Chapter 4 -- Changes in Motion

A *force* is something that can change the velocity of an object. (i.e. speed up, slow down, or change direction).

In other words, a force can cause an object to accelerate.
Changes in Motion

We often think of a force as a push or a pull.

We push a desk by exerting a force on it, and changing its velocity.
Changes in Motion

If we push an object we exert a force for a period of time. If we stop pushing, the object will eventually stop. That is because other forces continue to act on it, changing its velocity.

Like?.... FRICTION
Changes in Motion

Friction is only one example of a force. Forces can be divided into two major categories.

- **Contact forces** are forces that exist between two objects that are in contact with each other.

- **Field forces** are forces that exist between two objects that are separated by some distance.
Forces are measured in units called "Newtons" (N), where a net force of 1.0 N will cause a mass of 1.0 kg to accelerate at a rate of 1.0 m/s².

1 N = 1 kgm/s²

To convert a mass (in kg) to Newtons, you must multiply by acceleration due to gravity. To convert Newtons to mass (in kg), you must divide by acceleration due to gravity.
Changes in Motion

“Free-body diagrams” are used to focus on the forces acting on an object.
How would we draw a free-body diagram for the situation shown below?

- $F_w = \text{weight} = mg = \text{Newton}$
- $F_N = \text{force of table on book (this is called the Normal force)}$
Changes in Motion

How would we draw a free-body diagram for a 5N football being kicked by a 67 N force at an angle of 56 degrees above horizontal?
Changes in Motion

??

5 N

67 N

56°
Lesson 4-1 Changes in Motion

How would we draw a free-body diagram for the situation shown below?

\[ F = mg \]

Free-body diagram
Section Review pg. 128
Newton’s Laws

- **1st Law** - an object with no net force acting on it remains at rest or moves with a constant velocity in a straight line.
- When there are forces, up or right is positive, and down or left is negative.
- Inertia - the tendency of an object not to accelerate.
Acceleration is determined by Net External Force

- **External force** is a single force that acts on an object as a result of the interaction between the object and its environment.

- **Net external force** is the sum of all forces acting on an object (the resultant force).

  *Ex: Tug of War...*
Lesson 4-1 Changes in Motion

How would we draw a free-body diagram for the situation shown below?

\[ F_{N} \text{ is less than } mg \text{ because of the upward pull} \]
Lesson 4-1 Changes in Motion

How would we draw a free-body diagram for the situation shown below?
How would we draw a free-body diagram for the situation shown below?

$F_N$ is more than $mg$ because of the downward push.
A man is pulling a crate with a force of 89 N at an angle of 15 degrees above horizontal. What are the x and y components of this force?

\[
\begin{align*}
F_{Ax} &= F_A \cos 15 = \\
F_{Ay} &= F_A \sin 15 =
\end{align*}
\]
A dog is pulled to the left with a force of 56 N and to the right with a force of 176 N, upward with a force of 780 N and downward with a force of 350 N. What is the net external force?

\[ \sum F_x = 176 \text{N} - 56 \text{N} = 120 \text{N} \]

\[ \sum F_y = 780 \text{N} - 350 \text{N} = 430 \text{N} \]

\[ R^2 = 120^2 + 430^2 \]

\[ R = 446 \text{N} \]

\[ \tan^{-1}(430/120) = \theta \]
Problems 4A

- Problems on page 133
- Section Review page 135 (1, 2 and 3)
Newton’s Second Law

Newton’s Second Law states - “The acceleration of an object is directly proportional to the net external force acting on the object and inversely proportional to the object’s mass.”

\[ a = \frac{F_{\text{net}}}{m} \]
Newton’s Second Law

Newton’s Second Law is often written with the net force isolated, as shown below;

$$F_{\text{net}} = ma$$

Sometimes, the “net” is left out, because the “F” is understood to be the net force.

$$F = ma$$
Newton’s Second Law

Example 1... If the net external force on a desk with a mass of 35.0 kg is 45.0 N to the east, what acceleration (magnitude and direction) will the desk experience?

\[ F_{\text{net}} = ma \]

45.0 N = 35.0 kg \( (a) \)

\[ a = \frac{45.0 \text{N}}{35.0 \text{kg}} = 1.29 \text{ m/s}^2 \]

east
Example 2

- A dachshund starts from rest at the top of a water slide that is 450.0 cm long and slides down to the bottom in 0.700 seconds. If the net external force on the dachshund is 25.8 N then what is the mass of the dachshund?
A dachshund starts from rest at the top of a water slide that is 450.0 cm long and slides down to the bottom in 0.700 seconds. If the net external force on the dachshund is 25.8 N then what is the mass of the dachshund?

