Theme Music: Flanders & Swan

The Laws of Thermodynamics

Cartoon: Bob Thaves

Frank & Ernest
First Law of Thermodynamics

\[ \Delta U_{\text{int}} = Q + W \]

or

\[ \Delta U_{\text{int}} = Q - W \]
Real-World Intuition 1: Reconsidered

– If we have a cup of hot water and a cup of cold water and we put them aside for a while, what will happen to them?

– If you touch the cloth part of your chair and the metal part, which feels warmer?
Foothold ideas: Heat flow

- Objects in contact at different temperatures will tend to exchange energies so that the hotter cools down, the cooler warms up, until they reach the same temperature. (0\textsuperscript{th} Law)

- The rates at which thermal energy leaves or enters an object is a property of the material of which the object is made and its surface.

- When we touch an object, we measure the rate of flow of thermal energy – not temperature.
Foothold ideas: 
Non-conservative forces

- Work-energy theorem: $\Delta(\frac{1}{2}mv^2) = \vec{F}^{\text{net}} \cdot \Delta\vec{r}$
- For conservative forces (non-resistive), the work done by the force can be represented as a Potential Energy: $\vec{F} \cdot \Delta\vec{r} = -\Delta U$
- So when there are non-conservative forces, the work-energy theorem becomes:

$$\Delta(\frac{1}{2}mv^2 + U) = \vec{F}_{\text{non-cons}}^{\text{net}} \cdot \Delta\vec{r}$$
Where does the energy go?

- We were able to define a kind of energy for conservative forces. Can we define one for non-conservative forces?

\[
\Delta \left( \frac{1}{2} m v^2 + U \right) = \vec{F}_{\text{net non-cons}} \cdot \Delta \vec{r}
\]

- The answer lies in finding kinetic and potential energies at other scales that we can’t see directly – either because of many random motions or quantum mechanics.
Losing (or gaining) mechanical energy

- Resistive forces divert energy from coherent kinetic and potential energies of macroscopic objects to the kinetic and potential energies of microscopic atoms and molecules.

- Internal kinetic and potential energies of atoms and molecules can be exchanged with the kinetic and potential energies of the atoms and molecules themselves, and even with macroscopic objects.
Foothold ideas: Kinds of internal energy

- **Thermal Energy** – Energy of random motion of the atoms and molecules of an object. Can be kinetic or potential (for solids and liquids).

- **Chemical Energy** – Internal kinetic and potential energy of electrons inside an atom.
Thermodynamics and Statistical Mechanics

- The study of the thermal (random) energies of matter, how they exchange, and how they interact with the mechanical (coherent) and chemical (sub-atomic) energies of matter is called thermodynamics.
  - Focuses on implications for a macroscopic description

- The study of how the (macroscopic) thermodynamic properties arise from and relate to the motion of atoms and molecules is called statistical mechanics.
Disciplinary perspectives

■ In chemistry, the focus is often on the interaction of thermal and chemical energies. And chemistry often connects to microscopic descriptions.

■ In physics, the focus is often on the interaction of thermal and mechanic energies. And physics often connects to macroscopic motions.

■ In biology you need both. We’ll try to link them.

■ Often these three fields make different (unstated) assumptions about what they are ignoring! To make sense, we’ll have to be very explicit about what we are assuming.

And what notation we are using! For example: “U”
Foothold ideas:
Kinds of Energy and the 1st Law

■ It’s all KE and PE of something!
But we suppress it into “black boxes”
if we don’t want to talk about some
degrees of freedom.
  – Thermal
  – Chemical

■ First law of thermodynamics
  – Conservation of total energy but ...
  – What matters is how it divides and moves from one
    form to another and from one system to another.
  – And it matters what we assume stays constant!
Foothold ideas: Mechanical Energy & the 1st Law of Thermodynamics

\[ E = KE + PE + U_{\text{int}} \]

\[ \Delta E = \Delta(KE) + \Delta(PE) + \Delta U_{\text{int}} \]

Coherent energy
Kinetic and potential

Internal energy: random motion of small stuff we don’t want to talk about

Energy of System (not moving coherently)

Thermal energy Entering system

Work done on system

\[ \Delta U_{\text{int}} = Q + W \]