THE BIG IDEA

An object in mechanical equilibrium is stable, without changes in motion.

Things that are in balance with one another illustrate *equilibrium*.

Things in *mechanical equilibrium* are stable, without changes of motion.

The rocks are in mechanical equilibrium.

An unbalanced external force would be needed to change their resting state.

2.1 Force

A force is needed to change an object's state of motion.

2.1 Force

Net Force

A **force** is a push or a pull.

A force of some kind is always required to change the state of motion of an object.

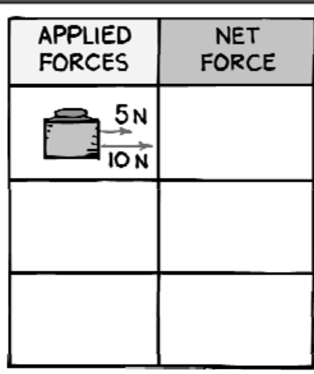
The combination of all forces acting on an object is called the **net force.** The net force on an object changes its motion.

The scientific unit of force is the *newton*, abbreviated N.

2.1 Force

Net Force

The net force depends on the magnitudes and directions of the applied forces.



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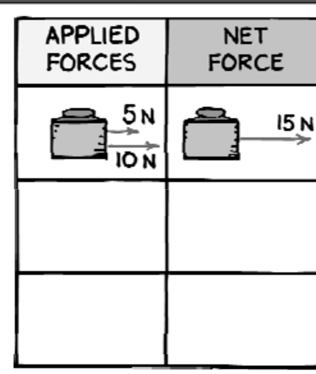

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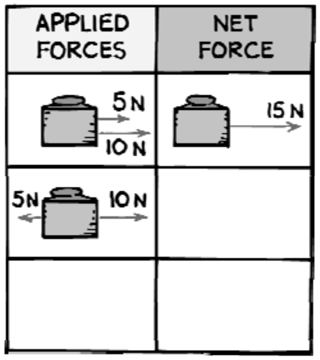

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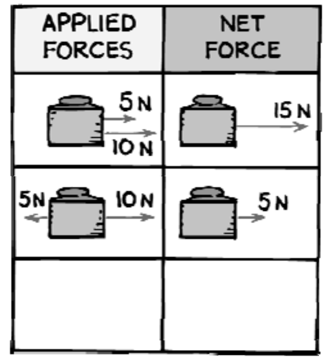

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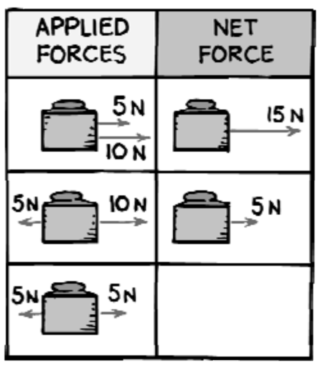

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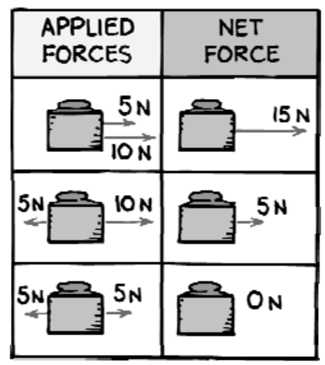
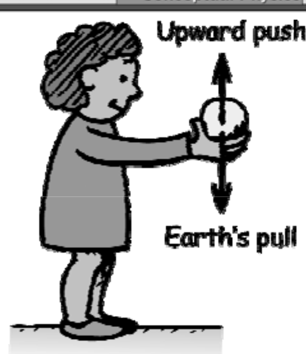


2.1 Force

Net Force

When the girl holds the rock with as much force upward as gravity pulls downward, the net force on the rock is zero.



2.1 Force

Tension and Weight

A stretched spring is under a “stretching force” called *tension*.

Pounds and newtons are units of weight, which are units of force.

