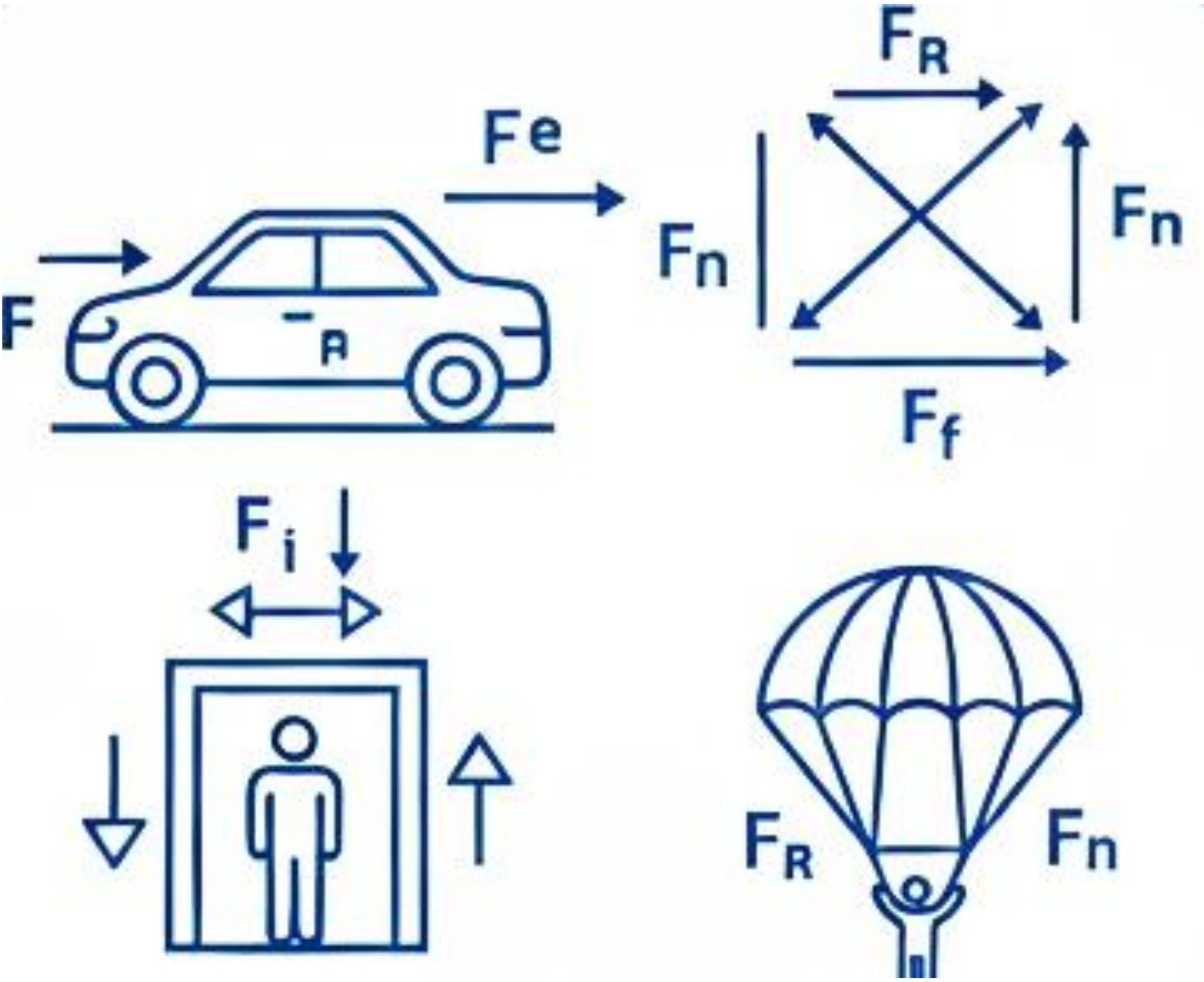
أوراق عمل Forces in one dimension منهج انسباير

Forces in One Dimension



يستخدم محتوى هذه الأوراق كأنشطة إضافية للتدريب ومصدره الأساسي الكتاب المدرسي ولا تغني هذه الأوراق بأي حال عن الكتاب المدرسي.

Mohamed
Ahmed Abdelbari

FORCE AND MOTION

What Causes a Change in Motion?

A change in an object's motion—starting, stopping, speeding up, slowing down, or changing direction—requires a **cause**. This cause is a **force**.

A force in physics is defined as a push or a pull exerted on an object.

If a textbook is resting on a table, you can move it by **pushing** or **pulling**. When you push harder, you exert a force of **greater magnitude**. Magnitude refers to the **size** or **amount** of the force.

Forces Are Vectors

Forces have:

1. **Magnitude** (how strong the force is, measured in newtons (N))
2. **Direction** (which way the force is applied)

Because they have both magnitude and direction, **forces are vectors**.

Vector notation is typically shown with an arrow symbol (e.g., $\vec{F}$).

To show only size (magnitude), we use **F**.

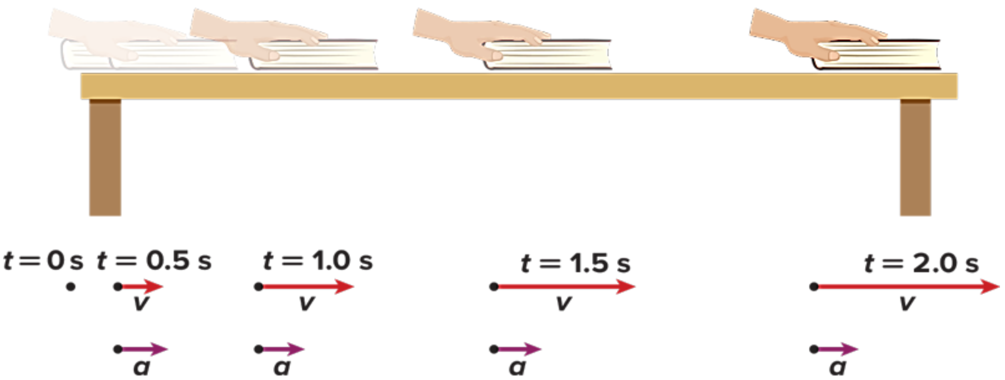
Unbalanced Forces and Acceleration

A **motion diagram** represents the position of an object at equal time intervals.

If the spacing between dots increases, the object is **speeding up**.

If the spacing decreases, it is **slowing down**.

Consider a book *at rest* at t_0. When you push it at time t_1, it begins to move *at 5m/s* and its speed increases. This increase in speed means **acceleration** is occurring.



The cause of that acceleration is the **unbalanced force** exerted by your hand.

Key idea:

All accelerations result from **unbalanced forces** acting on an object.

If forces are balanced, the object does not accelerate.

Systems and the External World

When analyzing forces, you must clearly identify:

- **System:** the object(s) you focus on
- **External world:** everything that interacts with the system

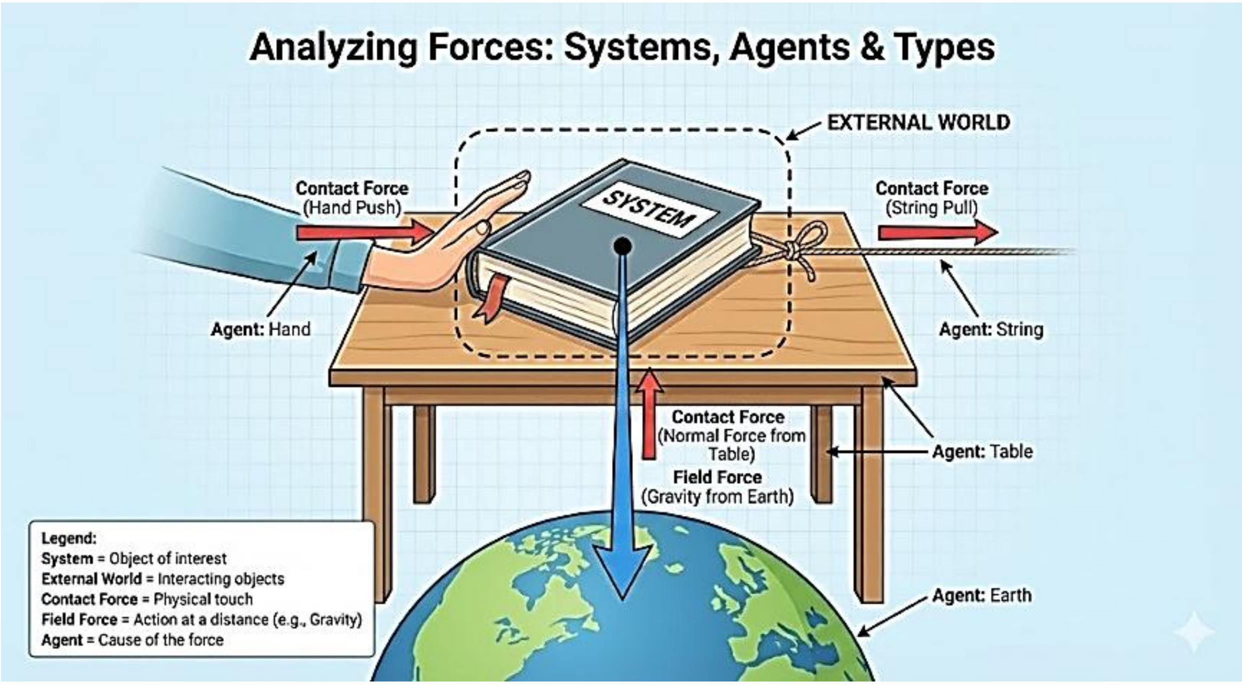
Example:

If the system is a **book**, the external world includes:

- Your hand * Earth
- A string tied to the book * The table

  All these can exert forces on the system.

Types of Forces



A. Contact Forces

A **contact force** occurs when an object physically touches the system.

Examples:

- Your hand pushing a book
- The table pushing upward on a book
- A string pulling the book

If two objects are touching, they can exert a contact force.

B. Field Forces

A **field force** acts **without contact**.

Examples:

- Gravity pulling the book toward Earth
- Magnetic forces between magnets

In this lesson, we focus on **gravitational force**:

Earth's mass exerts a force on all objects, whether or not it touches them.

Agents

Every force has:

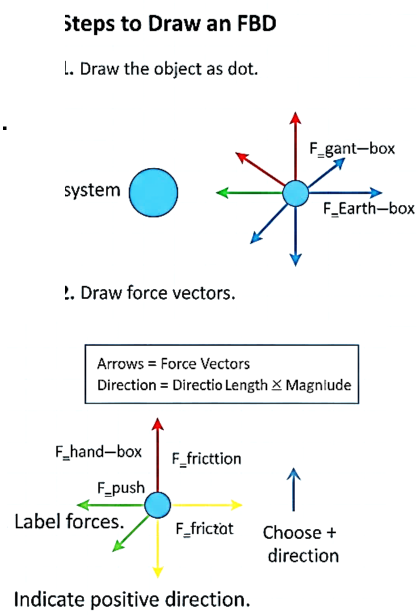
- **An agent** (the cause of the force)
- **A system** (the object the force acts on)

Example:

- Your hand (agent) exerts a force on the textbook (system).
- Earth (agent) exerts gravitational force on the book (system).

If you cannot identify both an agent and a system, **the force does not exist**.

Free-Body Diagrams

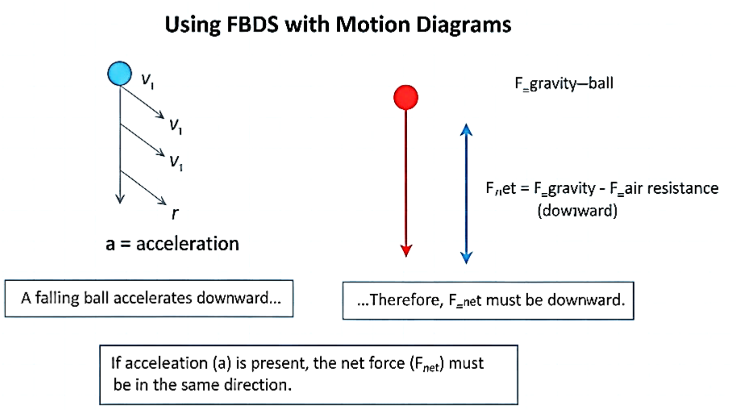


A **free-body diagram (FBD)** is a simple, powerful tool for analyzing forces.

Steps to draw an FBD:

1. Draw the object as a **dot** (particle model).
2. Draw **arrows (vectors)** for all forces acting on the system.
3. Arrows must:
   - Point **away** from the dot
   - Represent **direction** of force
   - Have lengths proportional to **magnitude**
4. Label forces using **F** with subscripts indicating agent and system (example: **Fhand→book**).
5. Choose and indicate the **positive direction**.

