Chapter 4 – Forces in One Dimension

4.1 Forces and Motion

What causes an acceleration?

Force – a push or pull exerted on an object.

A force causes a change in an object's velocity (magnitude and / or direction)

4.1 Forces and Motion

1. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the +x direction.
2. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the -x direction.
3. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the +y direction.
4. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the -y direction.
5. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the -y direction and another engine exerts a force in the -x direction.
6. The space probe has a constant velocity in the +x direction when suddenly an engine exerts a force on the probe in the +y direction and another engine exerts a force in the +x direction.
7. The space probe has a constant velocity in the +x direction when suddenly all four engines fire simultaneously.

4.1 Forces and Motion

Consider pushing a book on a table:

- The harder I push, the greater the effect on the motion
- If I push to the right, the book moves to the right

Since it has both magnitude and direction, force is a vector quantity

Force is represented with the letter, F

The unit of force is the Newton (N) – the amount of force needed to give a 1 kg mass an acceleration of 1 m/s^2

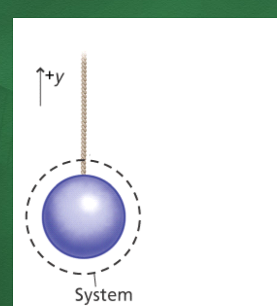
$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$

4.1 Forces and Motion

There are contact forces and field forces (e.g. – gravity)

4.1 Forces and Motion

Free-body diagram – a physical model, which represents the forces acting on a system



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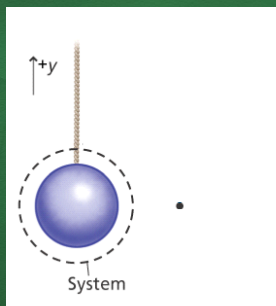

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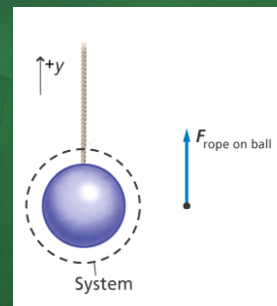
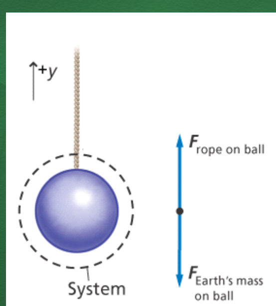


Force vector always drawn starting at the particle and in the direction of the applied force

4.1 Forces and Motion

Free-body diagram – a physical model, which represents the forces acting on a system



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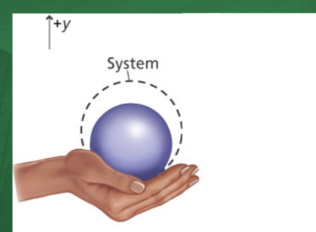

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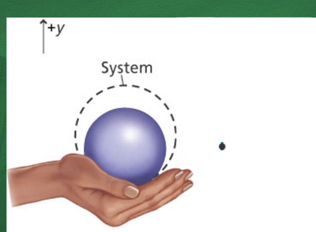

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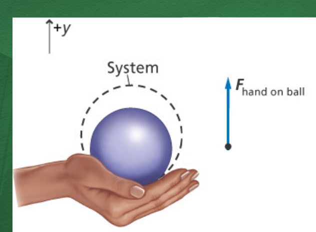
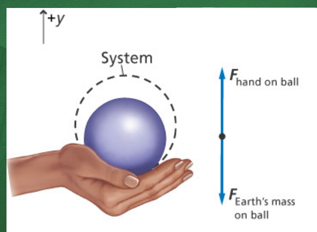
Free-body diagram – a physical model, which represents the forces acting on a system



Force vector always drawn starting at the particle and in the direction of the applied force

4.1 Forces and Motion

Free-body diagram – a physical model, which represents the forces acting on a system



Force vector always drawn starting at the particle and in the direction of the applied force

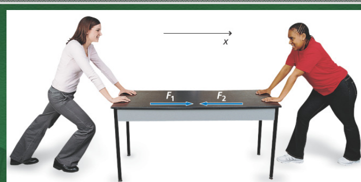
Remember, the length of each arrow should be proportional to the size of the force

