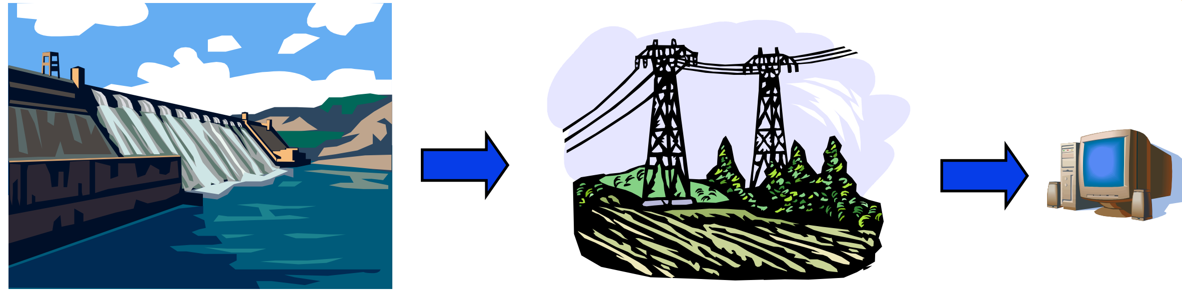
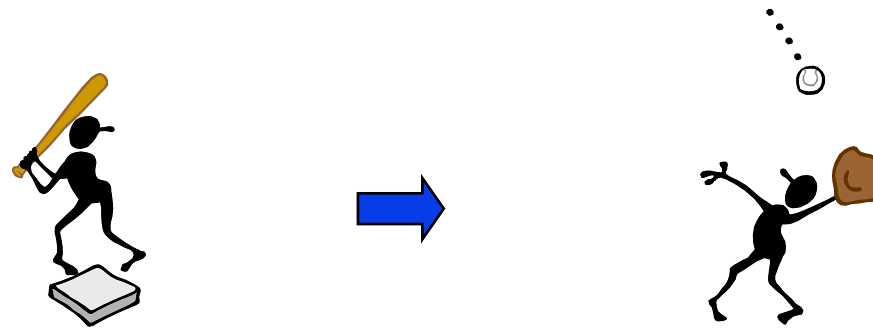


Energy Is Conserved -- Always



Ken Heller

School of Physics and Astronomy

University of Minnesota

Includes many contributions from Pat Heller

*** Supported in part by the NSF and the University of Minnesota**

Some Problems with the Presentation of Energy

- **Often introduced without the motivation of conservation.**
- **Does not build on students' ideas of interactions**
- **Conservation is not used as a primary organizing theme**

  A calculation trick that sometimes works, sometimes doesn't.
- **The validity of physical principles is conditional upon choice.**
- **Emphasis on Isolated Systems**

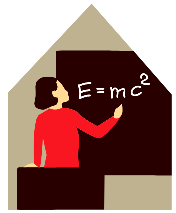
  Doesn't seem to apply to Biology, Engineering, …
- **Quantities are introduced for no apparent reason**

  Work (not necessary if KE + PE = constant)

  Impulse (not necessary if mv = constant)

What Conservation of Energy Means

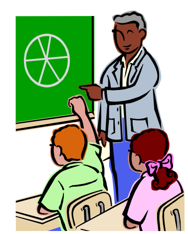
1. To Us



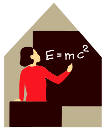
2. To Students

3. To Textbooks

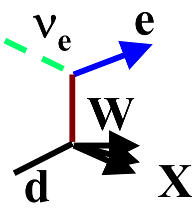
4. For Teaching Introductory Physics

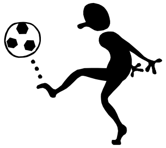


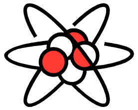
Conservation of Energy

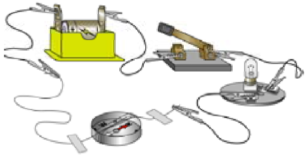


- **Powerful view of Universe**
  - Applies on every scale
    - Cosmological
    - Everyday
    - Microscopic
  - Does not require detailed knowledge of interaction mechanisms
  - Applies to any system



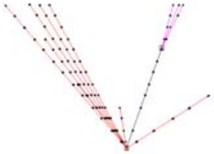






- **Very practical predictive power**
  - Thermodynamics

- **Important discovery tool**
  - Neutrino
  - Gravitational waves
  - Structure of space

