CHAPTER 4
Dynamics:
Newton’s Laws of Motion
http://www.physicsclassroom.com/Class/newtlaws/newtltoc.html

- Force
- Newton’s First Law of Motion
- Mass
- Newton’s Second Law of Motion
- Newton’s Third Law of Motion
- Weight – the Force of Gravity; and the Normal Force
- Solving Problems with Newton’s Laws: Free-Body Diagrams
- Applications Involving Friction, Inclines
- Problem Solving – A General Approach

Classical Mechanics

- Describes the relationship between the motion of objects in our everyday world and the forces acting on them
- Conditions when Classical Mechanics does not apply
  - very tiny objects (< atomic sizes)
  - objects moving near the speed of light

Forces

- Usually think of a force as a push or pull
- Vector quantity
- May be a contact force or a field force
  - Contact forces result from physical contact between two objects
  - Field forces act between disconnected objects
    - Also called “action at a distance”

Contact and Field Forces

- Contact forces
- Field forces

![Contact and Field Forces Diagram](image)
Fundamental Forces

- **Types**
  - Strong nuclear force
  - Electromagnetic force
  - Weak nuclear force
  - Gravity

- **Characteristics**
  - All field forces
  - Listed in order of decreasing strength
  - Only gravity and electromagnetic in mechanics

Sir Isaac Newton

- 1642 – 1727
- Formulated basic concepts and laws of mechanics
- Universal Gravitation
- Calculus
- Light and optics

Newton’s First Law of Motion

Newton’s first law is often called the law of inertia. Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.

External and Internal Forces

- **External force**
  - Any force that results from the interaction between the object and its environment
- **Internal forces**
  - Forces that originate within the object itself
  - They cannot change the object’s velocity
Inertia

Is the tendency of an object to continue in its original motion.

Mass

Mass is the measure of inertia of an object. In the SI system, mass is measured in kilograms. Mass is not weight: Mass is a property of an object. Weight is the force exerted on that object by gravity. If you go to the moon, whose gravitational acceleration is about \(1/6\ g\), you will weigh much less. Your mass, however, will be the same.

Newton’s Second Law of Motion

Newton’s second law is the relation between acceleration and force. Acceleration is proportional to force and inversely proportional to mass.

\[
\sum F = ma
\]

Units of Force

- SI unit of force is a Newton (N)
  \[
  1\ N = 1\ \frac{kg\ m}{s^2}
  \]
- US Customary unit of force is a pound (lb)
  \[
  1\ N = 0.225\ lb
  \]

Force is a vector, so \(\sum F = ma\) is true along each coordinate axis. The unit of force in the SI system is the newton (N). Note that the pound is a unit of force, not of mass, and can therefore be equated to newtons but not to kilograms.

<table>
<thead>
<tr>
<th>Units for Mass and Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
</tr>
<tr>
<td>SI</td>
</tr>
<tr>
<td>cgs</td>
</tr>
<tr>
<td>British</td>
</tr>
<tr>
<td>Conversion factors: 1 dyne = 10^{-5} N; 1 lb ≈ 4.45 N.</td>
</tr>
</tbody>
</table>
Example 1: What average net force is required to bring a 1500-kg car to rest from a speed of 100 km/h within a distance of 55 m?

\[ v^2 = v_o^2 + 2a(x-x_o) \]

\[ a = \frac{(v^2-v_o^2)}{2(x-x_o)} = \frac{0-(28 m/s)^2}{2(55m)} = -7.1 m/s^2 \]

\[ \sum F = ma = (1500 kg)(-7.1 m/s^2) = -1.1 \times 10^4 N \]

Example 2: An airboat with mass 350 kg, including passengers, has an engine that produces a net horizontal force of 110 N, after accounting for forces of resistance.

