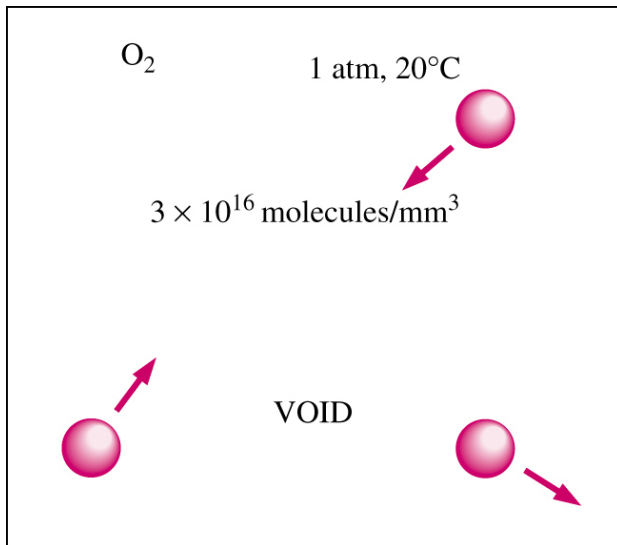


Chapter 2: Properties of Fluids

Introduction

- Any characteristic of a system is called a **property**.
 - Familiar: pressure P , temperature T , volume V , and mass m .
 - Less familiar: viscosity, thermal conductivity, modulus of elasticity, thermal expansion coefficient, vapor pressure, surface tension.
- *Intensive* properties are independent of the mass of the system. Examples: temperature, pressure, and density.
- *Extensive* properties are those whose value depends on the size of the system. Examples: Total mass, total volume, and total momentum.
- Extensive properties per unit mass are called **specific properties**. Examples include specific volume $v = V/m$ and specific total energy $e = E/m$.

Continuum



- Atoms are widely spaced in the gas phase.
- However, we can disregard the atomic nature of a substance.
- View it as a continuous, homogeneous matter with no holes, that is, a **continuum**.
- This allows us to treat properties as smoothly varying quantities.
- Continuum is valid as long as size of the system is large in comparison to distance between molecules.

Density and Specific Gravity

- Density is defined as the *mass per unit volume* $\rho = m/V$. Density has units of kg/m³
- Specific volume is defined as $v = 1/\rho = V/m$.
- For a gas, density depends on temperature and pressure.
- **Specific gravity**, or relative density is defined as *the ratio of the density of a substance to the density of some standard substance at a specified temperature* (usually water at 4°C), i.e., $SG = \rho/\rho_{H_2O}$. SG is a dimensionless quantity.
- The **specific weight** is defined as the weight per unit volume, i.e., $\gamma_s = \rho g$ where g is the gravitational acceleration. γ_s has units of N/m³.

Density and Specific Gravity

Specific gravities of some
substances at 0°C

Substance	SG
Water	1.0
Blood	1.05
Seawater	1.025
Gasoline	0.7
Ethyl alcohol	0.79
Mercury	13.6
Wood	0.3–0.9
Gold	19.2
Bones	1.7–2.0
Ice	0.92
Air (at 1 atm)	0.0013

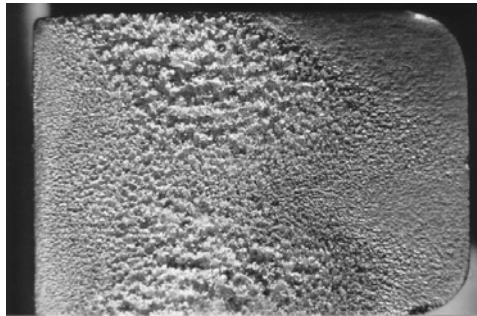
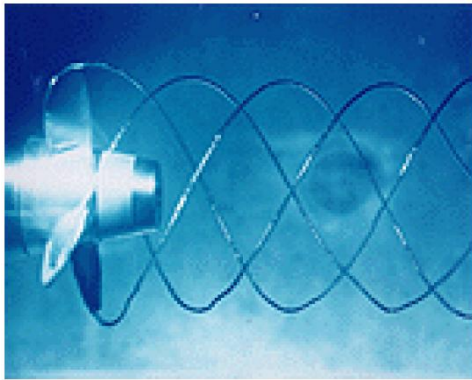
Density of Ideal Gases

- **Equation of State:** equation for the relationship between pressure, temperature, and density.
- The simplest and best-known equation of state is the ideal-gas equation.

$$P = \rho R T$$

- Ideal-gas equation holds for most gases.
- However, dense gases such as water vapor and refrigerant vapor should not be treated as ideal gases. Tables should be consulted for their properties, e.g., Tables A-3E through A-6E in textbook.

