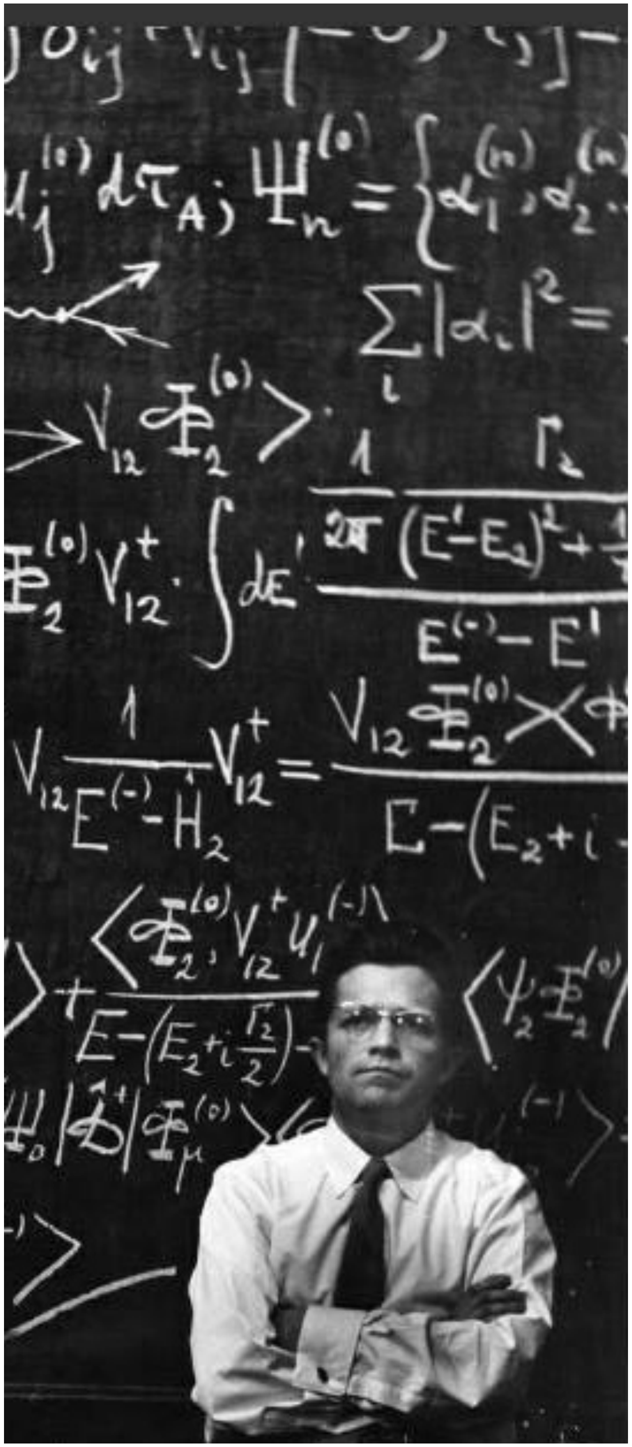
■ **Theme Music:** **Flanders & Swan**

***The Laws of Thermodynamics***

**Cartoon:** **Bob Thaves**

***Frank & Ernest***



# The Equation of the Day

First Law of Thermodynamics

$$\Delta U_{\text{int}} = Q + W$$

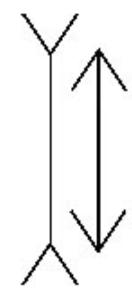
or

$$\Delta U_{\text{int}} = Q - W$$

# *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. ($0^{th}$ 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: $\Delta(\frac{1}{2}mv^2) = \vec{F}^{net} \cdot \Delta\vec{r}$
- 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:

$$\Delta(\frac{1}{2}mv^2 + U) = \vec{F}^{net}_{non-cons} \cdot \Delta\vec{r}$$

# 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?

$$\Delta(\tfrac{1}{2}mv^2 + U) = \vec{F}^{net}_{non-cons} \cdot \Delta\vec{r}$$

- 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

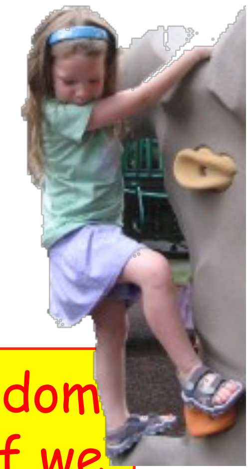
- In chemistry, the focus is often on the interaction of thermal and chemical energies. And chemistry often connects to microscopic descriptions.
- In physics, the focus is often on the interaction of thermal and mechanic energies. And physics often connects to macroscopic motions.
- In biology you need 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



Coherent energy
Kinetic and potential

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

$$E = \underbrace{KE + PE}_{} + U_{\text{int}}$$

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

Energy of System
(not moving coherently)

Thermal energy
Entering system

Work done
on system

$$\Delta U_{\text{int}} = Q + W$$