This lecture will help you understand:

• Newton’s First Law of Motion
• Newton’s Second Law of Motion
• Forces and Interactions
• Newton’s Third Law of Motion
• Summary of Newton’s Three Laws
Newton’s First Law of Motion

The law of inertia: (originating with Galileo)

Every object continues in a state of rest or of uniform speed in a straight line unless acted on by a nonzero force.
A sheet of paper can be quickly withdrawn from under a soft-drink can without the can toppling, because

A. gravity pulls harder on the can than on the paper.
B. the can has weight.
C. the can has inertia.
D. None of the above.
A sheet of paper can be quickly withdrawn from under a soft-drink can without the can toppling, because

A. gravity pulls harder on the can than on the paper.
B. the can has weight.
C. **the can has inertia.**
D. None of the above.
If you swing a stone overhead in a horizontal circle and the string breaks, the tendency of the stone is to follow a

A. curved path.
B. straight-line path.
C. spiral path.
D. vertical path.
If you swing a stone overhead in a horizontal circle and the string breaks, the tendency of the stone is to follow a

A. curved path.
B. straight-line path.
C. spiral path.
D. vertical path.
Examples of Inertia

Why will the coin drop into the glass when a force accelerates the card?

Why is it that a slow continuous increase in the downward force breaks the string above the massive ball, but a sudden increase breaks the lower string?

Why does the downward motion and sudden stop of the hammer tighten the hammerhead?
Inertia in Action

- Rapid deceleration is sensed by the driver who lurches forward.

- It is also an example of Newton’s Second Law because no force stops the driver while the brakes stop the vehicle.
Inertia in Action

• When you flip a coin in a high-speed airplane, it behaves as if the airplane were at rest.
• The coin keeps up with you.
Inertia in Action

• Can the bird drop down and catch the worm if the Earth moves at 30 km/s?
Newton’s Second Law of Motion

The law of acceleration:

The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.
Newton’s Second Law of Motion

Newton’s second law in equation form:

\[ \text{Acceleration} = \frac{\text{net force}}{\text{mass}} \]

\[ a = \frac{F}{m} \]

small net force, large mass \(\Rightarrow\) small acceleration

large net force, small mass \(\Rightarrow\) large acceleration
Consider a cart pushed along a track with a certain force. If the force remains the same while the mass of the cart decreases to half, the acceleration of the cart

A. remains the same.
B. halves.
C. doubles.
D. changes unpredictably.
Consider a cart pushed along a track with a certain force. If the force remains the same while the mass of the cart decreases to half, the acceleration of the cart

A. remains the same.
B. halves.
C. doubles.
D. changes unpredictably.
Push a cart along a track so twice as much net force acts upon it. If the acceleration remains the same, what is a reasonable explanation?

A. The mass of the cart doubled when the force doubled.
B. The cart experiences a force that it didn’t before.
C. The track is not level.
D. Friction reversed direction.
Push a cart along a track so twice as much net force acts upon it. If the acceleration remains the same, what is a reasonable explanation?

A. The mass of the cart doubled when the force doubled.
B. The cart experiences a force that it didn’t before.
C. The track is not level.
D. Friction reversed direction.
Newton’s Second Law of Motion

When acceleration is $g$—free fall.

When the only force acting on a falling object is gravity, with negligible air resistance, the object is in free fall.

An object in free fall accelerates toward Earth at 10 m/s per second.
At one instant an object in free fall has a speed of 40 m/s. Its speed one second later is

A. also 40 m/s.
B. 45 m/s.
C. 50 m/s.
D. none of the above.
At one instant an object in free fall has a speed of 40 m/s. Its speed one second later is

A. also 40 m/s.
B. 45 m/s.
C. **50 m/s.**
D. none of the above.

*Comment:*
We assume the object is falling downward.
Newton’s Second Law of Motion

When acceleration is $g$—free fall.

Twice the force on twice the mass ⇒ same acceleration as half the force on half the mass.

$$\frac{F}{m} = g$$  $$\frac{2F}{2m} = g$$
A 5-kg iron ball and a 10-kg iron ball are dropped from rest. For negligible air resistance, the acceleration of the heavier ball will be

A. less.
B. the same.
C. more.
D. undetermined.
A 5-kg iron ball and a 10-kg iron ball are dropped from rest. For negligible air resistance, the acceleration of the heavier ball will be

A. less.
B. the same.
C. more.
D. undetermined.
A 5-kg iron ball and a 10-kg iron ball are dropped from rest. When the free-falling 5-kg iron ball reaches a speed of 10 m/s, the speed of the free-falling 10-kg iron ball is

A. less than 10 m/s.
B. 10 m/s.
C. more than 10 m/s.
D. undetermined.
A 5-kg iron ball and a 10-kg iron ball are dropped from rest. When the free-falling 5-kg iron ball reaches a speed of 10 m/s, the speed of the free-falling 10-kg iron ball is

A. less than 10 m/s.
B. 10 m/s.
C. more than 10 m/s.
D. undetermined.
Newton’s Second Law of Motion

When acceleration is $g$—free fall.