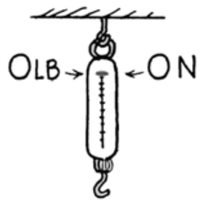
2 Mechanical Equilibrium | Conceptual Physics

2.1 Force

Tension and Weight

The upward tension in the string has the same magnitude as the weight of the bag, so the net force on the bag is zero.

The bag of sugar is attracted to Earth with a gravitational force of 2 pounds or 9 newtons.



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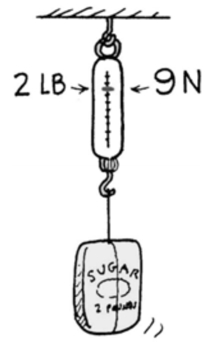


2 Mechanical Equilibrium | Conceptual Physics

2.1 Force

Tension and Weight

There are two forces acting on the bag of sugar:

- tension force acting upward
- weight acting downward

The two forces on the bag are equal and opposite. The net force on the bag is zero, so it remains at rest.

2 Mechanical Equilibrium | Conceptual Physics

2.1 Force

Force Vectors

A **vector** is an arrow that represents the magnitude and direction of a quantity.

A **vector quantity** needs both magnitude and direction for a complete description. Force is an example of a vector quantity.

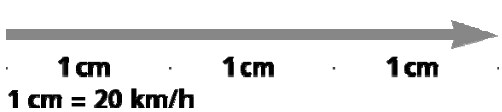
A **scalar quantity** can be described by magnitude only and has no direction. Time, area, and volume are scalar quantities.

2 Mechanical Equilibrium | Conceptual Physics

2.1 Force

Force Vectors

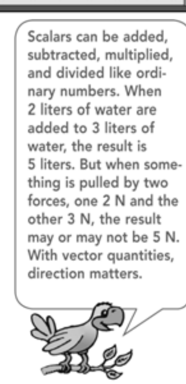
This vector represents a force of 60 N to the right.



2 Mechanical Equilibrium | Conceptual Physics

2.1 Force

Force Vectors



2.1 Force

CONCEPT CHECK: **How can you change an object's state of motion?**

2.2 Mechanical Equilibrium

You can express the equilibrium rule mathematically as $\Sigma F = 0$.

2.2 Mechanical Equilibrium

Mechanical equilibrium is a state wherein no physical changes occur.

Whenever the net force on an object is zero, the object is in mechanical equilibrium—this is known as the **equilibrium rule.**

2.2 Mechanical Equilibrium

$$\Sigma F = 0$$

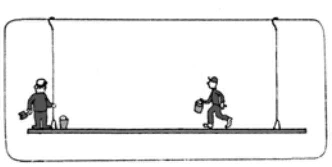
- The Σ symbol stands for "the sum of."
- F stands for "forces."

For a suspended object at rest, the forces acting upward on the object must be balanced by other forces acting downward.

The vector sum equals zero.

2.2 Mechanical Equilibrium

The sum of the upward vectors equals the sum of the downward vectors. $\Sigma F = 0$, and the scaffold is in equilibrium.



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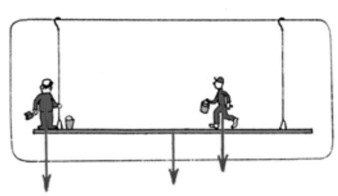

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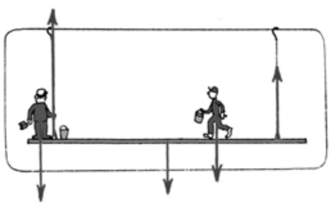

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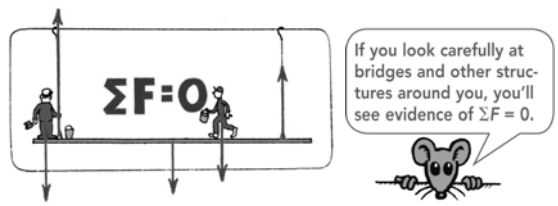
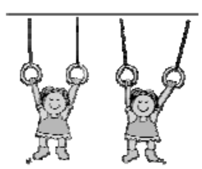


2.2 Mechanical Equilibrium

think!

