D02 APPLYING NEWTON'S LAWS & FRICTIONAL FORCES

SPH4U

EQUATIONS

- Force of Friction

$$F_f = \mu F_N$$

- Coefficients of Friction

$$\mu_S = \frac{F_{S,max}}{F_N} \qquad \mu_K = \frac{F_K}{F_N}$$

RECALL: NEWTON'S LAWS OF MOTION

1. The Law of Inertia:
   - If $\vec{F}_{net} = 0$, an object maintains uniform motion ($\vec{v}$ is constant)
2. $\sum \vec{F} = m\vec{a}$
   - For non-zero net force, an object will accelerate in the direction of the net force.
3. $\vec{F}_{12} = -\vec{F}_{21}$
   - Every action has an equal and opposite reaction.

SOLVING PROBLEMS IN A SYSTEMATIC WAY

1. Read the problem carefully and check the definitions of any unfamiliar words.
2. Draw a system diagram. Label all relevant information, including any numerical quantities given. (For simple situations, you can omit this step.)
3. Draw an FBD of the object (or group of objects) and label all the forces. Choose the x and y directions. (Try to choose one of these directions as the direction of the acceleration.)
4. Calculate and label the x- and y-components of all the forces on the FBD.
5. Write the second-law equation(s), $Fx \;\; max$ and/or $Fy \;\; may$, and substitute for the variables on both sides of the equation(s).
6. Repeat steps 3 to 5 for any other objects as required.
7. Solve the resulting equation(s) algebraically.
8. Check to see if your answers have appropriate units, a reasonable magnitude, a logical direction (if required), and the correct number of significant digits.