The ratio of weight to mass is the same for all falling objects in the same locality; hence, their accelerations are the same in the absence of air resistance.
Newton’s Second Law of Motion

When acceleration is \( g \) — free fall.

Demonstration of a feather and a coin in a vacuum.

In a vacuum, a feather and a coin fall together at \( g \)—the acceleration due to gravity.
Newton’s Second Law of Motion
A situation to ponder…

When an air-filled glass tube containing a coin and a feather is inverted, the coin falls quickly to the bottom of the tube while the feather flutters to the bottom.
When the air is removed by a vacuum pump and the activity is repeated,

A. the feather hits the bottom first, before the coin hits.
B. the coin hits the bottom first, before the feather hits.
C. both the coin and feather drop together side by side.
D. Not enough information.
When the air is removed by a vacuum pump and the activity is repeated,

A. the feather hits the bottom first, before the coin hits.
B. the coin hits the bottom first, before the feather hits.
C. both the coin and feather drop together side by side.
D. Not enough information.
Newton’s Second Law of Motion

When acceleration is less than $g$ — non-free fall.

Non-free fall occurs when two forces act on a falling object

- a force due to gravity acting downward
- air resistance acting upward
When a 20-N falling object encounters 5 N of air resistance, its acceleration of fall is

A. less than $g$.
B. more than $g$.
C. $g$.
D. terminated.
When a 20-N falling object encounters 5 N of air resistance, its acceleration of fall is

A. less than \( g \).
B. more than \( g \).
C. \( g \).
D. terminated.

Explanation:
Acceleration of non-free fall is always less than \( g \). Acceleration will actually be \( (20 \text{ N} - 5 \text{ N})/2 \text{ kg} = 7.5 \text{ N/kg} = 7.5 \text{ m/s}^2 \).
Newton’s Second Law of Motion

When acceleration is less than $g$—non-free fall

• as falling object gains speed, force exerted by surrounding air increases

• force of air resistance may continue to increase until it equals the weight

• at this point, net force is zero and no further acceleration

• object has reached terminal velocity—continues falling at constant velocity with no acceleration
If a 50-N person is to fall at terminal speed, the air resistance needed is

A. less than 50 N.
B. 50 N.
C. more than 50 N.
D. None of the above.
If a 50-N person is to fall at terminal speed, the air resistance needed is

A. less than 50 N.
B. 50 N.
C. more than 50 N.
D. None of the above.

*Explanation:*
Then \( \Sigma F = 0 \) and acceleration = 0.
As a skydiver falls faster and faster through the air, air resistance

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
As a skydiver falls faster and faster through the air, air resistance

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
As a skydiver continues to fall faster and faster through the air, net force

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
As a skydiver continues to fall faster and faster through the air, net force

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
As a skydiver continues to fall faster and faster through the air, her acceleration

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
As a skydiver continues to fall faster and faster through the air, her acceleration

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.
Consider a heavy and light person with same-size parachutes jumping together from the same altitude.
Who will reach the ground first?

A. The light person.
B. The heavy person.
C. Both at the same time.
D. Not enough information.

A situation to ponder…
CHECK YOUR NEIGHBOR
Who will reach the ground first?

A. The light person.
B. **The heavy person.**
C. Both at the same time.
D. Not enough information.

*Explanation:*
The heavier person has a greater terminal velocity.
Do you know why?
Forces and Interactions

**Force** is simply a push or a pull.

**Interaction** occurs between one thing and another.

*Example:*

When you push against a wall, you’re interacting with the wall.
Newton’s Third Law of Motion

Law of action and reaction:
Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

Example:
When your hand presses on the wall, the wall simultaneously presses on your hand. Hand and wall press on each other with equal and opposite forces.
Newton’s Third Law of Motion

Action and reaction forces

- one force is called the action force; the other force is called the reaction force
- are copairs of a single interaction
- neither force exists without the other
- are equal in strength and opposite in direction
- always act on different objects
A soccer player kicks a ball with 1500 N of force. The ball exerts a reaction force against the player’s foot of

A. somewhat less than 1500 N.
B. 1500 N.
C. somewhat more than 1500 N.
D. None of the above.
A soccer player kicks a ball with 1500 N of force. The ball exerts a reaction force against the player’s foot of

A. somewhat less than 1500 N.
B. 1500 N.
C. somewhat more than 1500 N.
D. None of the above.
Newton’s Third Law of Motion

Simple Rule to Identify Action and Reaction:

Action—
object A exerts a force on object B.