If the gymnast hangs with her weight evenly divided between the two rings, how would scale readings in both supporting ropes compare with her weight? Suppose she hangs with slightly more of her weight supported by the left ring. How would a scale on the right read?



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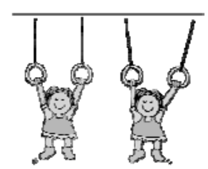


Answer: In the first case, the reading on each scale will be half her weight. In the second case, when more of her weight is supported by the left ring, the reading on the right reduces to less than half her weight. The sum of the scale readings always equals her weight.

2.2 Mechanical Equilibrium

CONCEPT CHECK **How can you express the equilibrium rule mathematically?**

2.3 Support Force

For an object at rest on a horizontal surface, the support force must equal the object's weight.

2.3 Support Force

What forces act on a book lying at rest on a table?

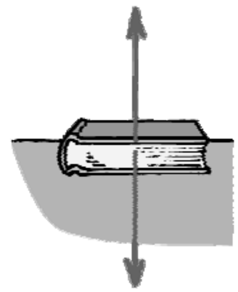
- One is the force due to gravity—the weight of the book.
- There must be another force acting on it to produce a net force of zero—an upward force opposite to the force of gravity.

The upward force that balances the weight of an object on a surface is called the **support force**.

A support force is often called the *normal force.*

2 Mechanical Equilibrium
PresentationEXPRESS Conceptual Physics

2.3 Support Force



The table pushes up on the book with as much force as the downward weight of the book.

2 Mechanical Equilibrium
PresentationEXPRESS Conceptual Physics

2.3 Support Force

The table supports the book with a **support force**—the upward force that balances the weight of an object on a surface.

A support force is often called the *normal force*.

2 Mechanical Equilibrium
PresentationEXPRESS Conceptual Physics

2.3 Support Force

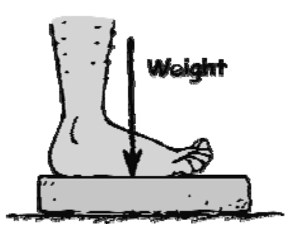
- The upward support force is positive and the downward weight is negative.
- The two forces add mathematically to zero.
- Another way to say the net force on the book is zero is $\Sigma F = 0$.

The book lying on the table compresses atoms in the table and they squeeze upward on the book. The compressed atoms produce the support force.

2 Mechanical Equilibrium
PresentationEXPRESS Conceptual Physics

2.3 Support Force

The upward support force is as much as the downward pull of gravity.



2 Mechanical Equilibrium
PresentationEXPRESS Conceptual Physics

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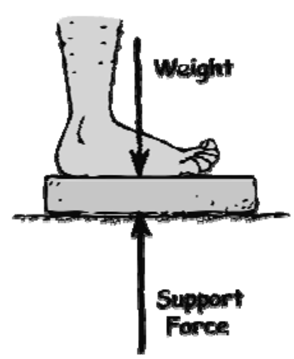


2.3 Support Force

think!

What is the net force on a bathroom scale when a 110-pound person stands on it?

2 Mechanical Equilibrium

2.3 Support Force

think!

What is the net force on a bathroom scale when a 110-pound person stands on it?

Answer: Zero–the scale is at rest. The scale reads the support force, not the net force.

2 Mechanical Equilibrium

2.3 Support Force

think!

Suppose you stand on two bathroom scales with your weight evenly distributed between the two scales. What is the reading on each of the scales? What happens when you stand with more of your weight on one foot than the other?

2 Mechanical Equilibrium

2.3 Support Force

think!

Suppose you stand on two bathroom scales with your weight evenly distributed between the two scales. What is the reading on each of the scales? What happens when you stand with more of your weight on one foot than the other?

