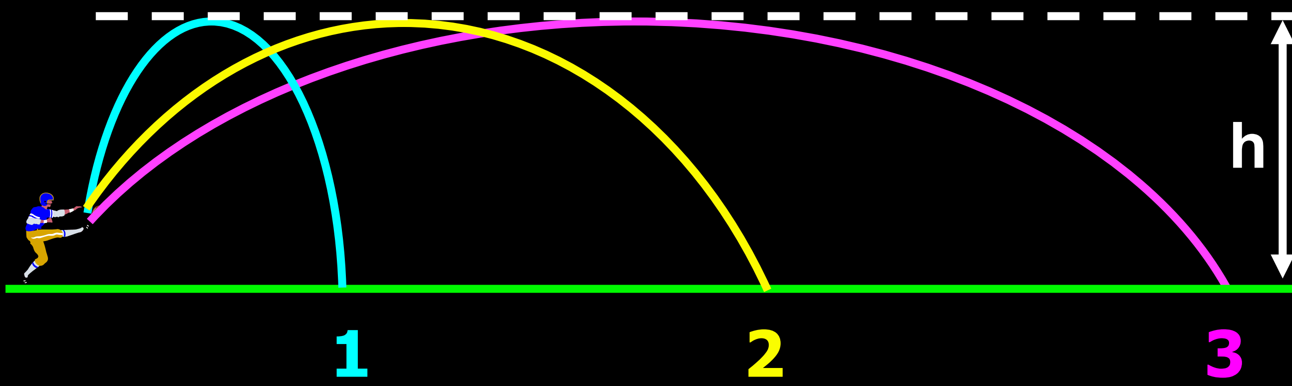
ConcepTest 3.7a Punts I

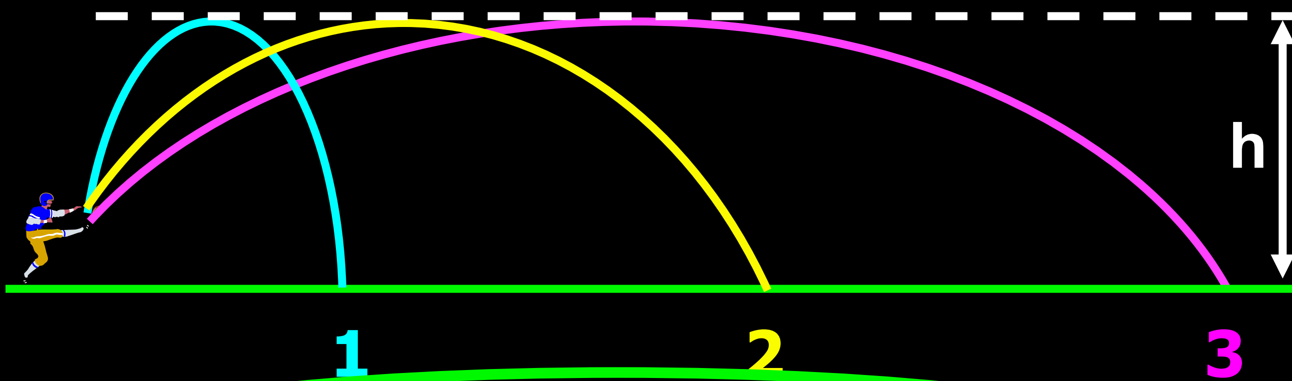
Which of the 3 punts has the longest hang time?



4) all have the same hang time

ConcepTest 3.7a Punts I

Which of the 3 punts has the longest hang time?



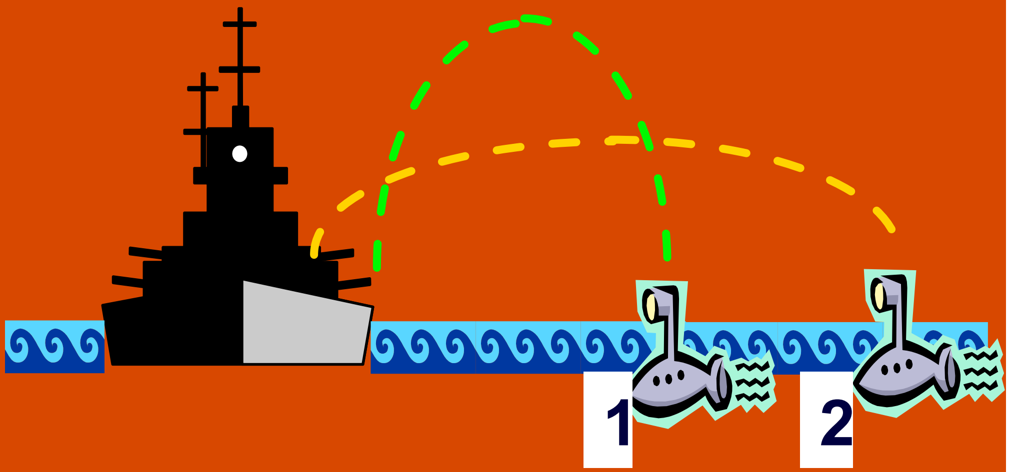
4) all have the same hang time

The time in the air is determined by the ***vertical motion*** ! Since all of the punts reach the **same height**, they all stay in the air for the **same time**.

Follow-up: Which one had the greater initial velocity?

ConcepTest 3.7b Punts II

A battleship simultaneously fires two shells at two enemy submarines. The shells are launched with the same initial velocity. If the shells follow the trajectories shown, which submarine gets hit first ?