Using Motion Diagrams with FBDs



- If a motion diagram shows that the object is **accelerating**,
- Then the FBD must show an **unbalanced force** in the **same direction** as the acceleration.

Example:

A falling ball accelerates downward ⇒ the net force must be downward (gravity > any upward forces).

Write T for True or F for False.

1. (   ) A force is defined as a push or pull exerted on an object.
2. (   ) All forces must involve physical contact between objects.
3. (   ) Forces have both magnitude and direction, making them vectors.
4. (   ) Earth exerts a gravitational force even when it is not touching an object.
5. (   ) Balanced forces can cause an object to accelerate.
6. (   ) The system is the object being analyzed in a force problem.
7. (   ) Field forces include gravity and magnetism.
8. (   ) In a free-body diagram, the object is represented by a particle (dot).
9. (   ) Every force must have an agent and a system.
10. (   ) Motion diagrams show the position of an object at equal time intervals.

Match each term in Column A with the correct description in Column B.

	Column A	Column B
	Force	1. A representation showing forces acting on a system
	Contact force	2. The cause of a force
	Field force	3. A push or pull
	System	4. A force requiring physical touching
	Agent	5. A force acting without contact
	Free-body diagram	6. The object being analyzed
	Motion diagram	7. Size or amount of a quantity
	Magnitude	8. A diagram showing an object's position at equal time intervals
	Vector	9. A quantity with magnitude and direction
	Unbalanced force	10. Causes acceleration because forces do not cancel

Choose the correct answer

1) *What is the definition of a force in physics?*

A. A push or pull exerted on an object
B. The amount of matter in an object
C. The resistance to motion
D. The speed of an object

2) *Which statement best describes a field force?*

A. A force that must involve direct physical contact
B. A force exerted without touching the object
C. A force that always acts horizontally
D. A force that only exists in liquids

3) *Which of the following is an example of a contact force?*

A. Gravity pulling an object downward

B. Earth pulling the Moon into orbit

C. A hand pushing a shopping cart

D. Magnetism between two magnets

4) *In a free-body diagram, what does the length of each arrow represent?*

A. The object's mass

B. The direction of motion

C. The magnitude of the force

D. The number of contact points

5) *Which of the following is considered the agent in the force of gravity acting on a book?*

A. The book

B. The table

C. The air surrounding the book

D. The mass of Earth

6) *What causes an object to accelerate?*

A. Balanced forces

B. A decrease in mass

C. Unbalanced forces

D. Contact forces only

7) *The system in a physics problem refers to:*

A. The object that exerts the force.

B. The external world

C. The object being analyzed

D. Any field force

8) *Which of the following is a property of vectors?*

A. They only have magnitude

B. They have direction only

C. They have magnitude and direction

D. They have no physical meaning

9) *Which of the following always points away from the particle in a free-body diagram?*

A. The velocity vector

B. The displacement

C. The mass

D. The force vectors

10) *Which of the following is part of the external world when the system is a book on a table?*

A. The book itself

B. The table

C. The pages inside the book

D. The mass of the book

COMBINING FORCES & NET FORCE

What Happens When More Than One Force Acts on an Object?

When you and a friend push a table, several forces act on the table at the same time. These forces combine to produce a single overall effect on the motion of the object. This overall effect is called the net force.

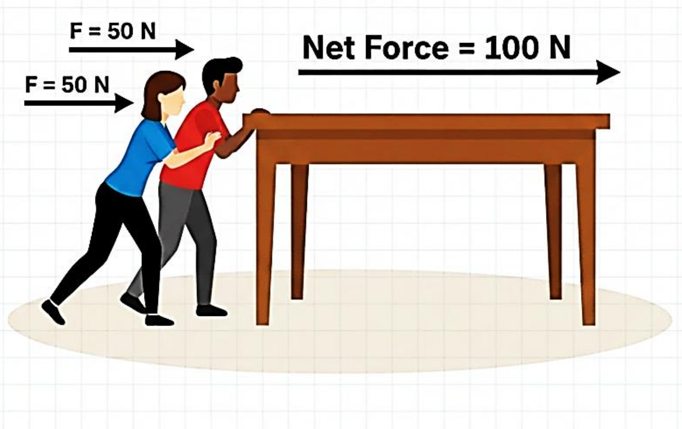
To understand combining forces, you must think in terms of **vectors**, because forces have both:

1. **Magnitude** (how strong the push or pull is)
2. **Direction** (which way the force is applied)

Two forces acting on the same object can either:

- Work **together**, increasing the total force.
- Work **against** each other, decreasing the total force or even canceling out.

Forces Acting in the Same Direction



If two people push a table **in the same direction**, the magnitudes add.

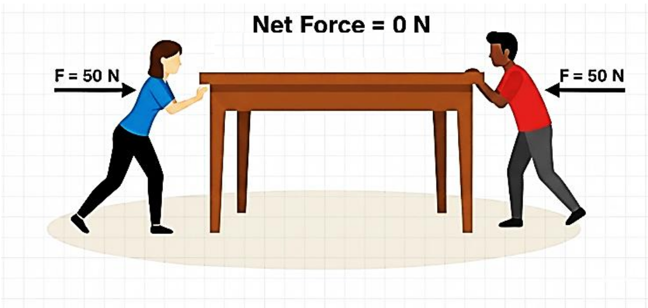
Example: You push the table with **F = 50 N**.

Your friend also pushes with **F = 50 N** in the same direction.

Combined force: **Net force = 50 N + 50 N = 100 N**

Because the net force is nonzero, the table will **accelerate** in that direction.

Forces Acting in Opposite Directions



If two forces act in opposite directions, they partially or completely cancel out.

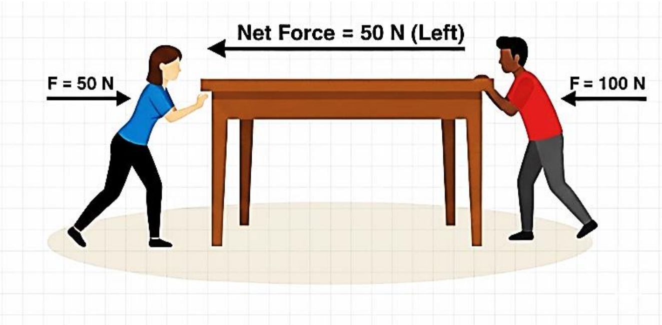
Example 1 (**equal forces**): You push right with **50 N**.

Your friend pushes left with **50 N**.

Net force = 50 N − 50 N = **0 N**

A net force of zero means:

- No acceleration
- Object remains at rest or moves with constant velocity



Example 2 (**unequal forces**):

You push right with **50 N**.

Your friend pushes left with **100 N**.

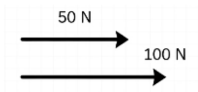
Net force = 50 N − 100 N = **–50 N**

(The negative sign means the net force is **to the left**.)

The table will accelerate **in your friend's direction.**

Vector Diagrams and Resultants

Force vectors can be represented using arrows:

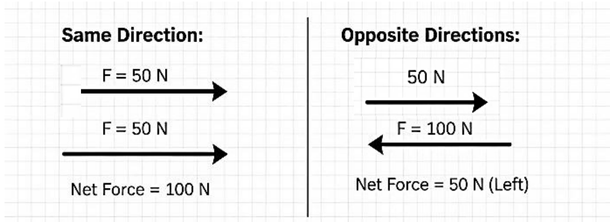


- Longer arrows = larger forces
- Arrow direction = force direction

When combining vectors:

- **Same direction:** add lengths
- **Opposite directions:** subtract lengths

The resulting single arrow is the **resultant** or **net force**.



Net Force (Important Definition)

The **net force** is the vector sum of all forces acting on an object.

Net force determines:

- Whether an object accelerates
- The direction of the acceleration
- The magnitude of the acceleration, according to Newton's Second Law

Mathematical Analysis of Net Force

Consider positive direction = your pushing direction.

Case	Your force	Friend's force	Net force
1	+50 N	−50 N	= 50 + (−50) = **0 N**
2	+50 N	−20 N	= 50 + (−20) = **+30 N** (accelerates in your direction)
3	+50 N	−100 N	= 50 + (−100) = **−50 N** (accelerates toward friend)

Write T or F.

11. (   ) When two equal forces act in opposite directions, the net force is zero.
12. (   ) Forces in the same direction are subtracted to find the net force.
13. (   ) A net force of zero means the object must be at rest.
14. (   ) The net force determines the object's acceleration.
15. (   ) If one force is larger than the other, the net force points toward the larger force.
16. (   ) Net force is the scalar sum of the forces acting on an object.
17. (   ) When two people push a table in the same direction, the forces add.
18. (   ) If the net force is not zero, the object will accelerate.
19. (   ) A negative net force means acceleration is in the negative direction.
20. (   ) Two forces acting in opposite directions can never produce acceleration.

Match each term to its correct description.

	Column A	Column B
☐	**Net Force**	1. Forces that cancel out to produce zero acceleration
☐	**Resultant Vector**	2. The single vector that represents the combined effect of two or more forces.
☐	**Balanced Forces**	3. Forces acting along the same line but toward opposite sides.
☐	**Unbalanced Forces**	4. The cause of acceleration when the vector sum is not zero.
☐	**Opposite Direction Forces**	5. The vector sum of all forces on an object.

PRACTICE PROBLEMS

For each situation:

- Identify the **system** / Draw a **motion diagram** / Draw a **free-body diagram**
- Label **all forces** with their agents / Indicate **directions** of acceleration and net force
- Draw vectors proportionally

1) A skydiver falls downward through the air at constant velocity. (Air exerts upward force.)

2) You hold a softball in your hand and toss it upward (draw while ball is still touching hand).

3) After the softball leaves your hand, it rises while slowing down.

4) After reaching maximum height, the softball falls while speeding up.

5) **CHALLENGE:** You catch the ball and bring it to rest.

Choose the correct answer

11) *What is the net force when two people push a box with 40 N each in the same direction?*

A. 80 N   B. 0 N   C. 40 N   D. 20 N

12) *Two forces act on an object: 60 N left and 40 N right. What is the net force?*

A. 60 N right   B. 20 N right   C. 100 N left   D. 20 N left

13) *When forces are balanced, the object must:*

A. Speed up   B. Move at constant velocity
C. Change direction   D. Accelerate

14) *Net force is defined as:*

A. The difference between mass and velocity   B. A scalar quantity
C. The vector sum of all forces acting on an object   D. The largest force acting on an object

15) *If F_1 = 30 N right and F_2 = 50 N left, the object accelerates:*

A. To the left   B. To the right   C. Upward   D. Not at all

16) *Which statement is true about opposite direction forces?*

A. They always add   B. They subtract
C. They create circular motion   D. They must have equal magnitude

17) *Which of the following describes unbalanced forces?*

A. They never cause motion
B. They always cancel out
C. They produce acceleration in the direction of the net force
D. They must have the same magnitude

18) *If the net force on an object is zero, the object:*

A. Speeds up   B. Slows down
C. Has no acceleration   D. Must move backward

19) *A net force of –15 N means:*

A. The object accelerates forward   B. The forces are balanced
C. The object must be moving left   D. The acceleration is in the negative direction

20) *Two equal forces act in opposite directions. The net force is:*

A. Twice either force   B. Equal to the larger force
C. The difference of the forces   D. Zero

21) *If F_1 = 25 N right and F_2 = 10 N left Net force is:*

A. 35 N right   B. 10 N right   C. 15 N right   D. 25 N left

Acceleration and Force

Introduction: Exploring How Forces Affect Motion

To understand how forces influence the motion of an object, imagine performing a set of controlled investigations. In these investigations, a single force is applied **horizontally** to an object, such as a cart. Working horizontally is beneficial because **gravity does not act horizontally**, so gravitational effects do not complicate the motion.

To further eliminate interfering factors, the investigation is performed on a **smooth, well-polished surface**. This reduces friction between the cart and the surface. The cart used should have **wheels that spin freely**, minimizing resistance.

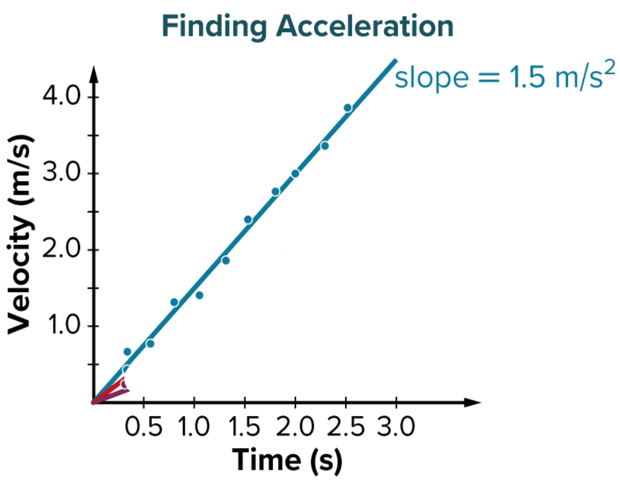
Applying a Constant Force

How can we ensure the force we apply remains constant?