- **Given:** \( F_{\text{net}} = 25.8 \text{ N} \) \( \Delta x = 450.0 \text{ cm} = 4.5 \text{ m} \) \( \Delta t = 0.700 \text{ sec} \)
- **Formula:** \( F = ma \)
- **Need:** \( a = ? \) And \( m = ? \)
- **Old Formula:** \( \Delta x = \frac{1}{2}a \Delta t^2 \)
- \( a = \frac{\Delta x}{(1/2 \Delta t^2)} = \frac{4.5 \text{ m}}{(1/2 (0.700)^2)} \)
- \( a = 18.4 \text{ m/s}^2 \)
- **\( F = ma, \) m=F/a = 25.8N/18.4\text{m/s}^2 = 1.4 \text{ kg}**
Questions to Consider

When a car hits a deer, why does the car take so much damage?

If you punch someone in the face, why does it hurt your hand?

When someone fires a gun, why do they feel a recoil?

When you blow up a balloon and release it, why does it fly around the room?
Answer \(\rightarrow\) Newton’s Third Law!
Newton’s Third Law

If two objects interact, the magnitude of the force exerted on object 1 by object 2 is equal to the magnitude of the force simultaneously exerted on object 2 by object 1, and these forces are opposite in direction.
Newton’s Third Law

What we call the “normal force” is a reaction force.
Newton’s Third Law can also be used to explain propulsion.
Newton’s Third Law can also be used to explain why your weight appears to change in an elevator.
Newton’s Third Law

If every object that you pull pulls back with an equal and opposite force, how can you ever move anything?
Newton’s Third Law

Remember, when considering whether or not something will move, we want to find the net force acting on the individual object...the reaction force is on your hand!!!
Football and Newton’s Laws of Motion
Problems 4B Due Thursday

- Problems on page 138 (all)
- Section Review pg. 140 (2, 3, 5)
Newton’s Laws Lab
Equilibrium

- Objects at rest or moving with a constant velocity are said to be in equilibrium.
  - Therefore the net external force acting on a body in equilibrium must be zero.
  - The vector sum of all the forces acting on it is zero.
    - $\Sigma F_x = 0$ and $\Sigma F_y = 0$
Using Newton’s Laws

- Friction - force that opposes the motion between two surfaces.
  - The direction of the force of friction is parallel to the SURFACE and in a direction that opposes the slipping of the two surfaces.
Static friction\((F_S)\) - force that opposes the start of motion.

If the magnitude of the force applied is greater than the magnitude of static friction, movement occurs.

- **As long as the object does not move, the force of static friction** \((F_S)\) **is always equal to and opposite in direction to the component of the applied force** \((F_A)\) **that is parallel to the surface**

\[ F_S = -F_A \quad \text{WHEN IT DOES NOT MOVE} \]

- Also, \(F_A\) is "just a hair" more than \(F_S\) at the start of motion (We'll assume \(=\) for the most part.)
- Kinetic friction $F_k$ - force between surfaces in relative motion
  - Always LESS than static friction
  - If moving at a **constant velocity**, $F_k = -F_A$

- **Variables Defined**
  - $F_A = $ Applied Force
  - $F_f = $ Force of friction
  - $F_N = $ Normal force
  - $F_W = F_g = $ Weight of the object
  - $F_s = $ Force of static friction
  - $F_k = $ Force of kinetic friction
Equations

\[ F_k = \mu_k F_n \]
\[ F_{s,\text{max}} = \mu_s F_n \]
\[ F_f = \mu F_n \]

\( \mu_s \) = coefficient of static friction
\( \mu_k \) = coefficient of kinetic friction

\( \mu \) is a constant that depends on the two surfaces in contact.

(See page 144)
Example

- A 24 kg crate initially at rest on a horizontal floor requires a 75 Newton horizontal force to *set it in motion* to the left (this is $F_A$ and $F_{s,\text{max}}$). Find the coefficient of static friction ($\mu_s$) between the crate and the floor.