Answer: In the first case, the reading on each scale is half your weight. In the second case, if you lean more on one scale than the other, more than half your weight will be read on that scale but less than half on the other. The total support force adds up to your weight.

2 Mechanical Equilibrium

2.3 Support Force

CONCEPT CHECK **For an object at rest on a horizontal surface, what is the support force equal to?**

2 Mechanical Equilibrium

2.4 Equilibrium for Moving Objects

Objects at rest are said to be in static equilibrium; objects moving at constant speed in a straight-line path are said to be in dynamic equilibrium.

2.4 Equilibrium for Moving Objects

The state of rest is only one form of equilibrium.

An object moving at constant speed in a straight-line path is also in a state of equilibrium. Once in motion, if there is no net force to change the state of motion, it is in equilibrium.

2.4 Equilibrium for Moving Objects

An object under the influence of only one force cannot be in equilibrium.

Only when there is no force at all, or when two or more forces combine to zero, can an object be in equilibrium.

2.4 Equilibrium for Moving Objects

When the push on the desk is the same as the force of friction between the desk and the floor, the net force is zero and the desk slides at an unchanging speed.

2.4 Equilibrium for Moving Objects

If the desk moves steadily at constant speed, without change in its motion, it is in equilibrium.

- Friction is a contact force between objects that slide or tend to slide against each other.
- In this case, $\Sigma F = 0$ means that the force of friction is equal in magnitude and opposite in direction to the pushing force.

2.4 Equilibrium for Moving Objects

think!

An airplane flies horizontally at constant speed in a straight-line direction. Its state of motion is unchanging. In other words, it is in equilibrium. Two horizontal forces act on the plane. One is the thrust of the propeller that pulls it forward. The other is the force of air resistance (air friction) that acts in the opposite direction. Which force is greater?

2.4 Equilibrium for Moving Objects

think!

An airplane flies horizontally at constant speed in a straight-line direction. Its state of motion is unchanging. In other words, it is in equilibrium. Two horizontal forces act on the plane. One is the thrust of the propeller that pulls it forward. The other is the force of air resistance (air friction) that acts in the opposite direction. Which force is greater?

Answer: Neither, for both forces have the same strength. Call the thrust *positive*. Then the air resistance is *negative*. Since the plane is in equilibrium, the two forces combine to equal zero.

2 Mechanical Equilibrium — Conceptual Physics

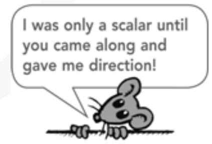
2.4 Equilibrium for Moving Objects

CONCEPT CHECK: **How are static and dynamic equilibrium different?**

2 Mechanical Equilibrium — Conceptual Physics

2.5 Vectors

To find the resultant of two vectors, construct a parallelogram wherein the two vectors are adjacent sides. The diagonal of the parallelogram shows the resultant.



2 Mechanical Equilibrium — Conceptual Physics

2.5 Vectors

The sum of two or more vectors is called their **resultant.**

Combining vectors is quite simple when they are parallel:

- If they are in the same direction, they add.
- If they are in opposite directions, they subtract.

2 Mechanical Equilibrium — Conceptual Physics

2.5 Vectors

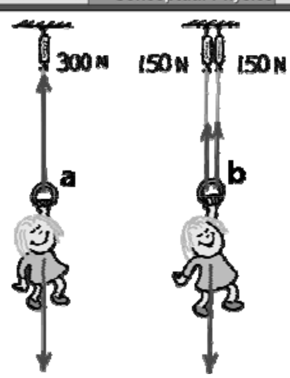
a. The tension in the rope is 300 N, equal to Nellie's weight.

2 Mechanical Equilibrium — Conceptual Physics

2.5 Vectors

a. The tension in the rope is 300 N, equal to Nellie's weight.

b. The tension in each rope is now 150 N, half of Nellie's weight. In each case, $\Sigma F = 0$.