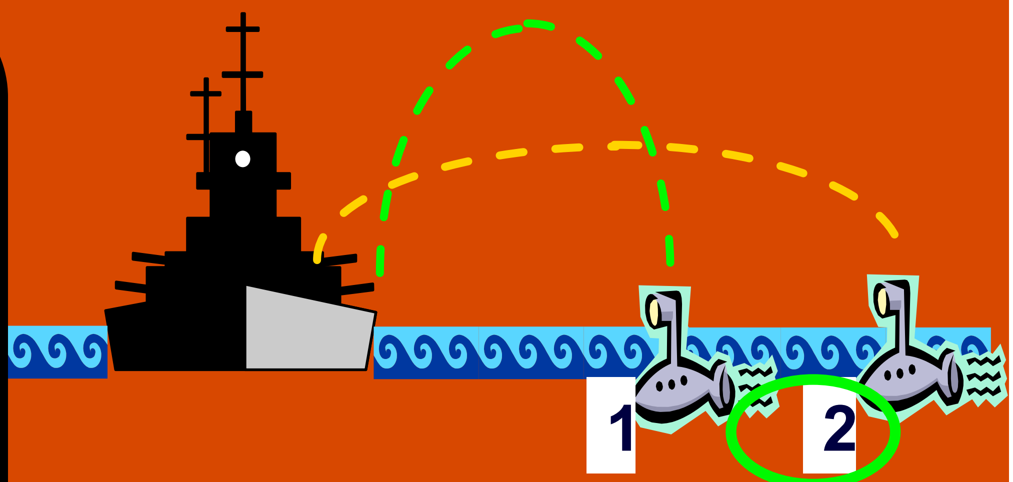


3) both at the same time

ConcepTest 3.7b Punts II

A battleship simultaneously fires two shells at two enemy submarines. The shells are launched with the **same** initial velocity. If the shells follow the trajectories shown, which submarine gets hit **first** ?

The flight time is fixed by the motion in the *y*-direction. The *higher* an object goes, the *longer* it stays in flight. The shell hitting ship #2 goes *less high*, therefore it stays in flight for *less time* than the other shell. Thus, ship #2 is hit first.

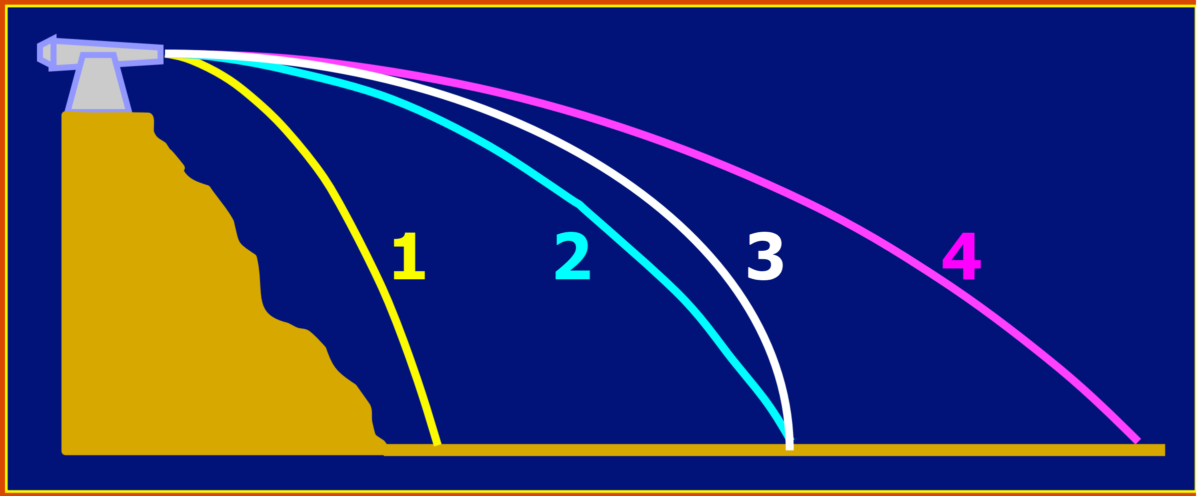


3) both at the same time

Follow-up: Which one traveled the greater distance?

ConcepTest 3.8 Cannon on the Moon

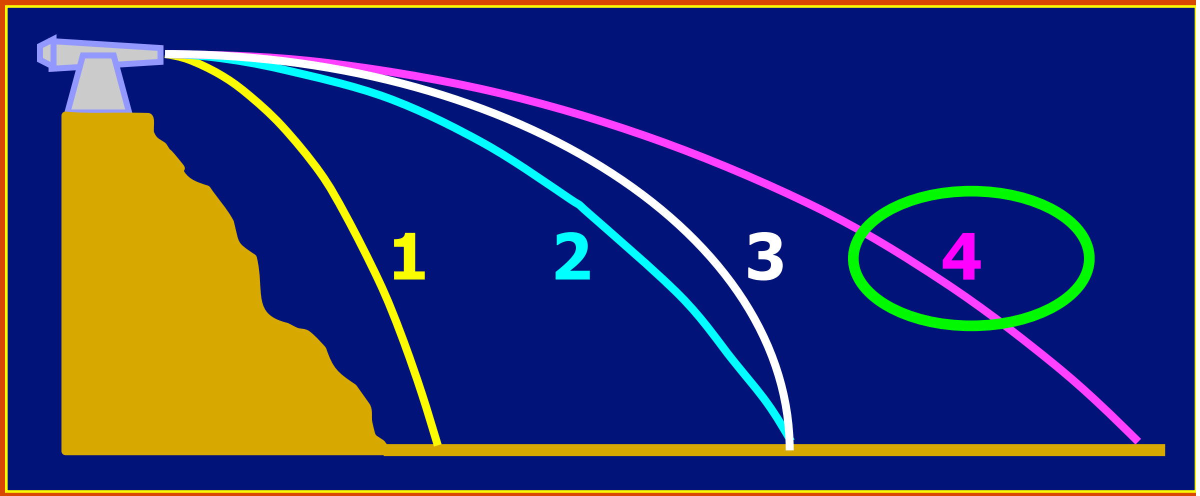
For a cannon on Earth, the cannonball would follow path 2. Instead, if the same cannon were on the Moon, where g = 1.6 m/s^2, which path would the cannonball take in the same situation?