4.1 Forces and Motion

Draw a free-body diagram for the following:

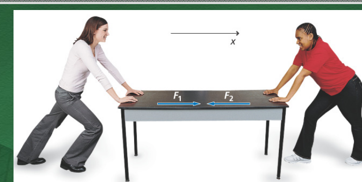
- a book at rest on a table top
- a flying squirrel is gliding from a tree to the ground at constant velocity. Consider air resistance
- a force is applied to the right to drag a sled across loosely-packed snow with a rightward acceleration.
- a rightward force is applied to a book in order to move it across a desk at constant velocity.
- a football is moving upwards towards its peak after having been booted by the punter. Neglect air resistance.
- a girl is suspended motionless from a bar which hangs from the ceiling by two ropes.

4.1 Forces and Motion



Suppose two people push a table with the same amount of force, but in opposite directions.

4.1 Forces and Motion



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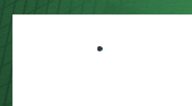

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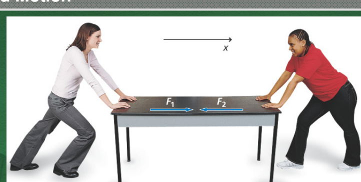

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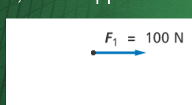

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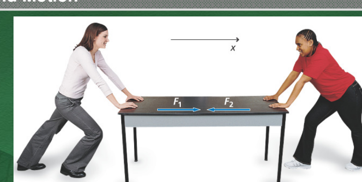

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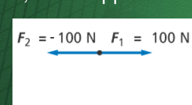

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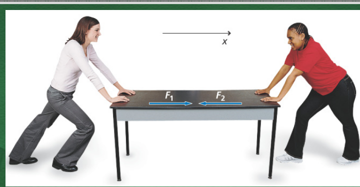

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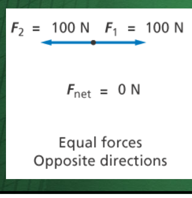


Net force – the vector sum of all the forces on an object.

The table will not move (no net force, no change in velocity)

4.1 Forces and Motion

Newton's 1st Law of Motion (Law of Inertia)

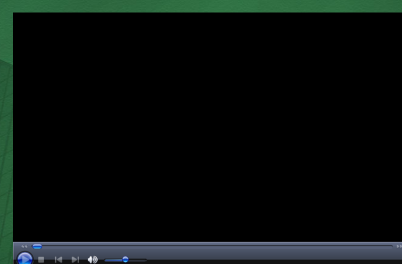
An object at rest will remain at rest, and an object in motion will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero

Inertia – the tendency of an object to resist a change in its state of motion.

- if an object is at rest, it remains at rest
- if an object is moving at a constant velocity, it continues to do so

4.1 Forces and Motion

4.1 Forces and Motion



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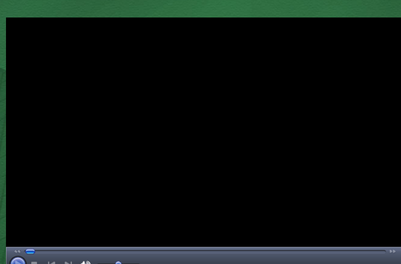

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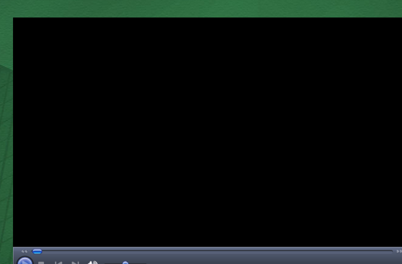

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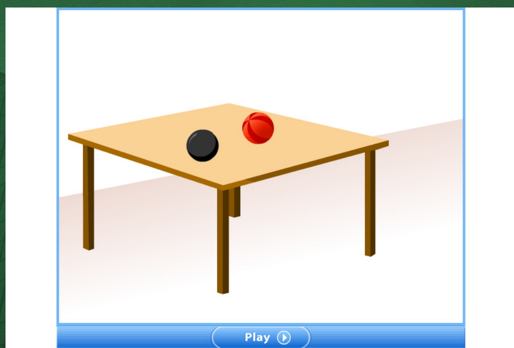

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Newton's 1st Law of Motion (Law of Inertia)

An object at rest will remain at rest, and an object in motion will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero

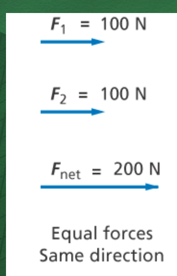
Inertia – the tendency of an object to resist a change in its state of motion.