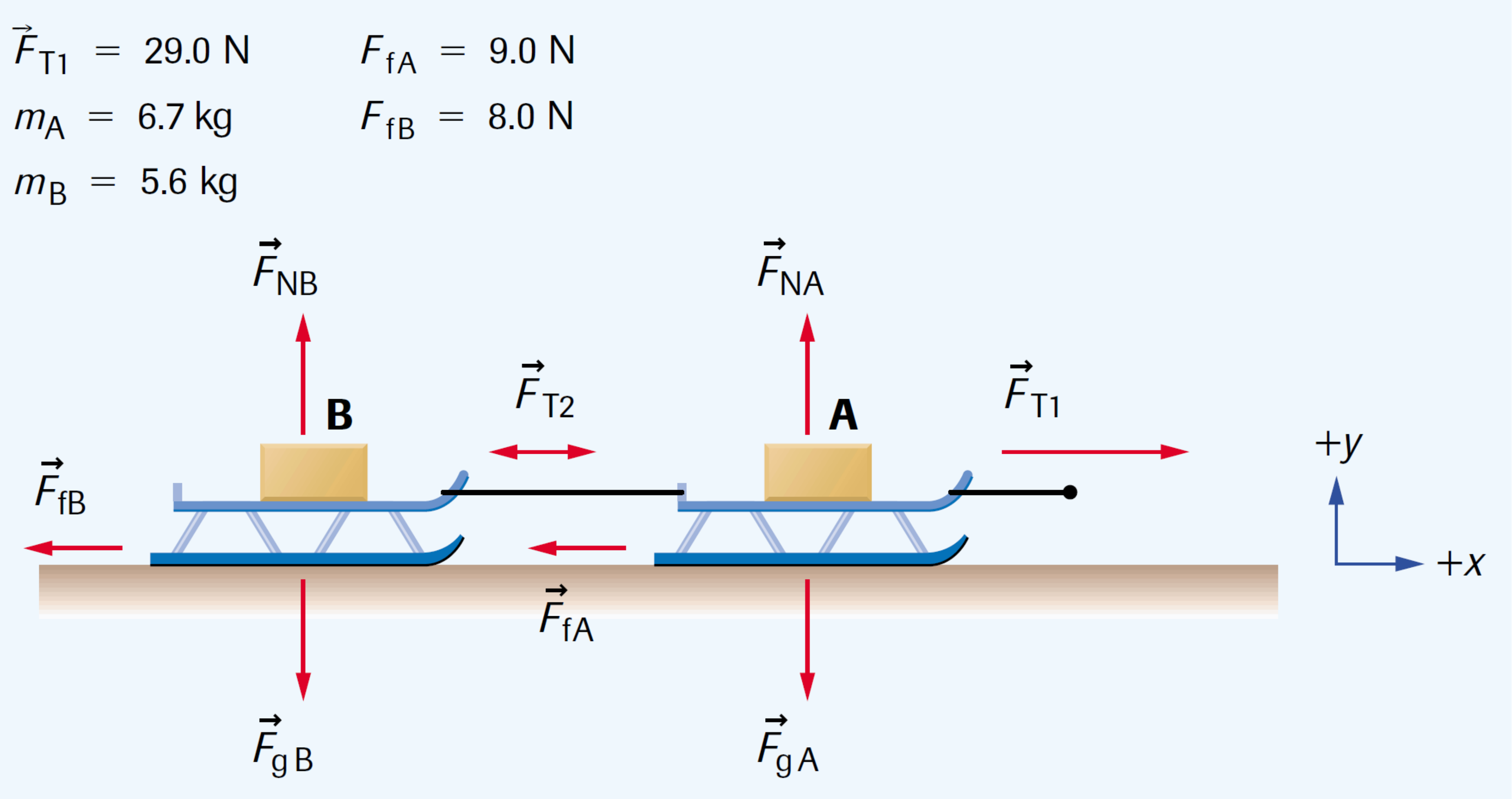
EXAMPLE 1

Sleds A and B are connected by a horizontal rope, with A in front of B. Sled A is pulled forward by means of a horizontal rope with a tension of magnitude 29.0 N. The masses of A and B are 6.7 kg and 5.6 kg, respectively. The magnitudes of friction on A and B are 9.0 N and 8.0 N, respectively. Calculate the magnitude of

(a) the acceleration of the two-sled system

(b) the tension in the rope connecting the sleds

EXAMPLE 1 – SOLUTIONS



EXAMPLE 1 – SOLUTIONS

(a) To determine the magnitude of the acceleration of the two-sled system, we note that the tension in the front rope, $\vec{F}_{T1}$, determines the acceleration of the entire system. **Figure 3** is the FBD of the system.

Horizontally for the system:

Applying Newton's second law:

$$\sum F_{\text{system},x} = m_{\text{system}} a_{\text{system},x}$$

$$a_x = \frac{\sum F_x}{m}$$

$$= \frac{F_{T1} + (-F_{f,\text{total}})}{m_A + m_B}$$

$$= \frac{29.0\text{ N} - (9.0\text{ N} + 8.0\text{ N})}{(6.7\text{ kg} + 5.6\text{ kg})}$$

$$a_x = 0.98\text{ m/s}^2$$

The magnitude of the acceleration is 0.98 m/s^2.

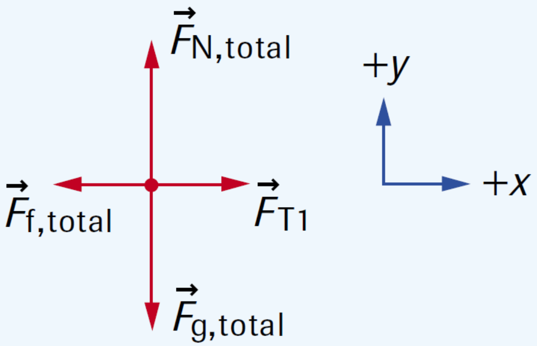


Figure 3
FBD of the two-sled system

EXAMPLE 1 – SOLUTIONS

(b) To determine the magnitude of the tension in the second rope, $\vec{F}_{T2}$, we analyze the forces that are acting only on sled B. **Figure 4** is the FBD of sled B. Knowing that the magnitude of the acceleration of sled B is the same as the acceleration of the system (i.e., 0.98 m/s^2), we can apply the second-law equation to the horizontal components of the motion:

$$\sum F_{Bx} = m_B a_{Bx}$$
$$F_{T2} - F_{fB} = m_B a_{Bx}$$
$$F_{T2} = F_{fB} + m_B a_{Bx}$$
$$= 8.0\ \text{N} + (5.6\ \text{kg})(0.98\ \text{m/s}^2)$$
$$F_{T2} = 13\ \text{N}$$