ConcepTest 3.8 Cannon on the Moon

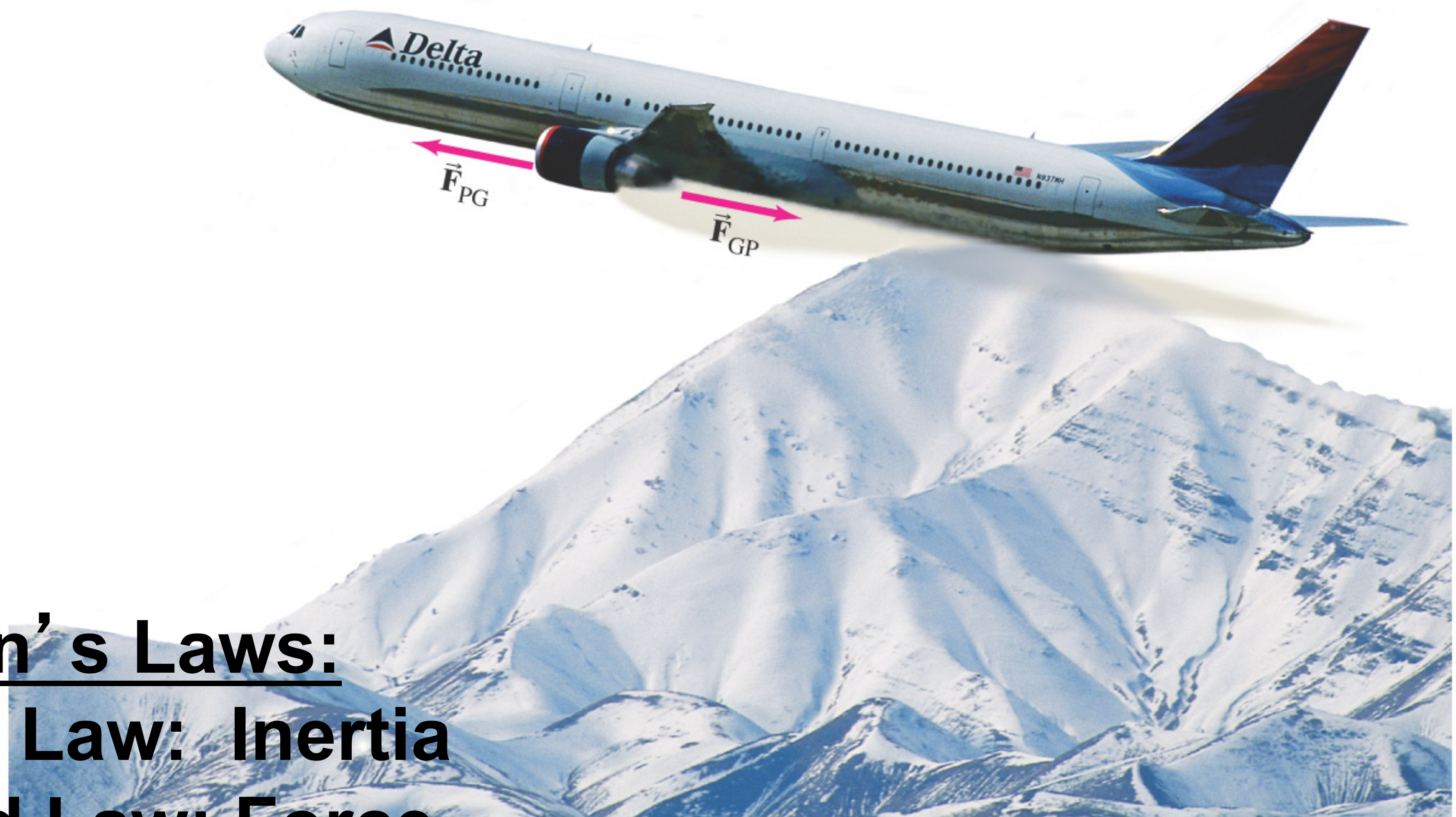
For a cannon on Earth, the cannonball would follow path 2. Instead, if the same cannon were on the Moon, where g = 1.6 m/s^2, which path would the cannonball take in the same situation?

The ball will spend **more time** in the air because $g_{Moon} < g_{Earth}$. With more time, it can travel **farther** in the horizontal direction.



Follow-up: Which path would it take in outer space?

Lecture 6: Chapter 4
Newton's Laws of Motion



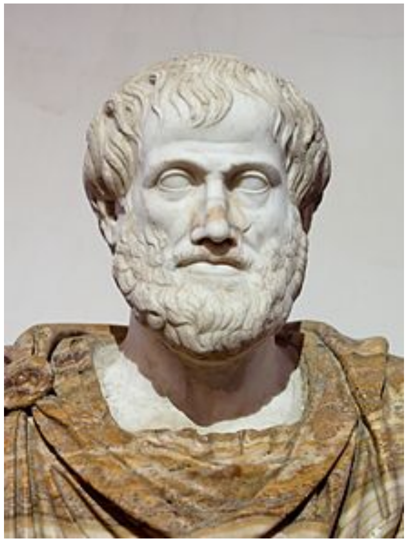
Newton's Laws:

- 1st Law: Inertia
- 2nd Law: Force
- 3rd Law: Action and Reaction

Units of Chapter 4

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

Isaac Newton
British: 25 December 1642 – 20 March 1727
English physicist, mathematician, astronomer, natural philosopher, alchemist and theologian, who has been "considered by many to be the greatest and most influential scientist who ever lived."



Aristotle
(Ancient Greek: (384–322 BC)

Greek philosopher and polymath, student of Plato and teacher of Alexander the Great. His writings cover many subjects, including physics, poetry, theater, music, logic, rhetoric, linguistics, politics, government, ethics, biology, and zoology.

Motion & Forces

- Aristotle said "No Motion without Force".
- Newton said "There is no **change** of motion without a force".
- What is a Force? In language of science we don't mean "a force of nature". But, we are familiar with the effects of force. E.g. A hurricane exerts a lot of force.
- Example-> Is the ground pushing up?
- Go back to Aristotle and reverse the meaning, does that help? -> If it did we could build a bridge out of Paper- so long as it didn't move it wouldn't fall down!
- Along as no motion occurs, no work is done, (looks ahead to chapter 6). So we can have force without motion, and inanimate objects do exert force.
- In physics Force is a vector whose magnitude is given by $F=Ma$

Newton's Laws of Motion

1. First law: If an object experiences no net force, then its velocity is constant: the object is either at rest, or it moves in a straight line with constant speed.

2. Second law: The acceleration a of a body is parallel to and directly proportional to the net force F acting on the body, is in the direction of the net force, and is inversely proportional to the mass m of the body, i.e., $F = ma$.

