December 12, 2012 Physics 131 Prof. E. F. Redish

- **Theme Music:** **Lorenzo Fuller**

  Too Darn Hot
- **Cartoon:** **Bob Thaves**

  Frank & Ernest

"The kind of motion we call heat"

- We have a natural sense of hot and cold.
- In the 19th century it was learned that the warmth of an object was a measure of a kind of random internal motion of the object's atoms.
- It was found that there was a surprisingly large amount of "hidden" energy that objects possessed as a result of their temperature – and that under the right conditions, this energy could be put to work.

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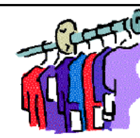
Real-World Intuition 1:



– 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?

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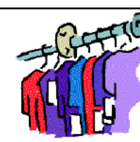
Real-World Intuition 2
How do objects exchange hot and cold?



- When two amounts of water at different temperatures are combined, they come to a temperature somewhere in between.
- We expect that the amount of each kind of water determines the final temperature.
- Try it!
  – Case 1: Equal amounts of water
  – Case 2: Different amounts of water

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Two Objects of the Same Kind but Different Temperatures

Physical idea:
The bigger mass changes temp less in proportion.

$$\frac{m_1}{m_2} = \frac{\Delta T_2}{\Delta T_1}$$

$$m_1 \Delta T_1 = -m_2 \Delta T_2$$

← the changes in temp are opposite— one goes up the other goes down

$$m_1 (T_f - T_1) = m_2 (T_2 - T_f)$$

$$m_1 T_f - m_1 T_1 = m_2 T_2 - m_2 T_f$$

$$m_1 T_f + m_2 T_f = m_1 T_1 + m_2 T_2$$

$$T_f = \frac{m_1 T_1 + m_2 T_2}{m_1 + m_2} = \left(\frac{m_1}{M}\right) T_1 + \left(\frac{m_2}{M}\right) T_2$$

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Implications

- From the equation $m_1 \Delta T_1 = -m_2 \Delta T_2$
  - it looks like something is being transferred from the hot object to the cold object
  - it looks like temperature is kind of a "density of hotness." You have to multiply by the mass to get the "amount of hotness" transferred.
- We will call the thing being transferred "thermal energy."

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What if we have different kinds of stuff?

- What happens if we have equal masses of water and something else — a copper cylinder, say?
- What's your intuition here?
  - Will the temperature settle down to halfway between?
  - Will it be closer to the water's temperature?
  - Will it be closer to the copper's temperature?
- Try it!

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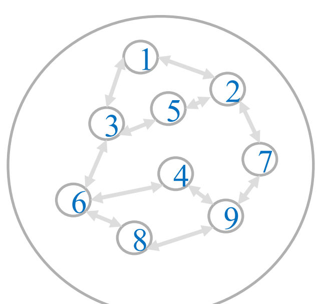
WHERE IS THE ENERGY INSIDE AN OBJECT?

Example: An object with 9 atoms.

- Each atom carries energy
  (motion of atom plus interactions WITHIN the atom)
- Each interaction line carries potential energy

Object A



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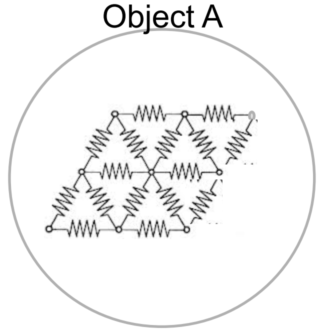
More concrete for 9 atoms

Object A



spring-like interaction potentials between atoms

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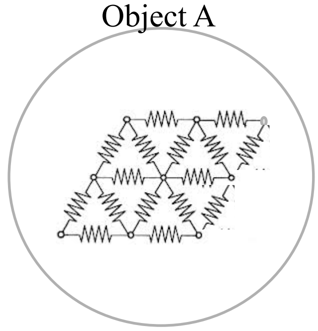
Temperature and Energy

Object A



- **Temperature:** Measures the average amount of energy in each atom or interaction – the key concept is that thermal energy is (on the average) equally distributed among all these possible locations where energy could reside.
- **Internal Energy of object A :** Measures the TOTAL energy in the whole object. Depends on temperature and the number of locations where energy could reside ("degrees of freedom").

