Section Summary

5.1 Friction

- Friction is a contact force between systems that opposes the motion or attempted motion between them. Simple friction is proportional to the normal force N pushing the systems together. (A normal force is always perpendicular to the contact surface between systems.) Friction depends on both of the materials involved. The magnitude of static friction f_s between systems stationary relative to one another is given by

  $$f_s \leq \mu_s N,$$

  where μ_s is the coefficient of static friction, which depends on both of the materials.
- The kinetic friction force f_k between systems moving relative to one another is given by

  $$f_k = \mu_k N,$$

  where μ_k is the coefficient of kinetic friction, which also depends on both materials.

5.2 Drag Forces

- Drag forces acting on an object moving in a fluid oppose the motion. For larger objects (such as a baseball) moving at a velocity v in air, the drag force is given by

  $$F_D = \frac{1}{2} C \rho A v^2,$$

  where C is the drag coefficient (typical values are given in Table 5.2), A is the area of the object facing the fluid, and ρ is the fluid density.
- For small objects (such as a bacterium) moving in a denser medium (such as water), the drag force is given by Stokes' law,

  $$F_s = 6\pi\eta r v,$$

  where r is the radius of the object, η is the fluid viscosity, and v is the object's velocity.

5.3 Elasticity: Stress and Strain

- Hooke's law is given by

  $$F = k\Delta L,$$

  where ΔL is the amount of deformation (the change in length), F is the applied force, and k is a proportionality constant that depends on the shape and composition of the object and the direction of the force. The relationship between the deformation and the applied force can also be written as

$$\Delta L = \frac{1}{Y}\frac{F}{A}L_0,$$

where Y is *Young's modulus*, which depends on the substance, A is the cross-sectional area, and L_0 is the original length.

- The ratio of force to area, $\frac{F}{A}$, is defined as *stress*, measured in N/m^2.
- The ratio of the change in length to length, $\frac{\Delta L}{L_0}$, is defined as *strain* (a unitless quantity). In other words,
  stress = Y × strain.
- The expression for shear deformation is

  $$\Delta x = \frac{1}{S}\frac{F}{A}L_0,$$

  where S is the shear modulus and F is the force applied perpendicular to L_0 and parallel to the cross-sectional area A.
- The relationship of the change in volume to other physical quantities is given by

  $$\Delta V = \frac{1}{B}\frac{F}{A}V_0,$$

  where B is the bulk modulus, V_0 is the original volume, and $\frac{F}{A}$ is the force per unit area applied uniformly inward on all surfaces.