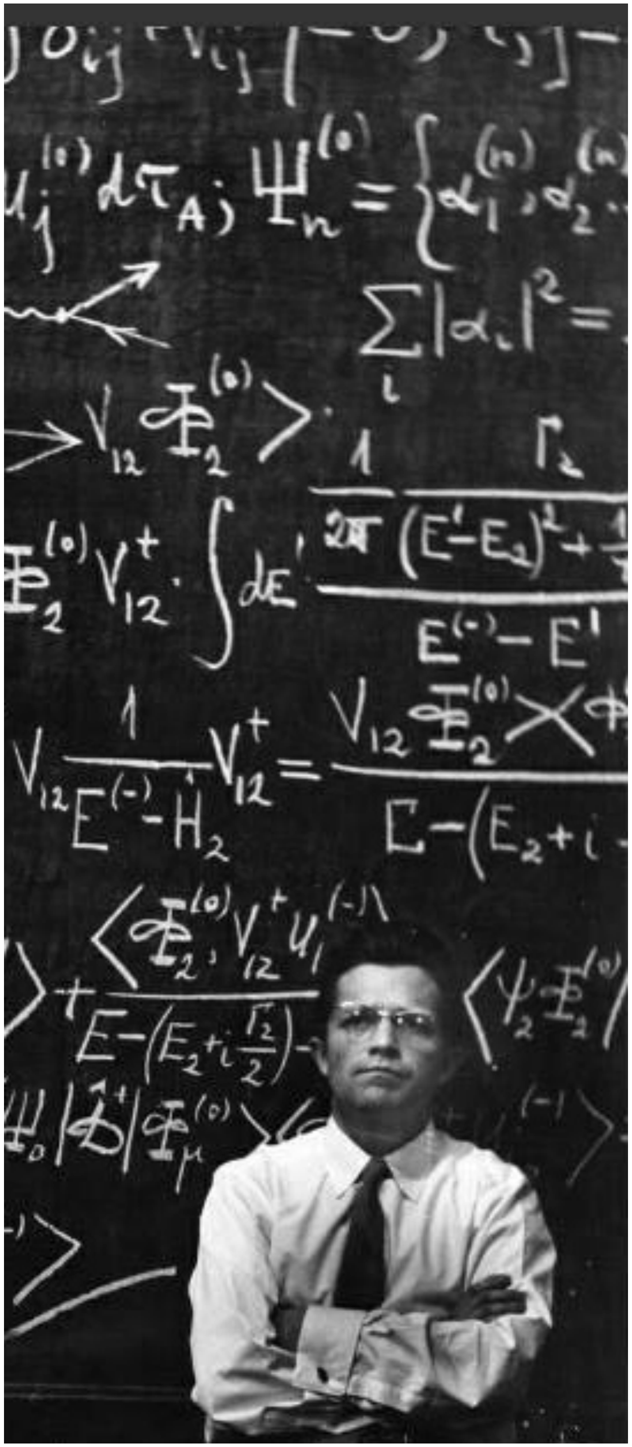
- **<u>Theme Music:</u>**
  M. C. Hawking
  Entropy

<u>Cartoon:</u>
S. Harris



The Equation of the Day

First Law of Thermodynamics

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

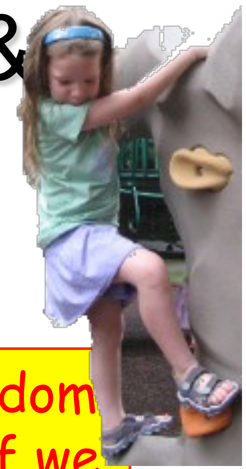
or

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

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

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

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

Energy of System (not moving coherently)

Thermal energy Entering system

Work done on system

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

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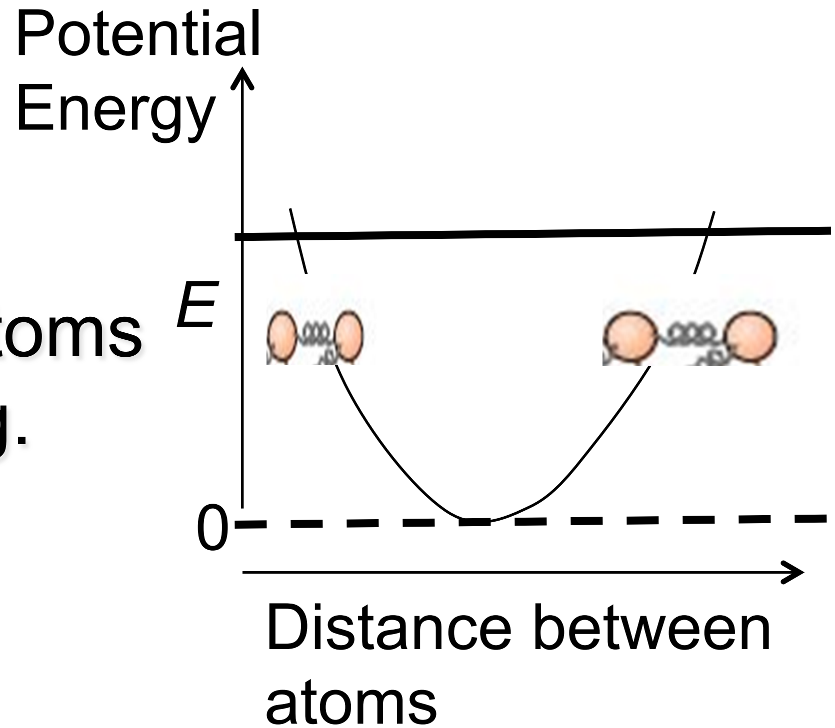
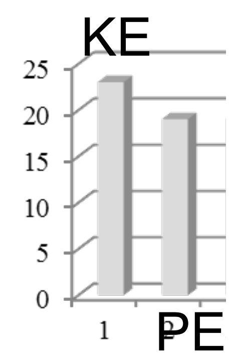
Definitions: Thermal energy