Vapor Pressure and Cavitation



- **Vapor Pressure** P_v is defined as *the pressure exerted by its vapor in phase equilibrium with its liquid at a given temperature*
- If P drops below P_v , liquid is locally vaporized, creating cavities of vapor.
- Vapor cavities collapse when local P rises above P_v .
- Collapse of cavities is a violent process which can damage machinery.
- Cavitation is noisy, and can cause structural vibrations.

Vapor Pressure

Saturation (or vapor) pressure of
water at various temperatures

Temperature $T, ^\circ\text{C}$	Saturation Pressure $P_{\text{sat}}, \text{kPa}$
-10	0.260
-5	0.403
0	0.611
5	0.872
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.38
50	12.35
100	101.3 (1 atm)
150	475.8
200	1554
250	3973
300	8581

Energy and Specific Heats

- Total energy E is comprised of numerous forms: thermal, mechanical, kinetic, potential, electrical, magnetic, chemical, and nuclear.
- Units of energy are *joule (J)* or *British thermal unit (BTU)*.
- Microscopic energy
 - Internal energy u is for a non-flowing fluid and is due to molecular activity.
 - Enthalpy $h=u+Pv$ is for a flowing fluid and includes flow energy (Pv).
- Macroscopic energy
 - Kinetic energy $ke=V^2/2$
 - Potential energy $pe=gz$
- In the absence of electrical, magnetic, chemical, and nuclear energy, the total energy is $e_{\text{flowing}}=h+V^2/2+gz$

Coefficient of Compressibility

- How does fluid volume change with P and T ?
- Fluids expand as $T \uparrow$ or $P \downarrow$
- Fluids contract as $T \downarrow$ or $P \uparrow$
- Need fluid properties that relate volume changes to changes in P and T .

- Coefficient of compressibility

$$\kappa = -v \left(\frac{\partial P}{\partial v} \right)_T = \rho \left(\frac{\partial P}{\partial \rho} \right)_T \quad \alpha = \frac{1}{\kappa} = -\frac{1}{v} \left(\frac{\partial v}{\partial P} \right)_T = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial P} \right)_T \quad \text{isothermal compressibility}$$

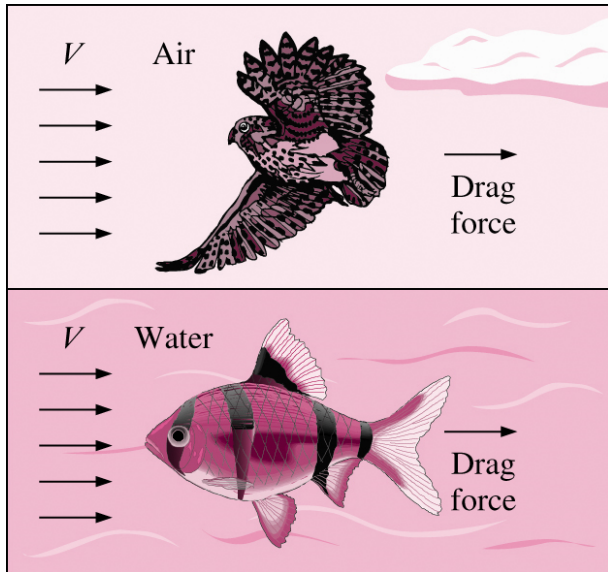
- Coefficient of volume expansion

$$\beta = \frac{1}{v} \left(\frac{\partial v}{\partial T} \right)_P = -\frac{1}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_P$$

