December 9, 2016 Physics 131 Prof. E. F. Redish

- **Theme Music: Flanders & Swan**

The Laws of Thermodynamics

Cartoon: Bob Thaves

Frank & Ernest

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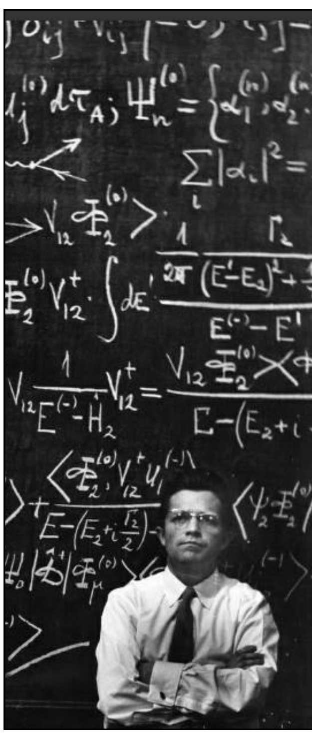

The Equation of the Day

First Law of Thermodynamics

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

or

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

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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.

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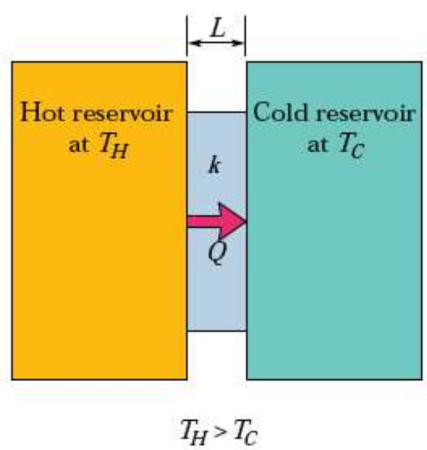
Heat Flow by Conduction

- Simplest case
  - Hot block at T_H
  - Cold block at T_C
  - Connecting block that carries ("conducts") thermal energy from the hot block to the cold.



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Foothold ideas: Heat flow

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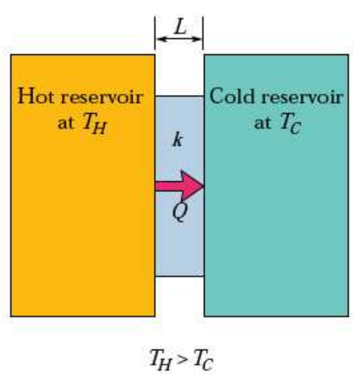
Creating an equation

- Φ = Flow
  = heat energy/sec
  $[\Phi]$ = Joules/s = Watts
- What drives the flow?
- How does the rate of flow depend on the property of the connecting block?



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The Heat Flow Equation (a gradient driven flow!)

$$\Delta T = Z\Phi$$

- We expect the flow to
  - Be less for a longer block (L)
  - Be more for a wider block (A)

$$Z = \rho \frac{L}{A}$$

- ρ = thermal resistivity – a property of the kind of substance the block is made of

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A more standard form

- We have written the heat flow equation to have it match the HP equation. It is more standardly written this way:

Heat flow per unit area → $\phi = \dfrac{\Phi}{A}$ $k = \dfrac{1}{\rho}$ ← Thermal conductance

- The equation then becomes

$$\Delta T = Z\Phi = \frac{\rho L}{A}\Phi = \left(\frac{L}{k}\right)\left(\frac{\Phi}{A}\right)$$

$$\Delta T = R\phi$$

R ← Thermal resistance (R-value)

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Some thermal conductances

Material	*k* (W/m-C)	Material	*k* (W/m-C)
Steel	12-45	**Water**	0.6
Aluminum	200	**Insulation**	0.04
Copper	400	**Air**	0.025

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Some specific heat

Material	*c* (J/gram/ºC)	Material	*c* (J/gram/ºC)
Iron	0.44	**Water**	4.2
Aluminum	0.90	**Glass**	0.84
Copper	0.39	**Air**	1.02

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We need to create a system schema for describing energy

- Consider a macroscopic object.
- Construct a system schema representation that shows the various places energy can reside in its internal structure (where "internal energy" can live).

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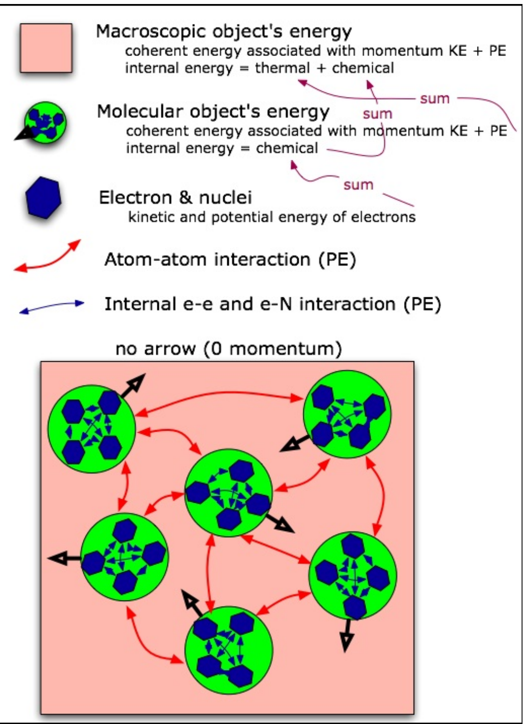
Zooming in on internal energy

(a generalization of the system schema)

As the system moves, energy is moving randomly among these locations ("bins").



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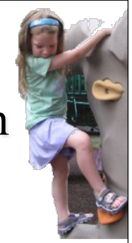

Foothold ideas: Thermal Equilibrium & Equipartition

- ***Degrees of freedom*** – places energy can reside in a system.
- ***Thermodynamic equilibrium is dynamic*** – Changes keep happening, but equal amounts flow in each direction so the net result is 0.
- ***Equipartition*** – At equilibrium, there is the same energy density in all space and in all DoFs – on the average.

Foothold ideas: Connecting micro and macro

- ***Microstate*** – A specific arrangement of energy among all the degrees of freedom of the system
- ***Different microstates may not be distinguishable when you are looking at many molecules*** – At the macro level (even as small as nm^3) some microstates look the same.
- ***Macrostate*** – A specification of things we care about at the macro level: pressure, temperature, concentration.

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*.

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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.

12/9/16 ***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!

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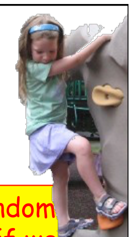
Foothold ideas: Mechanical Energy & the 1st Law of Thermodynamics



Coherent energy
Kinetic and potential

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

$$E = KE + PE + U_{int}$$

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

Energy of System
(not moving coherently)

Thermal energy
Entering system

Work done
on system

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

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Foothold ideas: Energy

- Kinds of energy (macro)
  - Kinetic
  - Potential
  - Thermal
  - Chemical
- Kinds of energy (micro)?
- First law of thermodynamics
  - Conservation of total energy

Internal energy

Thermal energy entering

Work done on the rest of the world

$$\Delta U = Q - W$$

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