Reaction—
object B exerts a force on object A.
When you step off a curb, Earth pulls you downward. The reaction to this force is

A. a slight air resistance.
B. nonexistent in this case.
C. you pull Earth upward.
D. None of the above.
When you step off a curb, Earth pulls you downward. The reaction to this force is

A. a slight air resistance.
B. nonexistent in this case.
C. you pull Earth upward.
D. None of the above.
Newton’s Third Law of Motion

Action and Reaction on Different Masses:
If the same force is applied to two objects of different masses,

greater mass object ⇒ small acceleration
smaller mass object ⇒ large acceleration
When a cannon is fired, the accelerations of the cannon and cannonball are different, because the

A. forces don’t occur at the same time.
B. forces, although theoretically are the same, in practice aren’t the same.
C. masses are different.
D. ratios of force to mass are the same.
When a cannon is fired, the accelerations of the cannon and cannonball are different, because the

A. forces don’t occur at the same time.
B. forces, although theoretically are the same, in practice aren’t the same.
C. masses are different.
D. ratios of force to mass are the same.
Consider a high-speed bus colliding head-on with an innocent bug. The force of impact splatters the unfortunate bug over the windshield.
Which is greater, the force on the bug or the force on the bus?

A. Bug.
B. Bus.
C. Both are the same.
D. Cannot say.
Which is greater, the force on the bug or the force on the bus?

A. Bug.
B. Bus.
C. Both are the same.
D. Cannot say.

Comment:
Although the forces are equal in magnitude, the effects are very different. Do you know why?
Two people of equal mass on slippery ice push off from each other. Will both move at the same speed in opposite directions?

A. Yes.
B. Yes, but only if both push equally.
C. No.
D. No, unless acceleration occurs.
Two people of equal mass on slippery ice push off from each other. Will both move at the same speed in opposite directions?

A. Yes.
B. Yes, but only if both push equally.
C. No.
D. No, unless acceleration occurs.

Explanation:
However they push, the result is equal-magnitude forces on equal masses, which produce equal accelerations and, therefore, equal changes in speed.
Newton’s Third Law of Motion

Defining Your System

• consider a single enclosed orange
  – applied external force causes the orange to accelerate in accord with Newton’s second law
  – action and reaction pair of forces is not shown
Newton’s Third Law of Motion

• consider the orange and the apple pulling on it
  – action and reaction do not cancel (because they act on different things)
  – external force by apple accelerates the orange
Newton’s Third Law of Motion

- consider a system comprised of both the orange and the apple
  - the apple is no longer external to the system
  - force pair is internal to system, which doesn’t cause acceleration
  - action and reaction within the system cancel
  - with no external forces, there is no acceleration of system
Newton’s Third Law of Motion

• consider the same system, but with external force of friction on it
  – same internal action and reaction forces (between the orange and apple) cancel
  – a second pair of action-reaction forces (between the apple’s feet and the floor) exists
Newton’s Third Law of Motion

– one of these acts by the system (apple on the floor) and the other acts on the system (floor on the apple)

– external frictional force of floor pushes on the system, which accelerates

– second pair of action and reaction forces do not cancel
When lift equals the weight of a helicopter, the helicopter

A. climbs down.
B. climbs up.
C. hovers in midair.
D. None of the above.
When lift equals the weight of a helicopter, the helicopter

A. climbs down.
B. climbs up.
C. hovers in midair.
D. None of the above.
When lift is greater, the helicopter

A. climbs down.
B. climbs up.
C. hovers in midair.
D. None of the above
When lift is greater, the helicopter

A. climbs down.
B. **climbs up.**
C. hovers in midair.
D. None of the above
A bird flies by

A. flapping its wings.
B. pushing air down so that the air pushes it upward.
C. hovering in midair.
D. inhaling and exhaling air.
A birds flies by

A. flapping its wings.
B. **pushing air down so that the air pushes it upward.**
C. hovering in midair.
D. inhaling and exhaling air.
Slightly tilted wings of airplanes deflect

A. oncoming air downward to produce lift.
B. oncoming air upward to produce lift.
C. Both of these.
D. Neither of these.
Slightly tilted wings of airplanes deflect

A. oncoming air downward to produce lift.
B. oncoming air upward to produce lift.
C. Both of these.
D. Neither of these.

Explanation:
When a wing diverts air downward, it exerts a downward force on the air. The air simultaneously exerts an upward force on the wing. The vertical component of this upward force is lift. (The horizontal component is drag.)
Compared with a light-weight glider, a heavier glider would have to push air