- if an object is at rest, it remains at rest
- if an object is moving at a constant velocity, it continues to do so

Equilibrium – when the net force on an object is zero.

4.1 Forces and Motion

Suppose two people push a table with the same amount of force, but in the same direction.

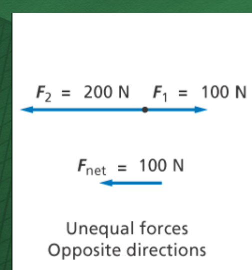


The net force is 200 N in the direction of the force

The table will accelerate in the direction of the net force

4.1 Forces and Motion

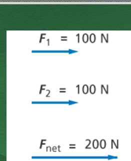
Suppose two people push with different amounts of force, in opposite directions.

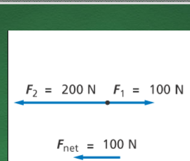


The net force is -100 N

The table will accelerate in the direction of the net force

4.1 Forces and Motion





In either of the last two situations, we know the table will accelerate in the direction of the applied force.

But, what will be the acceleration of the table?

We know from everyday experience that for a given force, the greater the mass of the object, the less its acceleration.

4.1 Forces and Motion

Newton's 2nd Law of Motion (Law of Acceleration)

The acceleration of an object is proportional to the net force and inversely proportional to the mass of the object being accelerated

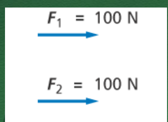
$$a = \frac{F_{net}}{m}$$

Newton's 2nd Law

$$\Sigma F = ma$$

Net force
Σ is Greek "Sigma" means "sum of"

4.2 Using Newton's Laws

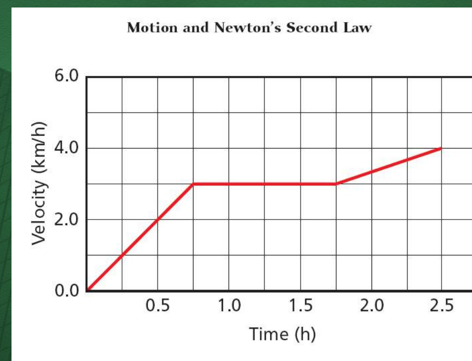


If two people pushed a 15.0 kg table in the same direction, each with a force of 100. N, what is the acceleration of the table?

If two people pushed a 15.0 kg table in opposite directions, one with a force of 100. N, and the other with a force of 200. N, what is the acceleration of the table?

4.2 Using Newton's Laws

Transparency 4-2



4.2 Using Newton's Laws

Two horses are pulling a 100-kg cart in the same direction, applying a force of 50 N each. What is the acceleration of the cart?

A. 2 m/s²

B. 1 m/s²

C. 0.5 m/s²

D. 0 m/s²

4.2 Using Newton's Laws

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A. 2 m/s²

B. 1 m/s²

C. 0.5 m/s²

D. 0 m/s²

4.2 Using Newton's Laws

Two friends Mary and Maria are trying to pull a 10-kg chair in opposite directions. If Maria applied a force of 60 N and Mary applied a force of 40 N, in which direction will the chair move and with what acceleration?

A. The chair will move towards Mary with an acceleration of 2 m/s².

B. The chair will move towards Mary with an acceleration of 10 m/s².

C. The chair will move towards Maria with an acceleration of 2 m/s².

D. The chair will move towards Maria with an acceleration of 10 m/s².

4.2 Using Newton's Laws

Two friends Mary and Maria are trying to pull a 10-kg chair in opposite directions. If Maria applied a force of 60 N and Mary applied a force of 40 N, in which direction will the chair move and with what acceleration?