- If it only requires 34 N to keep the crate moving at a *constant velocity* (this is $F_k$), what is the coefficient of kinetic friction ($\mu_k$)?
\[ F_s = 75 \text{N} = \mu_s F_N = \mu_s 235 \text{N} \quad \mu_s = \frac{75 \text{N}}{235 \text{N}} = 0.32 \]

\[ F_k = \mu_k F_N = \mu_k 235 \text{N} \quad \mu_k = \frac{34 \text{N}}{235 \text{N}} = 0.14 \]

\[ F_g = 24 \text{kg} \times 9.81 \text{m/s}^2 = 235 \text{N} \]
Motion on a Horizontal

A desk with a mass of 75.0 kg sits on a floor, where the coefficient of static friction in between the two surfaces is 0.40. How much force must someone apply in a direction parallel to the surface of the floor to get the desk moving?
Motion on a Horizontal

Sketch the diagram:

The net force in the y-dimension is zero.

The box will move when the applied force ($F_a$) just overcomes the maximum force of static friction.
Motion on a Horizontal

**Given:** \( \mu_s = 0.40 \)

\( m = 75.0 \text{ kg} \quad g = 9.81 \text{ m/s}^2 \)

**Find:** \( F_N \) and then, \( F_s \)

**Solution:**

\[
F_N = -F_w = mg = -(75.0 \text{ kg})(-9.81 \text{ m/s}^2) = 736 \text{ N}
\]

\[
F_s = \mu_s F_N = (0.40)(736 \text{ N}) = 290 \text{ N}
\]

so our applied force must be just greater than 290 N
Problems 4C, page 145
Motion on a Horizontal

A boy exerts a horizontal force of 12.0 N on a 20.0 N box to slide it across a table where the coefficient of kinetic friction between the surfaces is 0.34. Sketch the free-body diagram and find the acceleration on the box.
Motion on a Horizontal

Sketch the diagram.

Use $F_{\text{net}} = ma$. We will need to find the net force on the box and then divide it by the mass, in order to find the acceleration.
Motion on a Horizontal

Sketch the diagram.

The net force in the y-dimension will be zero.

We will need to calculate the force of friction ($F_k$), and subtract it from the applied force ($F_a$) to get the net force ($F_{Net}$).
Motion on a Horizontal

Given:
\[ F_w = 20.0 \text{ N} \quad g = 9.81 \text{ m/s}^2 \quad F_a = 12.0 \text{ N} \]
\[ \mu_k = 0.34 \]

Find: \( F_k \), \( F_{\text{net}} \), \( m \) and then \( a \)

Solution:
\[ F_k = \mu_k F_N = \mu_k F_w = (0.34)(20.0 \text{ N}) = 6.8 \text{ N} \]
\[ F_{\text{net}} = F_a - F_k = 12.0 \text{ N} - 6.8 \text{ N} = 5.2 \text{ N} \]
\[ m = \frac{F_w}{g} = \frac{20.0 \text{ N}}{9.81 \text{ m/s}^2} = 2.04 \text{ kg} \]
\[ a = \frac{F_{\text{net}}}{m} = \frac{5.2 \text{ N}}{2.04 \text{ kg}} = 2.5 \text{ m/s}^2 \]
Everyday Forces
Motion on a Horizontal

When the applied force \( (F_A) \) is exerted at an angle above the horizontal, it is necessary to resolve the applied force into \( x \) \( (F_{Ax}) \) and \( y \) \( (F_{Ay}) \) components and subtract \( F_{Ay} \) from the Weight.
Everyday Forces
Motion on a Horizontal

A girl is pulling a sled with a mass of 16.0 kg across a level patch of grass by exerting a force of 42.0 N along a rope that forms an angle of 33.0° above the ground. The coefficient of kinetic friction between the sled and the grass is 0.25. Sketch the free-body diagram and find the acceleration of the sled.
Everyday Forces
Motion on a Horizontal

Sketch the diagram.

Because a component of the applied force is in the y-dimension, the normal force is going to be less than the weight of the sled. The net force in the y-dimension is still zero, and $F_N = (F_w - F_{ay})$. 