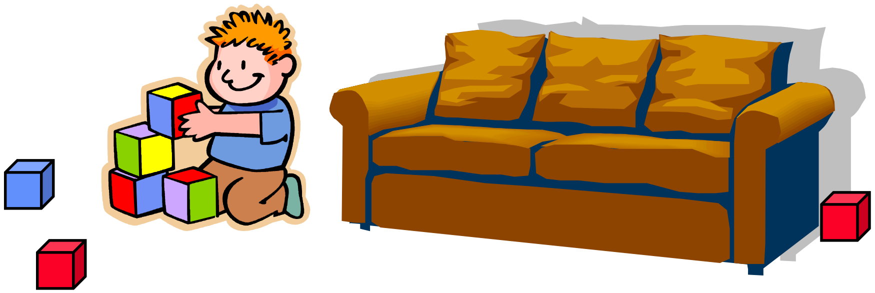


Conservation Laws are Universal

- Conservation of Mass
- Conservation of Energy
- Conservation of Momentum
- Conservation of Angular Momentum
- Conservation of Charge
- Conservation of Baryon Number
- Conservation of Lepton Number

Conservation principles give the structure of space-time

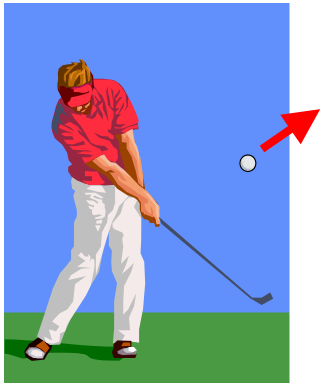
Persistence



At an early age children understand that objects have permanence.

Students believe that idea of persistence carries over to interactions.

Club puts a Force on the Ball



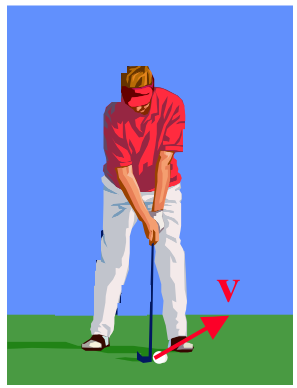
Force of Hit

Force is transferred from the Club to the Ball

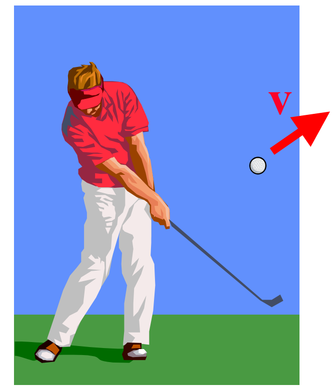
Transfer

Students believe that idea of persistence carries over to interactions.

Their intuition is correct but not for Force



Club transfers
Energy to the Ball



Energy of the Ball

Conservation of Energy

The amount of energy does not change.

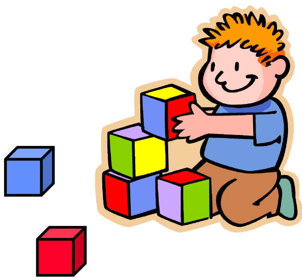
- Transferred from one system to another
- Change form within a system

Old Textbooks

For future physicists

Feynmann Lectures on Physics, vol. 1, 1963

Uses child with blocks to make analogy with conservation of energy



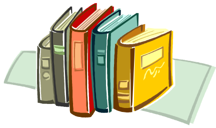
"sometimes some of it leaves the system and goes away, or sometimes it comes in. Energy has a large number of different forms."

For non-science students

Karplus Introductory Physics – A Model Approach, 1969

Focuses on energy transfer as a major theme by explicitly identifying a source and receiver in an interaction.

Current Textbooks define Conservation of Energy



Halliday, Resnick, Walker, 5th edition, 1997

"In an isolated system, energy may be transferred from one type to another, but the total energy E_{tot} of the system always remains constant. This conservation law is written as

$$\Delta E_{tot} = \Delta K + \Delta U + \Delta E_{int} + \text{(changes in other forms of energy)} = 0$$

Here ΔE_{int} is the change in the internal energy of the bodies within the system.

If, instead, the system is not isolated, then an external force can change the total energy of the system by doing work W. In that case

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

Statement 1 is a consequence of statement 2.
Statement 2 is not a consequence of statement 1.
Both statements have limited utility.