(a) Find the acceleration of the airboat.

\[ F = ma \rightarrow a = \frac{F}{m} = \frac{770 N}{350 kg} = 2.20 m/s^2 \]

(b) Starting from rest, how long does it take the airboat to reach a speed of 12.0 m/s?

\[ v = v_o + at \]

\[ 12.0 m/s = 0 + (2.20 m/s^2)t \rightarrow t = 5.45 s \]

(c) After reaching this speed, the pilot turns off the engine and drifts to a stop over a distance of 50.0 m. Find the resistance force, assuming it’s constant.

\[ v^2 - v_o^2 = 2a\Delta x \]

\[ 0 - (12 m/s)^2 = 2a(50.0 m) \rightarrow a = -1.44 m/s^2 \]

\[ F_{\text{resistance}} = ma = (350 kg)(-1.44 m/s^2) = -504 N \]
**Example 3:** What happens when a person pulls upward on a box with a force of 100N? The box has a weight of \( mg = 98N \).

\[
\sum F_y = F_p - mg = 100N - 98N = 2.0N
\]

\[
a_y = \frac{\sum F_y}{m} = \frac{2.0N}{10.0kg} = 0.20m/s^2
\]

\[1kg = 9.80N\]

**Example 4:** Calculate the sum of the two forces exerted on the boat by workers A and B.

The components of \( \vec{F}_A \)

\[F_{AX} = F_A \cos 45.0^\circ = (40.0N)(0.707) = 28.3N\]

\[F_{AY} = F_A \sin 45.0^\circ = (40.0N)(0.707) = 28.3N\]

The components of \( \vec{F}_B \)

\[F_{BX} = +F_B \cos 37.0^\circ = +(30.0N)(0.799) = +24.0N\]

\[F_{BY} = -F_B \sin 37.0^\circ = -(30.0N)(0.602) = -18.1N\]

The components of the resultant force are

\[F_{RX} = F_{AX} + F_{BX} = 28.3N + 24.0N = 52.3N\]

\[F_{RY} = F_{AY} + F_{BY} = 28.3N - 18.1N = 10.2N\]

The magnitude of the resultant force:

\[F_R = \sqrt{F_{RX}^2 + F_{RY}^2} = \sqrt{(52.3N)^2 + (10.2N)^2} = 53.3N\]

The angle that the net force makes with the x axis:

\[\tan \theta = \frac{F_{RY}}{F_{RX}} = \frac{10.2N}{52.3N} = 0.195 \quad \tan^{-1}(0.195) = 11.0^\circ\]
Example 5: A 10.0-kg box is pulled at a 30° angle with a force of $F_p = 40.0 \text{N}$.

(a) Calculate the acceleration of the box:

$$F_{px} = (40.0 \text{N})(\cos 30.0°) = (40.0 \text{N})(0.866) = 34.6 \text{N}$$

$$F_{py} = (40.0 \text{N})(\sin 30.0°) = (40.0 \text{N})(0.500) = 20.0 \text{N}$$

$$F = ma \rightarrow a = \frac{F_{px}}{m} = \frac{(34.6 \text{N})}{(10.0 \text{kg})} = 3.46 \text{m/s}^2$$

(b) Calculate the magnitude of the upward force:

$$F_N - mg + F_{py} = ma_y$$

$$F_N - 98.0 \text{N} + 20 \text{N} = 0 \rightarrow F_N = 78.0 \text{N}$$

Newton’s Third Law of Motion

Any time a force is exerted on an object, that force is caused by another object. Newton’s third law:

Whenever one object exerts a force on a second object, the second exerts an equal force in the opposite direction on the first.

Rocket propulsion can also be explained using Newton’s third law: hot gases from combustion spew out of the tail of the rocket at high speeds. The reaction force is what propels the rocket. **Note that the rocket does not need anything to “push” against.**
Weight

The weight of an object on the Earth’s surface is the gravitational force exerted on it by the Earth.

Apparent weight:
Your perception of your weight is based on the contact forces between your body and your surroundings.

If your surroundings are accelerating, your apparent weight may be more or less than your actual weight.

Definition: Weight, \( W \)

\[ W = mg \]

SI unit: newton, N

Weight – the Force of Gravity; and the Normal Force

An object at rest must have no net force on it. If it is sitting on a table, the force of gravity is still there; what other force is there? The force exerted perpendicular to a surface is called the normal force. It is exactly as large as needed to balance the force from the object (if the required force gets too big, something breaks!)

Action-Reaction Pairs

N is the normal force, the force the table exerts on the TV.
N is always perpendicular to the surface

\( F_g \) is the force the Earth exerts on the object. \( F_g \) is always straight down regardless of the angle of the object.
Normal Forces

The normal force may be equal to, greater than, or less than the weight.

The normal force is always perpendicular to the surface.