$F_{n} = (mg - F_{ay})$
Everyday Forces
Motion on a Horizontal

Sketch the diagram.

\[ F_n = (mg - F_{ay}) \]

The key to this problem is to decrease the normal force \((F_N)\) by the force applied in the \(y\) \((F_{ay})\), before you calculate the force of friction \((F_k)\).
Everyday Forces
Motion on a Horizontal

Given: \( m = 16.0 \text{ kg} \quad F_a = 42.0 \text{ N} \)
\( \theta = 33.0^\circ \quad \mu_k = 0.25 \)

Find: \( F_{ax}, F_{ay}, F_N, F_k, F_{net}, a \)

Solution:

\[ F_{ax} = F_a \cos \theta = (42.0 \text{ N})(\cos 33.0^\circ) = 35.2 \text{ N} \]

\[ F_{ay} = F_a \sin \theta = (42.0 \text{ N})(\sin 33.0^\circ) = 22.9 \text{ N} \]

\[ F_N = (F_w - F_{ay}) = (mg - F_{ay}) \]
\[ = (16.0 \text{ kg})(9.81 \text{ m/s}^2) - (22.9 \text{ N}) = 134 \text{ N} \]
Everyday Forces
Motion on a Horizontal

Given: \( m = 16.0 \text{ kg} \quad F_a = 42.0 \text{ N} \)
\( \theta = 33.0^\circ \quad \mu k = 0.25 \)

Find: \( F_{ax}, F_{ay}, F_N, F_f, F_{net}, a \)

Solution:

\[
F_k = \mu_k F_N = (0.25)(134 \text{ N}) = 33.5 \text{ N}
\]

\[
F_{net} = F_{ax} - F_k = 35.2 \text{ N} - 33.5 \text{ N} = 1.7 \text{ N}
\]

\[
a = \frac{F_{net}}{m} = \frac{1.7 \text{ N}}{16.0 \text{ kg}} = 0.106 \text{ m/s}^2
\]
Everyday Forces
Motion on a Horizontal

When the applied force \((F_a)\) is exerted below the horizontal, the \(y\) component of the applied force \((F_{ay})\) will \textit{increase the normal force} \((F_N)\).
Example. A woman applies a force of 125.0 N on the handle of a 180 N lawnmower, at an angle of 35.0° below the horizontal. The coefficient of kinetic friction between the grass and lawnmower is 0.35. Draw a free-body diagram, and find the force of kinetic friction.
Draw the free-body diagram and find the force of friction.

\[ F_N = (F_w + F_{ay}) = (180 \text{ N} + 71.7 \text{ N}) = 251.7 \text{ N} \]

\[ F_{ax} = F_a \cos \theta = (125.0 \text{ N})(\cos 35.0^\circ) = 102.4 \text{ N} \]

\[ F_{ay} = F_a \sin \theta = (125.0 \text{ N})(\sin 35.0^\circ) = 71.7 \text{ N} \]

\[ F_k = \mu_k F_N = (0.35)(251.7 \text{ N}) = 88 \text{ N} \]

You can find a the same way as the previous problem.
Practice 4D, 1 and 4 on page 147
The weight ($F_w$) is directed straight down. It ignores the incline.
Everyday Forces
Motion on an Inclined Plane

The y component of the weight is \( F_{wy} \) is perpendicular to the surface of the ramp.

\[ F_{wy} = mg \cos \theta \]

\[ F_w = F_g = mg \]
The x component of the weight is ($F_{wx}$) is parallel to the surface of the ramp.

- $F_w = mg$
- $F_{wy} = mg\cos\theta$
- $F_{wx} = mg\sin\theta$
Everyday Forces
Motion on an Inclined Plane

We can redraw the x component of the weight ($F_{wx}$), to make it clear that it helps to move the object down the ramp. We might also rename it $F_a$ if it is the only applied force working.

$$F_{wx} = mg \sin \theta$$

$$F_{wy} = mg \cos \theta$$

$$F_w = mg$$
If there is friction between the ramp and the object, it will oppose the motion of the object down the ramp.
Everyday Forces
Motion on an Inclined Plane