Current Textbooks define Conservation of Energy

Tipler, 4th edition, 1999

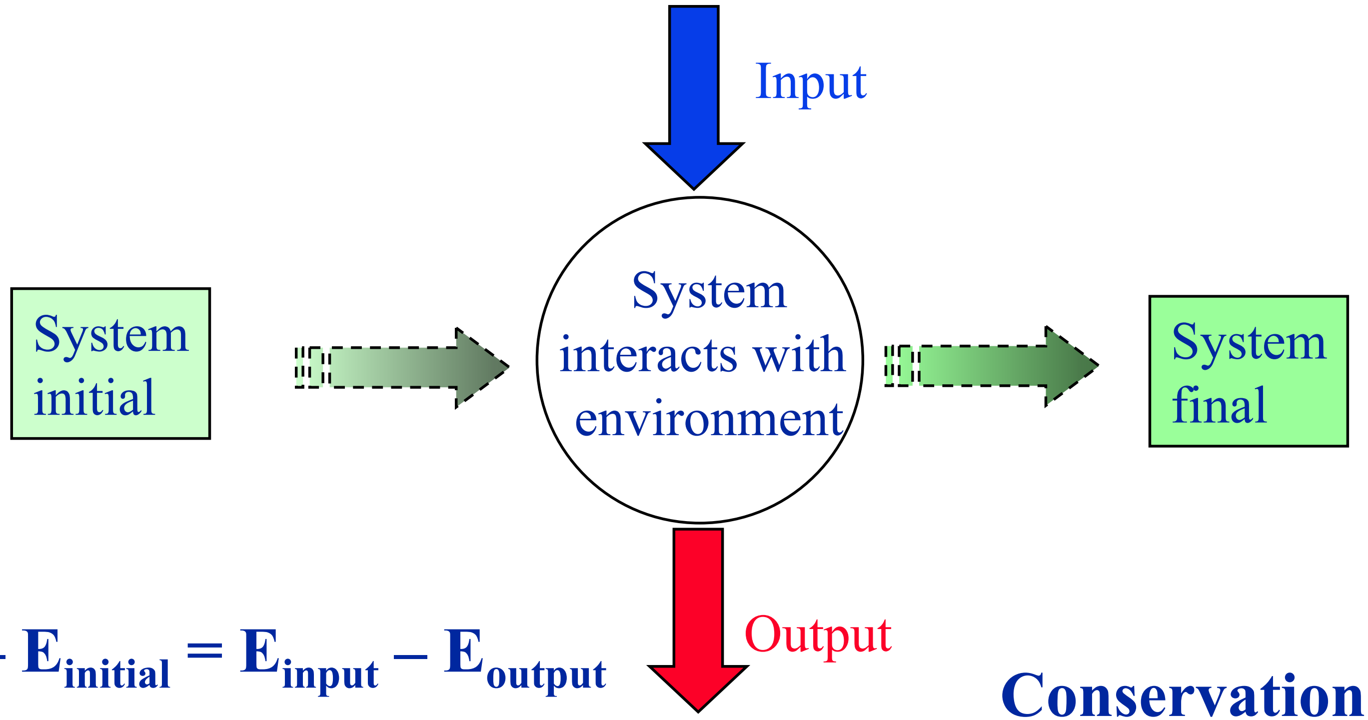
“Universe - The total energy of the universe is constant. Energy can be converted from one form to another, or transmitted from one region to another, but energy can never be created or destroyed.

System - The energy of a system can be changed by various means such as work done on the system, heat transfer, and emission or absorption of radiation. The increase or decrease in the energy of the system can always be accounted for by the appearance or disappearance of some kind of energy somewhere else.

$$E_{in} - E_{out} = \Delta E_{sys}\text{”}$$

Statement 1 is a consequence of statement 2.
Statement 2 is a consequence of statement 1.
Statement 2 is more useful than statement 1.

Energy Conservation



$$E_{final} - E_{initial} = E_{input} - E_{output}$$

or

$$E_{final} = E_{initial} + E_{input} - E_{output}$$

or

$$\Delta E_{system} = \Delta E_{transfer}$$

or

$$E_{input} = \Delta E_{system} + E_{output}$$

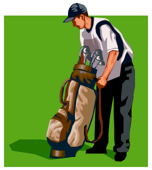
Conservation of Energy is always true

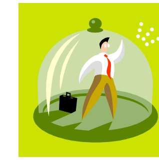
Need to be able to determine 3 of the 4 terms in the conservation of energy equation

It is not always useful

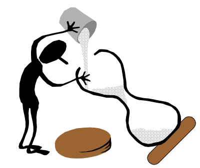
Conservation of Energy

- The energy of any system is always conserved.
  - The system does not have to be isolated
  - The validity of Conservation of Energy does not depend on how an individual chooses a system.