Free Body Diagram

- Must identify all the forces acting on the object of interest
- Choose an appropriate coordinate system
- If the free body diagram is incorrect, the solution will likely be incorrect
- The force \( T \) is the tension acting on the box
  - The tension is the same at all points along the rope
- \( n \) and \( F_g \) are the forces exerted by the earth and the ground
- Only forces acting directly on the object are included in the free body diagram
  - Reaction forces act on other objects and so are not included
  - The reaction forces do not directly influence the object’s motion

Solving Newton’s Second Law Problems

- **Read** the problem at least once
- **Draw** a picture of the system
  - Identify the object of primary interest
  - Indicate forces with arrows
- **Label** each force
  - Use labels that bring to mind the physical quantity involved
• **Draw** a free body diagram
  – If additional objects are involved, draw separate free body diagrams for each object
  – Choose a convenient coordinate system for each object

• **Apply Newton’s Second Law**
  – The \( x \)- and \( y \)-components should be taken from the vector equation and written separately

• **Solve** for the unknown(s)

**Equilibrium**

• An object either at rest or moving with a constant velocity is said to be in *equilibrium*
• The net force acting on the object is zero (since the acceleration is zero)
• Easier to work with the equation in terms of its components:
  \[
  \sum F_x = 0 \text{ and } \sum F_y = 0
  \]
• This could be extended to three dimensions

**Example 6**: A traffic light weighing 100N hangs from a vertical cable tied to two other cables that are fastened to a support. The upper cables make angles of 37.0° and 53.0° with the horizontal. Find the tension in each of the three cables.

\( T_3 = F_x = 100N \)

To resolve all three tension forces into components develop the following table:

<table>
<thead>
<tr>
<th>Force</th>
<th>( x )-component</th>
<th>( y )-component</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 )</td>
<td>(-T_1 \cos 37.0^\circ)</td>
<td>( T_1 \sin 37.0^\circ)</td>
</tr>
<tr>
<td>( T_2 )</td>
<td>( T_2 \cos 53.0^\circ)</td>
<td>( T_2 \sin 53.0^\circ)</td>
</tr>
<tr>
<td>( T_3 )</td>
<td>0</td>
<td>(-100N)</td>
</tr>
</tbody>
</table>

Apply the conditions for equilibrium to the knot, using the components of the table:

\[
\sum F_x = -T_1 \cos 37.0^\circ + T_2 \cos 53.0^\circ = 0 \\
\sum F_y = T_1 \sin 37.0^\circ + T_2 \sin 53.0^\circ - 100N = 0
\]

There are two equations and two remaining unknowns. Solve equation 1 for

\[
T_2 = T_1 \left( \frac{\cos 37.0^\circ}{\cos 53.0^\circ} \right) = T_1 \left( \frac{0.799}{0.602} \right) = 1.33T_1
\]
Substitute the result for $T_2$ into equation 2:

$$T_1 \sin 37.0^\circ + (1.33T_1)(\sin 53.0^\circ) - 100N = 0$$

$$T_1 = 60.1N$$

$$T_2 = 1.33T_1 = 1.33(60.0N) = 79.9N$$

### Inclined Planes

- Choose the coordinate system with $x$ along the incline and $y$ perpendicular to the incline
- Replace the force of gravity with its components

#### Example 7: A sled is held at rest on a frictionless, snow-covered hill. If the sled weighs 77.0 N, find the force exerted by the rope on the sled and the magnitude of the force $n$ exerted by the hill on the sled.

Apply Newton’s 2\textsuperscript{nd} law to the sled, with $a = 0$:

Find the $x$-component, normal force = 0

$$\sum F_x = T + 0 + F_x = 0$$

$$\sum F_x = T + 0 - mg \sin \theta = T - (77.0N) \sin 30.0^\circ = 0$$

$$T = 38.5N$$

Find the $y$-component, there is a normal force

$$\sum F_y = 0 + n - mg \cos \theta = n - (77.0N)(\cos 30.0^\circ) = 0$$

$$n = 66.7N$$

### Multiple Objects – Example

- When you have more than one object, the problem-solving strategy is applied to each object
- Draw free body diagrams for each object
- Apply Newton’s Laws to each object
- Solve the equations
Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion
  - This is due to the interactions between the object and its environment
- This is resistance is called friction
- Friction is proportional to the normal force
- The force of static friction is generally greater than the force of kinetic friction
- The coefficient of friction (µ) depends on the surfaces in contact
- The direction of the frictional force is opposite the direction of motion
- The coefficients of friction are nearly independent of the area of contact