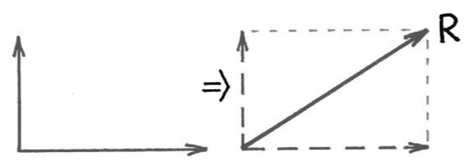
2 Mechanical Equilibrium — Conceptual Physics

2.5 Vectors

The Parallelogram Rule

To find the resultant of nonparallel vectors, we use the parallelogram rule.

Consider two vectors at right angles to each other, as shown below. The constructed parallelogram in this special case is a rectangle. The diagonal is the resultant *R*.



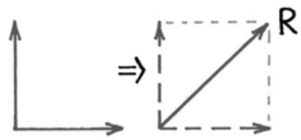
2.5 Vectors

The Parallelogram Rule

In the special case of two perpendicular vectors that are equal in magnitude, the parallelogram is a square.

The resultant is $\sqrt{2}$ times one of the vectors.

For example, the resultant of two equal vectors of magnitude 100 acting at a right angle to each other is 141.4.

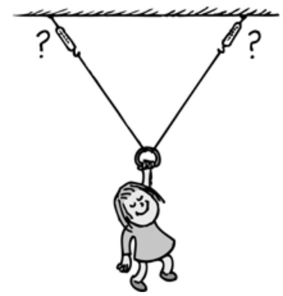


2.5 Vectors

Applying the Parallelogram Rule

When Nellie is suspended at rest from the two non-vertical ropes, is the rope tension greater or less than the tension in two vertical ropes?

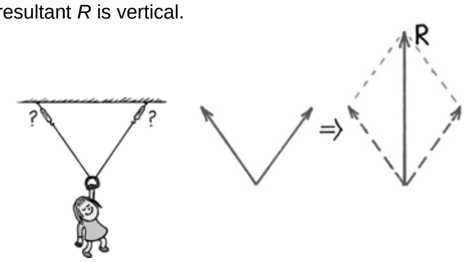
You need to use the parallelogram rule to determine the tension.



2.5 Vectors

Applying the Parallelogram Rule

Notice how the tension vectors form a parallelogram in which the resultant *R* is vertical.



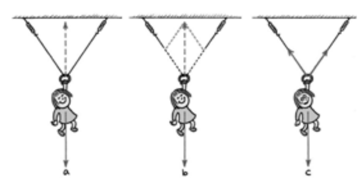
2.5 Vectors

Applying the Parallelogram Rule

Nellie's weight is shown by the downward vertical vector.

An equal and opposite vector is needed for equilibrium, shown by the dashed vector. Note that the dashed vector is the diagonal of the parallelogram defined by the dotted lines.

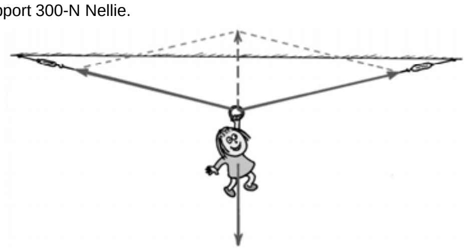
Using the parallelogram rule, we find that the tension in each rope is more than half her weight.



2.5 Vectors

Applying the Parallelogram Rule

As the angle between the ropes increases, tension increases so that the resultant (dashed-line vector) remains at 300 N upward, which is required to support 300-N Nellie.

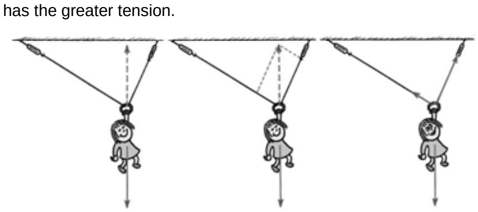


2.5 Vectors

Applying the Parallelogram Rule

When the ropes supporting Nellie are at different angles to the vertical, the tensions in the two ropes are unequal.

By the parallelogram rule, we see that the right rope bears most of the load and has the greater tension.



