Energy
Some Types of Potential Energy
Isolated and Nonisolated Systems
Energy Conservation

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Last time

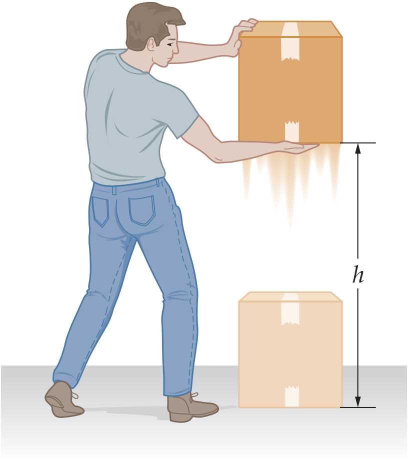
- work as an integral
- kinetic energy
- Work-Kinetic energy theorem
- potential energy

Overview

- conservative and nonconservative forces
- conservative forces and potential energy
- gravitational and elastic potential energy
- isolated and nonisolated systems
- conservation of energy (?)

Work Done Lifting a Box

Work done by person (applied force)
$W_{\text{app}} = F(\Delta y)\cos(0^\circ) = mgh.$



Work done by gravity $W_g = F(\Delta y)\cos(180^\circ) = -mgh.$

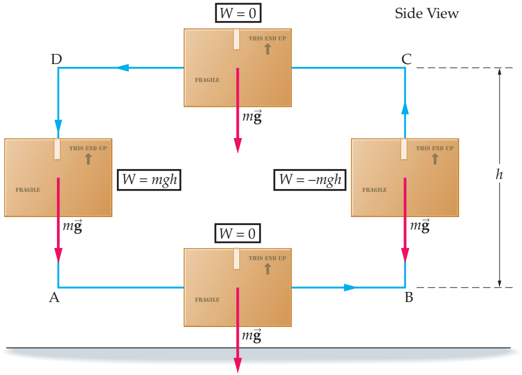
Potential Energy

When could we define a potential energy for a system and have it be meaningful?

When there is an **internal, conservative force** acting within our system.

Conservative Forces

The work done by gravity when raising and lowering an object around a closed path is zero.



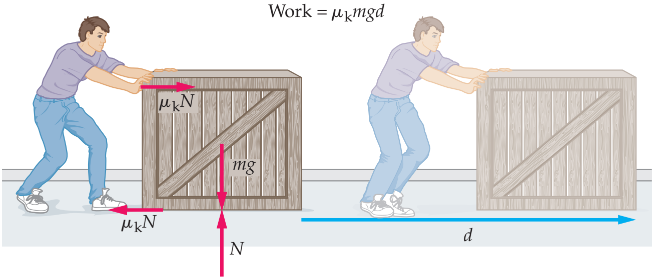
The path taken doesn't matter; if it comes back to the start, the work done is zero.

Forces (like gravity) that behave this way are called **conservative forces**.

Nonconservative Forces: Friction

The work done by kinetic friction is always negative.

Kinetic friction points in the opposite direction to the velocity / instantaneous displacement.

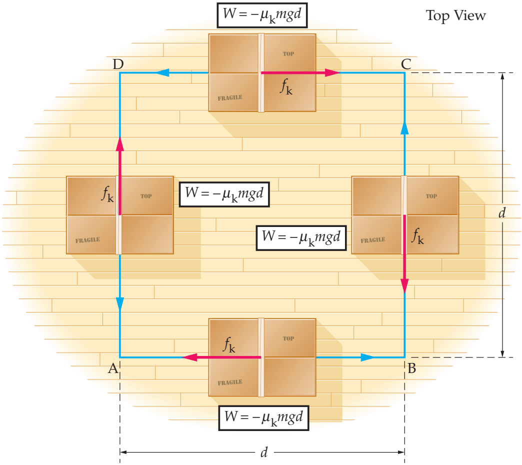


$$W_{f_k} = -f_k d = -\mu_k N d$$

where d is the distance the object moves along the surface.

Nonconservative Forces

The work done by friction when pushing an object around a closed path is **not** zero.



Forces (like friction) where the work done over a closed path is not zero are called **nonconservative forces**.