- Our model of matter as composed of many small moving particles allows us to extend energy conservation to include resistive forces.
- The energy associated with the motion of a macroscopic is ***coherent***; all parts of the object) move in the same way. The object has a net momentum associated with its kinetic energy.
- The internal energy of an object is ***incoherent***. The molecules of the object are moving in all directions randomly. Although the individual molecules have kinetic energy and momentum, the net momentum of the object as a result of its thermal energy is zero.
- The key idea in understanding thermal energy is ***equipartition*** – the equal sharing of energy any place it can go.

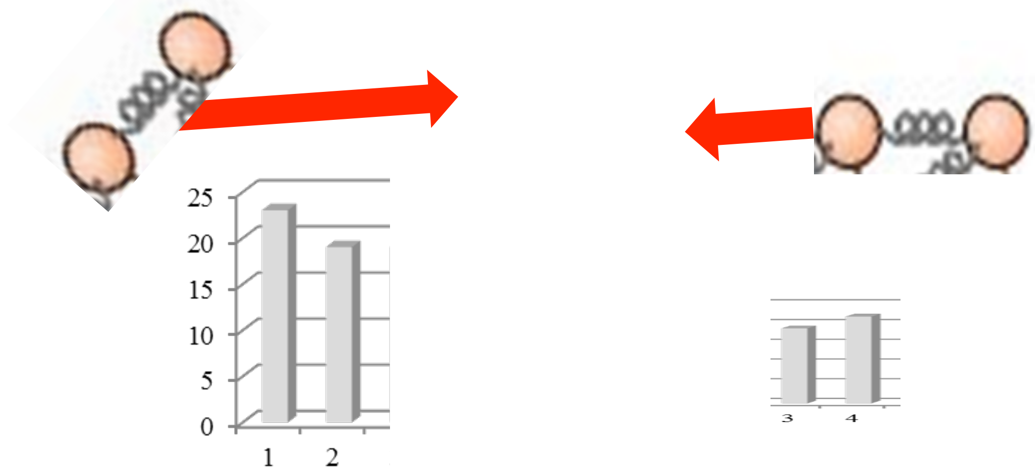
Energy in a 2-Atom Molecule

- For small displacements around the bond length, the PE of a pair of bound atoms can be modeled as a spring.
- Define the zero of potential energy as the <u>minimum</u> of the Potential Energy curve.
- With this definition, in a gas of these molecules, ON AVERAGE the energy is <u>the same</u> for both potential and kinetic energy