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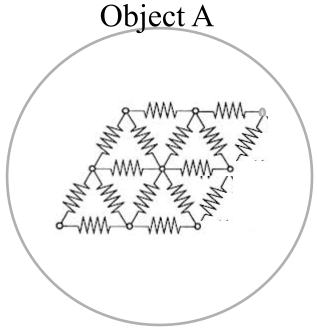
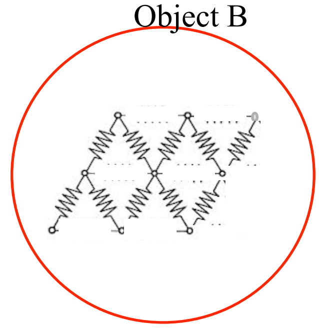
- You can have two objects with the same mass but a different number of atoms or a different number of interactions!

Object A



Object B



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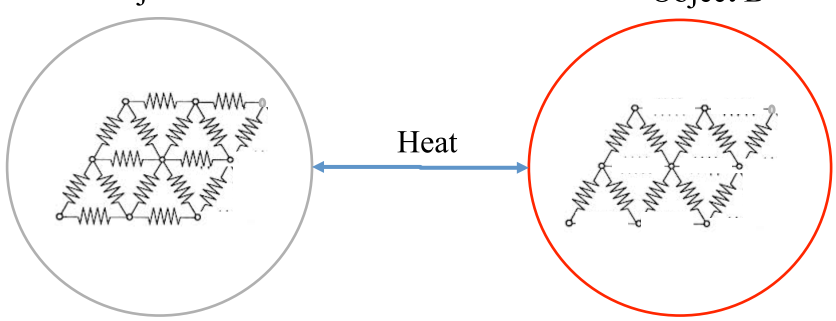
Interaction between two objects?

<u>When two objects touch and are brought to the same temperature:</u> There are **fewer** places to store the energy in object B, so to get object B to the same temperature we need **less** energy than for object A

Object A

Object B



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Thermal Energy is NOT Temperature

- Even if the masses are the same, the temperature does not wind up halfway between.
- Each kind of material translates thermal energy into temperature in its own way.

$$m_1 c_1 \Delta T_1 = -m_2 c_2 \Delta T_2$$

Specific Heat and Heat Capacity

- The amount of thermal energy needed to produce one degree of temperature change is an object is called its heat capacity.

$$Q = C\Delta T$$

- The amount of thermal energy per unit mass needed to produce one degree of temperature change in an object is called its specific heat.

$$C = mc$$

Scales and Units

- 1 cal = the amount of thermal energy needed to change the temperature of 1 gm of water by 1 degree C (from 14.5^o to 15.5^o) (by definition)
- 1 Cal = 1000 cal
- 1 Cal = 4184 J

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Reinterpreting Our Results

When two objects at different temperature are put together, thermal energy flows from the hotter body to the colder body until their temperatures are the same. (0th Law)

$$Q = m_1 c_1 \Delta T_1 = m_1 c_1 (T_f - T_1^i)$$

$$-Q = m_2 c_2 \Delta T_2 = m_2 c_2 (T_f - T_2^i)$$

$$m_1 c_1 (T_f - T_1^i) = -m_2 c_2 (T_f - T_2^i)$$

$$m_1 c_1 (T_f - T_1) = m_2 c_2 (T_2 - T_f)$$

$$T_f = \left(\frac{m_1 c_1}{m_1 c_1 + m_2 c_2} \right) T_1 + \left(\frac{m_2 c_2}{m_1 c_1 + m_2 c_2} \right) T_2$$

$$T_f = \left(\frac{C_1}{C_1 + C_2} \right) T_1 + \left(\frac{C_2}{C_1 + C_2} \right) T_2$$

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Foothold ideas: 1

- Temperature is a measure of how hot or cold something is. (We have a natural physical sense of hot and cold.)
- When two objects are left in contact for long enough they come to the same temperature.
- When two objects of the same material but different temperatures are put together they reach an average, weighted by the fraction of the total mass.
- The mechanism responsible for the above rule is that the same thermal energy is transferred from one object to the other: Q proportional to $m\Delta T$.

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Foothold ideas: 2

- When two objects of different materials and different temperatures are put together they come to a common temperature, but it is not obtained by the simple rule.
- Each object translates thermal energy into temperature in its own way. This is specified by a density-like quantity, c, the specific heat.
- The heat capacity of an object is $C = mc$.
- When two objects of different material and different temperatures are put together they reach an average, weighted by the fraction of the total heat capacity.
- When heat is absorbed or emitted by an object $Q = \pm mc\Delta T$

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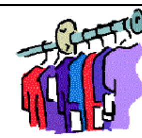
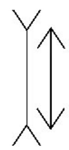


Real-World Intuition 1: Reconsidered

- 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?



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