Static Friction, $f_s$

- Static friction acts to keep the object from moving
- If $F$ increases, so does $f_s$
- If $F$ decreases, so does $f_s$
- $f_s \leq \mu \ n$

Kinetic Friction, $f_k$

- The force of kinetic friction acts when the object is in motion
- $f_k = \mu \ n$
  - Variations of the coefficient with speed will be ignored

### Coefficients of Friction*

<table>
<thead>
<tr>
<th>Material</th>
<th>$\mu_s$</th>
<th>$\mu_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel on steel</td>
<td>0.74</td>
<td>0.57</td>
</tr>
<tr>
<td>Aluminum on steel</td>
<td>0.61</td>
<td>0.47</td>
</tr>
<tr>
<td>Copper on steel</td>
<td>0.53</td>
<td>0.36</td>
</tr>
<tr>
<td>Rubber on concrete</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Wood on wood</td>
<td>0.25–0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Glass on glass</td>
<td>0.94</td>
<td>0.4</td>
</tr>
<tr>
<td>Waxed wood on wet snow</td>
<td>0.14</td>
<td>0.1</td>
</tr>
<tr>
<td>Waxed wood on dry snow</td>
<td>—</td>
<td>0.04</td>
</tr>
<tr>
<td>Metal on metal (lubricated)</td>
<td>0.15</td>
<td>0.06</td>
</tr>
<tr>
<td>Ice on ice</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Teflon on Teflon</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Synovial joints in humans</td>
<td>0.01</td>
<td>0.003</td>
</tr>
</tbody>
</table>

*All values are approximate.
Block on a Ramp, Example

- Axes are rotated as usual on an incline
- The direction of impending motion would be down the plane
- Friction acts up the plane
  - Opposes the motion
- Apply Newton’s Laws and solve equations

**Example 8:** A block is launched up a frictionless incline in the diagram to the right with an initial velocity of 5.5 m/s. What is the maximum displacement, d, of the block up the incline?

\[
D = \frac{v_o^2}{2g \sin \theta} = \frac{(5.5 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)(\sin 40^\circ)} = 2.4 \text{ m}
\]

**Example 9:** The block shown on the right remains at rest. What is the friction force acting on the block?

\[
F = ma = (0.50 \text{ kg})(9.80 \text{ m/s}^2) = 4.9 \text{ N}
\]

\[
F_{fr} = 4.9 \text{ N} \sin 40^\circ = 3.1 \text{ N}
\]

**Example 10:** A hockey puck is struck by a hockey stick and given an initial speed of 20.0 m/s. The puck remains on the ice and slides 120 m, slowing down steadily until it comes to a rest. Determine the coefficient of kinetic friction between the puck and the ice.

\[
v^2 = v_o^2 + 2a\Delta x
\]

\[
a = \frac{0 - (20.0 \text{ m/s})^2}{2(120 \text{ m})} = -1.67 \text{ m/s}^2
\]

\[
\mu_k = \frac{a}{g} = \frac{1.67 \text{ m/s}^2}{9.80 \text{ m/s}^2} = 0.170
\]
Connected Objects

- Apply Newton’s Laws separately to each object
- The magnitude of the acceleration of both objects will be the same
- The tension is the same in each diagram
- Solve the simultaneous equations

Example 11: A block with a mass of 4.00 kg and a ball with a mass of 7.00 kg are connected by a light string that passes over a frictionless pulley. The friction between the block and the surface is \( \mu_k = 0.300 \).

(a) Find the acceleration of the two objects and the tension on the string.

Find the acceleration by finding the components of \( m_1 \).

\[
\sum F_x = T - f_k = m_1 a_1 \quad \sum F_y = n - m_1 g = 0
\]

The equation for the y-component gives \( n = m_1 g \).