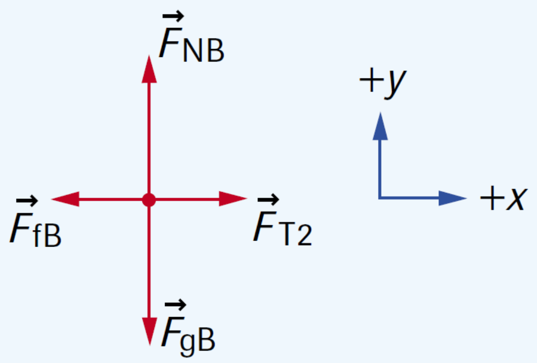


Figure 4
FBD of sled B

The magnitude of the tension in the connecting ropes is 13 N. We would have obtained the same value by drawing an FBD for sled A instead, since the tension force applied by the connecting rope to A is equal in magnitude, although opposite in direction, to the tension force applied by the connecting rope to B. The value of 13 N seems reasonable, since the tension must be large enough not only to overcome the friction of 8.0 N, but also to cause acceleration.

APPLYING NEWTON'S 3RD LAW OF MOTION

- Draw a system diagram of both objects
- Free body diagrams must be drawn separately for each object
  - Remember: only forces acting on the object are in the FBD

EXPLORING FRICTIONAL FORCES

- Static Friction
  - Coefficient of static friction (μ_S): the ratio of the magnitude of the maximum static friction to the magnitude of the normal force

$$\mu_S = \frac{F_{S,max}}{F_N}$$

- Kinetic Friction
  - Coefficient of kinetic friction (μ_K): the ratio of the magnitude of the kinetic friction to the magnitude of the normal force

$$\mu_K = \frac{F_K}{F_N}$$

- Note: all coefficients of friction are found empirically (through experimentation)

EXAMPLE 2

A crate of fish of mass 18.0 kg rests on the floor of a parked delivery truck. The coefficients of friction between the crate and the floor are $\mu_S = 0.450$ and $\mu_K = 0.410$. The local value of gravitational acceleration is, to three significant figures, 9.80 m/s^2. What are the force of friction and the acceleration (a) if a horizontal force of 75.0 N [E] is applied to the crate, and (b) if a horizontal force of 95.0 N [E] is applied?

EXAMPLE 2 – SOLUTIONS

Figure 4 shows both the system diagram and the FBD for this situation.

(a) $m = 18.0\text{ kg}$ $\qquad \mu_S = 0.450$

$\vec{F}_{app} = 75.0\text{ N [E]}$ $\qquad |\vec{g}| = 9.80\text{ N/kg}$

To determine whether the crate will accelerate or remain stationary, we find the maximum static friction. We first determine the normal force, using the equation for the second law in the vertical direction:

$$\sum F_y = ma_y = 0$$

$$F_N + (-mg) = 0$$

$$F_N = mg$$

$$= (18.0\text{ kg})(9.80\text{ N/kg})$$

$$F_N = 176\text{ N}$$

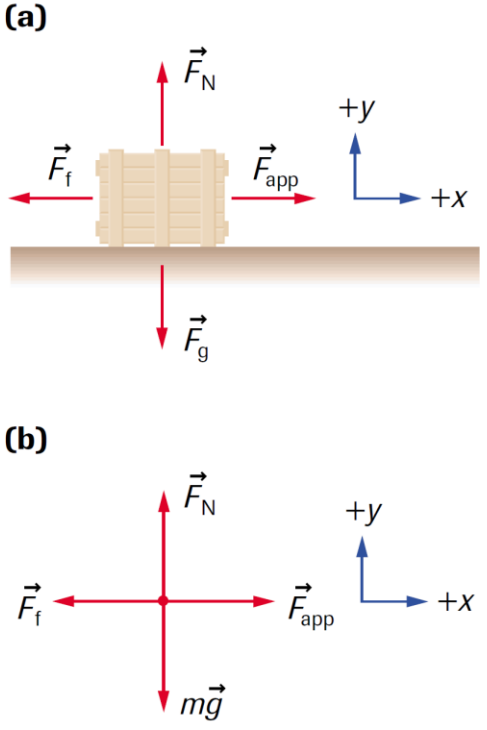


Figure 4
For Sample Problem 1
(a) System diagram for the crate
(b) FBD for the crate

EXAMPLE 2 – SOLUTIONS

We can now determine the magnitude of the maximum static friction:

$$F_{S,max} = \mu_S F_N$$
$$= (0.450)(176\ \text{N})$$
$$F_{S,max} = 79.4\ \text{N}$$

Since the applied force is 75.0 N [E], the static friction (a reaction force to the applied force) must be 75.0 N [W], which is less than the magnitude of the maximum static friction. Consequently, the crate remains at rest.

EXAMPLE 2 – SOLUTIONS

(b) In this case, the magnitude of the applied force is greater than the magnitude of the maximum static friction. Since the crate is, therefore, in motion, we must consider the kinetic friction:

$$\vec{F}_{app} = 95.0 \text{ N [E]}$$

$$F_N = 176 \text{ N}$$

$$\mu_K = 0.410$$

$$F_K = \mu_K F_N$$

$$= (0.410)(176 \text{ N})$$

$$F_K = 72.3 \text{ N}$$

EXAMPLE 2 – SOLUTIONS

To determine the acceleration of the crate, we apply the second-law equation in the horizontal direction:

$$
\begin{aligned}
\sum F_x &= ma_x \\
F_{app} + (-F_K) &= ma_x \\
a_x &= \frac{F_{app} + (-F_K)}{m} \\
&= \frac{95.0\ \text{N} - 72.3\ \text{N}}{18.0\ \text{kg}} \\
a_x &= 1.26\ \text{m/s}^2
\end{aligned}
$$

Since the applied force is eastward, the acceleration of the crate is 1.26 m/s^2 [E].

FLUID FRICTION & BERNOULLI'S PRINCIPLE

- **Fluid:** substance that flows and takes the shape of its container
- **Viscosity:** internal friction between molecules caused by cohesive forces
- **Laminar Flow:** stable flow of a viscous fluid where adjacent layers of a fluid slide smoothly over one another

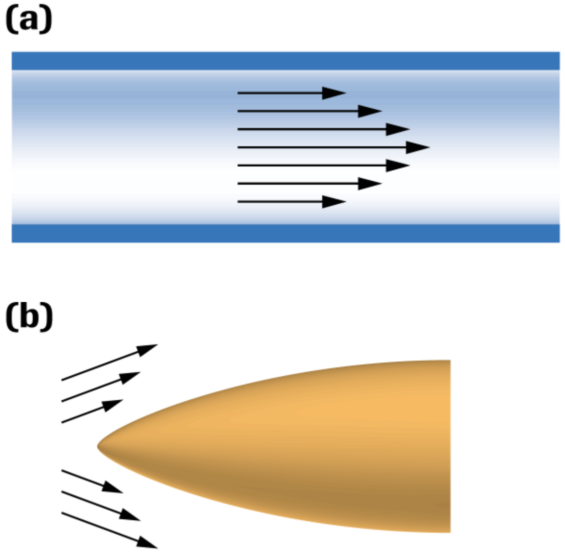


Figure 7
Laminar flow in fluids. The length of each vector represents the magnitude of the fluid velocity at that point.
(a) Water in a pipe
(b) Air around a cone

FLUID FRICTION & BERNOULLI'S PRINCIPLE – CONT.