A. The chair will move towards Mary with an acceleration of 2 m/s².

B. The chair will move towards Mary with an acceleration of 10 m/s².

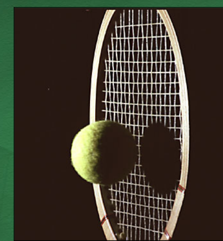
C. The chair will move towards Maria with an acceleration of 2 m/s².

D. The chair will move towards Maria with an acceleration of 10 m/s².

4.2 Using Newton's Laws

A .430 kilogram soccer ball lying on the ground is kicked and flies off at 23.0 m/s. If the duration of impact was 0.0090 seconds, what was the average force on the ball?

4.2 Using Newton's Laws



A 65.0 gram tennis ball approaches a racket at 35.0 m/s, is in contact with the racket's strings for .455 seconds, and then rebounds at 40.0 m/s. What was the average force the racket exerted on the ball?

4.2 Using Newton's Laws

1. Joyce and Efua are skating, Joyce pushes Efua, whose mass is 30.0 kg, with a force of 10.0 N. What is Efua's resulting acceleration?

2. A race car has a mass of 650 kg. It starts from rest and travels 30.0 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is exerted on it?

4.2 Using Newton's Laws

1. A car of mass 2000 kg slows down at a rate of 3.0 m/s² when approaching a stop sign. What is the magnitude of the net force causing it to slow down?

2. A race car has a mass of 650 kg. It starts from rest and travels 30.0 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is exerted on it?

4.2 Using Newton's Laws

What is weight?

The magnitude of an object's weight is equal to its mass times the acceleration it would have if it were falling freely.

We denote the weight of an object as F_g, measured in Newtons

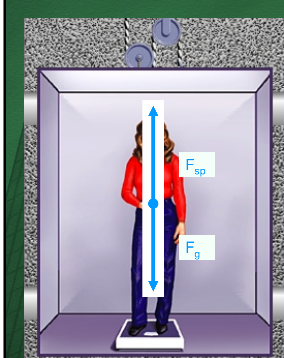
The weight of an object

$$\boxed{F_g = mg}$$

An astronaut on the moon weighs less than when he is on Earth, however, his mass remains the same at either place.

4.2 Using Newton's Laws

apparent weight – the force exerted by a scale



The woman has a mass of 75 kg

If the elevator is not accelerating, she is in equilibrium and the net force on her is zero

$\Sigma F = ma = 0$ and $\Sigma F = F_{sp} + F_g$

so, $F_{sp} + F_g = 0$

so, $F_{sp} = - F_g$

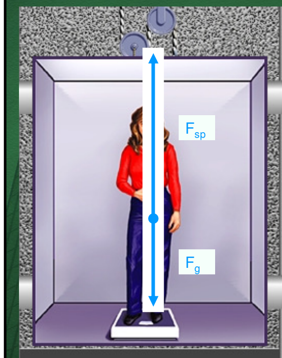
remember, $F_g = mg$

so, $F_{sp} = - mg$

so, $F_{sp} = - (75\ \text{kg})(-9.80\ \text{m/s}^2)$

$F_{sp} = 735\ \text{N}$

4.2 Using Newton's Laws



The woman has a mass of 75 kg

If the elevator is accelerating upward at 2.00 m/s², there is a net force applied to her

$\Sigma F = ma = (75\text{ kg})(2.00\text{ m/s}^2)$

and $\Sigma F = F_{sp} + F_g$

so, $F_{sp} + F_g = (75\text{ kg})(2.00\text{ m/s}^2)$

so, $F_{sp} = 150\text{ N} - F_g$

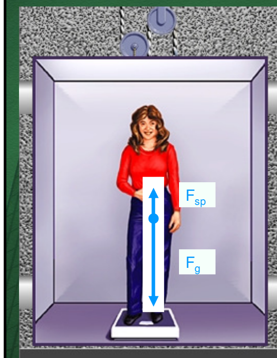
remember, $F_g = mg$

so, $F_{sp} = 150\text{ N} - mg$

so, $F_{sp} = 150\text{ N} - (75\text{ kg})(-9.80\text{ m/s}^2)$

$F_{sp} = 885\text{ N}$

4.2 Using Newton's Laws



The woman has a mass of 75 kg

If the elevator is accelerating downward at -2.00 m/s², there is a net force applied to her