Substitute this value for \( n \) and \( f_k = \mu_k n \) into the equation for the x-component.

\[
T - \mu_k m_1 g = m_1 a_1
\]

Apply Newton’s second law to the ball:

\[
\sum F_y = -m_2 g + T = m_2 a_2 = -m_2 a_1
\]

Subtract the second equation from the first, eliminating \( T \) and solve for \( a_1 \).

\[
m_2 g - \mu_k m_1 g = (m_1 + m_2) a_1 \quad a_1 = \frac{m_2 g - \mu_k m_1 g}{m_1 + m_2}
\]

\[
a_1 = \frac{(7.00 \text{ kg})(9.80 \text{ m/s}^2) - (0.300)(4.00 \text{ kg})(9.80 \text{ m/s}^2)}{(4.00 \text{ kg} + 7.00 \text{ kg})} = -5.17 \text{ m/s}^2
\]

Substitute the value for \( a_1 \) into the first equation to find \( T \).

\[
T - \mu_k m_1 g = m_1 a_1
\]

\[
T - (0.300)(4.00 \text{ kg})(9.80 \text{ m/s}^2) = (4.00 \text{ kg})(5.17 \text{ m/s}^2) \quad T = 32.45 \text{ N}
\]
Example 12: A flatbed truck slowly tilts its bed upward to dispose of a 95.0 kg crate. For small angles of tilt the crate does not move, but when the tilt angle exceeds 23.2°, the crate begins to slide.

What is the coefficient of static friction between the bed of the truck and the crate?

\[ W_x = mg \sin \theta \quad \quad W_y = -mg \cos \theta \]

\[ \Sigma F_y = N_y + f_{s,y} + W_y = N + 0 - mg \cos \theta = ma_y = 0 \]

\[ N = mg \cos \theta \]

\[ \Sigma F_x = N_x + f_{s,x} + W_x = ma_x = 0 \]

\[ = 0 - \mu_s N + mg \sin \theta \]

\[ = 0 - \mu_s mg \cos \theta + mg \sin \theta \]

\[ \mu_s mg \cos \theta = mg \sin \theta \]

\[ \mu_s = \frac{mg \sin \theta}{mg \cos \theta} = \tan \theta = \tan 23.2^\circ = 0.429 \]

Example 13: Atwood’s machine consists of two masses connected by a string that passes over a pulley. Find the acceleration of the masses for general \( m_1 \) and \( m_2 \), and evaluate for the specific case \( m_1 = 3.1 \text{kg}, m_2 = 4.4 \text{kg} \).

\[ \Sigma F_{1x} = T - m_1 g = m_1 a \]

\[ \Sigma F_{2x} = m_2 g - T = m_2 a \]

\[ T - m_1 g = m_1 a \]

\[ m_2 g - T = m_2 a \]

\[ \frac{m_2 g - m_1 g}{(m_2 - m_1) g} = \frac{m_1 a}{(m_1 + m_2) a} \]

\[ a = \frac{m_2 - m_1}{m_1 + m_2} g = \frac{4.4 \text{kg} - 3.1 \text{kg}}{3.1 \text{kg} - 4.4 \text{kg}} (9.81 \text{m/s}^2) = 1.7 \text{m/s}^2 \]
Example 14: Two blocks are connected by a string on a smooth inclined surface that makes an angle of 42° with the horizontal. The block on the incline has a mass of 6.7 kg. Find the mass of the hanging block that will cause the system to be in equilibrium.

\[ \sum F_x = T - Mg \sin \theta = 0 \]

\[ T = mg = Mg \sin \theta \]

\[ m = M \sin \theta = (6.7 \text{ kg}) \sin 42° = 4.5 \text{ kg} \]

Example 15: Two crates of masses 10.0 kg and 5.0 kg are connected by a light string that passes over a frictionless pulley. The 5.0 kg crate lies on a smooth incline of angle 40°. Find the acceleration of the 5.0 kg crate and the tension on the string.

Let \( m_1 = 10.0 \text{ kg} \), \( m_2 = 5.00 \text{ kg} \), and \( \theta = 40° \).

Applying the second law to each object gives

\[ m_1 a = m_1 g - T \quad (1) \]

and \[ m_2 a = T - m_2 g \sin \theta \quad (2) \]

Adding these equations yields

\[ a = \left( \frac{m_1 - m_2 \sin \theta}{m_1 + m_2} \right) g, \text{ or} \]

\[ a = \left( \frac{10.0 \text{ kg} - (5.00 \text{ kg}) \sin 40°}{15.0 \text{ kg}} \right) (9.80 \text{ m/s}^2) = 4.43 \text{ m/s}^2 \]

Then, Equation (1) yields

\[ T = m_1 (g - a) = (10.0 \text{ kg}) \left[ (9.80 - 4.43) \text{ m/s}^2 \right] = 53.7 \text{ N} \]
CHAPTER 4

LAWS OF MOTION

CONCEPTS

1. As the vector sum of all the forces acting on an object increases, the acceleration of the object increases.

2. Zero acceleration is an essential characteristic of an object in equilibrium.

3. An 800 N person is standing in an elevator. If the upward force of the elevator on the person is 600 N, the person is accelerating downward.