3. Third law: When a first body exerts a force F_1 on a second body, the second body simultaneously exerts a force $F_2 = -F_1$ on the first body. This means that F_1 and F_2 are equal in magnitude and opposite in direction.

The three laws of motion were first compiled by Sir Isaac Newton in his work Philosophiæ Naturalis Principia Mathematica, published in 1687.

Is this a correct statement of Newton's First Law?

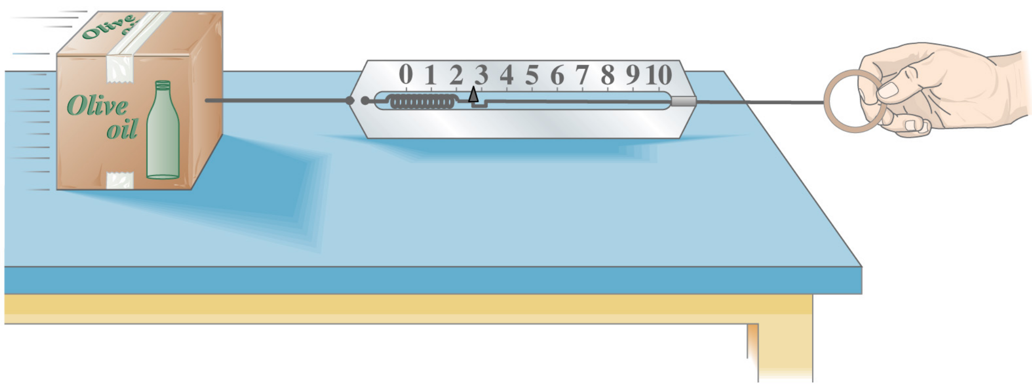
"Any object will seek a state of rest unless a force acts on it"

A. True

B. False

4-1 Force

A **force** is a **push** or **pull**. An object at rest needs a force to get it **moving**; a moving object needs a force to change its **velocity**.

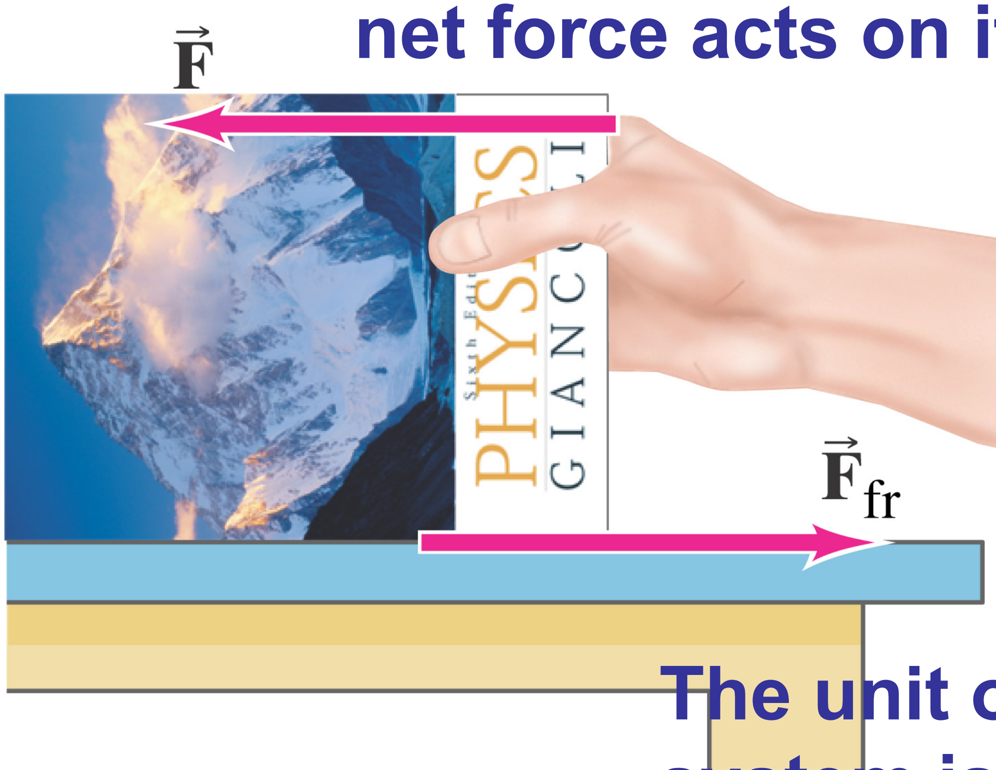


The **magnitude** of a force can be measured using a spring scale.

4-2 Newton's First Law of Motion

Newton's **first law** is often called the law of **inertia**.

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.



The unit of force in the SI system is the **newton** (N).

Inertia

- Inertia is an intrinsic property of an object
- So a “heavy” object has the same inertia on the Moon as on the Earth.
- Newton coined the word “Mass” to mean “amount of matter”.
- Mass and inertia appear synonymous.

ConcepTest 4.1a Newton's First Law I

A book is lying at rest on a table. The book will remain there at rest because:

1) there is a net force but the book has too much inertia
2) there are no forces acting on it at all
3) it does move, but too slowly to be seen
4) there is no net force on the book
5) there is a net force, but the book is too heavy to move

ConcepTest 4.1a Newton's First Law I

A book is lying at rest on a table. The book will remain there at rest because:

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3) it does move, but too slowly to be seen
4) there is no net force on the book
5) there is a net force, but the book is too heavy to move

There are forces acting on the book, but the only forces acting are in the *y*-direction. Gravity acts downward, but the table exerts an upward force that is equally strong, so the two forces cancel, **leaving no net force**.

ConcepTest 4.1d Newton's First Law IV

You kick a smooth flat stone out on a frozen pond. The stone slides, slows down and eventually stops. You conclude that:

1) the force pushing the stone forward finally stopped pushing on it
2) no net force acted on the stone
3) a net force acted on it all along
4) the stone simply "ran out of steam"
5) the stone has a natural tendency to be at rest

ConcepTest 4.1d Newton's First Law IV

You kick a smooth flat stone out on a frozen pond. The stone slides, slows down and eventually stops. You conclude that:

1) the force pushing the stone forward finally stopped pushing on it
2) no net force acted on the stone
3) a net force acted on it all along
4) the stone simply "ran out of steam"
5) the stone has a natural tendency to be at rest

After the stone was kicked, no force was pushing it along! However, there must have been **some force** acting on the stone **to slow it down and stop it**. This would be friction!!