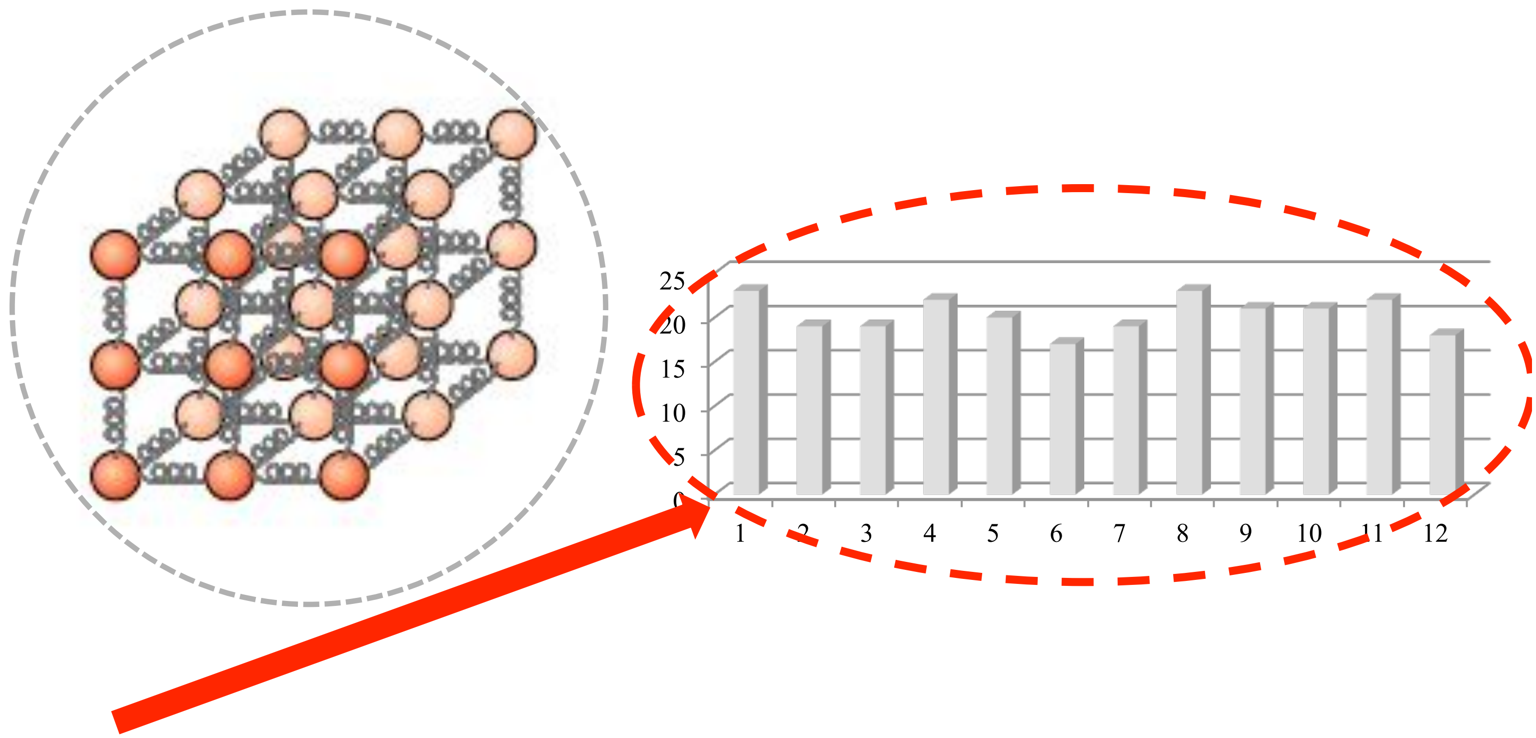
Interaction between two pairs of molecules in a gas



- After many random collisions, energy is ON AVERAGE the same for
  - Kinetic energy of motion of both pairs of atoms in each direction
  - Kinetic energy of rotation around each axis.
  - Kinetic energy of vibration of atomic pair pair
  - Potential energy of interaction (relative to potential minimum)

Thermal Energy in an object

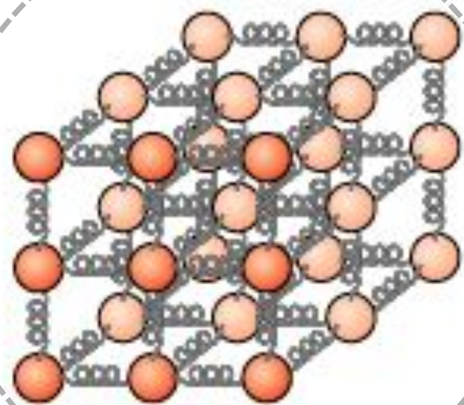
Object A



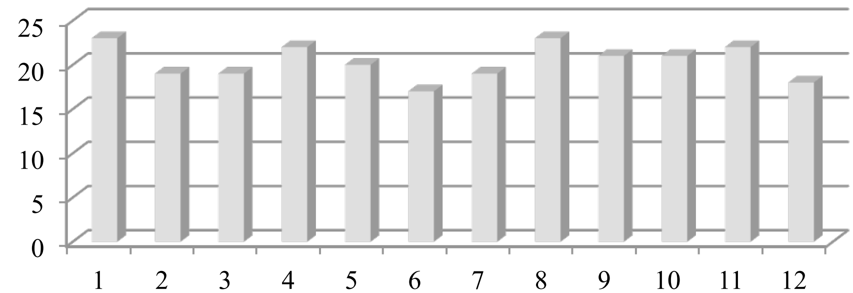
- **Thermal energy of object A :** Measures the TOTAL energy in the whole object. Depends on temperature and the number of “bins” where energy could reside.
- Energy in each bin: ½ $k_B T$

Temperature in any object

Object A



Object contains MANY atoms (kinetic energy) *and* interactions (potential energy)



- **Temperature:** Measures the amount of energy in each atom or interaction – thermal energy is **on average** equally distributed among all these possible "bins" in which energy could reside.
- **Note: Potential energy of each bin is here defined relative to each minimum of the Potential Energy Curve**

This is why each object translates energy into temperature in different ways. It has different numbers of places to put energy.

If energy is conserved, why do we need to conserve energy?

- In a thermal system (lots of things moving randomly) energy can be in various places and moves around through interactions.
- If more is in one place than another, the random motion will tend to spread it around – even it out. This is just like the diffusion of particles.

Foreshadowing of Critical Concepts to Come

- Energy spreading
- Probability
- Fluctuations
- Entropy
- Free Energy