December 1, 2010 Physics 121 Prof. E. F. Redish

- **Theme Music:** **Martha and the Vandellas**
  Heat Wave
- **Cartoon:** **Cantu & Castellanos**
  Baldo

Outline

- Quiz 10
- Fluid flow: series and parallel
- What do we mean by temperature?
- Thermal Energy is not Temperature
  - Heat Capacity and Specific Heat
  - Heat of Transformation

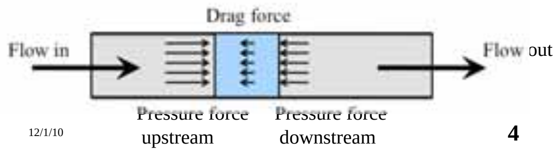
Viscous Drag

- A fluid flowing in a pipe doesn't slip through the pipe frictionlessly.
- The fluid sticks to the walls moves faster at the middle of the pipe than at the edges.
  As a result, it has to "slide over itself" (shear).
- There is friction between layers of fluid moving at different speeds that creates a viscous drag force, trying to reduce the sliding.
- The drag is proportional to the speed and the length of pipe.

$$F_{drag} = 8\pi\mu L v$$

Implication: Pressure drop

- If we have a fluid moving at a constant rate and there is drag, N2 tells us there must be another force to balance the drag.
- The internal pressure in the fluid must drop in the direction of the flow to balance drag.



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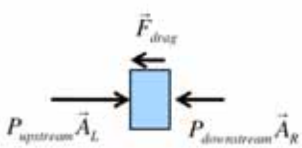
The Hagen-Poiseuille Law

- If the pressure drop balances the drag (and thereby maintains a constant flow) N2 tells us



$$\Delta P\, A = 8\pi\mu L v$$

$$\Delta P\, A = 8\pi\mu L\left(\frac{Q}{A}\right)$$

$$\Delta P = \left(\frac{8\pi\mu L}{A^2}\right)Q = \left(\frac{8\mu L}{\pi R^4}\right)Q$$

$$\Delta P = ZQ$$

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"The kind of motion we call heat"

- For the last two weeks of the class we will consider the topic of heat and temperature.
- We have a natural sense of hot and cold.
- In the 18th 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 surpisingly 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

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

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

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

$$m_1T_f - m_1T_1 = m_2T_2 - m_2T_f$$

$$m_1T_f + m_2T_f = m_1T_1 + m_2T_2$$

$$T_f = \frac{m_1T_1 + m_2T_2}{m_1 + m_2} = \left(\frac{m_1}{M}\right)T_1 + \left(\frac{m_2}{M}\right)T_2$$

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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." (We will see later that it can be transformed into other kinds of 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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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.

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

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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.

$$C = mc$$

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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)

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

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

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

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

$$T_f = \frac{m_1 c_1 T_1 + m_2 c_2 T_2}{m_1 c_1 + m_2 c_2}$$

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