Follow-up: What would you have to do to keep the stone moving?

ConcepTest 4.1b Newton's First Law II

A hockey puck slides on ice at **constant velocity**. What is the ***net*** force acting on the puck?

1) more than its weight
2) equal to its weight
3) less than its weight but more than zero
4) depends on the speed of the puck
5) zero

ConcepTest 4.1b Newton's First Law II

A hockey puck slides on ice at constant velocity. What is the *net* force acting on the puck?

1) more than its weight
2) equal to its weight
3) less than its weight but more than zero
4) depends on the speed of the puck
5) zero

The puck is moving at a constant velocity, and therefore it is not accelerating. Thus, there must be no net force acting on the puck.

Follow-up: Are there any forces acting on the puck? What are they?

ConcepTest 4.2a Cart on Track I

Consider a cart on a horizontal **frictionless** table. Once the cart has been given a push and released, what will happen to the cart?

1) slowly come to a stop
2) continue with constant acceleration
3) continue with decreasing acceleration
4) continue with constant velocity
5) immediately come to a stop

ConcepTest 4.2a Cart on Track I

Consider a cart on a horizontal **frictionless** table. Once the cart has been given a push and released, what will happen to the cart?

1) slowly come to a stop
2) continue with constant acceleration
3) continue with decreasing acceleration
4) continue with constant velocity
5) immediately come to a stop

After the cart is released, there is **no longer a force** in the x-direction. ***This does not mean that the cart stops moving!!*** It simply means that the cart will ***continue moving with the same velocity*** it had at the moment of release. The initial push got the cart moving, but that force is not needed to *keep* the cart in motion.

ConcepTest 4.2b Cart on Track II

We just decided that the cart continues with constant velocity. What would have to be done in order to have the cart continue with constant acceleration?

1) push the cart harder before release
2) push the cart longer before release
3) push the cart continuously
4) change the mass of the cart
5) it is impossible to do that

ConcepTest 4.2b Cart on Track II

We just decided that the cart continues with constant velocity. What would have to be done in order to have the cart continue with constant acceleration?

1) push the cart harder before release
2) push the cart longer before release
3) push the cart continuously
4) change the mass of the cart
5) it is impossible to do that

In order to achieve a non-zero acceleration, it is necessary to maintain the applied force. The only way to do this would be to continue pushing the cart as it moves down the track. This will lead us to a discussion of Newton's Second Law.

<u>Inertial reference frames</u>:

An inertial reference frame is a situation or location in which Newton's first law is valid.

This excludes rotating and accelerating frames.

So: In certain situations there are forces that do not <u>appear</u> to obey Newton's first law.

Examples:

- **Centrifugal forces affecting the tracks of hurricanes.**
- **Motion of unsecured objects in a vehicle during braking or acceleration**

ConcepTest 4.1c Newton's First Law III

You put your book on the bus seat next to you. When the bus stops suddenly, the book slides forward off the seat. Why?

1) a net force acted on it
2) no net force acted on it
3) it remained at rest
4) it did not move, but only seemed to
5) gravity briefly stopped acting on it

ConcepTest 4.1c Newton's First Law III

You put your book on the bus seat next to you. When the bus stops suddenly, the book slides forward off the seat. Why?

1) a net force acted on it
2) no net force acted on it
3) it remained at rest
4) it did not move, but only seemed to
5) gravity briefly stopped acting on it

The book was initially moving forward (since it was on a moving bus). When the bus stopped, the book **continued moving forward**, which was its **initial state of motion**, and therefore it slid forward off the seat.

Follow-up: What is the force that usually keeps the book on the seat?

Mass

Mass is the measure of inertia of an object. In the SI system, mass is measured in **kilograms**.

Mass is not **weight**:

Mass is a **property** of an object. Weight is the **force** exerted on that object by gravity.

If you go to the moon, whose gravitational acceleration is about 1/6 g, you will weigh much less. Your MASS, and your INERTIA however, will be the SAME.

Mass means amount of matter - philosophically this was a highly abstract notion in earlier times

ConcepTest 4.8 On the Moon

An astronaut on Earth kicks a bowling ball and hurts his foot. A year later, the same astronaut kicks a bowling ball on the Moon with the same force. His foot hurts...

1) more
2) less
3) the same

ConcepTest 4.8 On the Moon

An astronaut on Earth kicks a bowling ball and hurts his foot. A year later, the same astronaut kicks a bowling ball on the Moon with the same force. His foot hurts...

1) more
2) less
3) the same

The *masses* of both the bowling ball and the astronaut remain the same, so his foot feels the same resistance and hurts the *same* as before.

Follow-up: What is different about the bowling ball on the Moon?

Newton's Second Law of Motion

Newton's **second law** is the relation between **acceleration** and **force**.

Acceleration is proportional to force and inversely proportional to mass.

$$F = ma$$

Force equals Mass times Acceleration

Force is a **vector**, so $\sum\vec{F} = m\vec{a}$ is true along each coordinate axis.

ConcepTest 4.3 Truck on Frozen Lake

A very large truck sits on a frozen lake. Assume there is no friction between the tires and the ice. A fly suddenly smashes against the front window. What will happen to the truck?

1) it is too heavy, so it just sits there
2) it moves backward at const. speed
3) it accelerates backward
4) it moves forward at const. speed
5) it accelerates forward

ConcepTest 4.3 Truck on Frozen Lake

A very large truck sits on a frozen lake. Assume there is no friction between the tires and the ice. A fly suddenly smashes against the front window. What will happen to the truck?

1) it is too heavy, so it just sits there
2) it moves backward at const. speed
3) it accelerates backward
4) it moves forward at const. speed
5) it accelerates forward

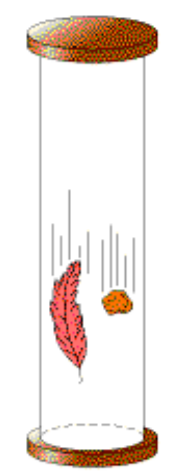
When the fly hit the truck, it exerted a force on the truck (only for a fraction of a second). So, in this time period, the truck accelerated (backwards) up to some speed. After the fly was squashed, it no longer exerted a force, and the truck simply continued moving at constant speed.