A. downward with greater force.
B. downward with the same force.
C. downward with less force.
D. none of the above
Compared with a light-weight glider, a heavier glider would have to push air

A. downward with greater force.
B. downward with the same force.
C. downward with less force.
D. none of the above

*Explanation:*
The force on the air deflected downward must equal the weight of the glider.
Net Force

Force
simply a push or a pull

Net force
• combination of all forces that act on an object
• changes an object’s motion

<table>
<thead>
<tr>
<th>Applied forces</th>
<th>Net force</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 N</td>
<td>10 N</td>
</tr>
<tr>
<td>5 N</td>
<td>0 N</td>
</tr>
<tr>
<td>5 N</td>
<td>5 N</td>
</tr>
</tbody>
</table>
A cart is pushed to the right with a force of 15 N while being pulled to the left with a force of 20 N. The net force on the cart is

A. 5 N to the left.
B. 5 N to the right.
C. 25 N to the left.
D. 25 N to the right.
A cart is pushed to the right with a force of 15 N while being pulled to the left with a force of 20 N. The net force on the cart is

A. 5 N to the left.
B. 5 N to the right.
C. 25 N to the left.
D. 25 N to the right.
The Equilibrium Rule

The **equilibrium rule:**

The vector sum of forces acting on a non-accelerating object or system of objects equals zero.

Mathematical notation: $\Sigma F = 0$. 
The equilibrium rule, $\Sigma F = 0$, applies to

A. vector quantities.
B. scalar quantities.
C. Both of the above.
D. Neither of the above.
The equilibrium rule, $\Sigma F = 0$, applies to

A. vector quantities.
B. scalar quantities.
C. Both of the above.
D. Neither of the above.

*Explanation:*
Vector addition takes into account + and – quantities that can cancel to zero. Two forces (vectors) can add to zero, but there is no way that two masses (scalars) can add to zero.
Support Force

Support force

• is force that supports an object on the surface against gravity
• is also normal force
When you stand on two bathroom scales, with one foot on each scale and weight evenly distributed, each scale will read

A. your weight.
B. half your weight.
C. zero.
D. actually more than your weight.
When you stand on two bathroom scales, with one foot on each scale and weight evenly distributed, each scale will read

A. your weight.
B. half your weight.
C. zero.
D. actually more than your weight.

*Explanation:*
You are at rest on the scales, so \( \Sigma F = 0 \). The sum of the two upward support forces is equal to your weight.
Dynamic Equilibrium

An object that moves at constant velocity is in equilibrium.

When two or more forces cancel to zero on a moving object, then the object is in equilibrium.
A bowling ball is in equilibrium when it

A. is at rest.
B. moves steadily in a straight-line path.
C. Both of the above.
D. None of the above.
A bowling ball is in equilibrium when it

A. is at rest.
B. moves steadily in a straight-line path.
C. Both of the above.
D. None of the above.
The Force of Friction

Friction

• the resistive force that opposes the motion or attempted motion of an object through a fluid or past another object with which it is in contact

• always acts in a direction to oppose motion
The Force of Friction

Friction (continued)

- between two surfaces, the amount depends on the kinds of material and how much they are pressed together
- due to surface bumps and also to the stickiness of atoms on the surfaces of the two materials
The force of friction can occur

A. with sliding objects.
B. in water.
C. in air.
D. All of the above.
The force of friction can occur

A. with sliding objects.
B. in water.
C. in air.
D. All of the above.

*Comment:*
Friction can also occur for objects at rest. If you push horizontally on your book and it doesn’t move, then friction between the book and the table is equal and opposite to your push.
When Nellie pushes a crate across a factory floor at constant speed, the force of friction between the crate and the floor is

A. less than Nellie’s push.
B. equal to Nellie’s push.
C. equal and opposite to Nellie’s push.
D. more than Nellie’s push.
When Nellie pushes a crate across a factory floor at constant speed, the force of friction between the crate and the floor is

A. less than Nellie’s push.
B. equal to Nellie’s push.
C. equal and opposite to Nellie’s push.
D. more than Nellie’s push.

The Force of Friction
CHECK YOUR ANSWER
When Nellie pushes a crate across a factory floor at an *increasing speed*, the amount of friction between the crate and the floor is

A. less than Nellie’s push.
B. equal to Nellie’s push.
C. equal and opposite to Nellie’s push.
D. more than Nellie’s push.
When Nellie pushes a crate across a factory floor at an increasing speed, the amount of friction between the crate and the floor is

A. less than Nellie’s push.
B. equal to Nellie’s push.
C. equal and opposite to Nellie’s push.
D. more than Nellie’s push.

Explanation:
The increasing speed indicates a net force greater than zero. Her push is greater than the friction force. The crate is not in equilibrium.