4. A baseball bat moving at high velocity strikes a feather. If air resistance is neglected compared to the force exerted by the bat on the feather, the force exerted by the feather on the bat will be the same.

5. A cart is uniformly accelerating from rest. The net force acting on the cart is constant.

6. In the diagram to the right, the numbers 1, 2, 3, and 4 represent possible directions in which a force could be applied to a cart. If the force applied in each direction has the same magnitude, the direction where the vertical component of the force will be the least is 4.

7. A lawnmower is pushed with a constant force $F$, as shown to the right. As the angle between the lawnmower handle and the horizontal increases the horizontal component of $F$ decreases.

8. In the diagram to the right, box M is on a frictionless table with forces $F_1$ and $F_2$ as shown. If the magnitude of $F_1$ is greater than the magnitude of $F_2$, then the box is accelerating in the direction of $F_1$.

9. The diagram to the right represents a car resting on a hill. The vector that best represents the weight of the car is B.
10. A cart rolls down an inclined plane with constant speed as shown to the right. The arrow D represents the direction of the frictional force.

11. As shown to the right, an inflated balloon released from rest moves horizontally with velocity v. The velocity of the balloon is most likely caused by action-reaction.

12. If you blow up a balloon, and then release it, the balloon will fly away. This is an illustration of Newton’s Third Law.

13. An object is acted upon by a constant unbalanced force. The graph C best represents the motion of the object.

14. The graph C best represents the motion of a moving object with no unbalanced force acting on it.

15. You are standing on a moving bus, facing forward, and you suddenly fall backwards. You can imply from this that the bus’s velocity has increased.

16. A packing crate slides down an inclined ramp at constant velocity. We can deduce that a frictional force is acting on it.

17. It is more difficult to start moving a heavy carton from rest than it is to keep pushing it with constant velocity because kinetic friction is less than static friction.
18. The number of forces acting on a car parked on a hill is three.

19. When you sit on a chair the resultant force on you is zero.

20. If two identical masses are attached by a massless cord passing over a massless, frictionless pulley of an Atwood’s machine, but at different heights, and then released, the masses will not move.

21. When the rocket engines on a starship are suddenly turned off, while traveling in empty space, the starship will move with constant speed.

22. In the absence of an external force, a moving object will move with constant speed.

23. If you exert a force F on an object, the force which the object exerts on you will be F in all cases.

24. An arrow is shot straight up. At the top of its path, the net force acting on it is equal to its weight.

25. Two identical masses are attached by a light string that passes over a small pulley, as shown. The table and the pulley are frictionless. The system is moving with acceleration less than g.

26. A box of mass M is resting on a flat board. One end of the board is lifted up until the box just starts to slide. The angle θ that the board makes with the horizontal, for this to occur depends on the coefficient of static friction.
27. A 20-kg fish is weighed with two spring scales, each of negligible weight, as shown to the right. The readings on each scale will read 20-kg.

28. A brick and a feather fall to the earth at their respective terminal velocities. The object that experiences the greater force of air friction is the brick.

29. A push or pull best expresses the meaning of the work “force”.

30. A rocket moves through empty space in a straight line with constant speed. It is far from the gravitational effect of a star or planet. Under these conditions, the force that must be applied to the rocket in order to sustain its motion is zero.

31. The force that keeps you from sliding on the sidewalk is static friction.

32. A mass rests on top of a frictionless inclined plane. The normal force acting on the mass decreases as the angle of elevation increases.

33. It is more difficult to start moving a heavy carton from rest than it is to keep pushing it with constant velocity, because \( \mu_k < \mu_s \).

34. If two identical masses are attached by a massless cord passing over a massless, frictionless pulley of an Atwood’s machine, but at different heights, and then released, the masses will not move.

35. A rope, tied between a motor and a crate, can pull the crate up a hill of ice (assume no friction) at constant velocity. The free-body diagram of the crate should contain 3 forces.

36. Two forces act on an object concurrently. The resultant will be the greatest when the angle between the forces is 0°.