Follow-up: What is the truck doing 5 minutes after the fly hit it?

ConcepTest 4.7a Gravity and Weight I

What can you say about the force of gravity F_g acting on a stone and a feather?

1) F_g is greater on the feather
2) F_g is greater on the stone
3) F_g is zero on both due to vacuum
4) F_g is equal on both always
5) F_g is zero on both always


Evacuated tube

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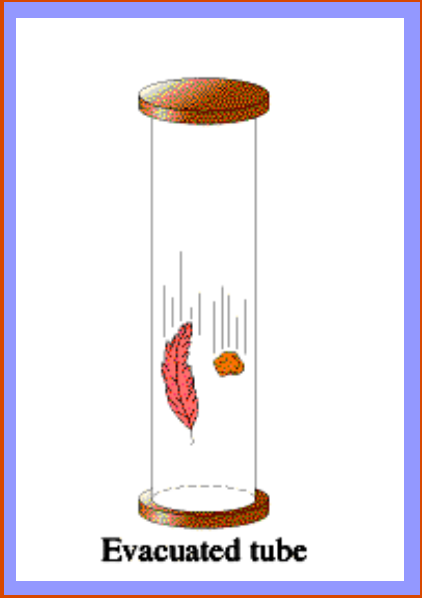
The force of gravity (weight) depends on the mass of the object!! The stone has more mass, therefore more weight.



ConcepTest 4.7b Gravity and Weight II

What can you say about the acceleration of gravity acting on the stone and the feather?

1) it is greater on the feather
2) it is greater on the stone
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4) it is equal on both always
5) it is zero on both always

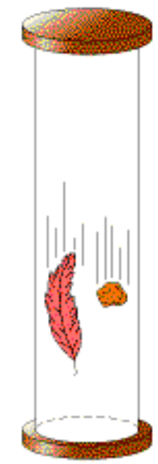
ConcepTest 4.7b Gravity and Weight II

What can you say about the acceleration of gravity acting on the stone and the feather?

1) it is greater on the feather
2) it is greater on the stone
3) it is zero on both due to vacuum
4) it is equal on both always
5) it is zero on both always

The acceleration is given by ***F/m*** so here the mass divides out. Since we know that the force of gravity (weight) is ***mg***, then we end up with acceleration ***g*** for both objects.

Follow-up: Which one hits the bottom first?



Evacuated tube

ConcepTest 4.9a Going Up I

A block of mass *m* rests on the floor of an elevator that is **moving upward at constant speed**. What is the relationship between the force due to gravity and the normal force on the block?

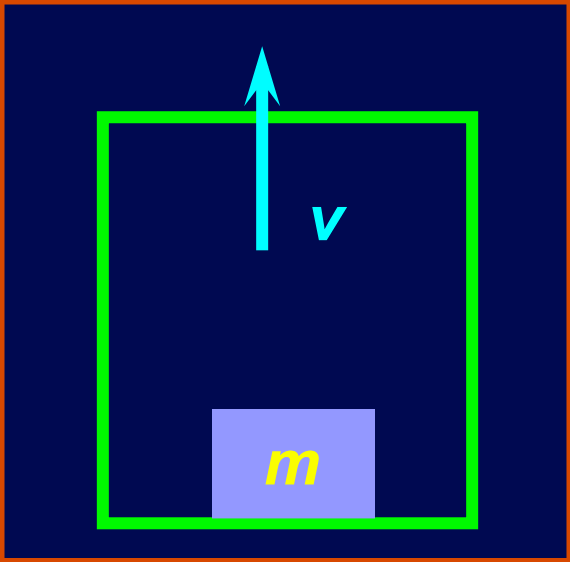
1) $N > mg$

2) $N = mg$

3) $N < mg$ (but not zero)

4) $N = 0$

5) depends on the size of the elevator



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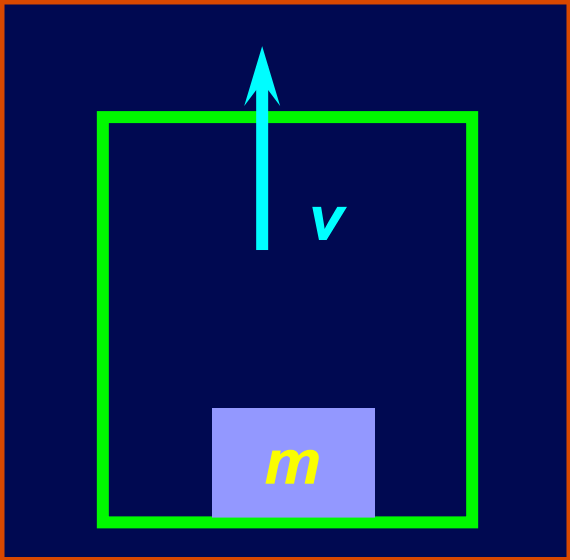
3) $N < mg$ (but not zero)
4) $N = 0$
5) depends on the size of the elevator

The block is moving at constant speed, so it must have no net force on it. The forces on it are *N* (up) and *mg* (down), so $N = mg$, just like the block at rest on a table.



ConcepTest 4.9b Going Up II

A block of mass *m* rests on the floor of an elevator that is accelerating upward. What is the relationship between the force due to gravity and the normal force on the block?