A **spring scale** is used. Inside the scale is a spring that stretches **in direct proportion** to the magnitude of the applied force. The scale is calibrated in **newtons (N)** on the front. When the person pulling keeps the reading steady, the applied force is constant.

In Figure, the spring scale pulls a low-resistance cart, providing a **constant unbalanced force**.

Velocity-Time Graph and Constant Acceleration



If the cart's **velocity is measured over time**, a **velocity–time graph** can be constructed.

For a constant applied force, the velocity-time graph is a **straight line with a constant slope** (like the green line described).

A constant slope means:

- Velocity increases at a constant rate
- This constant rate of change of velocity is called **constant acceleration**

Therefore:

A constant unbalanced force produces constant acceleration.

How Acceleration Depends on Force

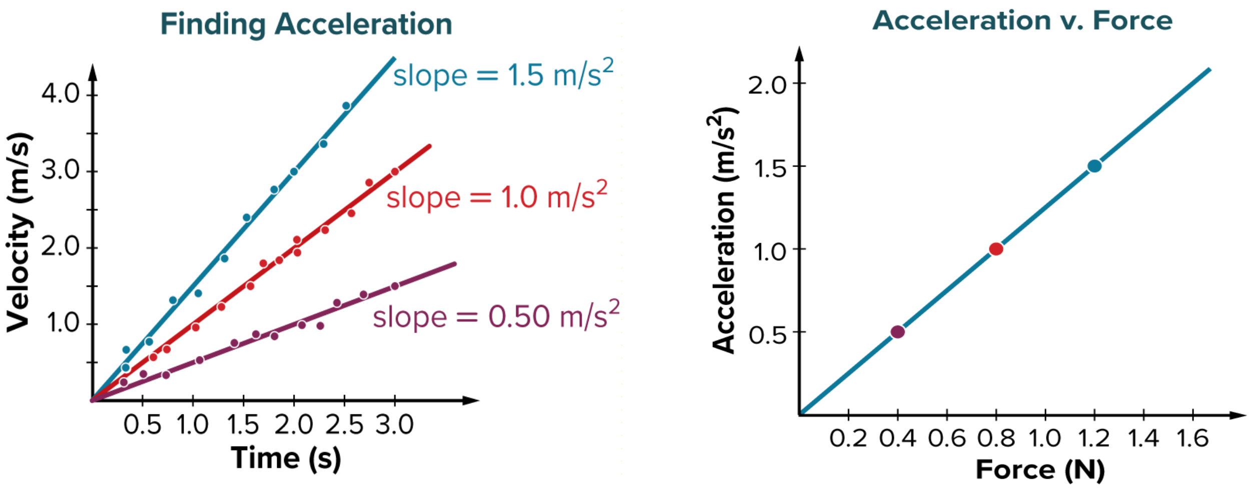
To investigate the relationship between force and acceleration:

- Repeat the experiment using a **larger constant force**
- Repeat again using an **even larger force**

Each trial produces a new velocity-time graph (red and blue lines).

The **slope of each line** represents the **acceleration** of the cart.

Plotting acceleration vs. force produces a straight-line relationship:



- This shows that **acceleration is directly proportional to the applied force**.
- The line passes through the origin (the y-intercept is zero), meaning:

$$\mathbf{a = (slope) \times F}$$

What Does the Slope Mean Physically?

To interpret the meaning of the slope in the acceleration-force graph, change the mass of the object:

- Add a second identical cart on top of the first
- Then add a third cart

For the same force:

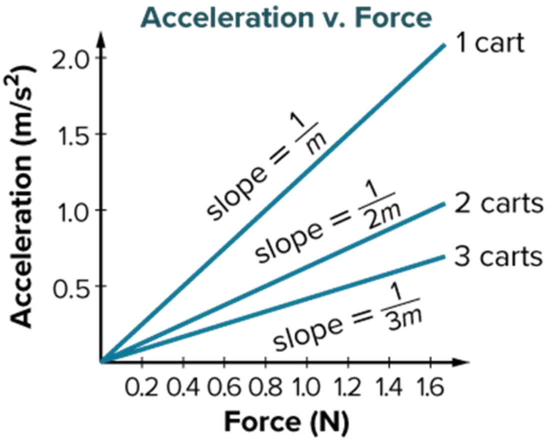
- Two carts accelerate at **half** the acceleration of one cart
- Three carts accelerate at **one-third** the acceleration of one cart

Thus, increasing mass decreases acceleration for the same applied force.

The slopes of the lines in the graph depend on the **total mass**.

The slope is equal to:

$$slope = 1 / mass$$



Substituting slope into the linear equation gives the fundamental physics equation:

$$a = (slope) \times F$$

$$F = 1/(slope) \times a$$

$$F = m \times a$$

$$F = m\,a$$

What This Equation Tells Us

1. A net force acting on an object causes it to accelerate.
2. For the **same object**, if you **double the force**, you **double the acceleration**.
3. For the **same force**, objects with **larger mass** have **smaller acceleration**, while objects with smaller mass accelerate more.
4. If **$a \propto F$**, then to cut the acceleration in half: **You must reduce the net force to half its original value.**

Understanding the Newton (Unit of Force)

Force is measured in **newtons (N)**.

Because: $1\ N = 1\ kg{\cdot}m/s^2$

A newton is approximately the force you feel from holding an apple.

Write TRUE or FALSE.

21. (   ) A constant unbalanced force produces a constant acceleration.
22. (   ) The slope of a velocity-time graph represents force.
23. (   ) Adding more identical carts increases the mass of the system.
24. (   ) Acceleration decreases when mass increases for the same applied force.
25. (   ) A spring scale can provide a constant force if the reading is kept steady.

Match each concept to its description.

	Column A	Column B
☐	Constant force	A. Rate of change of velocity
☐	Acceleration	B. Achieved by using a spring scale
☐	Velocity-time slope	C. Equals 1/mass in the force–acceleration graph
☐	Slope of acceleration-force graph	D. Represents acceleration

Choose the correct answer

22) *What does a constant slope on a velocity-time graph indicate?*

A. Constant acceleration B. Constant force C. Increasing mass D. Zero velocity

23) *Which tool is used to exert a constant unbalanced force in the investigation?*

A. Spring scale B. Barometer C. Thermometer D. Stopwatch

24) *When the applied force increases while mass stays constant, the acceleration will:*

A. Stay the same B. Increase proportionally C. Decrease proportionally D. Become zero

25) *The slope in the force–acceleration graph represents:*

A. The force applied B. The velocity of the cart

C. The reciprocal of mass D. The friction acting on the cart

26) *If mass increases and force stays the same, what happens to acceleration?*

A. It stays constant B. It becomes infinite C. It increases D. It decreases

27) *Which equation correctly represents the relationship among force, mass, and acceleration?*

A. F = m a B. s = d/t C. a = t/m D. F = v/m

28) *What must be done to reduce an object's acceleration by half?*

A. Double the force B. Keep the force constant C. Halve the force D. Double the mass

Adding more carts to the system results in:

A. Greater acceleration B. Smaller force C. Larger mass D. Zero motion

29) *A force of approximately 1 newton is closest to:*

A. The force of an apple on your hand B. The force of a person standing

C. The force of a rocket engine D. The force of gravity on a car

30) *If three identical carts are pulled with the same force as one cart, the acceleration will be:*

A. The same B. One-half C. Three times greater D. One-third

Net Force and Acceleration

Newton's Second Law explains how the motion of an object changes when forces act on it. If multiple forces act on the object, the **net force** must be found.

The **net force** is the **vector sum** of all forces acting on the system.

- If two forces act in the same direction, they **add**.
- If they act in opposite directions, they **subtract**.
- The direction of the net force determines the direction of acceleration.

Newton's Second Law is expressed mathematically as:

$$a = \frac{F_{net}}{m}$$

- (a) = acceleration
- (F_{net}) = net force
- (m) = mass

Understanding the Law

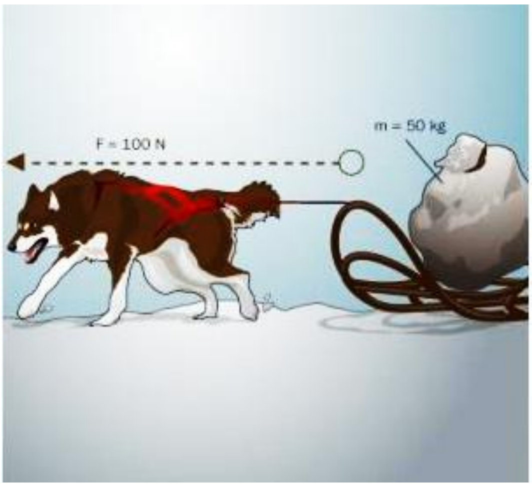
Newton's Second Law states:

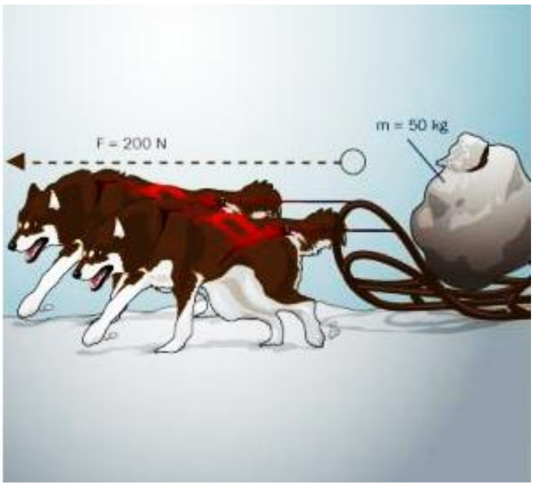
The acceleration of an object is proportional to the net force acting on it and inversely proportional to its mass.

This gives three key insights:

1. If the **net force increases**, acceleration **increases** (direct proportionality).
2. If the **mass increases**, acceleration **decreases** (inverse proportionality).
3. If the **same force** is applied to systems of different masses, the system with the **smaller mass** will accelerate more.

Example: Dogs Pulling a Sled





In Figure, two dogs each pull with a force of (F).

- If both dogs pull the sled, the net force is (2F).
- If one dog could pull alone with the same total force (2F), acceleration would be unchanged, because **what matters is the net force** Not the number of dogs.

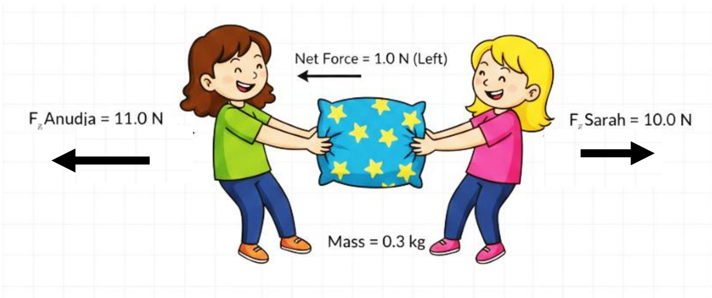
Using Free-Body Diagrams

To correctly apply Newton's Second Law:

1. Identify the **system** (object being analyzed).
2. Draw a **free-body diagram**, labeling each force and its direction.
3. Add all force vectors to find **net force**.
4. Apply the formula ($a = \frac{F_{net}}{m}$).
5. If velocity or position is needed, use equations of accelerated motion.

Example Problem – Fighting Over a Pillow

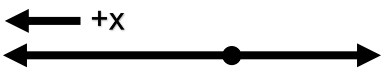
Anudja is holding a pillow with a mass of 0.3 kg when Sarah decides that she wants it and tries to pull it away from Anudja. If Sarah pulls horizontally on the pillow with a force of 10.0 N and Anudja pulls with a horizontal force of 11.0 N, what is the horizontal acceleration of the pillow?



Answer:

1. Identify the system

The system is **the pillow** (mass = 0.3 kg).



2. Draw a free-body diagram

Forces acting on the pillow horizontally:

- **Sarah's pull:** 10.0 N (to the right)
- **Anudja's pull:** 11.0 N (to the left)

3. Add all force vectors to find the net force

Choose Sarah's direction as positive.

$$\mathbf{F_{net} = 10.0 - 11.0 = -1.0\ N}$$

The negative sign indicates that the net force is **in Anudja's direction**.

4. Apply Newton's Second Law

$$a = \frac{F_{net}}{m}$$

$$a = \frac{-1.0\ \text{N}}{0.3\ kg} = -3.33\ m/s^2$$

5. Interpret the result

The pillow accelerates at: $3.33\ m/s^2$ toward Anudja

6. Two horizontal forces,225 N and 165 N , are exerted on a canoe. If these forces are applied in the same direction, find the net horizontal force on the dance.