If the object is in motion, the force of friction ($F_f$) can be calculated with $F_k = \mu_k F_N$. IF the object is being pulled up the ramp, then the force of friction will be the other direction and $F_g$ will also work against you.
Everyday Forces
Motion on an Inclined Plane

The normal force ($F_N$) will be equal and opposite to the y component of the weight (unless you are pulling up or pushing down at an angle).
The two triangles in the picture are similar, so they share like angles.
A crate with a mass of 35.0 kg is sliding down an inclined plane with an angle of 43.0° above the horizontal. If the crate is accelerating at a rate of 3.45 m/s², find the coefficient of kinetic friction between the ramp and crate. Start with a diagram.
Everyday Forces
Motion on an Inclined Plane

\[ F_w = 35.0 \text{kg} \times 9.81 \text{m/s}^2 = 343 \text{N} \]
Everyday Forces
Motion on an Inclined Plane

Given: \( \theta = 43.0^\circ \)
m = 35.0 kg \( g = 9.81 \text{ m/s}^2 \) \( a = 3.45 \text{ m/s}^2 \)

Find: \( F_N, F_{wx}, F_{net}, F_k, \mu_k \)

Solution:

\[
F_N = F_{wy} = F_w \cos \theta = mg \cos \theta = (35.0 \text{ kg})(9.81 \text{ m/s}^2)(\cos 43.0^\circ) = 251 \text{ N}
\]

\[
F_{wx} = mgsin\theta = (35.0 \text{ kg})(9.81 \text{ m/s}^2)(\sin 43.0^\circ) = 234 \text{ N}
\]

\[
F_{net} = ma = (35.0 \text{ kg})(3.45 \text{ m/s}^2) = 121 \text{ N}
\]

\[
F_k = F_{wx} - F_{net} = 234 \text{ N} - 121 \text{ N} = 113 \text{ N}
\]

\[
\mu_k = \frac{F_k}{F_N} = \frac{113 \text{ N}}{251 \text{ N}} = 0.450
\]
A 34.8kg BOX is moved up a ramp inclined at 26 degrees above horizontal. If the box starts from rest at the bottom of the ramp and is pulled at an angle of 35 degrees with respect to the incline and with a force of 372 N, what is the acceleration up the ramp? Assume that $\mu_K$ is 0.25.

\[ F_{A} = 372 \text{ N} \]

\[ F_{w_x} = mgsin\theta \]

\[ F_{w_y} = mgcos\theta \]

\[ F_{N} \]

\[ F_{A} = 372 \text{ N} \]

\[ 34.8\text{kg} \times 9.81 = 341 \text{ N} \]
Find \( F_N \), \( F_N = (F_{w,y} - F_{a,y}) = (341 \text{N}) \cos 26^\circ - 372 \text{N}(\sin 35^\circ) = 93 \text{ N} \)

Find \( F_K \), \( F_K = \mu_K F_N = (0.25)(93 \text{N}) = 23 \text{N} \)

Find \( a_x \), \( a_x = \frac{F_{\text{net},x}}{m} = \frac{(F_{A,x} - F_k - F_w \sin 26^\circ)}{m} \)

\[ = \frac{(372 \cos 35^\circ - 23 \text{N} - 341 \sin 26^\circ)}{34.8 \text{kg}} = 3.8 \text{ m/s}^2 \]
4D 2 and 3 on page 147
A 25kg crate is moved up a ramp inclined at 23 degrees above horizontal. If the box starts from rest at the bottom of the ramp and is pulled at an angle of 32 degrees with respect to the incline and with a force of 234 N, what is the acceleration up the ramp? Assume that $\mu_K$ is 0.19.
Find \( F_N \),

\[
F_N = (F_w - F_a) = (25\text{kg})(9.81\text{m/s}^2)\cos23^\circ - 234\text{N} \cdot \sin23^\circ = 102\text{N}
\]

\[ F_N = 245\text{N} \]

\[ 23^\circ \]

\[ 245\text{N} \quad \]

\[ F_{wx} = mg\sin\theta \]

\[ F_{wy} = mg\cos\theta \]

\[ F_A = 234\text{ N} \]

\[ 32^\circ \]

\[ F_{ax} \]

\[ F_{ay} \]
Find $F_K$, $F_K = \mu N = (0.19)(102\,\text{N}) = 19.38\,\text{N}$
Find $a_x$, \[ a_x = \frac{F_{\text{net},x}}{m} = \frac{(F_A,x - F_k - F_w \sin 23^\circ)}{m} = \frac{(234 \cos 32^\circ - 19.38 \text{N} - 245 \sin 23^\circ)}{m} = 83 \text{ kgm/s}^2 \]

\[ \frac{23^\circ}{25 \text{ kg}} = 3.3 \text{ m/s} \]

WEIGHT and $F_k$ are subtracted because they are working against the box going up the ramp.

