Archimedes’ Principle (Again)

- Applies for air as well as water!
- An object surrounded by air is buoyed up by a force equal to the weight of the air displaced.
- 1 m$^3$ of air has a mass of about 1.2 kg, whereas 1 m$^3$ of water has a mass of 1000 kg!
- Buoyant force due to air is usually very small

Floating Depends on Average Density

- Imagine a solid block of iron, and a sheet of iron bent into a boat-like shape.
- We have increased the effective volume of the sheet of iron.
- This lowers its average density, allowing it to float.

A floating object displaces a weight of fluid equal to its own weight.

More Floating

- Remember Archimedes’ Principle: An immersed object feels a buoyant force equal to the weight of the fluid it displaces.
- Objects with density less than the fluid will float.
- How do modern ships float???

Pascal’s Principle

“A change in pressure at any point in an enclosed fluid is transmitted undiminished to all points in the fluid.”

Pascal’s Principle: Example

- Remember, Pressure = force / area
- Pressure on both piston is the same (due to Pascal’s Principle)
- Imagine the area of the small piston is 1 m$^2$, and the area of the large piston is 5 m$^2$.
- What force acts on the large piston?

Continuity and Fluid Flow

Imagine water flowing through a pipe that goes from wide to narrow: speed of water increases through narrow portion of the pipe. (what goes in must come out)

\[ A_1 \nu_1 = A_2 \nu_2 \]

A = cross-sectional area of pipe
\( \nu \) = velocity
Bernoulli’s Principle

“Where the speed of a fluid increases, internal pressure in the fluid decreases.”

• Additional way to change the pressure in a liquid (other was depth)

Bernoulli’s Equation

\[ P_1 + \frac{1}{2} \rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho gh_2 \]

Bernoulli’s equation comes from conservation of energy: \( P \) term comes from work done on a fluid, \( \frac{1}{2} \rho v \) term comes from kinetic energy, and \( \rho gh \) term comes from gravitational potential energy.

Archimedes’ Principle Example

A piece of wood is tied to a string inside a tub filled with water. The string is attached to the bottom of the tub, and the wood is completely submerged. If the wood has a volume of 8 cm\(^3\) and a density of 600 kg/m\(^3\), what is the tension in the string?

Bernoulli’s Equation Example

The buildup of plaque on the walls of an artery may decrease its diameter from 1.1 cm to 0.75 cm. If the speed of the blood flow was 15 cm/s before reaching the region of plaque buildup, find:

a) The speed of blood flow  
b) The pressure drop within the plaque region.

Transforming Energy

• Recall: energy is always conserved, just changes from one form to another  
• Thermal energy is not very useful (incredibly difficult to transform into another form of energy!), we mostly consider thermal energy to be “lost” to surrounding objects, air, etc.  
• Other forms (\( U_{sp} \), \( KE \), \( U_{grav} \), work done by conservative forces) are not considered lost in this way.
Efficiency

- Real-life processes always include some friction, which means we’ll always lose some energy to heat (more on this later). How much we lose determines the efficiency of the process:

\[ e = \frac{\text{Energy out}}{\text{Energy in}} \]

(Efficiency is a percentage, so no units)

Temperature

- Temperature (T) is a measure of how “hot” or “cold” something is
- Temperature measures the random KE of each particle in an object.
  - The greater the motion/vibration the greater the T
  - The smaller the motion/vibration the lower the T
- SI Unit: kelvin (K)
  - Room temperature is about 295K-300K

Kelvin Temp. Scale

- The Kelvin scale has the same step size (size of one degree) as the Celsius scale, but the Kelvin scale has its zero at absolute zero.
- Conversion between a Celsius temperature and a Kelvin temperature:

\[ T = T_C + 273.15 \]

Thermometers

- Thermometers are instruments designed to measure temperature. In order to do this, they take advantage of some property of matter that changes with temperature.
  - Length of a solid or liquid column
  - Volume of a solid, liquid, or gas
  - Electromagnetic waves (infrared light) given off by hot objects

Thermal Expansion

- When you heat something up, it expands! (usually…)
- The effect is less dramatic in solids than in liquids or gases
Common Thermometers

- Liquid-in-tube
- Bimetallic Strip

Thermal Expansion

- (most) Objects expand when heated up
- \[ \Delta V = \beta V_i \Delta T \]
- \( \beta \) = coefficient of volume expansion (K\(^{-1}\))
- \[ \Delta L = \alpha L_i \Delta T \] (for solids only)
- \( \alpha \) = coefficient of linear expansion (K\(^{-1}\))