7. If the same two forces as in the previous problem are exerted on the canoe in opposite directions, what is the net horizontal force on the canoe? Be sure to indicate the direction of the net force.

8. **CHALLENGE** Three confused sled dogs are trying to pull a sled across the Alaskan snow. Alutia pulls east with a force of 35 N , Seward also pulls east but with a force of 42 N , and big Kodiak pulls west with a force of 53N . What is the net force on the sled? Explain how Newton's second law accurately predicts the sled's change in motion.

9. A spring scale is used to exert a net force of 2.7 N on a cart. If the cart's mass is 0.64 kg , what is the cart's acceleration?

10. Kamaria is learning how to ice skate. She wants her mother to pull her along so that she has an acceleration of 0.80 m/s^2. If Kamaria's mass is 27.2 kg , with what force does her mother need to pull her? (Neglect any resistance between the ice and Kamaria's skates.)

11. **CHALLENGE** Two horizontal forces are exerted on a large crate. The first force is 317 N to the right. The second force is 173 N to the left.

a. Draw a force diagram for the horizontal forces acting on the crate.

b. What is the net force acting on the crate?

c. The box is initially at rest. Five seconds later, its velocity is 6.5 m/s to the right. What is the crate's mass?

True or False

26. ( ) The net force on an object is the sum of all individual forces acting on it.
27. ( ) If the net force on an object is zero, the object must be moving at constant velocity or at rest.
28. ( ) According to Newton's Second Law, if mass increases while force stays constant, acceleration increases.
29. ( ) Two equal forces acting in opposite directions produce a net force of zero.
30. ( ) Acceleration always occurs in the direction opposite to the net force.
31. ( ) A free-body diagram shows all forces acting on a system.
32. ( ) Doubling the net force while keeping mass constant doubles the acceleration.
33. ( ) For the same net force, a larger mass results in a larger acceleration.

Match the term in Column A with the correct description in Column B.

	Column A	Column B
	Net force	A. Diagram showing all forces acting on an object
	Free-body diagram	B. Quantity proportional to acceleration
	Mass	C. Sum of all vectors acting on a system
	Acceleration	D. Inversely proportional to acceleration

Choose the correct answer

31) *Newton's Second Law states that acceleration is proportional to which quantity?*

A. Distance B. Velocity C. Time D. Net force

32) *If two forces act on an object in opposite directions, the net force is:*

A. The sum of the two forces B. The difference between the two forces
C. Always zero D. Equal to the mass divided by time

33) *A large net force is applied to a very small mass. What happens to acceleration?*

A. It becomes negative B. It remains constant C. It becomes very large D. It becomes zero

34) *Which statement correctly describes mass in Newton's Second Law?*

A. It is proportional to acceleration B. It determines the direction of acceleration
C. It resists changes in motion D. It is equal to the net force

35) *If the net force on a system doubles, what happens to acceleration (mass constant)?*

A. It is cut in half B. It becomes negative C. It becomes zero D. It doubles

36) *What must be known first when solving Newton's Second Law problems?*

A. Net force B. Distance traveled C. Velocity D. Time

37) *A free-body diagram is used to show:*

A. Only the applied force B. The mass of the object
C. Only gravitational force D. All forces acting on the object

38) *If the same force acts on two objects of different masses, which object accelerates more?*

A. The heavier object B. Both accelerate equally
C. The lighter object D. Neither object accelerates

39) *What happens to acceleration if mass is doubled while force stays the same?*

A. It is reduced to half B. It doubles C. It stays the same D. It becomes zero

40) *Which of the following represents the correct unit of force in Newton's Second Law?*

A. kg/m B. m/s C. kg·m D. $kg \cdot m/s^2$

Newton's First Law of Motion (Law of Inertia)

Newton's First Law states:

"An object at rest will remain at rest, and an object in motion will continue moving in a straight line with constant speed, if and only if the net force acting on it is zero."

This means:

- If **net force = 0**, then **acceleration = 0**.
- If acceleration is zero, the object's **velocity does not change**.
- A stationary object stays at rest.
- A moving object continues with constant velocity (same speed and direction).

Why Objects Slow Down in Real Life

Real surfaces (carpet, grass, rough floor) exert **forces that oppose motion**—mainly **friction**.

- A ball on a thick carpet stops quickly because friction is large.
- A ball on a smooth surface (like a bowling alley) keeps rolling longer because friction is small.

Galileo concluded that if we could remove all opposing forces (like friction), then **horizontal motion would continue forever**.

Newton built on this to form the First Law.

Inertia

Inertia is the tendency of an object to resist changes in its motion.

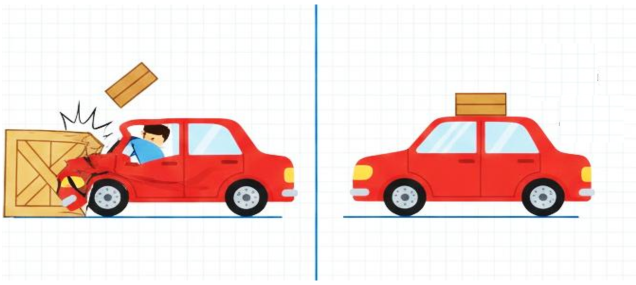
Important notes:

- Inertia is **not a force**.
- Inertia is a **property of matter**, related to **mass**.
- A more massive object has **more inertia** (harder to start moving or to stop).

Example:

A car hits a wooden box and stops because the box applies a force on the car.

But the block on top experiences no force from the box, so it continues moving forward.



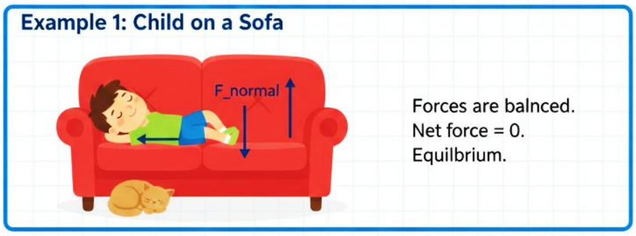
Equilibrium

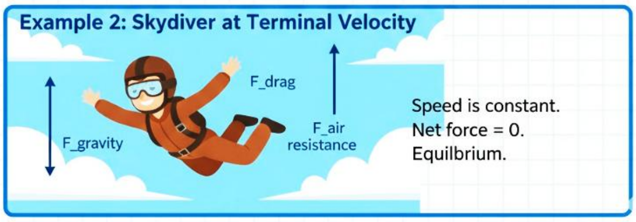
An object is in **equilibrium** when the **net force on it is zero**.

This can happen when:

1. The object is at **rest**.
2. The object is moving at **constant velocity**.

Examples:





- A Child lying on a sofa → forces are balanced → equilibrium.
- A skydiver falling at terminal velocity → speed is constant → net force = zero → equilibrium.

Newton's First Law tells us that only a **net force** can change an object's speed or direction.

Example Problem 1: Inertia in Motion

A small wooden block slides across a smooth table. There is almost no friction. After being pushed, why does the block continue sliding at nearly constant speed?

Solution

- Once pushed, there is **no significant net force** acting on the block.
- According to **Newton's First Law**, with zero net force the object continues moving with **constant velocity**.
- The block keeps sliding due to **inertia**, resisting changes in motion.

Choose the correct answer

41) *Newton's First Law applies when the net force acting on an object is:*

A. Increasing B. Zero C. At maximum D. Opposite to motion

42) *An object in equilibrium must:*

A. Be at rest only B. Move in a circular path

C. Have zero net force acting on it D. Have increasing acceleration

43) *A ball rolling on a smooth ice surface slows down very slowly because:*

A. Ice pushes it forward B. Friction is very small

C. Gravity increases D. Inertia decreases on ice

44) *Inertia is:*

A. A force B. The tendency to resist changes in motion

C. The same as acceleration D. The friction acting on an object

45) *Which situation shows equilibrium?*

A. A car slowing down B. A book sliding faster and faster

C. A cup at rest on a table D. A ball speeding up on a hill

46) *A moving object with zero net force will:*

A. Stop immediately
B. Move with constant velocity
C. Change direction only
D. Accelerate to the right

47) *If a block on a cart moves forward when the cart suddenly stops, it is because of:*

A. Friction
B. Weight
C. Inertia
D. Gravity

48) *A skydiver falling at terminal velocity is in equilibrium because:*

A. Gravity becomes zero
B. Air resistance becomes zero
C. Net force is zero
D. Mass decreases

49) *Which of the following is NOT an example of Newton's First Law?*

A. A hockey puck sliding almost forever on ice
B. A ball rolling on carpet and stopping quickly
C. A spacecraft drifting in space without propulsion
D. A cup staying at rest unless pushed

50) *An object changes its motion only when:*

A. Its mass increases
B. A net force acts on it
C. Energy is constant
D. It has no inertia

True or False

34. (   ) Inertia is a force that keeps objects moving.
35. (   ) If net force = 0, the object's velocity stays constant.
36. (   ) Being at rest is a special case of equilibrium.
37. (   ) Real objects never stop unless friction acts.
38. (   ) A net force is required to maintain constant velocity.

Matching

Match each term to its correct description.

	Term	Description
☐	**Inertia**	A. An object continues in constant motion unless acted upon by net force
☐	**Equilibrium**	B. Resistance to changes in velocity
☐	**Newton's First Law**	C. Net force equals zero

Short-Answer / Problem-Solving

I. A ball is rolling on a very smooth floor. Why does it continue rolling for a long distance? Explain using Newton's First Law.

II. When a bus suddenly stops, passengers move forward. Explain why using the concept of inertia.

III. A skydiver reaches terminal velocity after 8 seconds. What does this say about the forces acting on the skydiver?

IV. Describe one example in daily life where equilibrium occurs.

V. Explain why inertia is not considered a force.

Short Answers (Suggested Responses)

1. It experiences almost no opposing force, so net force ≈ 0 → constant velocity.
2. Their bodies keep moving forward due to inertia when the bus stops.
3. Net force = 0 because air resistance = weight → equilibrium.
4. Any object at rest or moving at constant velocity (e.g., book on table, car on highway at constant speed).
5. Inertia is a property of mass Not an interaction between two objects.

Forces **Classification**

12. **Identify** each of the following as:

	Mass
	Inertia
	Push of a hand
	Friction
	Air resistance
	Spring force
	Gravity
	Acceleration

a) Contact force
b) Field force
c) Not a force

13. **Free-Body Diagram** Draw a free-body diagram of a bag of sugar being lifted by your hand at an increasing speed. Specifically identify the system. Use subscripts to label all forces with their agents. Remember to make the arrows the correct lengths.

14. **Free-Body Diagram** Draw a free-body diagram of a water bucket being lifted by a rope at a decreasing speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.

15. **Critical Thinking** A force of 1 N is the only horizontal force exerted on a block, and the horizontal acceleration of the block is measured. When the same horizontal force is the only force exerted on a second block, the horizontal acceleration is three times as large. What can you conclude about the masses of the two blocks?

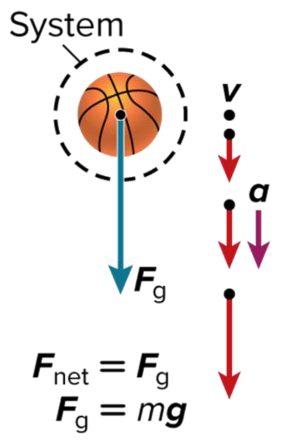
Weight and Drag Force

Focus Question:

How does the drag force change after a skydiver deploys their parachute?

Weight

- From Newton's Second Law, an object accelerates if unbalanced forces act on it.
- Consider a falling ball. The only force acting on it (ignoring air resistance) is **gravity**, directed toward the center of the Earth.
- The gravitational force experienced by an object is called its **weight**. Weight is a **field force** because it acts at a distance without direct contact.
- **Magnitude:** Weight (W) is proportional to mass (m):



$$W = m \times g$$

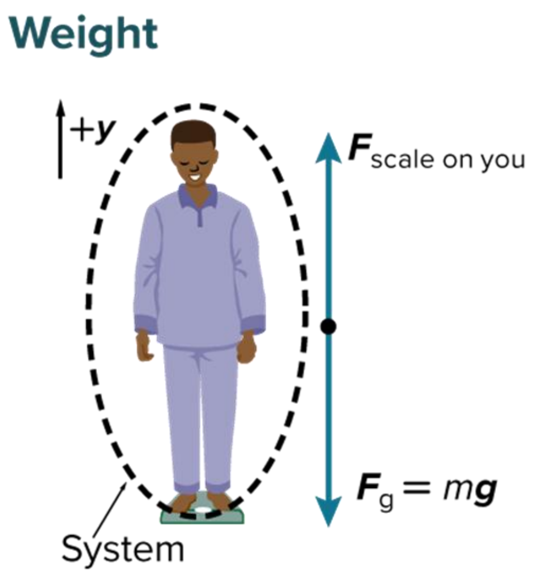
- (m) = mass of the object (kg)
- (g) = gravitational field near Earth (≈ 9.8 N/kg), a **vector quantity** pointing toward the Earth's center

Forces on a Person Standing on a Scale

- When standing on a scale, **you are in equilibrium**, meaning net force = 0.
- Two forces act:
  1. (W = m × g) downward (gravity)
  2. (F_{scale}) upward (from springs in the scale)

- Because you are <u>not accelerating</u>, the upward force equals the downward force.