$F_{\text{wy}} = mg\cos \theta$

$F_{\text{wx}} = mg\sin \theta$
Using Newton’s Laws

- **When an object is resting with no additional external forces on a horizontal surface, then** \( F_W = F_n \)
- **When pushing down at an angle, force is added to** \( F_N \) (\( F_{ay} + \text{Weight} \)), so \( F_N \) **increases to** \( \text{Weight} + F_{Ay} \).
- **When pulling up at an angle, force is subtracted from the** \( F_N \) (\( \text{weight} - F_{Ay} \)), so \( F_N \) **decreases to** \( \text{Weight} - F_{Ay} \).
- **When moving at constant velocity** \( F_k = F_{Ax} \), so \( F_k = \mu F_n \) or \( F_{Ax} = \mu F_n \). This is also true of static friction until the maximum is reached.
- \( F_{Ax} \) **means parallel to the surface**
- **When on an incline,** \( F_{gx} \) **makes the object go down and** \( F_{gy} \) **equals the normal force (unless pulled up at an angle, then** \( F_{gy} \) **is subtracted from the normal force.)** \( F_f \) **always opposes the motion.**
Everyday Forces
Motion on an Inclined Plane

A block with a mass of 5.00 kg is placed on a frictionless inclined plane at an angle of 48.0° above the horizontal. Draw a diagram for the problem and find the acceleration of the block.
Everyday Forces  
Motion on an Inclined Plane

**Given:**

\[ m = 5.00 \text{ kg} \quad \theta = 48.0^\circ \quad g = 9.81 \text{ m/s}^2 \]

**Find:** \( F_w, F_{wx}, m \) and \( a \)

**Solution:**

Weight = \( F_w = mg = (5.00 \text{ kg})(9.81 \text{ m/s}^2) = 49.1 \text{ N} \)

Parallel Force = \( F_{wx} = F_w \sin \theta = (49.1 \text{ N})(\sin 48.0^\circ) = 36.5 \text{ N} \)

acceleration (a) = \[ \frac{F_{\text{net}}}{m} = \frac{F_p}{m} = \frac{36.5 \text{ N}}{5.00 \text{ kg}} = 7.30 \text{ m/s}^2 \]

*Remember...there is no friction in this example.*
Lesson 4-1 Changes in Motion

How would we draw a free-body diagram for the situation shown below?

$mgsin\theta$ is the applied force!

$F_w = mg$
Lesson 4-1 Changes in Motion

How would we draw a free-body diagram for the situation shown below?

How would we draw a free-body diagram for the situation shown below?

(a)

(b)

Free-body diagram
Example 2
What forces are at work on a 22N physics book on a 15 degree incline where the force of friction is 3N? What is the net external force?
Now...can we figure out whether it will move? What else do we need?
Now...sum all the x and y components!!!!!!!!!!!!!!!!!!
Assume x is in the direction of the inclined plane...

- X components
  - \((F_w \sin 15 - F_{friction})\)
  - \(22\sin 15 - 3N = 5.7N - 3N = +2.7N\)

- Y components cancel
  - \(F_w \cos 15 - \text{Normal Force} (= F_w \cos 15) = 0\)

- So....the book does move!
  - *Newton’s Second Law can tell us how fast, but we’ll get to that later.*
Newton’s Third Law tells us that forces always come in pairs.
Newton’s Third Law

Newton’s Third Law tells us that forces always come in pairs.
Newton’s Third Law

These force pairs are called “action-reaction forces”, or “action-reaction pairs”.

\[
\begin{align*}
\text{(a)} & \quad P = 0 \\
\text{(b)} & \quad F_b = -F_r \\
\text{(c)} & \quad P = p_b + p_r = m_b v_b - m_r v_r = 0
\end{align*}
\]