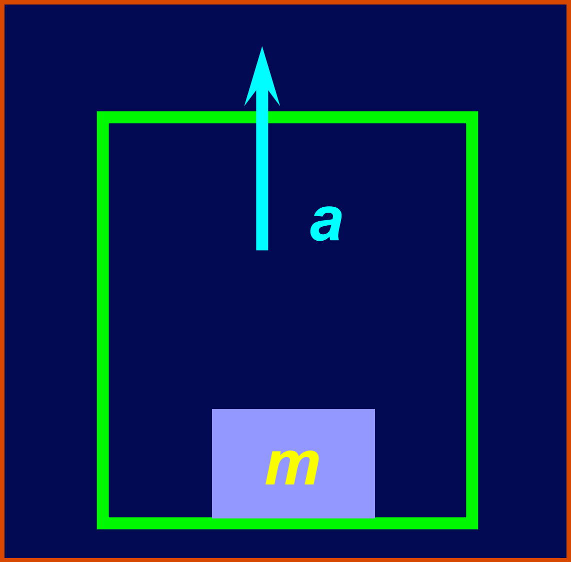
1) $N > mg$

2) $N = mg$

3) $N < mg$ *(but not zero)*

4) $N = 0$

5) depends on the size of the elevator

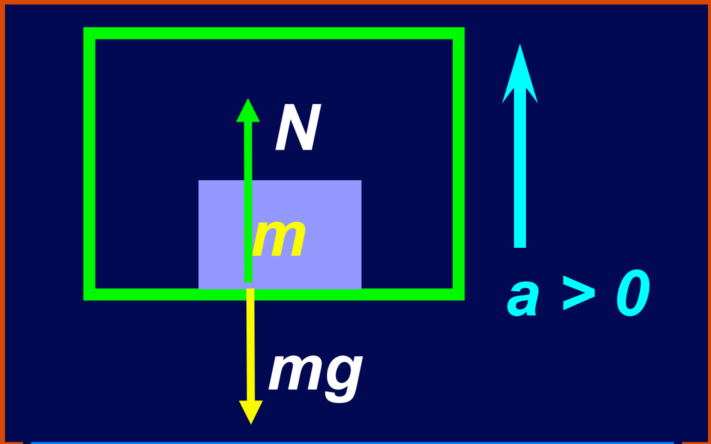


ConcepTest 4.9b Going Up II

A block of mass *m* rests on the floor of an elevator that is accelerating upward. What is the relationship between the force due to gravity and the normal force on the block?

1) $N > mg$
2) $N = mg$
3) $N < mg$ *(but not zero)*
4) $N = 0$
5) depends on the size of the elevator

The block is accelerating upward, so it *must* have a net upward force. The forces on it are N (up) and mg (down), so N must be greater than mg in order to give the net upward force!



$$\Sigma F = N - mg = ma > 0$$
$$\therefore \quad N > mg$$

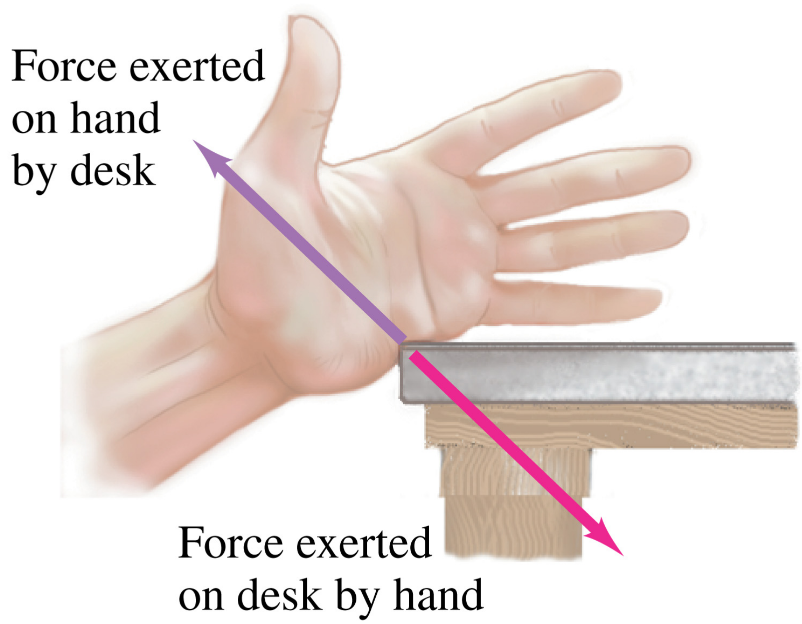
Follow-up: What is the normal force if the elevator is in free fall downward?

4-5 Newton's Third Law of Motion

Any time a **force** is exerted on an object, that force is caused by another object.

Newton's **third law:**

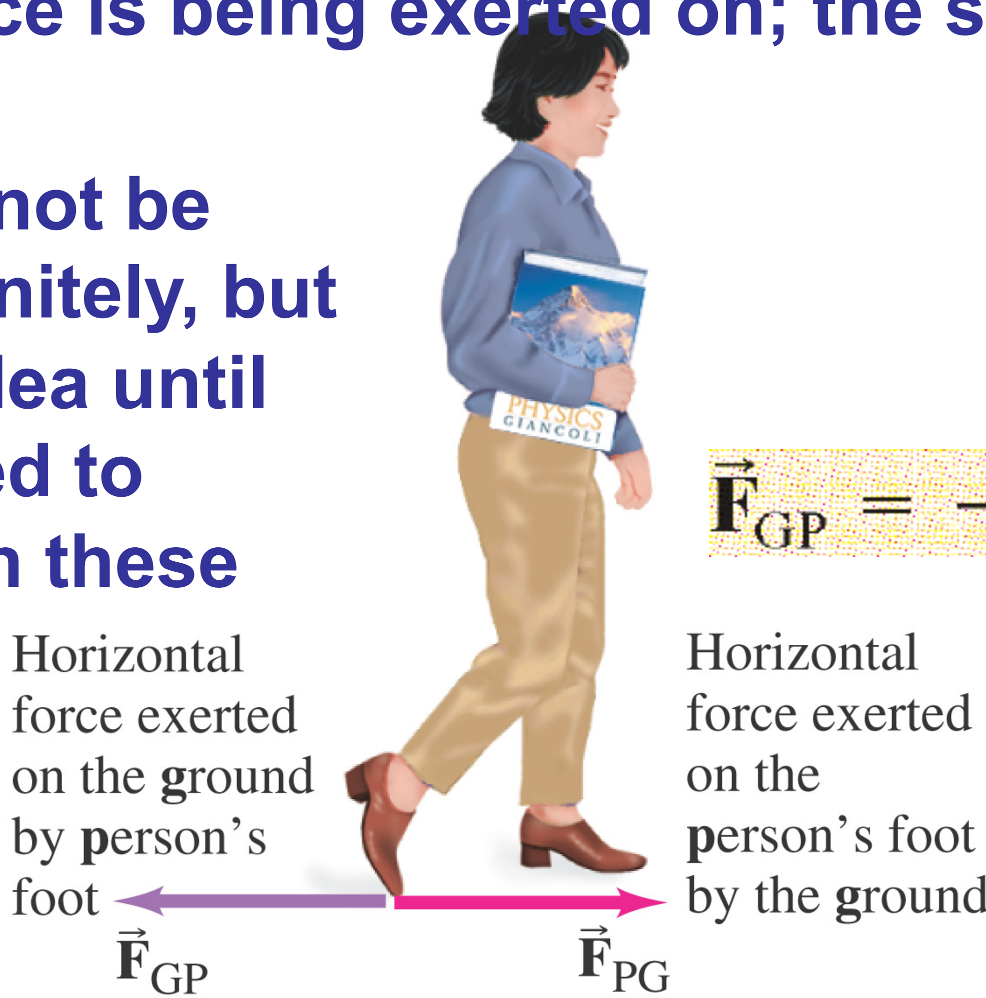
Whenever one object exerts a **force** on a second object, the second exerts an equal force in the **opposite direction** on the first.