$\Sigma F = ma = (75\text{ kg})(-2.00\text{ m/s}^2)$

and $\Sigma F = F_{sp} + F_g$

so, $F_{sp} + F_g = (75\text{ kg})(-2.00\text{ m/s}^2)$

so, $F_{sp} = -150\text{ N} - F_g$

remember, $F_g = mg$

so, $F_{sp} = -150\text{ N} - mg$

so, $F_{sp} = -150\text{ N} - (75\text{ kg})(-9.80\text{ m/s}^2)$

$F_{sp} = 585\text{ N}$

4.2 Using Newton's Laws

cable breaks!!!

The woman has a mass of 75 kg

If the cable breaks, the elevator is accelerating downward at –9.80 m/s², there is a net force applied to her

$\Sigma F = ma = (75\text{ kg})(-9.80\text{ m/s}^2)$

and $\Sigma F = F_{sp} + F_g$

so, $F_{sp} + F_g = (75\text{ kg})(-9.80\text{ m/s}^2)$

so, $F_{sp} = -735\text{ N} - F_g$

remember, $F_g = mg$

so, $F_{sp} = -735\text{ N} - mg$

so, $F_{sp} = -735\text{ N} - (75\text{ kg})(-9.80\text{ m/s}^2)$

$F_{sp} = 0\text{ N}$

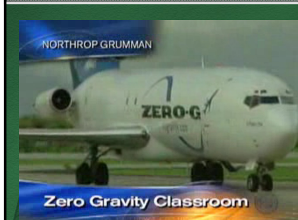
4.2 Using Newton's Laws

$F_{sp} = 0\text{ N}$

The woman has an apparent weight of 0 N.

She is experiencing weightlessness – an object's apparent weight of zero that results when there are not contact forces pushing up on the object

4.2 Using Newton's Laws



4.2 Using Newton's Laws

A 4.0 kg bucket of water is raised from a well by a rope. If the upward acceleration of the bucket is 2.0 m/s², find the force exerted by the rope on the bucket of water.

4.2 Using Newton's Laws

If mass of a person on Earth is 20 kg, what will be his mass on moon? (Gravity on Moon is six times less than the gravity on Earth.)

A. $(20\text{ kg})\,(6\times g\text{ m/s}^2)$

B. $(20\text{ kg})\left(\dfrac{6}{g\text{ m/s}^2}\right)$

C. 20 kg

D. $(20\text{ kg})\left(\dfrac{g\text{ m/s}^2}{6}\right)$

4.2 Using Newton's Laws

If mass of a person on Earth is 20 kg, what will be his mass on moon? (Gravity on Moon is six times less than the gravity on Earth.)

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B. $(20\text{ kg})\left(\dfrac{6}{g\text{ m/s}^2}\right)$

C. 20 kg

D. $(20\text{ kg})\left(\dfrac{g\text{ m/s}^2}{6}\right)$

4.2 Using Newton's Laws

Your mass is 100 kg, and you are standing on a bathroom scale in an elevator. What is the scale reading when the elevator is falling freely?

A. $(100\text{ kg})(g\text{ m/s}^2)$

B. 0 N

C. $(100\text{ kg})(2\times g\text{ m/s2})$

D. $\left(\dfrac{100\text{ kg}}{2\times g\text{ m/s}^2}\right)$

4.2 Using Newton's Laws

Your mass is 100 kg, and you are standing on a bathroom scale in an elevator. What is the scale reading when the elevator is falling freely?

A. $(100\text{ kg})(g\text{ m/s}^2)$

B. 0 N

C. $(100\text{ kg})(2\times g\text{ m/s2})$

D. $\left(\dfrac{100\text{ kg}}{2\times g\text{ m/s}^2}\right)$

4.2 Using Newton's Laws

In which of the following cases will your apparent weight be greater than your real weight?

A. The elevator is at rest.

B. The elevator is accelerating in upward direction.

C. The elevator is accelerating in downward direction.

D. Apparent weight is never greater than real weight.

4.2 Using Newton's Laws

In which of the following cases will your apparent weight be greater than your real weight?