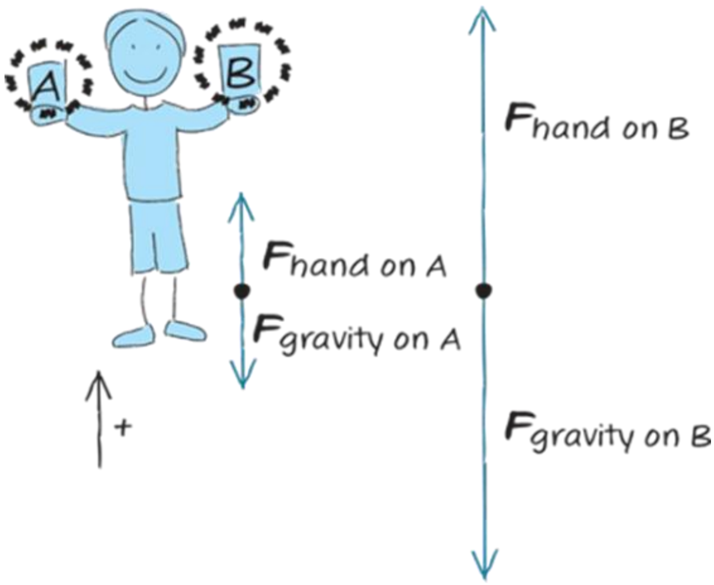
- The scale measures this **upward force**, which equals your weight in **newtons**.
- If on a planet with different (g), the scale reading would change.



Category	Requires Contact	Acts at a Distance	Example
Contact force	Yes	No	Friction
Field force	No	Yes	Gravity
Not a force	—	—	Speed

Example Problem 2: Comparing Weights

Kiran holds a brass cylinder in each hand. Cylinder A has a mass of 100.0 g and cylinder B has a mass of 300.0 g . What upward forces do his two hands exert to keep the cylinders at rest? If he then drops the two, with what acceleration do they fall? (Ignore air resistance.)



Given

Cylinder A mass: (m_A = 100.0 g = 0.100 kg)

Cylinder B mass:(m_B = 300.0 g = 0.300 kg)

Gravitational acceleration:(g = 9.8 m/s^2)

Condition at rest,

Since the cylinders are at rest, their acceleration is zero:

$$a = 0$$

Therefore, the net force on each cylinder is zero.

Forces on each cylinder

- Downward force: weight (= mg)
- Upward force: force exerted by Kiran's hand

For equilibrium:

$$F_{hand} = mg$$

Calculate the forces

Cylinder A

$$F_{hand} = mg$$

$$F_{hand} = (0.100)(9.8) = 0.98\ \text{N up}$$

Cylinder B

$$F_{hand} = mg$$

$$F_{hand} = (0.300)(9.8) = 2.94\ \text{N up}$$

Part 2: Acceleration after the cylinders are dropped

Forces after release

Once released, the only force acting on each cylinder is gravity.

Apply Newton's Second Law $a = \frac{F_{net}}{m}$

Cylinder A

$$a_A = \frac{F_{net\ on\ A}}{m_A}$$

$$a_A = \frac{m_A \times g}{m_A}$$

$$a_A = g = -9.8 m/s^2$$

Cylinder B

$$a_B = \frac{F_{net\ on\ B}}{m_B}$$

$$a_B = \frac{m_B \times g}{m_B}$$

$$a_B = g - 9.8 m/s^2$$

Scales & Units

- Weight is measured in **newtons (N)** because it is a force.
- $1\ N = 1\ kg \cdot m/s^2$

Identify each item as:

	Terms	Forces
☐	Weight of a watermelon	**a. Contact force**
☐	Spring scale push	
☐	Mass of the watermelon	**b. Field force**
☐	Gravity	
☐	Air resistance	**c. Not a force**

True or False

39. (   ) Weight is the same on all planets.

40. (   ) The reading on a scale equals the upward force it exerts.

41. (   ) Drag force increases when the parachute opens.

42. (   ) An object in equilibrium experiences no net force.

Practice Problems

16. You place a 4.0 kg watermelon on a spring scale that measures in newtons. What is the scale's reading?

____

____

17. You place a 22.5 kg television on a spring scale. If the scale reads 235.2 N, what is the gravitational field?

____

____

____

18. A 0.50 kg guinea pig is lifted up from the ground. What is the smallest force needed to lift it? Describe the particular motion resulting from this minimum force.

____

____

____

19. CHALLENGE A grocery sack can withstand a maximum of 230N before it rips. Will a bag holding 15kg of groceries that is lifted from the checkout counter at an acceleration of 7.0 m/s^2 hold?

Choose the correct answer

51) *What is the weight of an object?*

A. The object's mass
B. The gravitational force on the object
C. The upward force of a scale
D. The acceleration of an object

52) *If a skydiver deploys a parachute, the drag force:*

A. Decreases
B. Remains the same
C. Increases
D. Becomes zero

53) *What unit is used to measure weight?*

A. kg
B. N
C. m/s^2
D. J

54) *A scale measures:*

A. The weight of the object
B. The mass of the object
C. The force needed to move the object
D. The volume of the object

55) *Gravity near Earth's surface has a magnitude of:*

A. 9.8 N/kg
B. 9.8 m/s^2
C. Both A and B
D. 1 N/kg

56) *An object in equilibrium has:*

A. Net force = 0
B. Constant acceleration
C. Constant velocity or at rest
D. Both A and C

57) *The minimum upward force to lift an object equals:*

A. $F > mg$
B. $F = mg$
C. $F < mg$
D. $F = 0$

58) *When a parachute opens, the falling object's velocity:*

A. Decreases
B. Becomes zero instantly
C. Remains constant
D. Increases

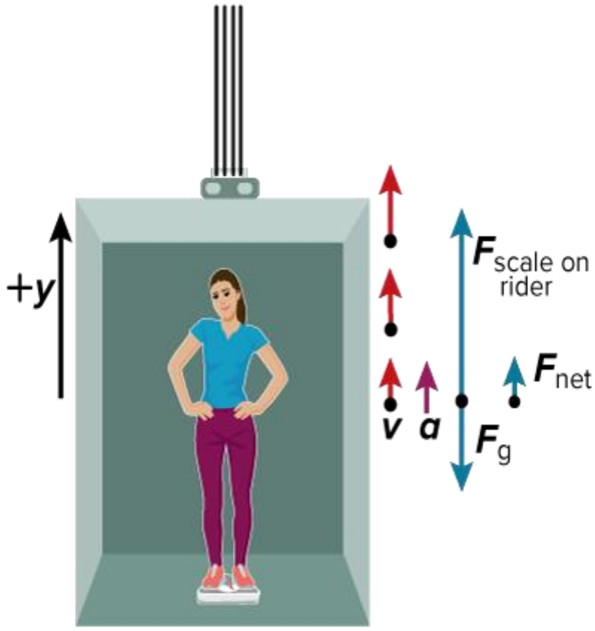
59) *The drag force acts:*

A. Upward
B. Downward
C. Opposite to motion
D. In the same direction as motion

60) *If a grocery bag is lifted with acceleration (a), the required force is:*

A. $F = mg$
B. $F = ma$
C. $F = mg + ma$
D. $F = mg – ma$

Apparent Weight



Focus Question:

How does the apparent weight change when a person is in an elevator accelerating in different directions?

Weight vs. Apparent Weight

- **Weight** ((W)) is the **gravitational force** acting on an object:

$$W = m \times g$$

(m) = mass of the object

(g) = gravitational field (≈ 9.8 N/kg near Earth's surface).

- **Apparent weight** is the **support force** a scale or surface exerts on an object. It can differ from the actual weight when the object is **accelerating**.

Examples of Apparent Weight

1. **Standing on a scale:**
   - Scale reading = weight if not accelerating ((a = 0))
   - If a friend pushes down: scale reading increases
   - If a friend lifts up: scale reading decreases
2. **Standing on a scale in an elevator:**
   - **At rest** → scale reads actual weight
   - **Accelerating upward** → scale reads more than actual weight (apparent weight > W)
   - **Accelerating downward** → scale reads less than actual weight (apparent weight < W)
   - **Free fall / cable breaks** → apparent weight = 0 → object feels weightless

Key Concept: Weightlessness does **not** mean zero mass; it means no contact force supports the object. Astronauts in orbit experience weightlessness because both they and their spacecraft are in free fall.

Problem-Solving Strategy for Apparent Weight

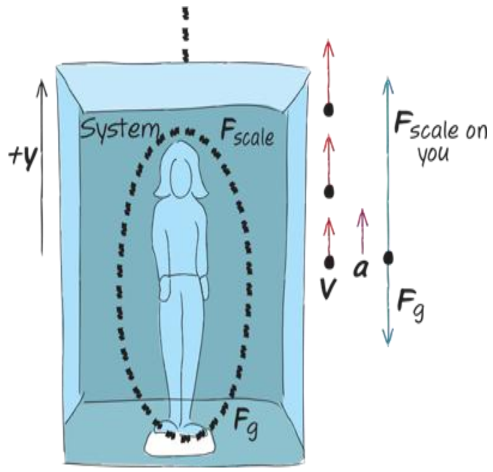
1. Read carefully and sketch the scenario.
2. Identify the system and choose a coordinate system (upward positive).
3. Determine known and unknown quantities.
4. Draw a motion diagram indicating acceleration.
5. Draw a **free-body diagram** with all forces labeled.
6. Use Newton's Second Law: $F_{net} = m\,a$
7. Solve for the unknown force: $F_{scale} = W \pm m\,a$ ("+" if accelerating upward, "–" if downward)
8. Substitute numerical values and check units (N).
9. Check magnitude and sign for realism.

Example Problem 3: Real vs. Apparent Weight

Your mass is 75.0 kg , and you are standing on a bathroom scale in an elevator. Starting from rest, the elevator accelerates upward at 2.00 m/s^2 for 2.00 s and then continues at a constant speed. Is the scale reading during acceleration greater than, equal to, or less than the scale reading when the elevator is at rest?

ANALYZE AND SKETCH THE PROBLEM

- Sketch the situation.
- Choose a coordinate system with the positive direction as upward.
- Draw the motion diagram. Label v and a.
- Draw the free-body diagram. The net force is in the same direction as the acceleration, so the upward force is greater than the downward force.



KNOWN

- ⊙ m = 75.0 kg
- ⊙ a = 2.00 m/ s 2
- ⊙ t = 2.00 s
- ⊙ g = 9.8 N/kg

UNKNOWN

- ○ F scale = ?

SOLVE FOR THE UNKNOWN

$F_{net} = ma$

$F_{net} = F_{scale} + (-F_g)$ *F_g is negative because it is in the negative direction defined by the coordinate system*

Solve for F_{scale} .

$F_{scale} = F_{net} + F_g$

Elevator at rest:

$F_{scale} = F_{net} + F_g$ *the elevator is not accelerating. Thus, F net = 0.00 N.*

$= F_g$ *Substitute F net = 0.00 N.*

$= mg$ *Substitute F g = mg.*

$= (75.0\ kg)(9.8\ N/kg)$ *Substitute m = 75.0 kg, g = 9.8 N/kg.*

$= 735\ N$

Elevator accelerating upward:

$F_{scale} = F_{net} + F_g$

$= ma + mg$ *Substitute F net = ma, F g = mg*

$= (75.0\ kg)(2.00\ m/s^2) + (75.0\ kg)(9.8\ N/kg)$ *Substitute m = 75.0 kg, a = 2.00 m/s^2 , g = 9.8 N/kg*

$= 885\ N$

The scale reading when the elevator is accelerating (885 N) is larger than the scale reading when the elevator is at rest (735 N).

20. On Earth, a scale shows that you weigh 585 N .

a. What is your mass?

b. What would the scale read on the Moon (g = 1.60 N/kg) ?

21. CHALLENGE Use the results from Example Problem 3 to answer questions about a scale in an elevator on Earth. What force would be exerted by the scale on a person in the following situations?

a. The elevator moves upward at constant speed.

b. It slows at 2.0 m/s^2 while moving downward.

c. It speeds up at 2.0 m/s^2 while moving downward.

d. It moves downward at constant speed.

e. In what direction is the net force as the elevator slows to a stop as it is moving down?