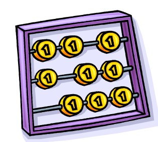




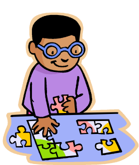
- Conserved is not the same as constant.
  - The energy of the system can change



- Conserved means accountable

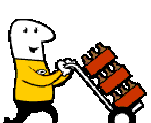


Important concepts

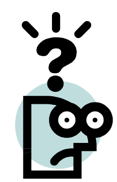


- System
  - Student's choice

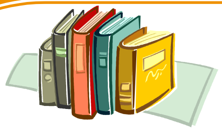
- State of a System
  - Kinetic, potential, internal



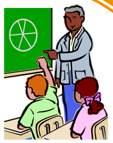
- Transfer
  - Work, Heat, Radiation, ….



This simplicity becomes confused by the presentation.



Textbook order



HRW (better intro)

- Kinetic Energy
- Work as Energy Transfer
- Kinetic Energy and Work
- Potential Energy and System Configuration
  - ~~Conservative forces~~
  - ~~Non-conservative forces~~
- ~~Conservation of Mechanical Energy~~
  - ~~Not always conserved~~
- Conservation of Energy

Tipler (better finish)

- Work Defined as Energy Transfer
- Work - Kinetic Energy Theorem
- Potential Energy and System Configuration
  - ~~Conservative forces~~
  - ~~Non-conservative forces~~
- ~~Conservation of Mechanical Energy~~
  - ~~Not always conserved~~
- Conservation of Energy

In both cases, the reason to invent the concept of energy is not given until the end.

Feynman and Karplus start with the idea of conservation

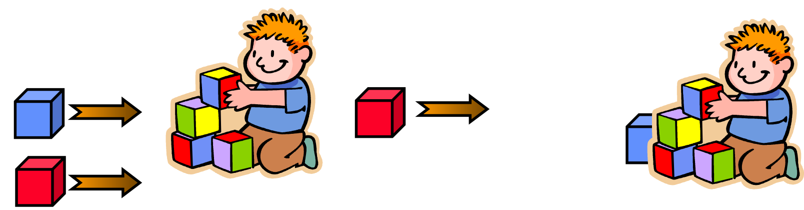
Build Idea of Conservation

Connect to students' experience

Bank Accounts

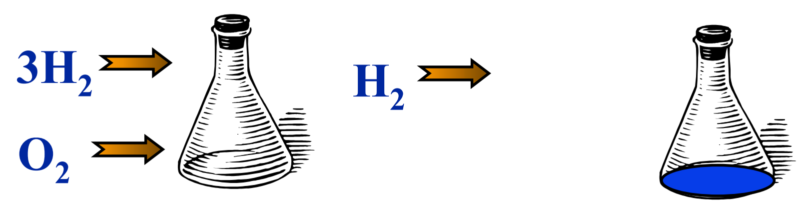
$$M_{final} - M_{initial} = M_{input} - M_{output}$$

Objects



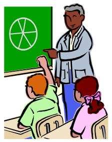
$$B_{final} - B_{initial} = B_{input} - B_{output}$$

Elements (chemistry)



$$H_2O_{final} - H_2O_{initial} = 3H_2 + O_2 - H_2$$

Conservation Exercises



Mass

If 16 grams of oxygen are combined with 4 grams of hydrogen to make 18 grams of water with some left over hydrogen, how much hydrogen is left over?