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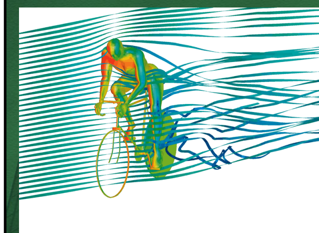
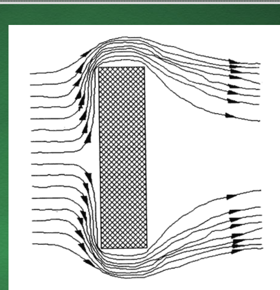
4.2 Using Newton's Laws

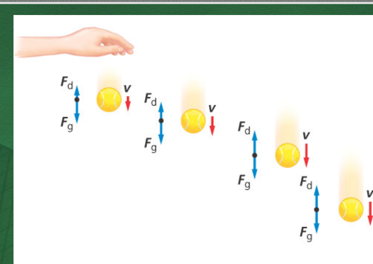




drag force – the force exerted by a fluid on an object moving through the fluid

as velocity increases, the drag force increases

4.2 Using Newton's Laws



terminal velocity – the constant velocity that is reached when the drag force equals the force of gravity

4.3 Interaction Forces

What causes the nail to be driven into the wood?

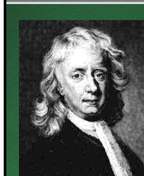
What causes the hammer to stop?

In both cases there is a change in velocity.

Each object underwent an acceleration.

Each object had a force applied to it.

4.3 Interaction Forces



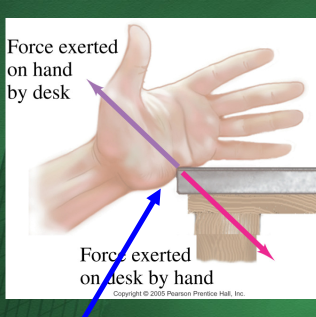
Newton's 3rd Law of Motion (Law of Interaction)

Whenever one object exerts a force on a second object, the second exerts an equal and opposite force on the first

"to every action there is an equal and opposite reaction"

Remember that the "**action**" force and the "**reaction**" force are acting on **different** objects!!!

4.3 Interaction Forces



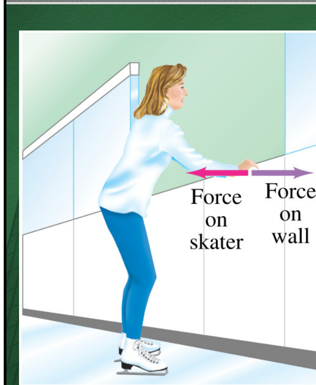
If you push on the desk, the desk pushes back on you.

The harder you push, the harder it pushes on you!

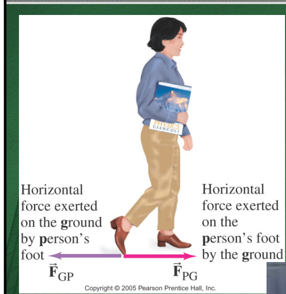
You feel the force exerted on you, NOT what you exert on something else

Interaction pair – two forces in opposite directions, but equal in magnitude

4.3 Interaction Forces



4.3 Interaction Forces



Think of the difficulty where friction is reduced; walking on ice or driving in the mud

4.3 Interaction Forces

Wings push on the air; air pushes on the wings

4.3 Interaction Forces

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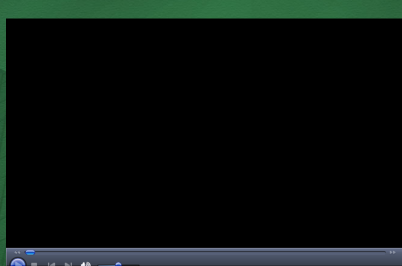

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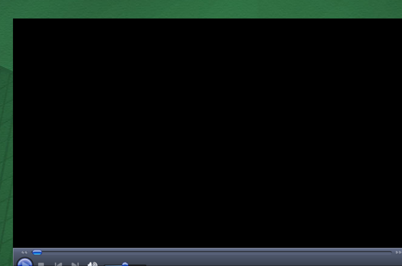