Match each situation to:

	situation	weight
☐	Standing on a stationary scale	**a. Actual weight**
☐	Elevator accelerating upward	
☐	Astronaut in orbit	**b. Apparent weight**
☐	Free-falling elevator	
☐	Elevator moving downward at constant speed	**c. Weightless**

True or False

43. (   ) Apparent weight equals actual weight when there is no acceleration.

44. (   ) An upward acceleration decreases the scale reading.

45. (   ) Weightlessness means zero mass.

46. (   ) The net force points in the direction of acceleration.

Choose the correct answer

61) *When an elevator accelerates upward, the apparent weight:*

A. Increases B. Decreases C. Remains the same D. Becomes zero

62) *If an elevator accelerates downward, the scale reading:*

A. Increases B. Decreases C. Becomes negative D. Remains constant

63) *Weightlessness occurs when:*

A. Mass = 0 B. Net force upward

C. Gravity = 0 D. No contact/support force exists

64) *Apparent weight is:*

A. The support force measured by a scale
B. Always equal to actual weight
C. The gravitational field
D. Mass × acceleration due to gravity only

65) *If an elevator moves at constant speed upward, the scale reads:*

A. More than weight
B. Less than weight
C. Equal to weight
D. Zero

66) *A scale in free fall reads:*

A. W
B. Greater than W
C. Half of W
D. Zero

67) *A person feels heavier when:*

A. Accelerating downward
B. At rest
C. Accelerating upward
D. In free fall

68) *Net force on a person in an elevator accelerating downward is:*

A. Upward
B. Downward
C. Zero
D. Horizontal

69) *If a 70 kg person accelerates upward at 2 m/s^2, apparent weight =?*

A. 826 N
B. 686 N
C. 700 N
D. 750 N

70) *The apparent weight differs from actual weight because:*

A. Mass changes
B. Scale is faulty
C. Gravity changes
D. Acceleration changes the contact/support force

Drag Force and Terminal Velocity

Focus Question:

How does the drag force change when a skydiver deploys a parachute?

What is Drag Force?

- As an object moves through a fluid (air or water), the fluid exerts a force **opposite to the direction of motion**. This is called **drag force** (F_{dra}
- Factors affecting drag force:
  1. **Speed of the object** – as speed increases, drag
  2. **Size and shape of the object** – larger surface drag.
  3. **Properties of the fluid** – density and viscosity c

Example: Wingsuits increase the surface area of a skydiver reducing their terminal velocity.

PHYSICS CHALLENGE

A 415-kg container of food and water is dropped from an airplane at an altitude of 300 m. First, consider the situation ignoring air resistance. Then calculate the more realistic situation involving a drag force provided by a parachute.

1. If you ignore air resistance, how long will it take the container to fall 300 m to the ground?

2. Again, ignoring air resistance, what is the speed of the container just before it hits the ground?

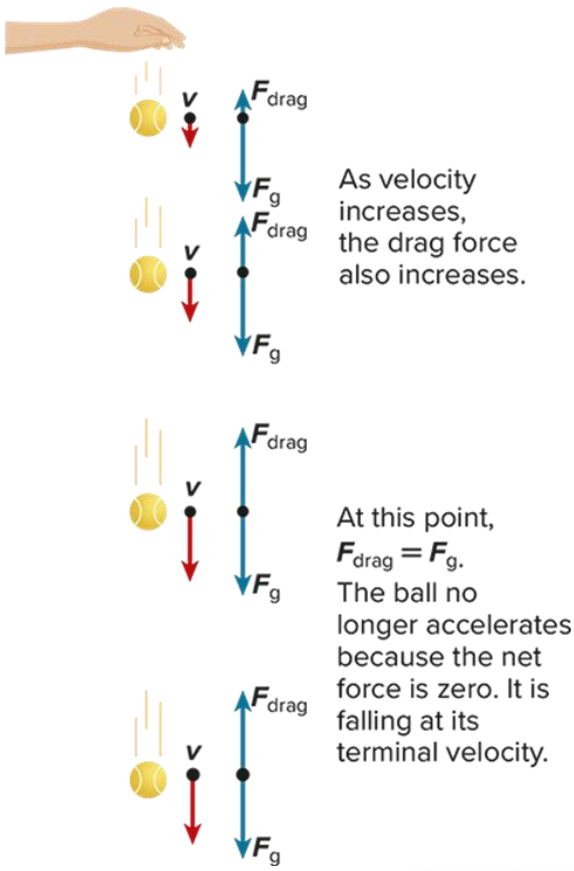
3. The container is attached to a parachute designed to produce a drag force that allows the container to reach a constant downward velocity of 6 m/s. What is the magnitude of the drag force when the container is falling at a constant 6 m/s down?

Terminal Velocity

- Terminal velocity depends on:
  - Mass of the object
  - Surface area of the object
  - Shape of the object
- Examples:
  - Table-tennis ball: small mass, large surface area → low terminal velocity
  - Baseball: larger mass, compact shape → higher terminal velocity
  - Skydivers:
    - Horizontal spread-eagle shape → slower terminal velocity
    - After opening parachute → surface area increases → drag increases → terminal velocity decreases

Newton's Second Law and Drag Force

- While falling:
  $F_{net} = m\,a = F_{gravity} - F_{drag}$
- Initially: ($F_{drag} < F_{gravity}$)
  net force downward → acceleration downward
- As speed increases:
  (F_{drag}) increases → acceleration decreases.
- Terminal velocity: ($F_{drag} = F_{gravity}$)
  ($a = 0$) → object falls at constant speed



Match each factor with its effect on drag:

	factor	effect on drag
☐	Increasing speed	**a. Increases drag**
☐	Streamlining the shape	
☐	Increasing surface area	**b. Decreases drag**
☐	Denser fluid	

True or False

47. (   ) Drag force always acts in the direction of motion.
48. (   ) Terminal velocity occurs when net force = 0.
49. (   ) Larger surface area reduces drag.
50. (   ) Skydivers can change terminal velocity by changing body orientation.

Choose the correct answer

71) *Drag force acts:*

A. Only upward
B. In the direction of motion
C. Opposite to motion
D. Only downward

72) *Terminal velocity occurs when:*

A. Drag = weight
B. Drag < weight
C. Drag > weight
D. Acceleration = g

73) *A heavier object with small surface area:*

A. Reaches terminal velocity quickly
B. Reaches terminal velocity slowly
C. Not affected by drag
D. Accelerates downward faster initially

74) *Increasing the fluid's density:*

A. Decreases drag
B. Increases drag
C. Has no effect
D. Stops the object

75) *A skydiver in spread-eagle position:*

A. Slower terminal velocity
B. Faster terminal velocity
C. Constant acceleration
D. Free fall

76) *A parachute opening:*

A. Reduces drag, increases terminal velocity
B. Increases drag, reduces terminal velocity
C. Keeps terminal velocity same
D. Increases weight

77) *Drag force is affected by:*

A. Object's speed
B. Object's shape
C. Object's color
D. Both A and B

78) *Net force during falling before reaching terminal velocity:*

A. Downward B. Upward C. Zero D. Horizontal

79) *Terminal velocity of a baseball is:*

A. Zero
B. Lower than a table-tennis ball
C. Higher than a table-tennis ball
D. Equal for all objects

80) *Skydiver can reduce terminal velocity by:*

A. Pulling arms in
B. Lying flat horizontal
C. Opening parachute
D. Both B and C

Check Your Progress

22. Terminal Velocity The skydiver shown in Figure falls at a constant speed in the spread-eagle position. Immediately after opening the parachute, is the skydiver accelerating? If so, in which direction? Explain your answer using Newton's laws.

23. Lunar Gravity Compare the force holding a 10.0-kg rock on Earth and on the Moon. The gravitational field on the Moon is 1.6 N/kg.

24. Motion of an Elevator You are riding in an elevator holding a spring scale with a 1-kg mass suspended from it. You look at the scale and see that it reads 9.3 N. What, if anything, can you conclude about the elevator's motion at that time?

25. Apparent Weight You take a ride in a fast elevator to the top of a tall building and ride back down. During which parts of the ride will your apparent and real weights be the same? During which parts will your apparent weight be less than your real weight? More than your real weight? Sketch free-body diagrams to support your answers.

26. Acceleration Tecle, with a mass of 65.0 kg, is standing on an ice-skating rink. His friend applies a force of 9.0 N to him. What is Tecle's resulting acceleration?

27. Critical Thinking You have a job at a meat warehouse loading inventory onto trucks for shipment to grocery stores. Each truck has a weight limit of 10,000 N of cargo. You push each crate of meat along a low-resistance roller belt to a scale and weigh it before moving it onto the truck. One night, right after you weigh a 1000-N crate, the scale breaks. Describe a way in which you could apply Newton's laws to approximate the masses of the remaining crates.

Focus Question

If you push on a wall, what force does the wall exert on you?

- When you push on a wall, the wall pushes back on you with a force **equal in magnitude and opposite in direction**. This is an example of **Newton's Third Law**.
- Newton's Third Law applies to **all forces**: every force has a corresponding force acting on a **different object**, equal in strength and opposite in direction.

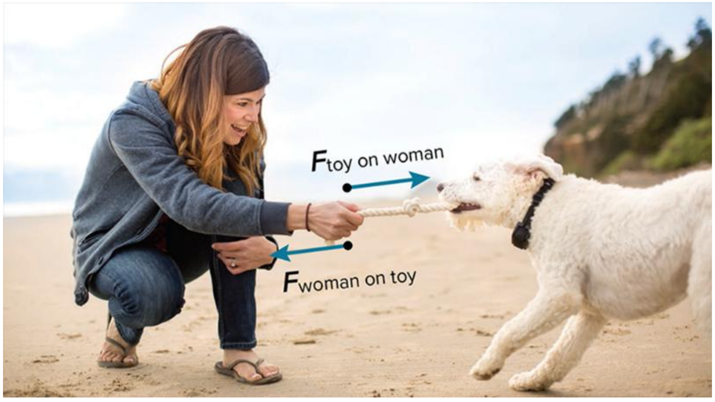
Interaction Pairs

- Forces **always come in pairs**, called **interaction pairs** or **action-reaction pairs**.
- Each force in the pair acts on a **different object**.
- The two forces are **equal in magnitude** and **opposite in direction**.
- **Important:** The forces **do not cancel** because they act on different objects.

Example:

A woman pulls a dog's toy.

- Woman → Toy: (F_{woman} on toy)
- Toy → Woman: (F_{toy} on woman)
- These two forces occur **simultaneously**. One does not "cause" the other; they exist together.

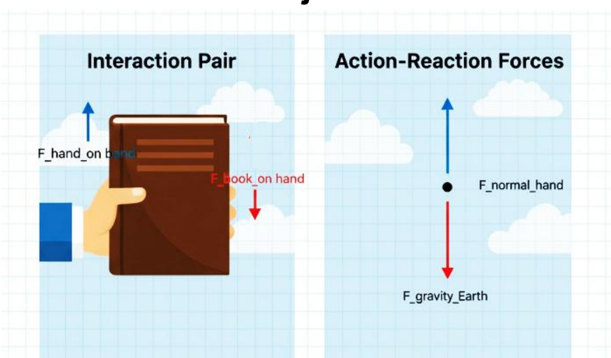


Newton's Third Law

- **Statement:** For every action, there is an equal and opposite reaction.
- **Mathematical form:**

$$F_{A \text{ on } B} = - F_{B \text{ on } A}$$

- **Key points:**
  1. The two forces act on **different objects**.
  2. They are **equal in magnitude**.
  3. They are **opposite in direction**.
- **Not all opposite forces are third law pairs**: only forces on **different objects** count.

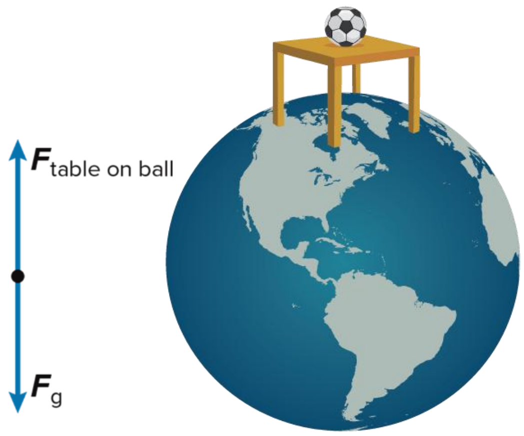


Examples of Interaction Pairs

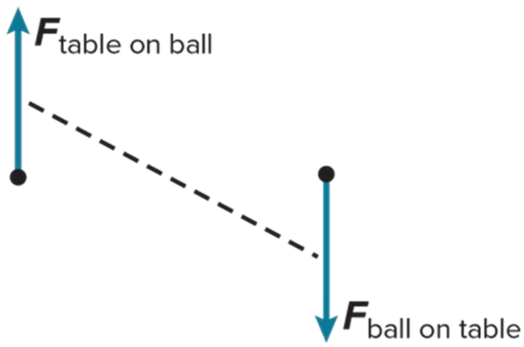
1. **Book on hand:**
   - Hand → Book: upward force
   - Book → Hand: downward force
   - These forces are an interaction pair.

