Section Summary

12.1 Flow Rate and Its Relation to Velocity

- Flow rate Q is defined to be the volume V flowing past a point in time t, or $Q = \frac{V}{t}$ where V is volume and t is time.
- The SI unit of volume is m^3.
- Another common unit is the liter (L), which is 10^{-3} m^3.
- Flow rate and velocity are related by $Q = A\bar{v}$ where A is the cross-sectional area of the flow and $\bar{v}$ is its average velocity.
- For incompressible fluids, flow rate at various points is constant. That is,
- $$\left.\begin{aligned} Q_1 &= Q_2 \\ A_1\bar{v}_1 &= A_2\bar{v}_2 \\ n_1A_1\bar{v}_1 &= n_2A_2\bar{v}_2 \end{aligned}\right\}.$$

12.2 Bernoulli's Equation

- Bernoulli's equation states that the sum on each side of the following equation is constant, or the same at any two points in an incompressible frictionless fluid:
- $P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho \mathrm{g h}_2$.
- Bernoulli's principle is Bernoulli's equation applied to situations in which depth is constant. The terms involving depth (or height h) subtract out, yielding
- $P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$.
- Bernoulli's principle has many applications, including entrainment, wings and sails, and velocity measurement.

12.3 The Most General Applications of Bernoulli's Equation

- Power in fluid flow is given by the equation $\left(P_1 + \frac{1}{2}\rho v^2 + \rho \mathrm{gh}\right) Q = \text{power}$, where the first term is power associated with pressure, the second is power associated with velocity, and the third is power associated with height.

12.4 Viscosity and Laminar Flow; Poiseuille's Law

- Laminar flow is characterized by smooth flow of the fluid in layers that do not mix.
- Turbulence is characterized by eddies and swirls that mix layers of fluid together.
- Fluid viscosity η is due to friction within a fluid. Representative values are given in Table 12.1. Viscosity has units of $(\mathrm{N/m}^2)\mathrm{s}$ or $\mathrm{Pa \cdot s}$.

- Flow is proportional to pressure difference and inversely proportional to resistance:
- $Q = \frac{P_2 - P_1}{R}$.
- For laminar flow in a tube, Poiseuille's law for resistance states that
- $R = \frac{8\eta l}{\pi r^4}$.
- Poiseuille's law for flow in a tube is
- $Q = \frac{(P_2 - P_1)\pi r^4}{8\eta l}$.
- The pressure drop caused by flow and resistance is given by
- $P_2 - P_1 = RQ$.

12.5 The Onset of Turbulence

- The Reynolds number N_{R} can reveal whether flow is laminar or turbulent. It is
- $N_{\mathrm{R}} = \frac{2\rho \mathrm{vr}}{\eta}$.
- For N_{R} below about 2000, flow is laminar. For N_{R} above about 3000, flow is turbulent. For values of N_{R} between 2000 and 3000, it may be either or both.

12.6 Motion of an Object in a Viscous Fluid

- When an object moves in a fluid, there is a different form of the Reynolds number $N_{\mathrm{R}}^{\prime} = \frac{\rho \mathrm{vL}}{\eta}$(object in fluid), which indicates whether flow is laminar or turbulent.
- For $N_{\mathrm{R}}^{\prime}$ less than about one, flow is laminar.
- For $N_{\mathrm{R}}^{\prime}$ greater than 10^6, flow is entirely turbulent.

12.7 Molecular Transport Phenomena: Diffusion, Osmosis, and Related Processes

- Diffusion is the movement of substances due to random thermal molecular motion.
- The average distance x_{rms} a molecule travels by diffusion in a given amount of time is given by
- $x_{\mathrm{rms}} = \sqrt{2D\mathrm{t}}$,

  where D is the diffusion constant, representative values of which are found in Table 12.2.
- Osmosis is the transport of water through a semipermeable membrane from a region of high concentration to a region of low concentration.

- Dialysis is the transport of any other molecule through a semipermeable membrane due to its concentration difference.
- Both processes can be reversed by back pressure.
- Active transport is a process in which a living membrane expends energy to move substances across it.