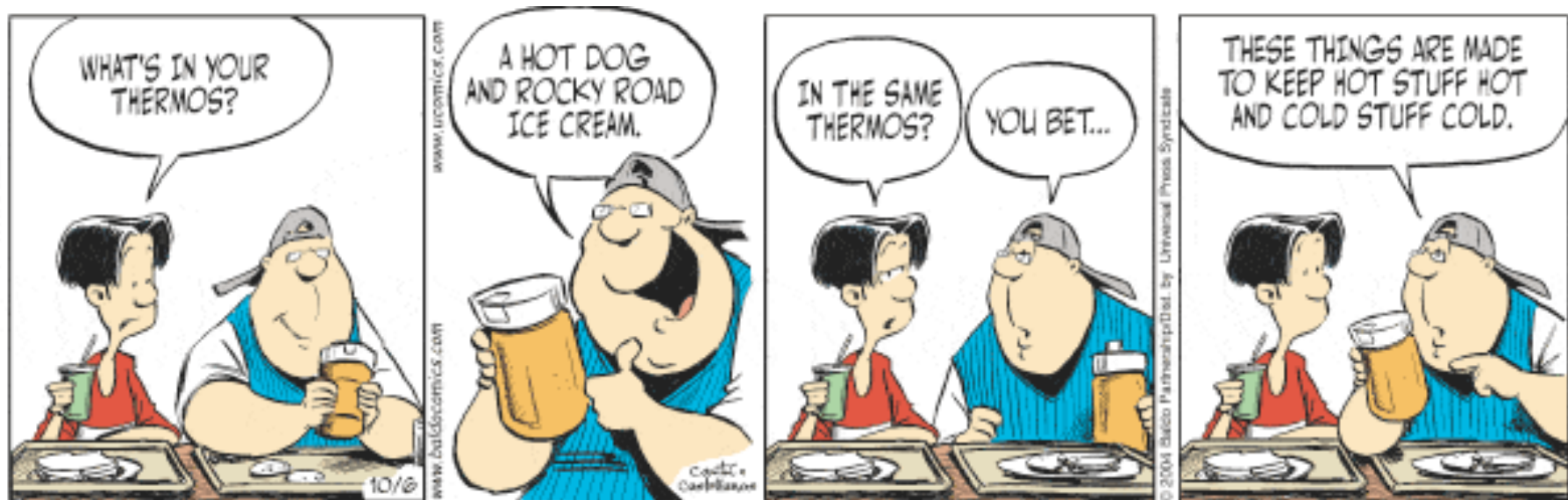# ■ <u>Theme Music:</u> Martha and the Vandellas

Heat Wave

■ <u>Cartoon:</u> 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.

$$F_{drag} = 8\pi\mu Lv$$

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.

Drag force

Flow in

Flow out

Pressure force upstream

Pressure force downstream
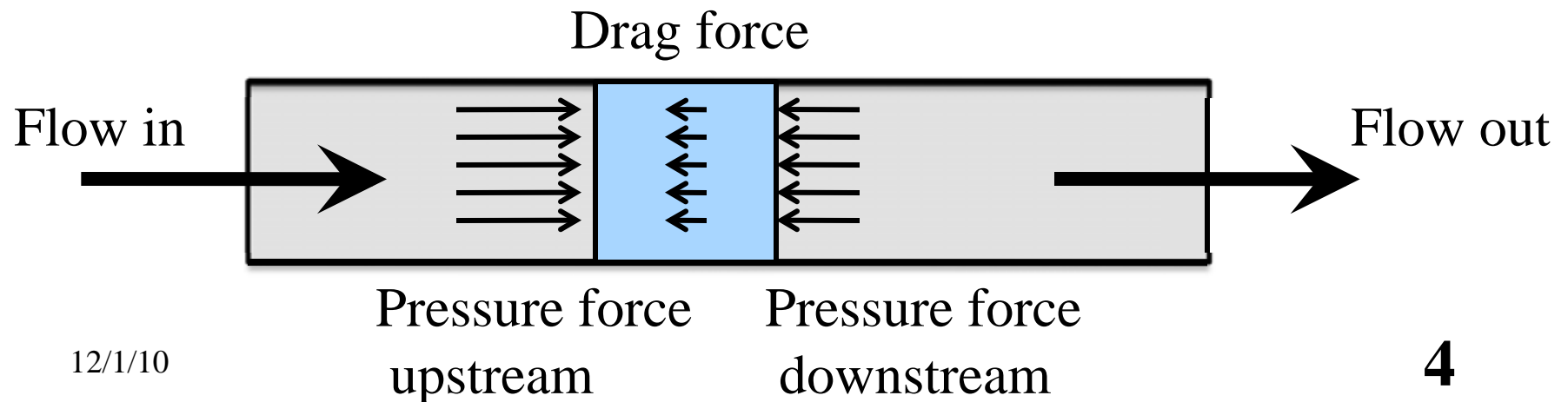
The Hagen-Poiseuille Law

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

$$\vec{F}_{drag}$$

$$P_{upstream}\vec{A}_L \qquad P_{downstream}\vec{A}_R$$
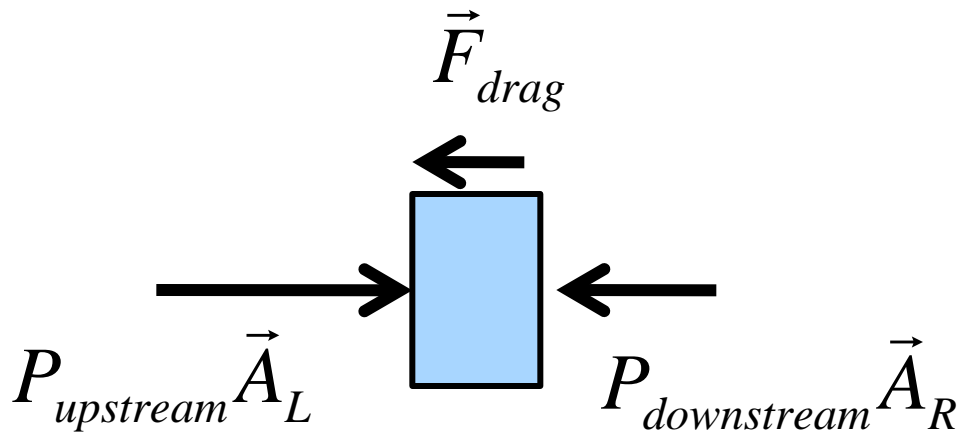
$$\Delta P\,A = 8\pi\mu L v$$

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

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

$$\Delta P = ZQ$$

"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.

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?

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

Two Objects of the Same Kind but Different Temperatures

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

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

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

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

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

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

Implications

- From the equation $\quad m_1 \Delta T_1 = -m_2 \Delta T_2$

  – 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.)

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!

Thermal Energy is <u>NOT</u> 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 <u>heat capacity</u>.

$$Q = C\Delta T$$

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

$$C = mc$$

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

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)

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

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

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

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

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