Conservative and Nonconservative Forces

Conservative force

A force that has the property that the work done by the force on a particle that moves between any given initial and final points is independent of the path taken by the particle.

Equivalently, the work done by the force as the particle moves through a *closed path* is zero.

examples:

- gravity
- spring force

Nonconservative force

Any force that is not a conservative force.

examples:

- friction
- air resistance

Conservative Forces: Potential Energy

Any box that has been lifted a height h has had the same work done on it: mgh.

The path the box took to get to that height doesn't matter.

This is because gravity is a **conservative force**.

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Potential energy

energy that system has as a result of its configuration. Is always the result of the effect of a **conservative force**.

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Only changes in the potential energy correspond to something that can be measured physically.

We can call the $U = 0$ configuration of our system whatever we want.

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The "configuration" of the system refers to how close the box is to center of the Earth.

To have a potential energy, we must *include the Earth* in the system and make the weight of the box an **internal force**.

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Any time a potential energy is introduced, the **source of the conservative force becomes part of the system**.

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Only conservative forces can have associated potential energies!

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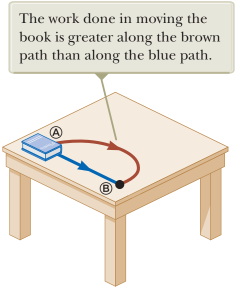
If a nonconservative force, like friction, acts, any work done to displace the system (at constant velocity) is transformed into a thermal energy and/or sound.

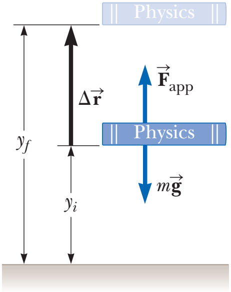
That energy isn't stored $\Rightarrow$ no potential energy.

For a nonconservative force, just considering the initial and final configurations of our system is not enough to determine how much work was done on it.

friction:



Gravitational Potential Energy, Uniform G-Field



When lifting a mass near the Earth's surface, the work done *by gravity*:

$$\begin{aligned} W_g &= \int_{y_i}^{y_f} \vec{\mathbf{F}}_g \cdot \overrightarrow{\boldsymbol{\Delta y}} \\ &= \int_{y_i}^{y_f} (-mg\hat{\mathbf{j}}) \cdot (\mathrm{d}y\hat{\mathbf{j}}) \\ &= -mg(y_f - y_i) \end{aligned}$$

$$\Delta U_g = -W_g$$

Gravitational potential energy for a uniform gravitational field of strength, g:

$$\Delta U_g = mg\,\Delta y$$

Gravitational Potential Energy

Page 207, #42

42. W A 400-N child is in a swing that is attached to a pair of ropes 2.00 m long. Find the gravitational potential energy of the child–Earth system relative to the child's lowest position when (a) the ropes are horizontal, (b) the ropes make a 30.0° angle with the vertical, and (c) the child is at the bottom of the circular arc.

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(c) $U = 0$.

Elastic Potential Energy

Springs also can store potential energy when they are compressed or extended.

$$\begin{aligned} \Delta U_s &= -W_s \\ &= \frac{1}{2}kx_f^2 - \frac{1}{2}kx_i^2 \end{aligned}$$

so we define:

Spring potential energy

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

where x is the amount by which the spring is compressed or extended from its natural length.

(Defining $U_s = 0$ when the spring is relaxed.)

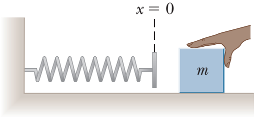
Mechanical Energy

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

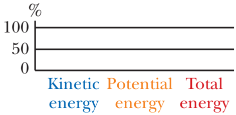
It is defined as the sum of the system's kinetic and potential energy:

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

Work, Kinetic Energy, Potential Energy



Before the spring is compressed, there is no energy in the spring–block system.



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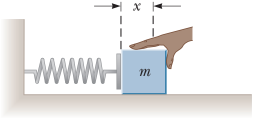
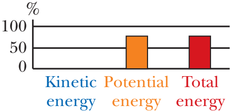


When the spring is partially compressed, the total energy of the system is elastic potential energy.