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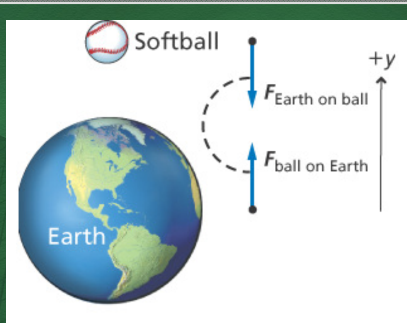
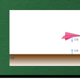


The Earth "pulls" on the ball and the ball "pulls" on the Earth



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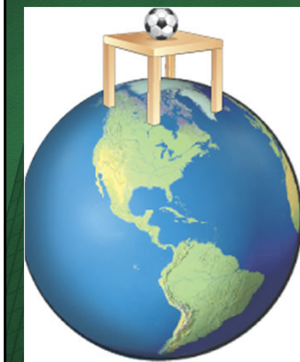
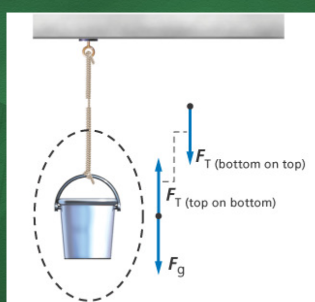


What action-reaction pairs is the soccer ball involved in?

4.3 Interaction Forces

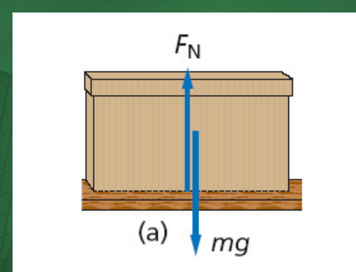
Tension – the force exerted by a string or rope



The tension in the rope is equal to the weight of the bucket

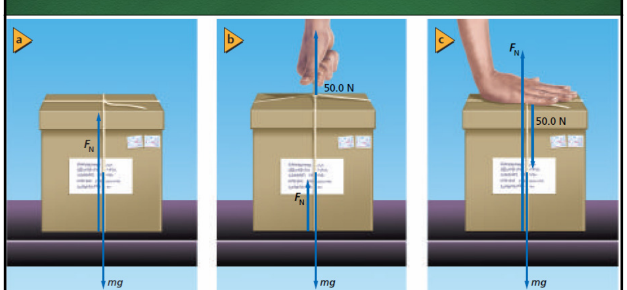
4.3 Interaction Forces

Normal force – the perpendicular contact force exerted by a surface on another object



Weight and normal force are **NOT** action-reaction pairs

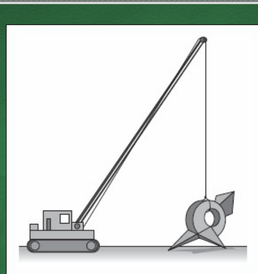
4.3 Interaction Forces



4.3 Interaction Forces

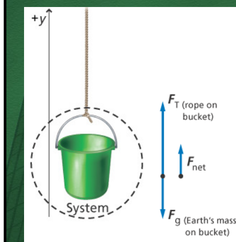
You are walking along when you slip on some ice and fall. For a moment your are in free fall. During this time, what force do you exert on Earth if your mass is 55.0 kg?

4.3 Interaction Forces



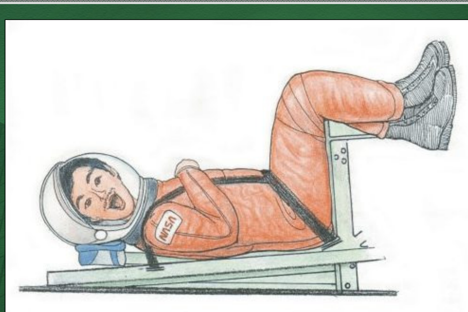
A large sculpture is lowered into place by a crane. The sculpture has a mass of 2100 kg. When the sculpture makes contact with the ground, the crane slowly releases the tension in the cable as the workers make the final adjustments to its position on the ground. What is the normal force on the sculpture when the tension in the cable is 18,400 N?