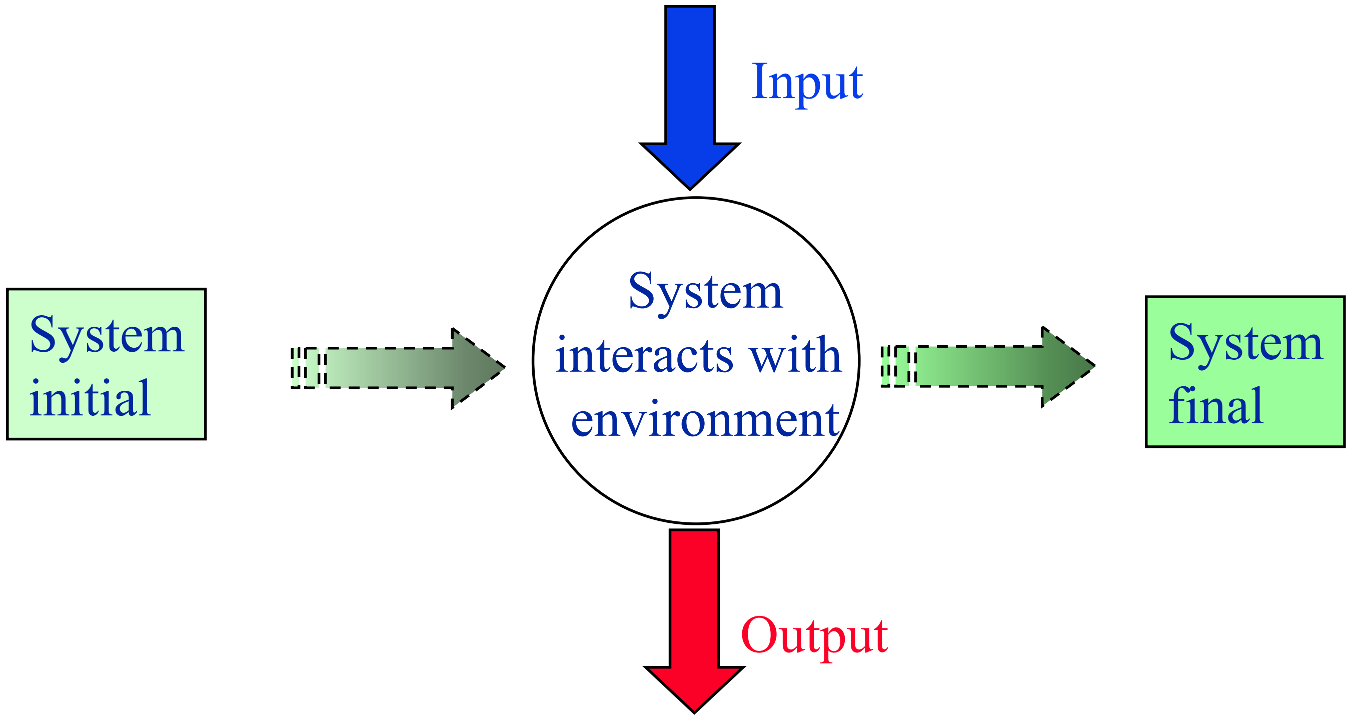
$$M_{final} - M_{initial} = M_{input} - M_{output}$$

Charge

If a capacitor is charged to 16 microcoulombs and then connected to another uncharged capacitor. 10 minutes later the charge on the first capacitor is measured to be 5 microcoulombs. What is the charge on the second capacitor?

$$Q_{final} - Q_{initial} = Q_{input} - Q_{output}$$

Repetition of Concepts



- **Choosing a system**
- **Choosing the initial and final times**
- **Determining the state of system at specific times**

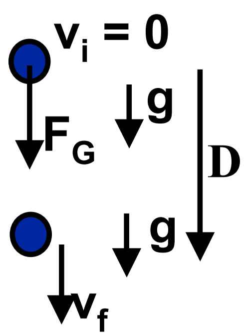
  $E_{initial}$, E_{final} $\vec{p}_{initial}$, $\vec{p}_{final}$ $\vec{L}_{initial}$, $\vec{L}_{final}$
- **Identifying inputs and outputs from system's interactions**

  E_{input}, E_{output} $\vec{p}_{input}$, $\vec{p}_{output}$ $\vec{L}_{input}$, $\vec{L}_{output}$

Single "point" Object

Energy state of that system is always Kinetic Energy

Example



Drop a ball. How does its speed depend on the distance it falls?

Approach: Use conservation of energy.

Choose system to be the ball

$$E_i = 0 \qquad E_f = \frac{1}{2}mv_f^2$$

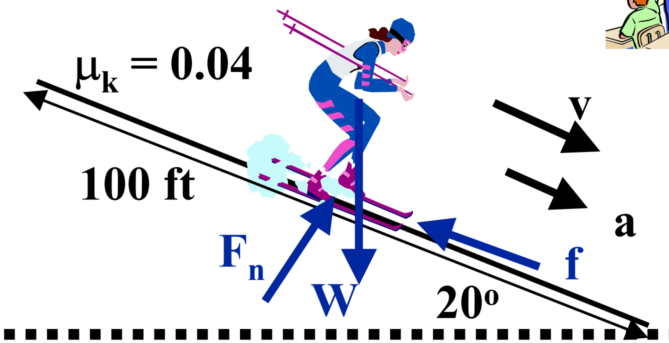
External force on the ball is the gravitational force

$$E_{in} = \int_0^D \vec{F}_G \bullet d\vec{\lambda} = \int_0^D mg\,dy = mgD \qquad E_{out} = 0$$

Conservation of Energy: $$\frac{1}{2}mv_f^2 - 0 = mgD - 0$$

Practice on Context-Rich Problems

While cross country skiing, you find yourself at the top of a small hill. The hill side is a slope at 20 degrees to the horizontal. You are new at this and afraid of going too fast since you are not good at stopping. You stop at the top of the hill and estimate that the slope is 100 feet to the bottom. If you glide straight down the hill, how fast will you be going at the bottom? The coefficient of kinetic friction between your skis and the dry snow is 0.04.