2.5 Vectors

Applying the Parallelogram Rule

You can safely hang from a clothesline hanging vertically, but you will break the clothesline if it is strung horizontally.

2.5 Vectors

think!

Two sets of swings are shown at right. If the children on the swings are of equal weights, the ropes of which swing are more likely to break?

2.5 Vectors

think!

Two sets of swings are shown at right. If the children on the swings are of equal weights, the ropes of which swing are more likely to break?

Answer: The tension is greater in the ropes hanging at an angle. The angled ropes are more likely to break than the vertical ropes.

2.5 Vectors

think!

Consider what would happen if you suspended a 10-N object midway along a very tight, horizontally stretched guitar string. Is it possible for the string to remain horizontal without a slight sag at the point of suspension?

2.5 Vectors

think!

Consider what would happen if you suspended a 10-N object midway along a very tight, horizontally stretched guitar string. Is it possible for the string to remain horizontal without a slight sag at the point of suspension?

Answer: No way! If the 10-N load is to hang in equilibrium, there must be a supporting 10-N upward resultant. The tension in each half of the guitar string must form a parallelogram with a vertically upward 10-N resultant.

2.5 Vectors

CONCEPT CHECK **How can you find the resultant of two vectors?**

Assessment Questions

1. When you hold a rock in your hand at rest, the forces on the rock
   a. are mainly due to gravity.
   b. are mainly due to the upward push of your hand.
   c. cancel to zero.
   d. don't act unless the rock is dropped.

2 Mechanical Equilibrium
Conceptual Physics

Assessment Questions

1. When you hold a rock in your hand at rest, the forces on the rock
   a. are mainly due to gravity.
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   c. cancel to zero.
   d. don't act unless the rock is dropped.

Answer: C

Assessment Questions

2. Burl and Paul have combined weights of 1300 N. The tensions in the supporting ropes that support the scaffold they stand on add to 1700 N. The weight of the scaffold itself must be
   a. 400 N.
   b. 500 N.
   c. 600 N.
   d. 3000 N.

2 Mechanical Equilibrium
Conceptual Physics

Assessment Questions

2. Burl and Paul have combined weights of 1300 N. The tensions in the supporting ropes that support the scaffold they stand on add to 1700 N. The weight of the scaffold itself must be
   a. 400 N.
   b. 500 N.
   c. 600 N.
   d. 3000 N.

Answer: A

Assessment Questions

3. Harry gives his little sister a piggyback ride. Harry weighs 400 N and his little sister weighs 200 N. The support force supplied by the floor must be
   a. 200 N.
   b. 400 N.
   c. 600 N.
   d. more than 600 N.

2 Mechanical Equilibrium
Conceptual Physics

Assessment Questions

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   a. 200 N.
   b. 400 N.
   c. 600 N.
   d. more than 600 N.

Answer: C

Assessment Questions

4. When a desk is horizontally pushed across a floor at a steady speed in a straight-line direction, the amount of friction acting on the desk is
   a. less than the pushing force.
   b. equal to the pushing force.
   c. greater than the pushing force.
   d. dependent on the speed of the sliding crate.

Assessment Questions

4. When a desk is horizontally pushed across a floor at a steady speed in a straight-line direction, the amount of friction acting on the desk is
   a. less than the pushing force.
   b. equal to the pushing force.
   c. greater than the pushing force.
   d. dependent on the speed of the sliding crate.

Answer: B

Assessment Questions

5. When Nellie hangs at rest by a pair of ropes, the tensions in the ropes
   a. always equal her weight.
   b. always equal half her weight.
   c. depend on the angle of the ropes to the vertical.
   d. are twice her weight.

Assessment Questions

5. When Nellie hangs at rest by a pair of ropes, the tensions in the ropes
   a. always equal her weight.
   b. always equal half her weight.
   c. depend on the angle of the ropes to the vertical.
   d. are twice her weight.

Answer: C