4.3 Interaction Forces



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 is moving at 3.0 m/s. If the acceleration is constant, is the rope in danger of breaking?

4.3 Interaction Forces



A rocket blasts off from rest and attains a speed of 45 m/s in 15 s. An astronaut has a mass of 57 kg. What is the astronaut's apparent weight during takeoff?

4.3 Interaction Forces

A woman stands on a scale in a moving elevator. Her mass is 60.0 kg, and the combined mass of the elevator and scale is an additional 815 kg. Starting from rest, the elevator accelerates upward. During the acceleration, there is a tension of 9410 N in the hoisting cable. What is the reading on the scale during the acceleration?

4.3 Interaction Forces

Is it possible to have motion in the absence of a force?

If an object is at rest, can we conclude that there are not external forces acting on it?

A large crate is placed on the bed of a truck but not tied down.

a) As the truck accelerates forward, the crate slides across the bed until it hits the tailgate. Explain what causes this.

b) If the driver slammed on the brakes, what could happen to the crate?

4.3 Interaction Forces

A space explorer is moving through space far from any planet or star and notices a large rock, taken as a specimen from an alien planet, floating around the cabin of the ship. Should the explorer push it gently or kick it toward the storage compartment. Why?

A 1850 kg car is moving to the right at a constant velocity of 1.44 m/s. What is the net force on the car?

A 5.0 kg bucket of water is raised from a well by a rope. If the upward acceleration of the bucket is 3.0 m/s^2, find the force exerted by the rope on the bucket of water.

4.3 Interaction Forces

A 0.150 kg baseball is thrown upward with an initial speed of 20.0 m/s

a) What is the force on the ball when it reaches half its maximum height?
b) What is the force on the ball when it reaches its peak?

An astronaut is orbiting the earth in a space vehicle. The acceleration due to gravity at that distance is half it value on the surface of the Earth. Which of the following is true?

a) His weight is zero.
b) His mass is zero.
c) His weight is half its original value.
d) His mass is half it original values.
e) His weight remains the same.
f) His mass remains the same.

4.3 Interaction Forces

Chapter 4 Vocabulary

tension
terminal velocity
weightlessness
inertia
Newton's first law
apparent weight
Newton's second law
normal force
equilibrium
free-body diagram
interaction pair
drag force
net force
force
Newton's third law

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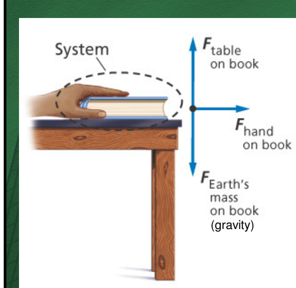
free-body diagram

4.1 Forces and Motion



When considering a force it is necessary to identify the object of interest (the book)

The book is the system

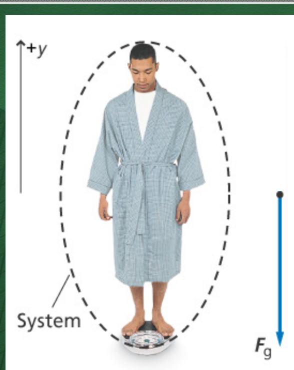
Everything else is the external world

4.1 Forces and Motion

Free-body Diagrams

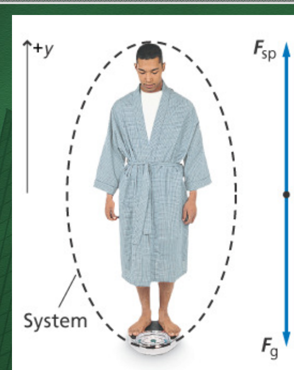
4.2 Using Newton's Laws

4.2 Using Newton's Laws



Force of gravity pulling system down

4.2 Using Newton's Laws



Force of spring in scale pushing system up

Force of gravity pulling system down

$\Sigma F = F_{sp} + F_g = ma$ but $ma = 0$

so $F_{sp} + F_g = 0$

The reading on the scale is determined by the amount of force the springs inside it exert on you → $F_{sp} = -F_g$

4.3 Interaction Forces