Question:

What is the skier's speed at the bottom of the hill?

Approach:

Use conservation of energy

System: skier

Initial energy

Kinetic Energy at top

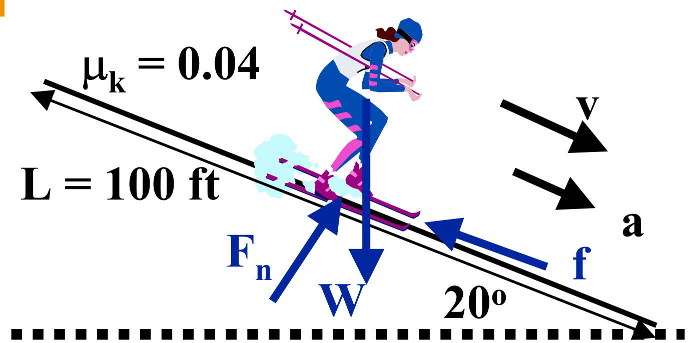
Final energy

Kinetic Energy at bottom

Energy transfer

Examine forces on skier

Practice analyzing forces



Question:

What is the skier's speed at the bottom of the hill?

Approach:

Use conservation of energy

System: skier

Initial energy

Kinetic Energy at top

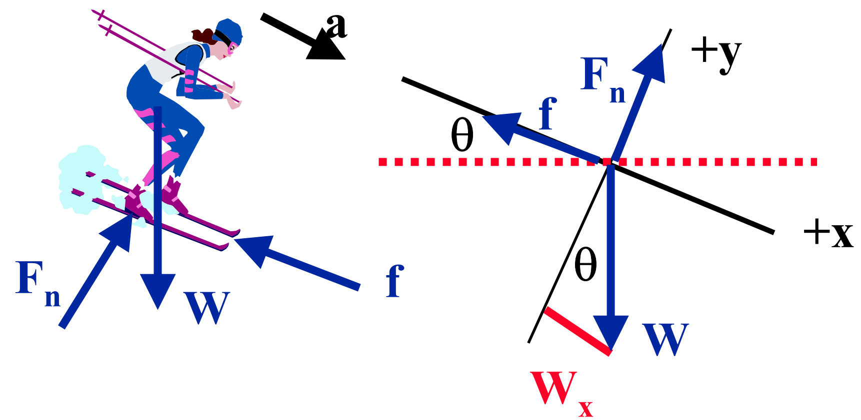
Final energy

Kinetic Energy at bottom

Energy transfer

Examine forces on skier

Free-body diagram



Energy inputs:

$$E_{input} = \int_{top}^{bottom} W_x dx$$

Energy outputs:

$$E_{output} = \int_{top}^{bottom} f\,dx$$

Conservation of Energy:

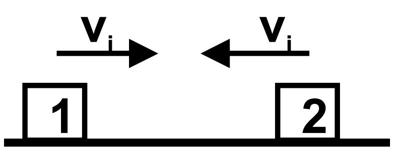
$$\frac{1}{2}mv_f^2 - 0 = mg\sin\theta L - fL$$

A Tool for Exploration

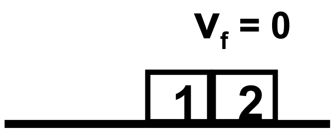
Two objects on a low friction surface go towards each other