Example: Railroad tracks

- A 10-cm wide steel railroad tie is heated from 275 K to 310 K (about 35F to 100F). How much wider is the railroad tie after this?
- \( \alpha \) for steel is \( 1.2 \times 10^{-5} \text{ K}^{-1} \)

Heat (Q)

Definition of heat:
- Heat is the energy transferred between objects because of a temperature difference, or through work.
- Objects are in thermal contact if heat can flow between them.
- Connection from momentum: we treat collisions between atoms as perfectly elastic collisions

Thermal Equilibrium

- When the transfer of heat between objects in thermal contact stops, they are in thermal equilibrium.
- The objects will then be at the same temperature (they won’t necessarily have the same thermal energy!)

Units of Heat

- Since heat is just a flow of energy, the SI unit is the energy unit, the joule (J).
- Other heat units
  - calorie (cal): Heat needed to raise temperature of 1 gram of water by 1°C (or 1 K)
  - Calorie (Cal or kcal or food Cal): Heat needed to raise temperature of 1 kg of water by 1°C (or 1 K)
- Conversions:
  - 1 cal = 4.186 J
  - 1 kcal = 1 Cal (food Cal.) = 4.186 kJ
Specific Heat Capacity

- Specific heat capacity is the amount of heat energy required to raise the temperature of one unit mass of a material by one degree.
- SI Unit: J/(kg*K)

Heat Capacity vs. Specific Heat

- Heat capacity, C [J/K]
  - Q needed for a given \( \Delta T \)
- Specific Heat, \( c \) [J/kg K] (this is more frequently used)
  - Q needed for a given \( \Delta T \) for a particular amount of material
- Both \( c \) and \( C \) are particular to a given substance (water, glass, etc.) See Table 16-2.

Heat Transfer Methods

- Conduction: Thermal kinetic energy passed from particle-to-particle along a length of material.
- Convection: Thermal energy carried by moving fluid.
- Radiation: Thermal energy carried by electromagnetic waves (light)

Conduction

- Heat conduction can be visualized as occurring through molecular collisions.
- Thermal kinetic energy is passed along as “hotter” particles collide with “colder” ones.

Conduction

- Rate of heat transferred via conduction:
  \[
  Q/t = (kA/L) \Delta T
  \]
  \( k \) = thermal conductivity (W/m K)
  \( A \) = cross-sectional area
  \( L \) = length
  \( T \) = temperature
  \( t \) = time elapsed
Example: Imagine standing on a cold wood floor vs. a carpeted floor. If you stand around for 5 minutes and the temperature in your foot drops by 30K, which foot did you lose more heat from? How much more?

Convection
- Convection is flow of fluid due to difference in temperatures, such as warm air rising.
- Fluid “carries” heat with it as it moves.
- “Natural” convection: Warm fluid will rise because it is less dense than cold fluid.

Convection
- Heat transfer in a fluid often occurs mostly by convection.
- Buoyancy causes warm air to rise, which carries thermal energy directly by its motion.

Fiberglass Insulation
- Air is a poor thermal conductor but easily transfers heat by convection.
- Fiberglass insulation is mostly air, with the fibers disrupting the convection flow.

Radiation
- How does energy get from the Sun to Earth?
- No atmosphere out in space, so it’s can’t be convection or conduction.
- The energy is transferred through radiation; specifically, electromagnetic radiation.

Radiation
- Infrared light can radiate away from an object even in a vacuum (no air = no convection).
- Heat flow:
  \[
  \frac{Q}{\Delta t} = e \sigma AT^4
  \]
  \(A\) = surface area
  \(e\) = emissivity
  \(\sigma\) = Stefan-Boltzmann constant
  \(5.67 \times 10^{-8} \text{ W/(m}^2 \text{ K}^4)\)
If you were trying to warm your hands with a bonfire, where would you place your hands to warm them up as quickly as possible?

A. To the left of the bonfire  
B. To the right of the bonfire  
C. Above the bonfire  
D. Anywhere; the exact location doesn’t matter

Conceptual Check:

Spend a few minutes discussing with a neighbor how you could cool a hot cup of coffee. Try to explain how the cooling would happen using the ideas we’ve learned about heat transfer.