &= mgh \\
v &= \sqrt{2gh}
\end{aligned}$$

Energy Conservation

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However, the energy of our system, which is only a tiny part of the universe, may gain or lose energy if it is nonisolated.

This can be expressed as:

$$W_{\text{ext}} = \Delta K + \Delta U$$

$$\text{or } W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$$

The work done by external forces can include work done by nonconservative forces and applied forces.

How to Solve Energy Conservation Problems

1. Draw (a) diagram(s). Free body diagrams or full pictures, as needed.
2. Identify the system. State what it is. Is it isolated?
3. Identify the initial point / configuration of the system.
4. Identify the final point / configuration of the system.
5. Write the energy conservation equation.
6. Fill in the expressions as needed.
7. Solve.
8. (Analyze answer: reasonable value?, check units, etc.)

Energy Conservation Example

3. A block of mass 0.250 kg is placed on top of a light, vertical spring of force constant 5 000 N/m and pushed downward so that the spring is compressed by 0.100 m. After the block is released from rest, it travels upward and then leaves the spring. To what maximum height above the point of release does it rise?

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System: block + spring + Earth.

Initial point, ⓘ: release point (max compression of spring),
choose $y = 0$, $U = 0$ at this point

Final point, ⓕ: point of max height of block

System is isolated.

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$$\Delta K \quad + \quad \Delta U \quad = \quad 0$$

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U_{g,f} &= U_{s,i} \\
mgh &= \frac{1}{2}kx^2 \\
h &= \frac{kx^2}{2mg} \\
h &= \underline{10.2\ \text{m}}
\end{aligned}
$$

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Thermal Energy / Internal Energy

Whether you include the change in internal energy ΔE_{th} in the expression of energy conservation depends on what you choose to include in your system.

If you include in the system only the mass of the object and NOT the "internal degrees of freedom" of an object and a surface that it interacts with, then use the expression:

$$W_{\text{ext}} = \Delta K + \Delta U$$

In this case, the external forces include any nonconservative forces, for example kinetic friction:

$$W_{\text{ext}} = W_{\text{app}} + W_{\text{fric}}$$

where for a straight line path of length d:

$$W_{\text{fric}} = -f_k d$$

The work done by kinetic friction is always negative.

Thermal Energy / Internal Energy

Whether you include the change in internal energy ΔE_{th} in the expression of energy conservation depends on what you choose to include in your system.

If you include in the system the "internal degrees of freedom" of an object and a surface that it interacts with, then use the expression:

$$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$$

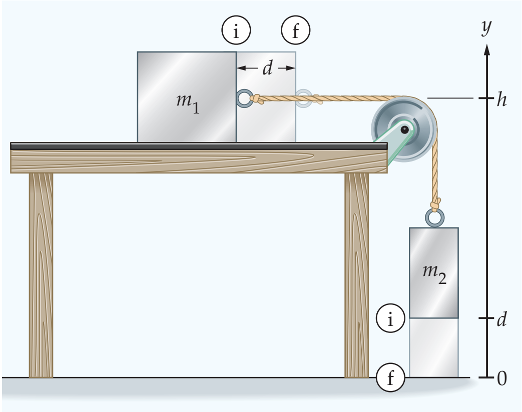
This says that the system can store energy as heat. When a kinetic friction force acts over a straight line path of length d:

$$\Delta E_{\text{th}} = f_k d$$

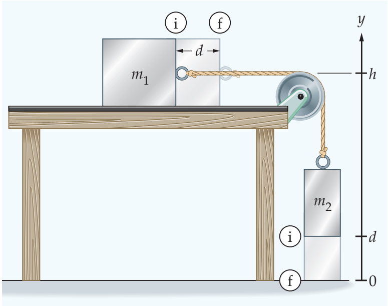
E_{th} will never decrease, so $\Delta E_{\text{th}} \geqslant 0$.

Energy Conservation: Example 8-10

A block of mass $m_1 = 2.40$ kg is connected to a second block of mass $m_2 = 1.80$ kg. When the blocks are released from rest, they move through a distance $d = 0.500$ m, at which point m_2 hits the floor. Given that the coefficient of kinetic friction between m_1 and the horizontal surface is $\mu_k = 0.450$, find the speed of the blocks just before m_2 lands.



Example 8-10



System: Masses m_1 and m_2, modeled as point particles, and the Earth.

$$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$$

Here:

$W_{\text{ext}} = 0$ and $\Delta E_{\text{th}} = f_k d$

ΔK is the change in K.E. of **both** masses

ΔU is the change in Grav. P.E. of the masses (only m_2's changes)

Example 8-10

Points ⓘ and ⓕ are as labelled in the diagram.

$$\cancelto{0}{W_{\text{ext}}} = \Delta K + \Delta U + \Delta E_{\text{th}}$$

$$0 = (K_{1,f} + K_{2,f} - \cancelto{0}{K_{1,i}} - \cancelto{0}{K_{2,i}}) + (\cancelto{0}{U_f} - U_i) + f_k d$$

$$0 = (\frac{1}{2}(m_1 + m_2)v^2 - 0) + (0 - m_2 g d) + \mu_k m_1 g d$$

$$v = \sqrt{\frac{2(m_2 - \mu_k m_1)gd}{m_1 + m_2}}$$

$$= \underline{1.30\ \text{m/s}}$$

Conservation Laws

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Noether's Theorem: conservation laws correspond to symmetries in the equations of motion of a system.

Energy conservation comes from a time symmetry.

Summary

- isolated and nonisolated systems
- mechanical energy
- conservation of energy
- how to solve energy problems

2nd Test Thursday Nov 15 ??

Homework

- Ch 8 Probs: 11, 15, 19, 21, 29, 43, 53, 57, 69
- Take home quiz, due Monday.