Main points of last lecture:

- Buoyancy:
  \[ F_B = W_{\text{displaced}} = \rho_f V_{\text{displaced}} g \]
- Bernoulli’s equation
  \[ P_f + \frac{1}{2} \rho v_f^2 + \rho g y_f = P_0 + \frac{1}{2} \rho v_0^2 + \rho g y_0 \]

Main points of today’s lecture:

- Viscous flow
  \[ F = \eta \frac{Av}{d} \]
- Poiseuille’s law
  \[ \frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8 \eta L} \]
- Temperature
- Thermal expansion
  \[ \Delta L = \alpha \Delta TL; \quad \Delta A = \gamma A_0 \Delta T; \quad \Delta V = \beta V_0 \Delta T \]
Conceptual question

- When a hole is made in the side of a container holding water, water flows out and follows a parabolic trajectory. If the container is dropped in free fall, the water flow
  - a) diminishes.
  - b) stops altogether.
  - c) goes out in a straight line.
  - d) curves upward.
Conceptual quiz

• A lead weight is fastened to a large solid piece of Styrofoam that floats in a container of water. Because of the weight of the lead, the water line is flush with the top surface of the Styrofoam. If the piece of Styrofoam is turned upside down, so that the weight is now suspended underneath it, the water level in the container
  – a) rises.
  – b) drops.
  – c) remains the same.
Viscous flow

- Viscosity limits the relative velocity between a fluid, the walls of its container and between two nearby points in the fluid.
- Assume a viscous fluid between two solid surfaces.
- Because the fluid “sticks” to the surfaces a force is required to move the upper surface relative to the lower surface.

\[ F = \eta \frac{Av}{d} \]

- \( \eta \) is the viscosity coefficient
- SI units are Ns/m²
- cgs units are Poise
  - 1 Poise = 0.1 Ns/m²

<table>
<thead>
<tr>
<th>Material</th>
<th>( \eta ) at T=20 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>1.9x10⁻⁵ N⋅s/m²</td>
</tr>
<tr>
<td>water</td>
<td>1.0x10⁻³ N⋅s/m²</td>
</tr>
<tr>
<td>glycerin</td>
<td>1.5 N⋅s/m²</td>
</tr>
</tbody>
</table>
Example

- A thin 1.5-mm coating of glycerine ($\eta=1.5 \text{ N} \cdot \text{s/m}^2$) has been placed between two microscope slides of width 1.0 cm and length 4.0 cm. Find the force required to pull one of the microscope slides at a constant speed of 0.30 m/s relative to the other.

$$F = \frac{\eta Av}{d} = \frac{1.5 \text{ N} \cdot \text{s/m}^2 (0.01 \text{m})(0.04 \text{m})(0.3 \text{m/s})}{0.0015 \text{m}} = 0.12 \text{N}$$
Poisseuilles’s Law

• Gives the *rate of flow* of a fluid in a tube with a pressure difference $\Delta P = P_1 - P_2$

\[
\text{Rate of flow} = \frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8\eta L}
\]

• Example: A blood vessel is 0.1 m in length and has a radius of $1.5 \times 10^{-3}$ m. Blood flow at a rate of $1.0 \times 10^{-7}$ m$^3$/s through this vessel. Determine the difference in pressure that must be maintained between the two ends of the vessel. ($\eta = 3 \times 10^{-3}$ N·s/m$^2$)

\[
\frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8\eta L} \Rightarrow P_1 - P_2 = \frac{\Delta V}{\Delta t} \cdot \frac{8\eta L}{\pi R^4} = \frac{\left(1 \times 10^{-7} \text{ m}^3/\text{s}\right) \cdot 8 \cdot \left(3 \times 10^{-3} \text{ N} \cdot \text{s} / \text{m}^2\right) \cdot (0.1 \text{ m})}{3.14159 \cdot \left(1.5 \times 10^{-3} \text{ m}\right)^4}
\]

\[
\Rightarrow P_1 - P_2 = 15 \text{ Pa}
\]
Zeroth Law of Thermodynamics

- If objects A and B are in thermal equilibrium with a third object, C, then A and B are in thermal equilibrium with each other.
- Allows a definition of temperature
Different Temperature Scales

- Three different temperature scales are commonly in use:
  - Fahrenheit
  - Celsius
  - Kelvin

- Celsius define such that the freezing point of water is at a temperature of about 0°C and boiling temperature is at about 100°C.

- The conversions from Celsius to Fahrenheit and to Kelvin are as follows:

$$ T_F = \frac{9}{5} T_C + 32 $$
$$ T_K = T_C + 273.15 $$

- At $T_K=0$, molecules in gas are nearly at rest and many material have unusual properties. What is this temperature in Fahrenheit?

$$ T_C = T_K - 273.15 = -273.15^0C $$
$$ T_F = \frac{9}{5} T_C + 32 = \frac{9}{5}(-273.15) + 32 = -459.67^0F $$
Thermometers

- While we know what is hot or cold. Much of what we think is simply perception:
  - Wind makes day “feel” colder because moving air strips away the insulating layer of warm air next to our skin.
  - Cold metal feels colder than equally cold wood.
  - Humid winter days feel colder than dry winter days. How do we construct a reliable thermometer?

- Need a quantity that has a unique dependence on temperature. Example the length of a column of mercury in a thermometer grows linearly with temperature.

- Many solids and liquids expand linearly with T: \( \Delta L = \alpha L_0 \Delta T \)

- Example: A aluminum rod which is 1.0000 m long at 0°C. What is its length at 100 °C? (\( \alpha_{Al} = 23 \times 10^{-6} / ^\circ C \))

\[
\Delta L = \alpha L_0 \Delta T = \left(23 \times 10^{-6} / ^\circ C \right)\left(1.0000 m \right)\left(100 ^\circ C \right)
\]

\[
\Delta L = 0.0023 m
\]

\[
L = L_0 + \Delta L = 1.0023 m
\]
Example

- A brass ring of diameter 10.00 cm at 20.0°C is heated and slipped over an aluminum rod of diameter 10.01 cm at 20.0°C. Assuming the average coefficients of linear expansion are constant, to what temperature must this combination be cooled to separate them? Is this attainable? (α_{Al}=24\times10^{-6} \degree C, \alpha_{Br}=19\times10^{-6} \degree C)

Want \( D_{Br} > D_{Al} \)

\[
D_{Br} = D_{Br,0} + \Delta D_{Br}; \quad D_{Al} = D_{Al,0} + \Delta D_{Al}
\]

\[
D_{Br,0} + \Delta D_{Br} > D_{Al,0} + \Delta D_{Al} \Rightarrow D_{Br,0} - D_{Al,0} > \Delta D_{Al} - \Delta D_{Br}
\]

\[
10.00 - 10.01 = -0.01 > \alpha_{Al} D_{Al} \Delta T - \alpha_{Br} D_{Br} \Delta T = (\alpha_{Al} D_{Al} - \alpha_{Br} D_{Br}) \Delta T
\]

\[
\Rightarrow -0.01 > (24\times10^{-6} \cdot 10.01 - 19\times10^{-6} \cdot 10.00) \Delta T = (5.0\times10^{-5}) \Delta T
\]

\[
\Rightarrow \frac{-0.01}{5.0\times10^{-5}} \degree C > \Delta T \Rightarrow -199 \degree C > \Delta T
\]

\[
\Rightarrow T_f = 20 \degree C + \Delta T = -179 \degree C
\]