2. **Ball on table:**

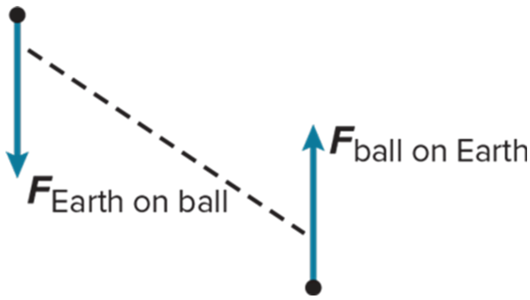
Situation	Forces acting on the ball.
Systems	One system.
1st force	The table exerts an upward force on the ball.
2nd force	The mass of Earth exerts a downward gravitational force on the ball.
Interaction pair?	Not an interaction pair.
Why?	They act on the same object.



Situation	Ball / Table.
Systems	Two systems.
1st force	Upward force exerted by the table on the ball
2nd force	The ball exerts a downward force on the table.
Interaction pair?	Interaction pair.
Why?	They act on different objects.



Situation	Ball / Earth.
Systems	Two systems.
1st force	Ball has a weight, ball experiences a force due to Earth's mass.
2nd force	Force on Earth's mass due to the ball.
Interaction pair?	Interaction pair.
Why?	They act on different objects.



Effect of Mass on Acceleration

- An unbalanced force on Earth would cause acceleration.
- Acceleration is inversely proportional to mass.
- Earth's mass is extremely large compared to ordinary objects.
- Earth's resulting acceleration is negligibly small.
- Earth's motion can usually be ignored.
- Earth is often treated as part of the external world.
- Interaction pairs can be handled using simplified problem-solving strategies.

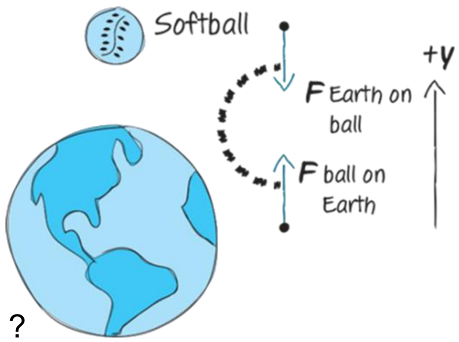
Step-by-Step Problem Solving

1. **Choose the system:** Identify objects involved.
2. **Draw diagrams:** Include free-body diagrams for each object.
3. **Label forces:** Include magnitude and direction.
4. **Connect interaction pairs** with dashed lines.
5. **Use Newton's second law** for each object: (Fnet = m a)
6. **Apply Newton's third law**: forces in pairs are equal and opposite.
7. Solve for unknowns.
8. Check **units, magnitude, and direction**.

Examples

EARTH'S ACCELERATION A softball has a mass of 0.18 kg. What is the gravitational force on Earth due to the ball, and what is Earth's resulting acceleration? Earth's mass is 6.0×10^{24} kg.

ANALYZE AND SKETCH THE PROBLEM



• Draw free-body diagrams for the two systems: the ball and Earth.
• Connect the interaction pair by a dashed line.

KNOWN

⊙ m_{ball} = 0.18 kg
⊙ m_{Earth} = 6.0×10^{24} kg
⊙ g = 9.8 N/kg

UNKNOWN

○ $F_{Earth\ on\ ball}$ = ?
○ a_{Earth} = ?

SOLVE FOR THE UNKNOWN

Use Newton's second law to find the weight of the ball.

$$F_{Earth\ on\ ball} = m_{ball}\, g$$
$$= (0.18\ kg)(-9.8\ N/kg) = -1.8\ N$$

Use Newton's third law to find $F_{ball\ on\ Earth}$.

$$F_{ball\ on\ Earth} = -F_{Earth\ on\ ball}$$
$$= -(-1.8\ N) = +1.8\ N$$

Use Newton's second law to find a_{Earth} .

$$a_{Earth} = \frac{F_{net}}{m_{Earth}}$$
$$a_{Earth} = \frac{1.8\ N}{6.0\times10^{24}\ kg}$$
$$= 2.9\times10^{-25}\ m/s^2 \text{ toward the softball}$$

PRACTICE Problems

28. You lift a relatively light bowling ball with your hand, accelerating it upward. What are the forces on the ball? What forces does the ball exert? What objects are these forces exerted on?

29. A brick falls from a construction scaffold. Identify any forces acting on the brick. Also identify any forces the brick exerts and the objects on which these forces are exerted. (Air resistance may be ignored.)

30. A suitcase sits on a stationary airport luggage cart, as in **Figure.** Draw a free-body diagram for each object and specifically indicate any interaction pairs between the two.

31. **CHALLENGE** You toss a ball up in the air. Draw a free-body diagram for the ball after it has lost contact with your hand but while it is still moving upward. Identify any forces acting on the ball. Also identify any forces that the ball exerts and the objects on which these forces are exerted. Assume that air resistance is negligible.

True/False

51. ( ) Interaction pairs always act on the same object.

52. ( ) Newton's third law implies one force causes the other.

53. ( ) Forces of gravity between Earth and a falling ball are an interaction pair.

54. ( ) If you push a wall, the wall exerts an equal and opposite force on you.

55. ( ) The ball's weight and the table's upward force on the ball are an interaction pair.

Match the force with the object it acts on:

	Force	Object acted on
☐	Hand → Book	A. Hand
☐	Book → Hand	B. Book
☐	Ball → Table	C. Table
☐	Table → Ball	D. Ball

Choose the correct answer

81) *Newton's third law states that:*

A) Forces always occur in equal and opposite pairs acting on different objects
B) A larger force always causes a smaller reaction
C) Forces act only in the direction of motion
D) Acceleration is always caused by gravity

82) *If a book rests on a table, the interaction pair includes:*

A) Gravity on the book ↔ Gravity on Earth
B) Table friction ↔ Book weight
C) Table pushing up on book ↔ Book pushing down on table
D) Book weight ↔ Table weight

83) *Forces on the same object in opposite directions are:*

A) Interaction pairs
B) Not interaction pairs
C) Equal and opposite always
D) Always cause acceleration

84) *When you push on a wall, the wall exerts a force:*

A) Equal in magnitude and opposite in direction
B) Smaller than your push
C) Only if the wall moves
D) Acting on you

85) *In the softball-Earth example, Earth's acceleration is:*

A) Huge
B) Very small
C) Same as the ball
D) Zero

86) *Interaction pairs exist because:*

A) Forces always come in pairs
B) Forces are vectors
C) Mass is constant
D) Acceleration is opposite

87) *The ball's weight and table's upward force are:*

A) An interaction pair
B) Equal in magnitude and opposite
C) Not an interaction pair
D) Acting on two objects

88) *Forces exerted by a falling brick on the scaffold are:*

A) Equal and opposite to gravity
B) Part of an interaction pair with the scaffold
C) Only friction
D) Acting on the brick only

89) *A bowling ball lifted upward interacts with:*

A) Your hand
B) The air
C) The floor
D) Another ball

90) *After tossing a ball upward, while it moves in the air:*

A) Ball pushes air
B) Hand pushes upward
C) Gravity on ball ↔ Gravity on Earth
D) Ball's weight increases

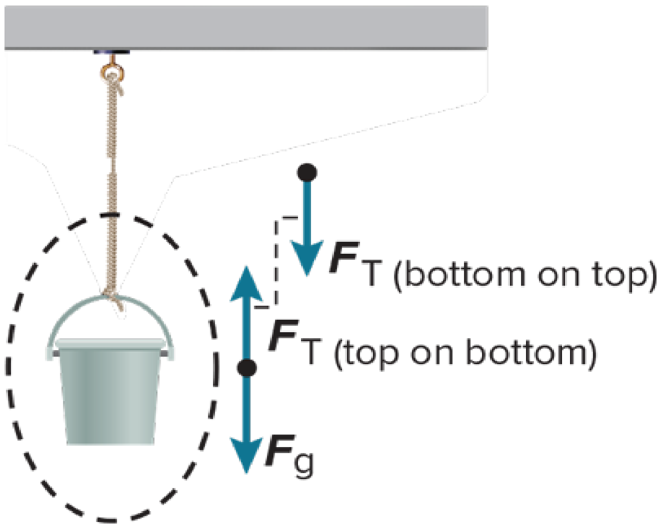
Tension

Focus Question, *What force does a rope exert on objects hanging from it?*

- The force a rope or string exerts on an object is called **tension**.
- **Simplification:** We usually assume ropes are **massless** so we don't have to consider the rope's own weight.
- Tension is transmitted **equally throughout the rope** if the rope is massless and not accelerating.

Definition of Tension

- **Tension:** The force that a rope, string, or cable exerts along its length.
- Acts **away from the object on both ends** of the rope.
- Always **pulling** Never pushing.



Example:

A bucket hangs from a rope.

- Rope pulls upward on the bucket.
- Bucket pulls downward on the rope.
- These two forces form an **interaction pair** (Newton's Third Law).

Tension and Equilibrium

- When the object is **stationary or moving at constant velocity**, it is in **equilibrium**.

Net force = 0, so:

$$T = W$$

(T) = tension in the rope

(W = mg) = weight of the object

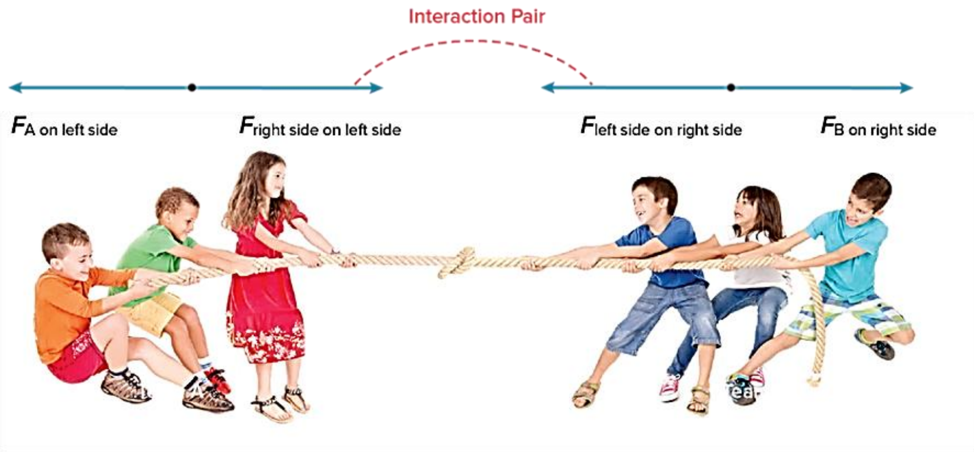
Example:

- Bucket mass: 10 kg
- Weight: ($W = mg = 10 \times 9.8 = 98$ N)
- Rope tension: ($T = 98$ N)
- At **any point in the rope**, tension equals the weight of all objects below that point.

Tension as an Interaction Pair

- Newton's Third Law applies to tension forces:
  - Rope pulls **up** on the object.
  - Object pulls **down** on the rope.
- Magnitude is equal; direction is opposite.

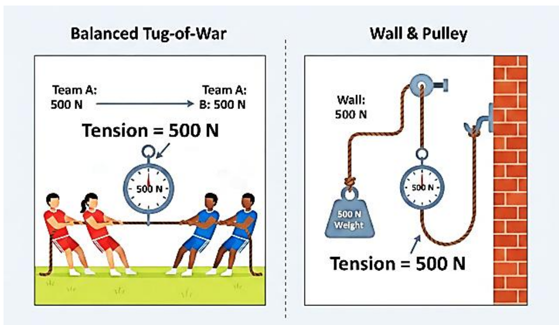
Ropes Pulled by Two Teams



Understanding Tension: The Tug-of-War Rule

- **Static Equilibrium:** If a rope is not moving or accelerating, the forces pulling on both ends must be equal.
- **The Pull Factor:** If Team A pulls with 500 N, Team B must also pull with 500 N for the rope to stay still.
- **The Tension Paradox:** Even though there is 500 N of force at *each* end, the tension in the rope is **500 N** Not 1000 N.
- **Newton's Third Law:** The two halves of the rope pull on each other with equal and opposite force (an interaction pair).
- **The Scale Test:** If you placed a spring scale in the middle of the rope, it would measure the pull from one side: **500 N**.