same mass, same speed

stick together after they hit and stop



initial time



final time

System: both objects

initial time: before collision

$$E_i = (KE)_{1i} + (KE)_{2i}$$

final time: after collision

$$E_f = (KE)_{1f} + (KE)_{2f} = 0$$

No energy transfer between initial and final time

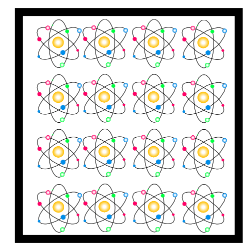
Conservation of Energy

$$E_f - E_i = E_{input} - E_{output}$$

$mv_i^2 = 0$ Not true

System energy not just Kinetic Energy

The objects in our system are not really single objects



Internal Structure

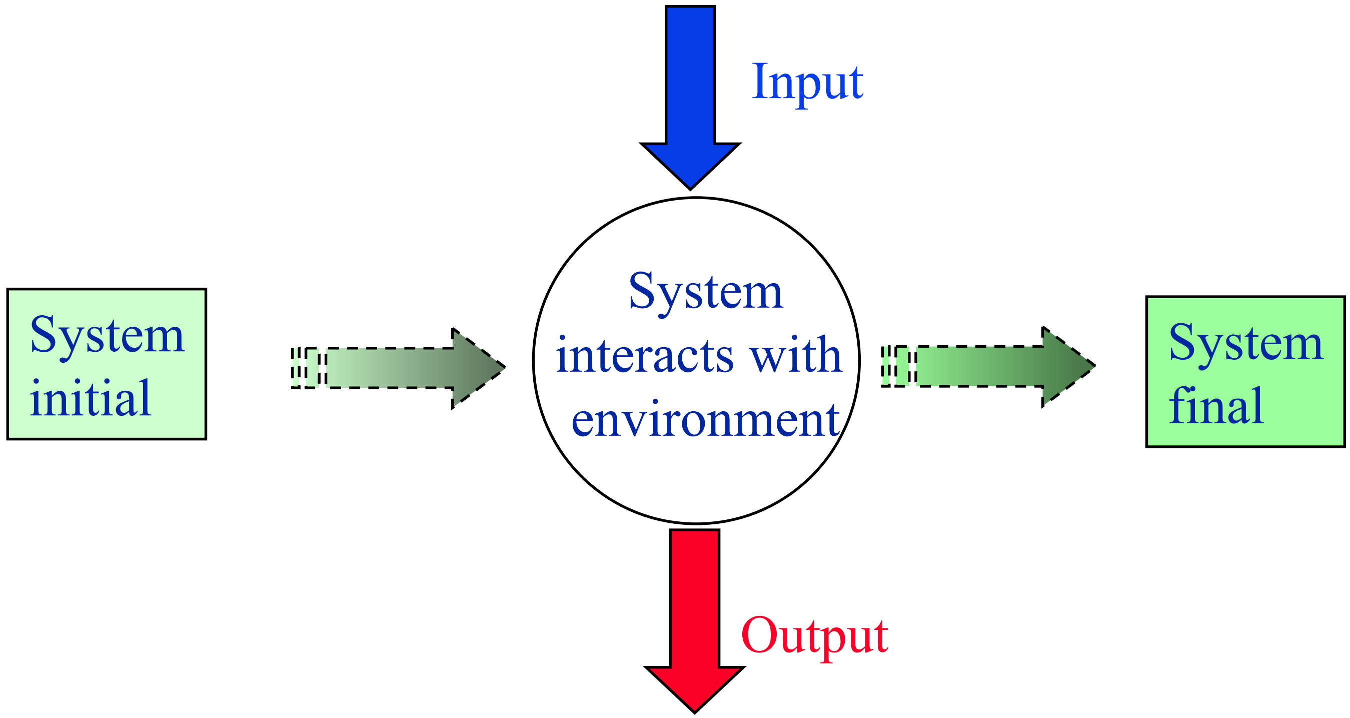
Internal parts have energy

$$E_i = KE_i + IE_i$$

$$E_f = KE_f + IE_f$$

Conservation of Energy uncovers microscopic structure

Conservation



$$\Delta M_{system} = \Delta M_{transfer}$$

$$\Delta E_{system} = \Delta E_{transfer} \qquad \Delta E_{transfer} = \int_{path} \vec{F} \bullet d\vec{l}$$

$$\Delta \vec{p}_{system} = \Delta \vec{p}_{transfer} \qquad \Delta \vec{p}_{transfer} = \int \vec{F} dt$$

$$\Delta \vec{L}_{system} = \Delta \vec{L}_{transfer} \qquad \Delta \vec{L}_{transfer} = \int \vec{\tau} dt$$

Current Textbooks define Conservation of Momentum

Halliday, Resnick, Walker, 5th edition, 1997

"If a system is isolated so that no net external force acts on the system, the linear momentum P of the system remains constant:

P = constant (closed, isolated system)"

Tipler, 4th edition, 1999

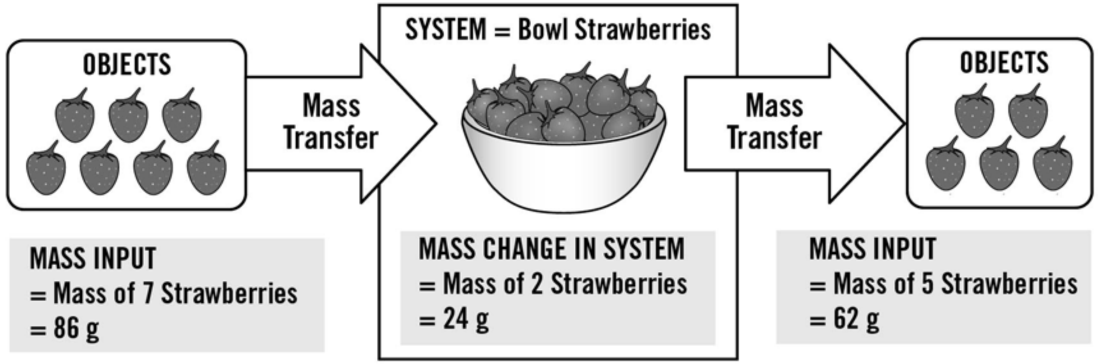
"If the net external force acting on a system is zero, the total momentum of the system is conserved."