- **Turbulence:** irregular fluid motion

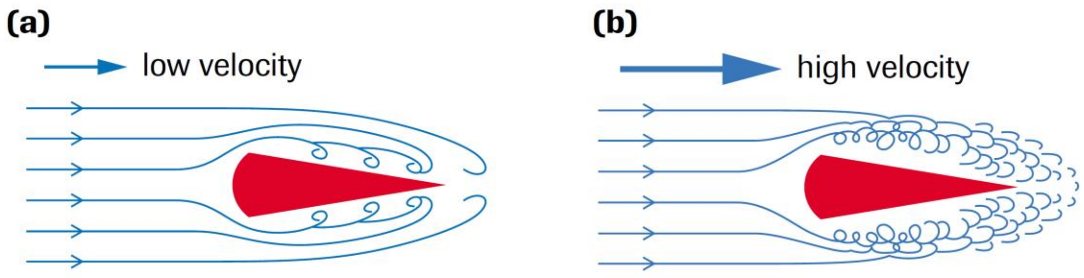


Figure 8
The turbulence caused by eddies increases as the fluid velocity increases.
(a) Low turbulence at a low velocity
(b) Higher turbulence at a high velocity

- **Streamlining:** the process of reducing turbulence by altering the design of an object
  - Research using large wind tunnels and water tanks