Scenario	Force on Left	Force on Right	Tension in Rope
Balanced Tug-of-War	500 N	500 N	**500 N**
Wall & Pulley	500 N Weight	Wall (reaches back)	**500 N**



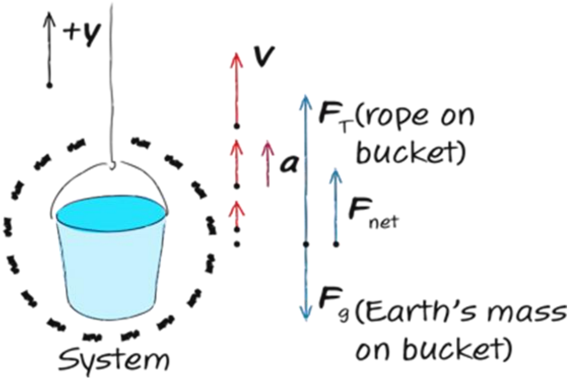
If you tie one end of a rope to a tree and pull 500 N, how much does the tree pull back?

---

the tree pulls with 500 N, and the tension is clearly 500 N. A tug-of-war is just replacing the tree with another person.

EXAMPLE PROBLEM 5

LIFTING A BUCKET A 50.0-kg bucket is being lifted by a rope. The rope will not break if the tension is 525 N or less. The bucket started at rest, and after being lifted 3.0 m, it moves at 3.0 m/s. If the acceleration is constant, is the rope in danger of breaking?



ANALYZE AND SKETCH THE PROBLEM

- Draw the situation and identify the forces on the system.
- Establish a coordinate system with the positive axis upward.
- Draw a motion diagram; include v and a.
- Draw the free body diagram and label the forces.

KNOWN		UNKNOWN
m = 50.0 kg	v_f = 3.0 m/s	F_T = ?
v_i = 0.0 m/s	d = 3.0 m	

SOLVE FOR THE UNKNOWN

F $_{net}$ is the sum of the positive force of the rope pulling up (F_T) and the negative weight force ($-F_g$) pulling down as defined by the coordinate system.

$$F_{net} = F_T + (-F_g)$$

$$F_T = F_{net} + F_g$$

$$F_T = \ = ma + mg$$

Calculating a

$$a = \frac{v_f^2 - v_i^2}{2d}$$

$$a = \frac{3.0\, m/s - 0.0 m/s}{2 \times 3.0\ \text{m}} = 0.5\ m/s^2$$

Calculating F_T

$$F_T = \ = ma + mg$$

$$F_T = 50.0\ kg \times 0.5\ m/s^2 + 50.0\ kg \times 9.8\ N/kg$$

$$F_T = 560\ N$$

The rope is in danger of breaking because the tension exceeds 525 N.

PRACTICE PROBLEMS

32. Diego and Mika are trying to fix a tire on Diego's car, but they are having trouble getting the tire loose. When they pull together in the same direction, Mika with a force of 23 N and Diego with a force of 31 N, they just barely get the tire to move off the wheel. What is the magnitude of the force between the tire and the wheel?

33. CHALLENGE You are helping to repair a roof by loading equipment into a bucket that workers hoist to the rooftop. If the rope is guaranteed not to break as long as the tension does not exceed 450 N and you fill the bucket until it has a mass of 42 kg, what is the greatest acceleration that the workers can give the bucket as they pull it to the roof?

True/False

56. ( ) Tension always acts along the rope.

57. ( ) Tension can push objects.

58. ( ) Tension at any point in a massless rope is the same.

59. ( ) Upward tension force always equals weight. (False – only in equilibrium)

60. ( ) Rope pulling up on a bucket is part of an interaction pair.

Match forces to objects:

	Force	Object acted on
☐	Rope → Bucket	A. Rope above bucket
☐	Bucket → Rope	B. Bucket
☐	Rope → Ceiling	C. Worker
☐	Rope → Worker	D. Ceiling

Choose the correct answer

91) *Tension is a force exerted by:*

A) Gravity B) Rope on an object C) Air resistance D) Friction

92) *In a stationary rope holding a bucket, tension equals:*

A) Weight of bucket B) Upward push by hand C) Force of air D) Mass of rope

93) *Two teams pull a rope in tug-of-war and it does not accelerate. Tension is:*

A) Sum of forces B) Equal to one team's force C) Twice each team's force D) Zero

94) *Rope exerts a force on an object. Interaction pair is:*

A) Object → rope B) Object → ground C) Rope → ceiling D) None

95) *Rope will break if tension exceeds: 500 N. Bucket mass = 20 kg. Max upward acceleration?*

A) 15 m/s^2 B) 10 m/s^2 C) 7.1 m/s^2 D) 5 m/s^2

96) *If rope is massless, tension:*

A) Varies along rope B) Depends on rope color C) Acts downward only D) Same at all points

97) *Bucket* moves upward with acceleration 3 m/s^2. Tension > weight. (True/False)

A) True B) False C) Cannot tell D) Only if massless

98) *Rope → ceiling = 100 N. Rope → bucket = ?*

A) 50 N B) 100 N C) 150 N D) 200 N

99) *Newton's third law for tension:*

A) Rope pulls air ↔ Air pulls rope

B) Rope pulls bucket ↔ Gravity

C) Rope pulls ceiling ↔ Hand pulls rope

D) Rope pulls bucket ↔ Bucket pulls rope

100) *Rope breaks in middle. Interaction pair forces:*

A) Acting on same object

B) Unequal

C) Equal and opposite

D) Horizontal only

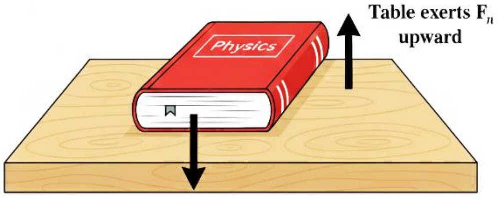
Focus Question

What is the normal force and how does it change under different situations?

Definition of the Normal Force

- **Normal force ((FN))**: The perpendicular contact force that a surface exerts on an object resting on it.
- Always acts **perpendicular** to the surface.
- Exists whenever **two surfaces are in contact**.
- It is a **reaction force** to prevent interpenetration of surfaces.

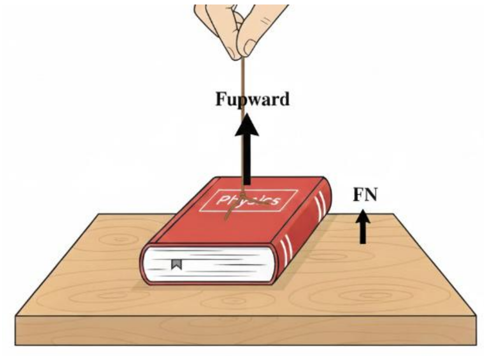
Example:



- A book rests on a table.
  - Weight of book: (W = mg) downward.
  - Table exerts (F_N) upward to balance the book.
  - If the book is **stationary**,
  - Equation:

$$F_N = mg\ , \qquad F_{net} = 0$$

When the Normal Force ≠ Weight



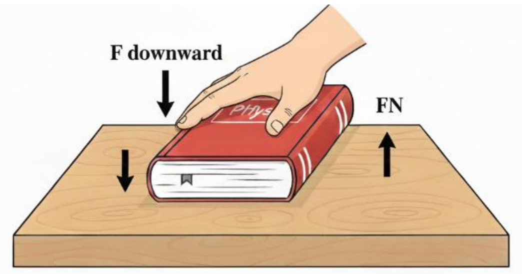
- The normal force is **not always equal to the object's weight**.
- Situations affecting normal force:

1. **Pulling the book upward with a string** (but not enough to lift):
   - The net upward force partially offsets weight.
   - Normal force decreases.
   - Equation:

$$F_N = mg - F_{upward}\ , \qquad F_{net} = 0$$

$$F_N = F_g - F_{string}$$

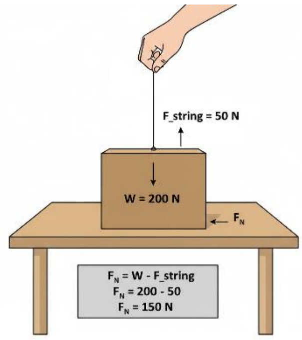
2. **Pushing downward** on the book:
   - Normal force increases because extra downward force adds to weight.
   - Equation:



$$F_N = mg + F_{downward}, \qquad F_{net} = 0$$

$$F_N = F_g + F_{hand}$$

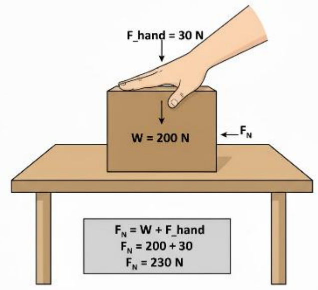
Example 1: Pulling Up Slightly



- Box weight: (W = 200 N)
- You pull upward with (F_{string} = 50 N)
- Find the normal force:

$$F_N = W - F_{string} = 200 - 50 = 150\ N$$

Example 2: Pushing Down



- Box weight: (W = 200 N)
- You push down with (F_{hand} = 30 N)
- Normal force:

$$F_N = W + F_{hand} = 200 + 30 = 230\ N$$

Practice Questions

True/False

61. (   ) The normal force is always equal to the weight of an object.
62. (   ) Normal force acts perpendicular to the surface.
63. (   ) Pulling an object upward slightly decreases the normal force.
64. (   ) Pushing down on an object increases the normal force.
65. (   ) Normal force can act along an inclined surface.

Match each scenario with the correct normal force relationship:

	Scenario	Normal Force Expression
☐	Box on flat table, stationary	A. (FN = W + Fdown)
☐	Pull upward with string	B. (FN = W - Fup)
☐	Push downward	C. (FN = W)

Problem-Solving Questions

1. A 50-kg box rests on a horizontal floor. You pull upward with 100 N. Find (FN).

---

2. You push down on the same 50-kg box with 50 N. Find (FN).

---

3. A 20-kg object hangs from a rope on a table. Rope pulls upward 50 N. Normal force?

Choose the correct answer

101) *Normal force acts:*

A) Parallel to surface
B) Perpendicular to surface
C) Along gravity
D) Opposite tension

102) *Box sits on floor No other forces. Normal force = ?*

A) 0
B) W
C) W/2
D) Twice W

103) *Pulling upward on box decreases normal force. (True/False)*

A) True
B) False
C) Cannot tell
D) Only if massless

104) *Pushing down on box increases normal force. (True/False)*

A) True
B) False
C) Only on incline
D) Only if accelerating

105) *Box weight 100 N, pull up 30 N. (FN) = ?*

A) 30 N
B) 100 N
C) 130 N
D) 70 N

106) *Box on incline, weight 50 N, angle 30°: (FN = ?)*

A) 50 N
B) 25 N
C) 43.3 N
D) 0 N

107) *Normal force is important because:*

A) Measures tension
B) Pushes objects sideways
C) Acts as gravity
D) Determines friction

108) *Tied string pulls upward on box: normal force formula:*

A) ($F_N = W/2$)
B) ($F_N = W + F_{up}$)
C) ($F_N = W - F_{up}$)
D) ($F_N = 0$)

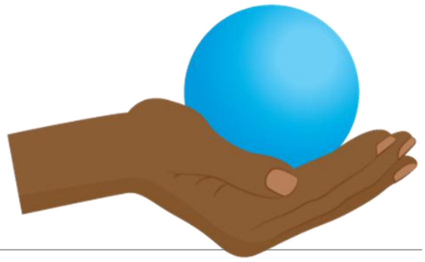
109) *Box on flat table, additional downward force: (FN = ?)*

A) $W - F_{down}$
B) $W + F_{down}$
C) W/2
D) W^2

110) *Why is normal force not always equal to weight?*

A) Other vertical forces present
B) Weight changes
C) Friction changes
D) Tension

Lesson 3 Check Your Progress



34. Interaction Pair Identify each force acting on the ball and its interaction pair in **Figure.**

35. Force Imagine lowering the ball in Figure at increasing speed. Do any of the forces or their interaction-pair partners change? Draw separate free-body diagrams for the forces acting on the ball and for each set of interaction pairs.

36. Tension A block hangs from the ceiling by a massless rope. A second block is attached to the first block and hangs below it on another piece of massless rope. If each of the two blocks has a mass of 5.0 kg, what is the tension in each rope?

37. Tension A block hangs from the ceiling by a massless rope. A 3.0-kg block is attached to the first block and hangs below it on another piece of massless rope. The tension in the top rope is 63.0 N. Find the tension in the bottom rope and the mass of the top block.

38. Critical Thinking A curtain prevents two tug-of-war teams from seeing each other. One team ties its end of the rope to a tree. If the other team pulls with a 500-N force, what is the tension in the rope? Explain.