November 21, $2011 \quad$ Physics 131 Prof. E. F. Redish
$■$ Theme Music: Ella Fitzgerald
Too Darn Hot
■ Cartoon: Bob Thaves
Frank \& Ernest
Frank and Ernest


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## Outline

■ Quiz 9
■ What do we mean by temperature?
■ Thermal Energy is not Temperature

- Heat Capacity and Specific Heat
- Heat of Transformation
- Heat Capacity and Specific Heat

■ Summary: Heat and Temperature

## Reading questions

$\square$ Since thermal energy is never lost, only shared evenly with surrounding objects, how does the sun fit into this?
It generates heat which then travels to the earth to heat it up, if the heat was never lost then the world would have shriveled up from this unyielding heat a long time ago.

## "The kind of motion we call heat"

■ We have a natural sense of hot and cold.
■ In the $19^{\text {th }}$ 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.

Physics 131 5

## 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?


11/21/11

## 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.
$\square$ 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


## Critical Experiment 1

If we have equal amounts
of the same kinds
of materials at different
temperatures
and put them together, what happens?

1. pretty close to 50 C
2. pretty close to 80 C
3. pretty close to 20 C

4. greater than 80 C
5. less than 20 C

## Critical Experiment 2

If we have unequal amounts
of the same kinds
of materials at different temperatures and put them together, what happens?

1. pretty close to 40 C
2. pretty close to 80 C
3. pretty close to 20 C
4. greater than 60 C
5. something else


## Two Objects of the Same Kind but Different Temperatures

$$
\begin{array}{ll}
m_{1} \Delta T_{1}=-m_{2} \Delta T_{2} \\
m_{1}\left(T_{f}-T_{1}\right)=m_{2}\left(T_{2}-T_{f}\right) & \begin{array}{l}
\text { the changes in } \\
\text { temp are opposite- } \\
\text { one goes up } \\
\text { the other goes down }
\end{array} \\
m_{1} T_{f}-m_{1} T_{1}=m_{2} T_{2}-m_{2} T_{f} \\
m_{1} T_{f}+m_{2} T_{f}=m_{1} T_{1}+m_{2} T_{2} \\
T_{f}=\frac{m_{1} T_{1}+m_{2} T_{2}}{m_{1}+m_{2}}=\left(\frac{m_{1}}{M}\right) T_{1}+\left(\frac{m_{2}}{M}\right) T_{2}
\end{array}
$$

## 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."


## 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?
$\square$ Try it!


## Critical Experiment 3

If we have equal amounts of different kinds of materials at different temperatures and put them together, what happens?


1. pretty close to 50 C
2. pretty close to 80 C
3. pretty close to 20 C
4. greater than 80 C
5. less than 20 C

## Thermal Energy is NOT Temperature

$\square$ 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.

$$
C=m c
$$

## Scales and Units

■ $1 \mathrm{cal}=$ the amount of thermal energy needed to change the temperature of 1 gm of water by 1 degree C (from $14.5^{\circ}$ to $15.5^{\circ}$ ) (by definition)
■ $1 \mathrm{Cal}=1000 \mathrm{cal}$
■ $1 \mathrm{Cal}=4184 \mathrm{~J}$

## Reinterpreting Our Results

- When two objects at different temperature are put together, thermal energy flows

$$
-Q=m_{2} c_{2} \Delta T_{2}=m_{2} c_{2}\left(T_{f}-T_{2}^{i}\right)
$$ from the hotter body to the colder body until their temperatures are the

$$
Q=m_{1} c_{1} \Delta T_{1}=m_{1} c_{1}\left(T_{f}-T_{1}^{i}\right)
$$

$m_{1} c_{1}\left(T_{f}-T_{1}^{i}\right)=-m_{2} c_{2}\left(T_{f}-T_{2}^{i}\right)$
$m_{1} c_{1}\left(T_{f}-T_{1}\right)=m_{2} c_{2}\left(T_{2}-T_{f}\right)$
$T_{f}=\left(\frac{m_{1} c_{1}}{m_{1} c_{1}+m_{2} c_{2}}\right) T_{1}+\left(\frac{m_{2} c_{2}}{m_{1} c_{1}+m_{2} c_{2}}\right) T_{2}$ same. ( $0^{\text {th }}$ Law)

## Foothold ideas: 1

■ Temperature is a measure of how hot or cold somethin
 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 $m \Delta T$.


## 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 $C=m c$.
- 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 $Q= \pm m c \Delta T$ 11/21/11 Physics $131 \quad 19$


## 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?