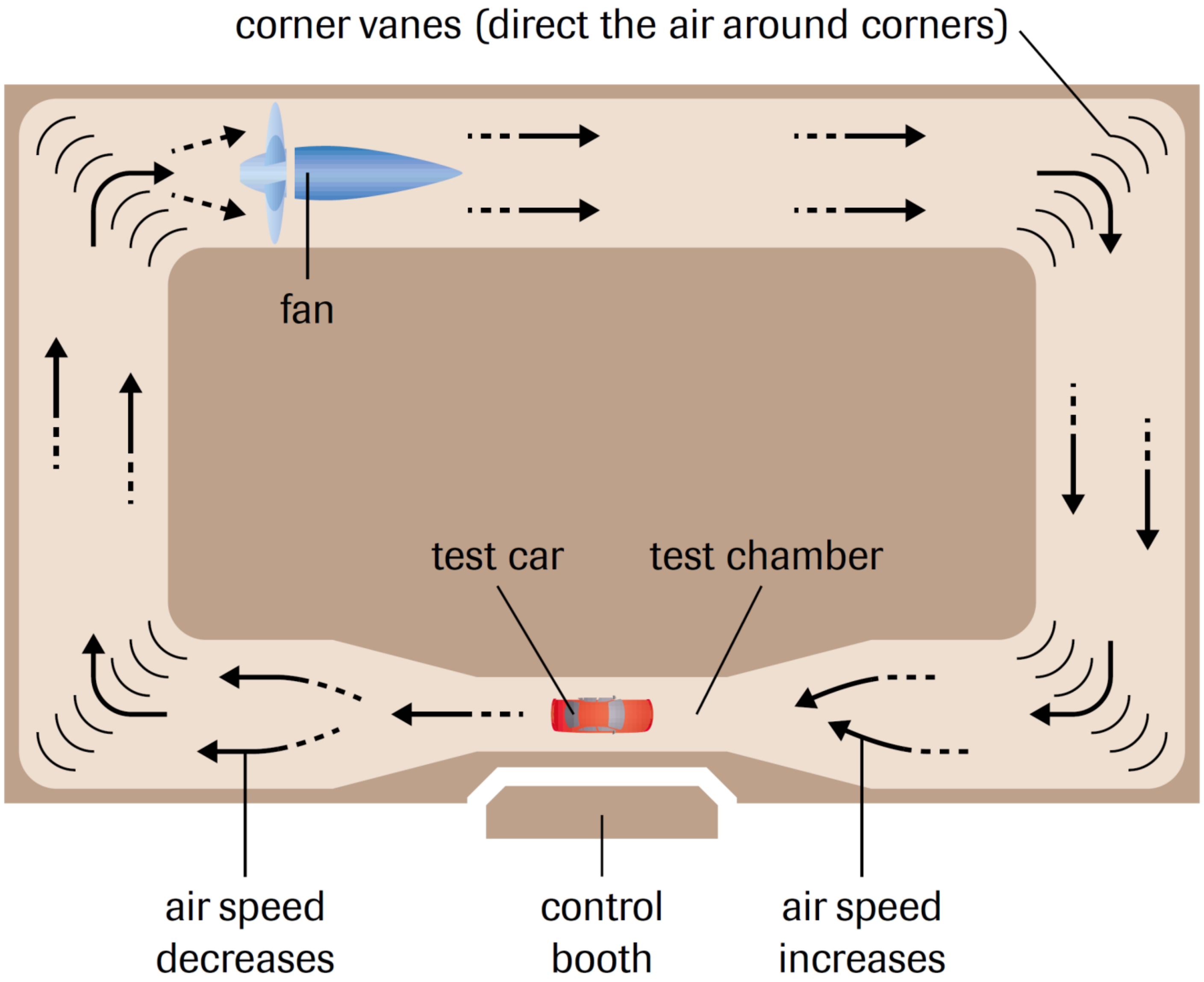


Figure 9
A typical wind tunnel for analyzing the streamlining of automobiles

BERNOULLI'S PRINCIPLE

- Where the speed of a fluid is low, the pressure is high.
- Where the speed of a fluid is high, the pressure is low.

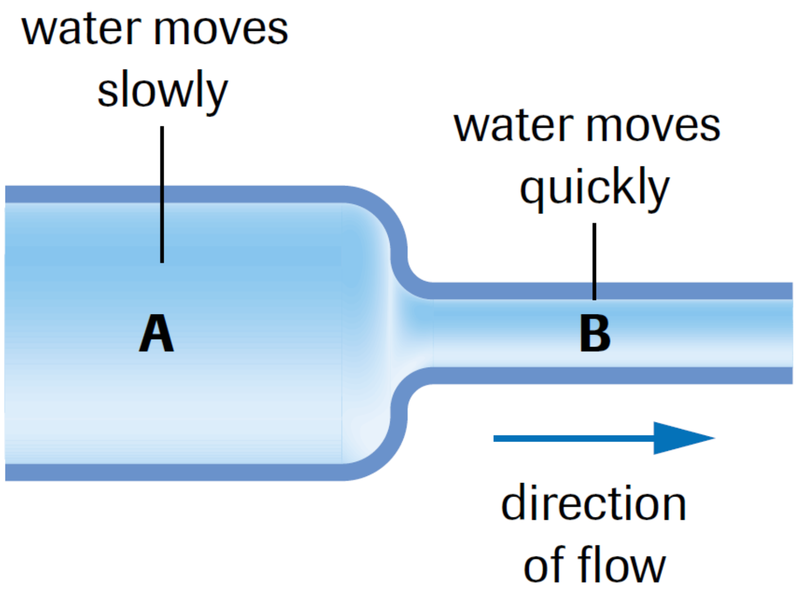


Figure 11
The flow speed depends on the diameter of the pipe.