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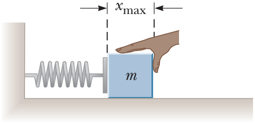
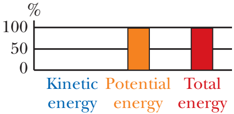


The spring is compressed by a maximum amount, and the block is held steady; there is elastic potential energy in the system and no kinetic energy.



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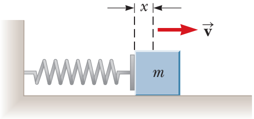
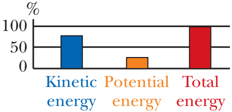


After the block is released, the elastic potential energy in the system decreases and the kinetic energy increases.



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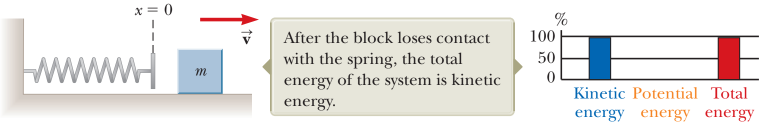


Work, Kinetic Energy, Potential Energy

Doing work (positive) on a system will increase its potential energy.

That potential can be converted to kinetic energy.

This illustrates the *conservation of energy*. Energy is not created or destroyed, but it is exchanged and transformed.

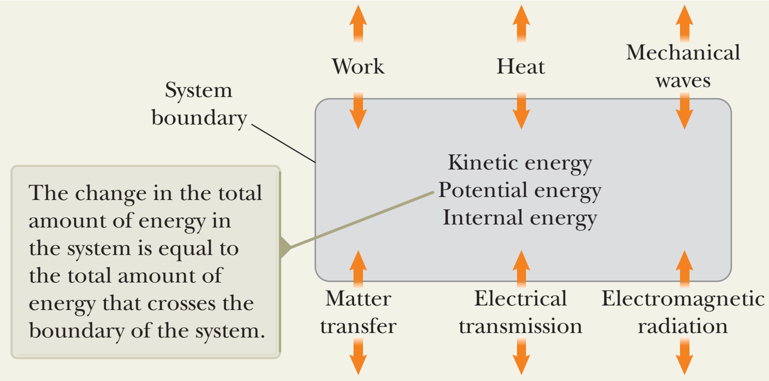
Isolated and Nonisolated Systems

Isolated systems do **not** exchange energy with the environment.
$(W_{\text{net}} = 0)$

Nonisolated systems do. Non-isolated systems can lose energy to the environment or gain energy from it.
(For this course: $W_{\text{net}} \neq 0$)

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.

Tracking Energy in a System

energy transferred = change in system's energy

$$W = \Delta K + \Delta U + \Delta E_{\text{int}}$$

where

- W covers **energy transfers** into or out of the system by work of an external force
- ΔK is the energy of **change in motion** of parts of the system
- ΔU is the energy of **change of configuration** of the system
- ΔE_{int} is energy converted to **heating effects from friction** in the system (or other non-conservative effects)

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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. W 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.

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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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[1] Problem from Serway & Jewett, 9th ed, page 236.

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$$
\begin{aligned}
\Delta K \quad + \quad \Delta U &= 0 \\
(\cancelto{0}{K_f} - \cancelto{0}{K_i}) + (\cancelto{0}{U_{s,f}} - U_{s,i}) + (U_{g,f} - \cancelto{0}{U_{g,i}}) &= 0 \\
U_{g,f} &= U_{s,i} \\
mgh &= \frac{1}{2}kx^2 \\
h &= \frac{kx^2}{2mg} \\
h &= \underline{10.2 \text{ m}}
\end{aligned}
$$

[1] Problem from Serway & Jewett, 9th ed, page 236.

Summary

- gravitational and elastic potential energy
- isolated and nonisolated systems
- conservation of energy (?)

Assignment 2 due Wednesday, Feb 19.

Next Test (Friday, Feb 28 OR Mon, Mar 2).

(Uncollected) Homework Serway & Jewett,

- Ch 7, onward from page 207. Probs: 41, 51
- Read ahead in chapter 8.
- Ch 8, onward from page 236. Prob: 4[1]

[1] Ans: (a) 1.85×10^4 m, 5.10×10^4 m ; (b) 1.00×10^7 J for both