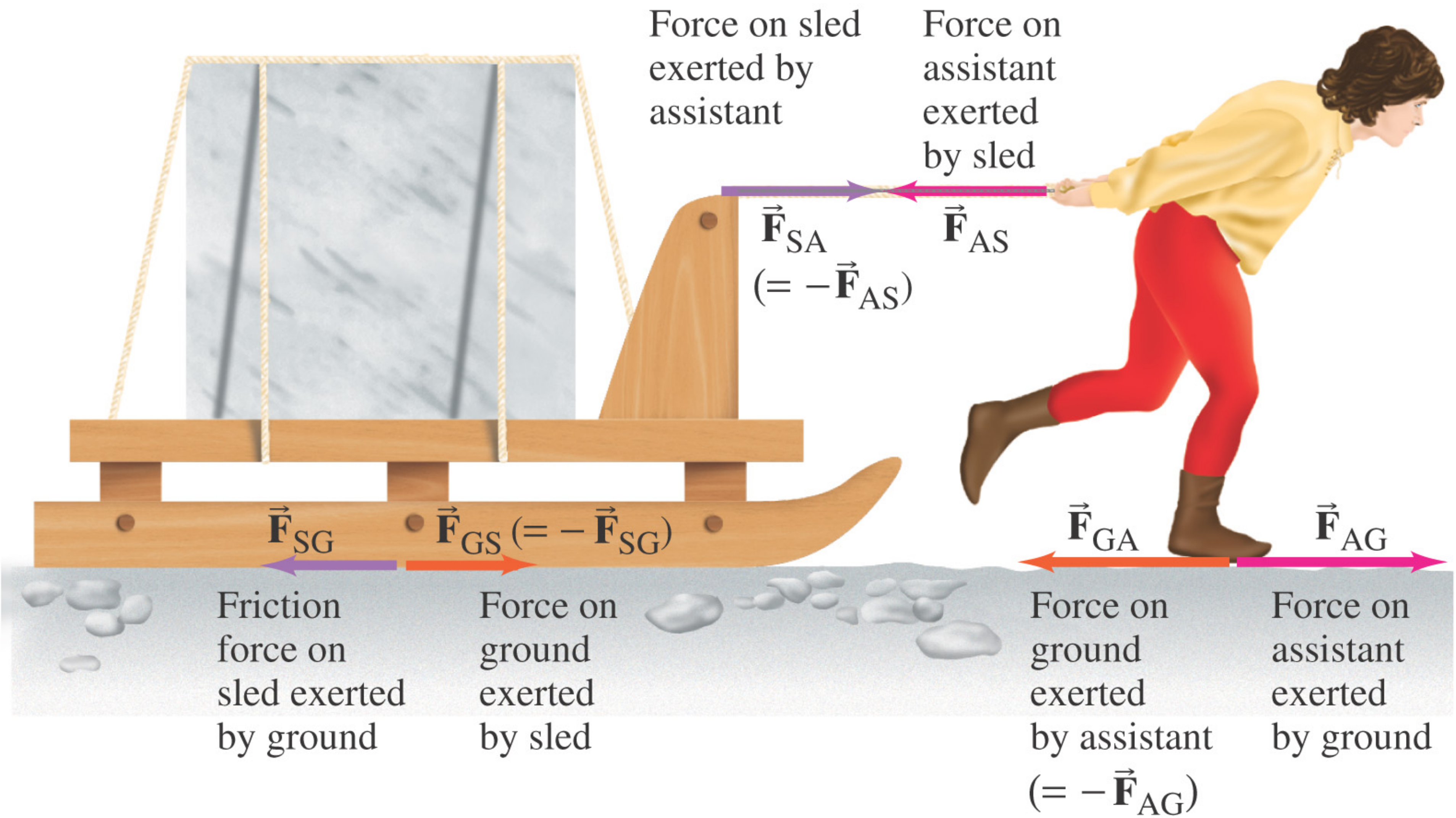


Newton's Third Law of Motion

- The Paired forces act on different objects
- Helpful notation: the first **subscript** is the object that the force is being exerted on; the second is the source.
- This need not be done indefinitely, but is a good idea until you get used to dealing with these forces.

$$\vec{F}_{GP} = -\vec{F}_{PG} \quad (4\text{-}2)$$




Force on sled exerted by assistant
Force on assistant exerted by sled
$\vec{\mathbf{F}}_{SA}$ $(= -\vec{\mathbf{F}}_{AS})$
$\vec{\mathbf{F}}_{AS}$
$\vec{\mathbf{F}}_{SG}$
$\vec{\mathbf{F}}_{GS}$ $(= -\vec{\mathbf{F}}_{SG})$
$\vec{\mathbf{F}}_{GA}$
$\vec{\mathbf{F}}_{AG}$
Friction force on sled exerted by ground
Force on ground exerted by sled
Force on ground exerted by assistant $(= -\vec{\mathbf{F}}_{AG})$
Force on assistant exerted by ground