THROWING A CURVEBALL

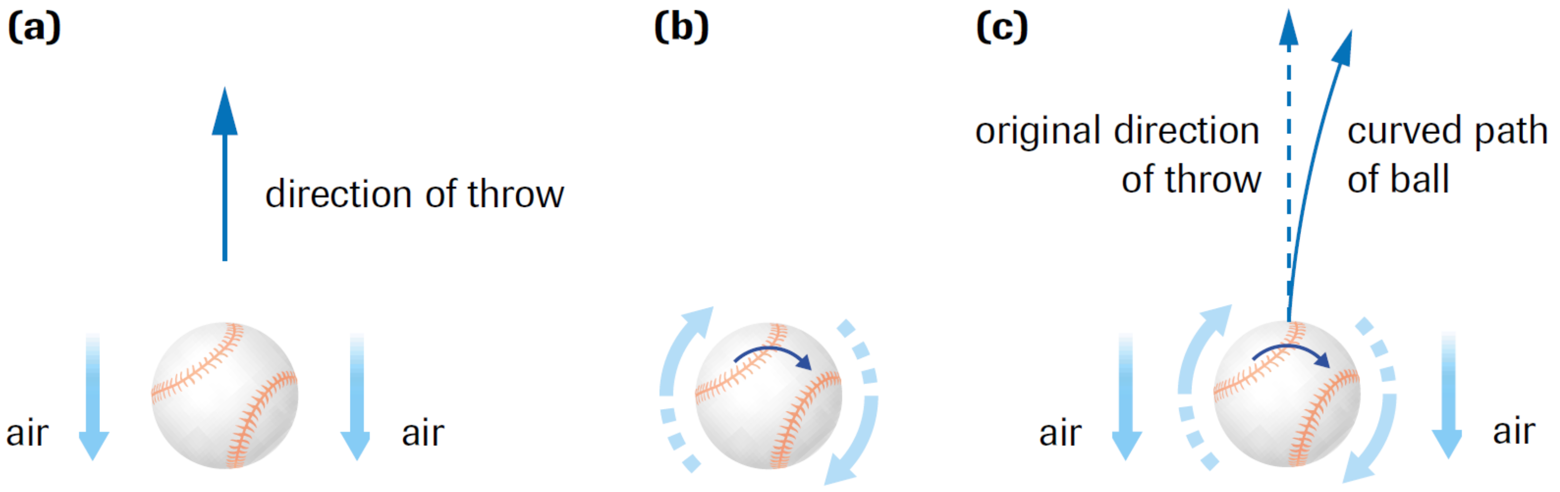


Figure 12
Bernoulli's principle explains curve balls as viewed from above.
(a) A ball thrown without spin is undeflected.
(b) Air is dragged around the surface of a spinning ball.
(c) Since the flow speed around a spinning ball is not equal on both sides, the pressure is not equal. The ball is deflected in the direction of lower pressure.

SUMMARY: APPLYING NEWTON'S LAWS OF MOTION

- It is wise to develop a general strategy that helps solve the great variety of types of problems involving forces, no matter how different each problem may at first appear.
- The skill of drawing an FBD for each object in a given problem is vital.
- For motion in two dimensions, it is almost always convenient to analyze the perpendicular components of the forces separately and then bring the concepts together.

SUMMARY: EXPLORING FRICTIONAL FORCES

- As the force applied to an object increases, the static friction opposing the force increases until the maximum static friction is reached, at which instant the object begins to move. After that instant, kinetic friction opposes the motion.
- The coefficients of static friction and kinetic friction are the ratios, respectively, of the magnitude of the static friction force and the kinetic friction force to the normal force between an object and the surface with which it is in contact. These coefficients have no units.
- Internal friction in a fluid is called viscosity and depends on the nature and temperature of the fluid.
- Laminar flow of a fluid occurs when the layers of the fluid flow smoothly over one another.
- The irregular flow of a fluid is called turbulence; this problem can be reduced by streamlining.
- Bernoulli's principle states:Where the speed of a fluid is low, the pressure is high, and where the speed of the same fluid is high, the pressure is low. Among the illustrations of this principle is the throwing of curve balls in baseball.

PRACTICE

Readings

- Section 2.3 (pg 88)
- Section 2.4 (pg 97)

Questions

- pg 96 #1-11
- pg 106 #1-7