- Combined effects of P and T can be written as

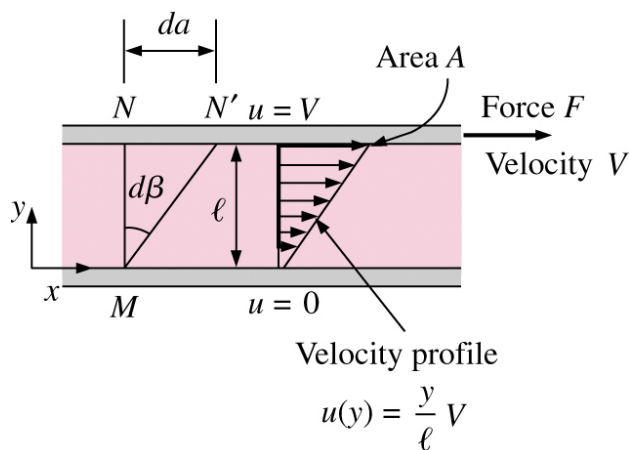
$$dv = \left(\frac{\partial v}{\partial T} \right)_P dT + \left(\frac{\partial v}{\partial P} \right)_T dP$$

Viscosity



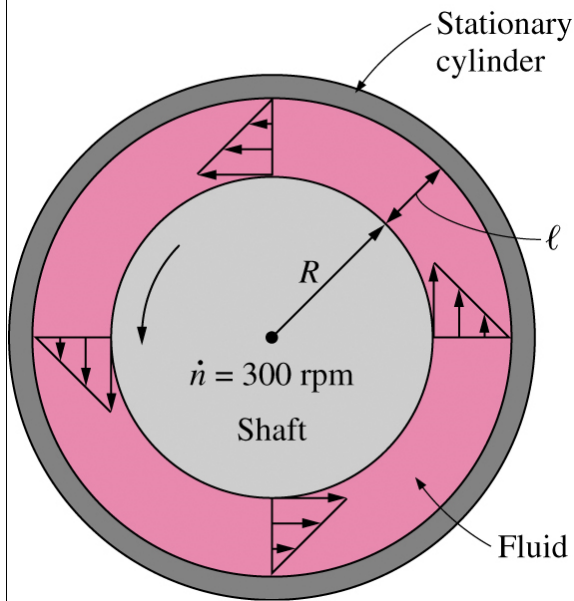
- **Viscosity** is a property that represents the internal resistance of a fluid to motion.
- The force a flowing fluid exerts on a body in the flow direction is called the **drag force**, and the magnitude of this force depends, in part, on viscosity.

Viscosity



- To obtain a relation for viscosity, consider a fluid layer between two very large parallel plates separated by a distance ℓ
- Definition of shear stress is $\tau = F/A$.
- Using the no-slip condition, $u(0) = 0$ and $u(\ell) = V$, the velocity profile and gradient are $u(y) = Vy/\ell$ and $du/dy = V/\ell$
- Shear stress for Newtonian fluid: $\tau = \mu du/dy$
- μ is the **dynamic viscosity** and has units of $kg/m \cdot s$, $Pa \cdot s$, or **poise**.

Viscometry



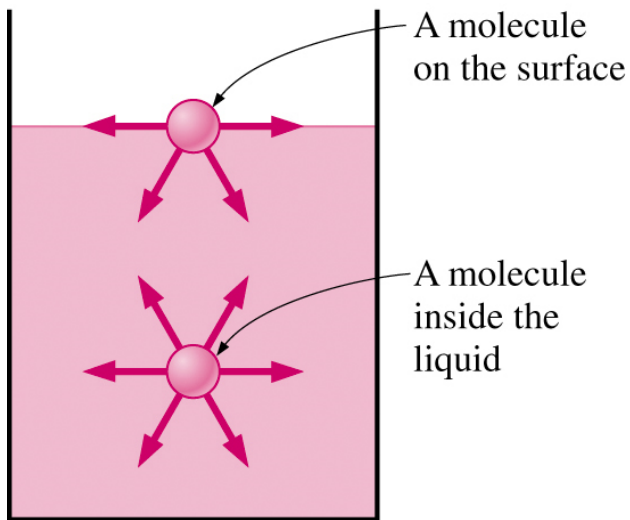
- How is viscosity measured? A rotating viscometer.
 - Two concentric cylinders with a fluid in the small gap ℓ .
 - Inner cylinder is rotating, outer one is fixed.
- Use definition of shear force:
 - If $\ell/R \ll 1$, then cylinders can be modeled as flat plates.
 - Torque $T = FR$, and tangential velocity $V = \omega R$
 - Wetted surface area $A = 2\pi RL$.
 - Measure T and ω to compute μ