Both are true but they are not statements of conservation of momentum
They are consequences of it.

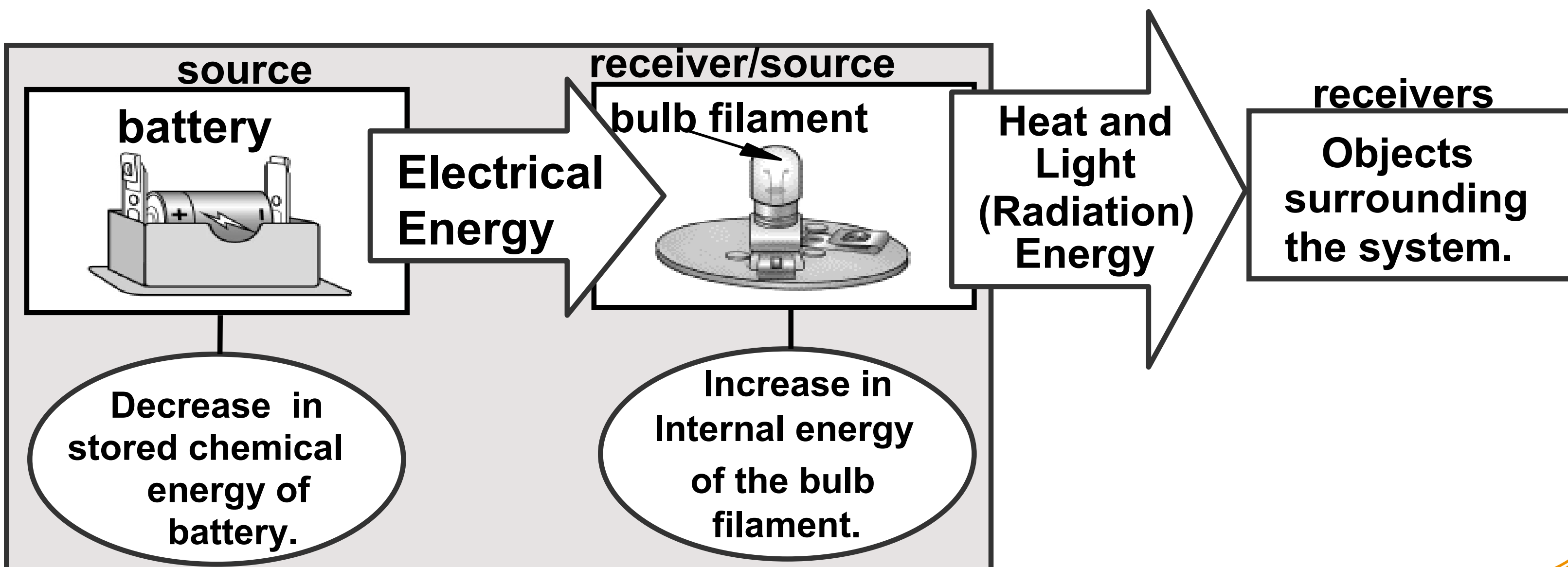
The statements (and the books) ignore the term they define as impulse.

$$\Delta \vec{p}_{transfer} = \int \vec{F} dt$$

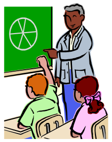
New Curriculum at 8th Grade
CIPS (F. Goldberg, P. Heller, et al)



When we keep track, then the mass put into a system is equal *to* the mass change in the system plus the mass taken out of the system. Mass In is equal to the Mass Change plus Mass Out.



Integrate Energy into Physics



- **Emphasize universal physical principles**
  - Don’t sometimes conserve mechanical energy
  - Student’s choose analysis techniques
- **Don’t emphasize isolated systems**
  - Transfer is part of students’ preconceptions
  - Non-isolated systems are more realistic.
- **Make full use of Conservation of Energy in solving problems before introducing potential energy.**
  - Avoid the terminology of conservative and nonconservative force if possible.
- **Use conservation as a tool to investigate nature.**
  - Discuss internal energy. Students know that objects have a molecular structure.
- **Reinforce the same ideas, concepts, and procedures by using them for conservation of momentum and conservation of angular momentum.**

The End

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http://www.physics.umn.edu/groups/physed/