Viscometry

Dynamic viscosities of some fluids
at 1 atm and 20°C (unless
otherwise stated)

Fluid	Dynamic Viscosity μ , kg/m · s
Glycerin:	
−20°C	134.0
0°C	10.5
20°C	1.52
40°C	0.31
Engine oil:	
SAE 10W	0.10
SAE 10W30	0.17
SAE 30	0.29
SAE 50	0.86
Mercury	0.0015
Ethyl alcohol	0.0012
Water:	
0°C	0.0018
20°C	0.0010
100°C (liquid)	0.00028
100°C (vapor)	0.000012
Blood, 37°C	0.00040
Gasoline	0.00029
Ammonia	0.00015
Air	0.000018
Hydrogen, 0°C	0.0000088

Surface Tension



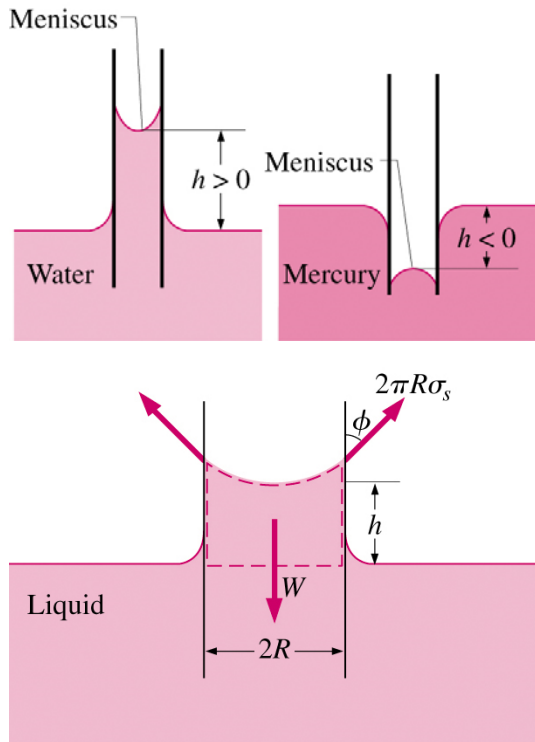
- Liquid droplets behave like small spherical balloons filled with liquid, and the surface of the liquid acts like a stretched elastic membrane under tension.
- The pulling force that causes this is
 - due to the attractive forces between molecules
 - called **surface tension** σ_s .
- Attractive force on surface molecule is not symmetric.
- Repulsive forces from interior molecules causes the liquid to minimize its surface area and attain a spherical shape.

Surface Tension

Surface tension of some fluids in air at 1 atm and 20°C (unless otherwise stated)

Fluid	Surface Tension σ_s , N/m*
Water:	
0°C	0.076
20°C	0.073
100°C	0.059
300°C	0.014
Glycerin	0.063
SAE 30 oil	0.035
Mercury	0.440
Ethyl alcohol	0.023
Blood, 37°C	0.058
Gasoline	0.022
Ammonia	0.021
Soap solution	0.025
Kerosene	0.028

Capillary Effect



- **Capillary effect** is the rise or fall of a liquid in a small-diameter tube.
- The curved free surface in the tube is called the **meniscus**.
- Water meniscus curves up because water is a *wetting fluid*.
- Mercury meniscus curves down because mercury is a *nonwetting fluid*.
- Force balance can describe magnitude of capillary rise.

Homework

4c,5,7,9E,11c-13c,16,21c-24c,27c,28c,30-35,37,38c-40c,**43-51**,
53,55c,57c,58c,**60e**