Week 1

NEWTON’S LAWS OF MOTION

THE CONCEPT OF EQUILIBRIUM

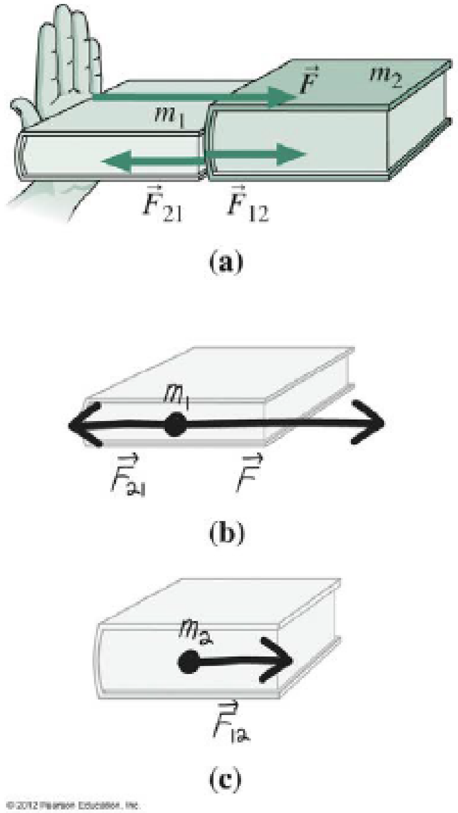
Moment of Inertia
Deflections
Modulus of Elasticity

NEWTON'S LAWS OF MOTION

- **First Law:** A particle originally at rest, or moving in a straight line at constant velocity, will remain in this state if resultant force acting on particle is zero. ($\Sigma F = 0$ …statics)
- **Second Law:** If the resultant force on particle is not zero, particle experiences an acceleration in same direction as resultant force. This acceleration has magnitude proportional to resultant force.
- ($\Sigma F = R = m\,a$ …dynamics)
- **Third Law:** Mutual forces of action and reaction between two particles are equal, opposite and collinear. ($F_{12} = -F_{21}$)

FORCES

- Forces come in pairs.
  - If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.
  - Obsolete language: "For every action there is an equal but opposite reaction."
  - Important point: The two forces always act on *different* objects; therefore they can't cancel each other.
- Example:
  - Push on book of mass m_1 with force $\vec{F}$.
  - Note third-law pair $\vec{F}_{21}$ and $\vec{F}_{12}$.
  - Third law is necessary for a consistent description of motion in Newtonian physics.



FORCES

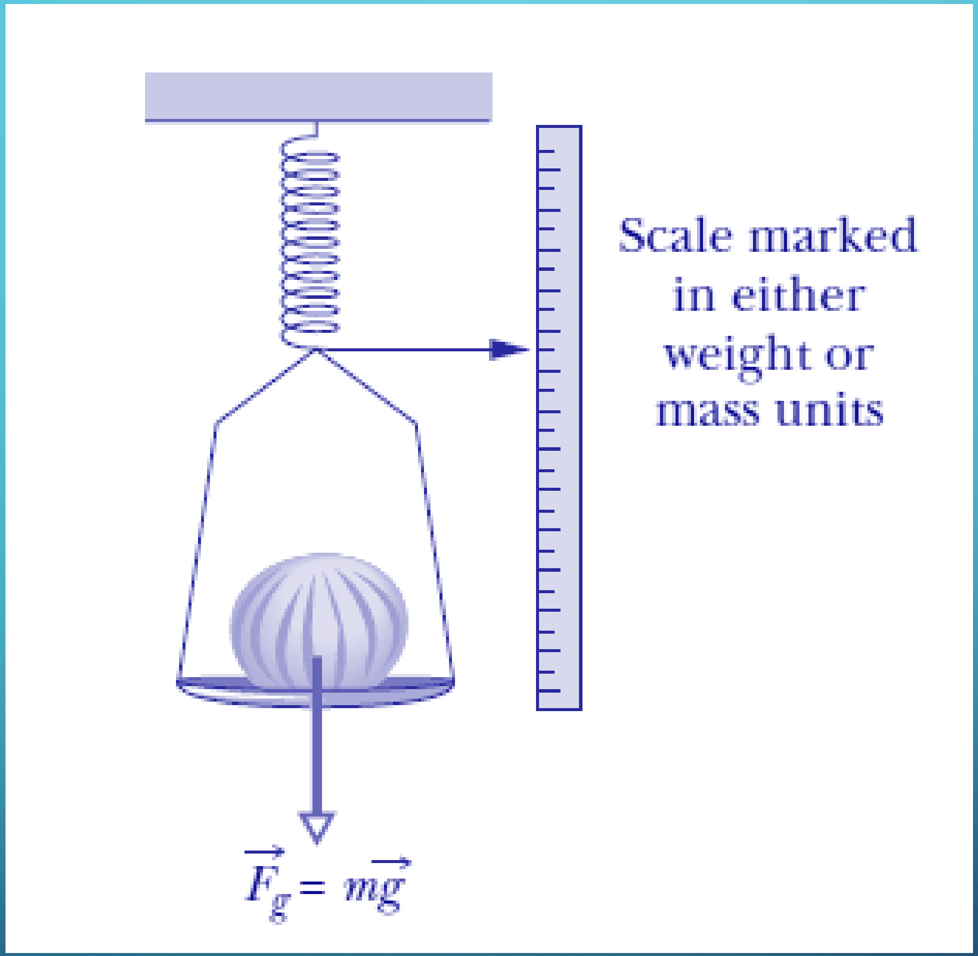
- Weight
- Spring force
- Normal reaction
- Tension in cables
- Friction

WEIGHT

- The force of gravitational attraction on objects is called weight.

$$F_g = m(g)$$
$$F_g = mg = W$$

- We are generally aware of our weight through some other force that balances it. For example the force exerted on our feet by the floor. The force that balances our weight is often called apparent weight. It is the ***apparent weight*** that is recorded by a spring scale for example:


Scale marked in either weight or mass units
$\vec{F}_g = m\vec{g}$

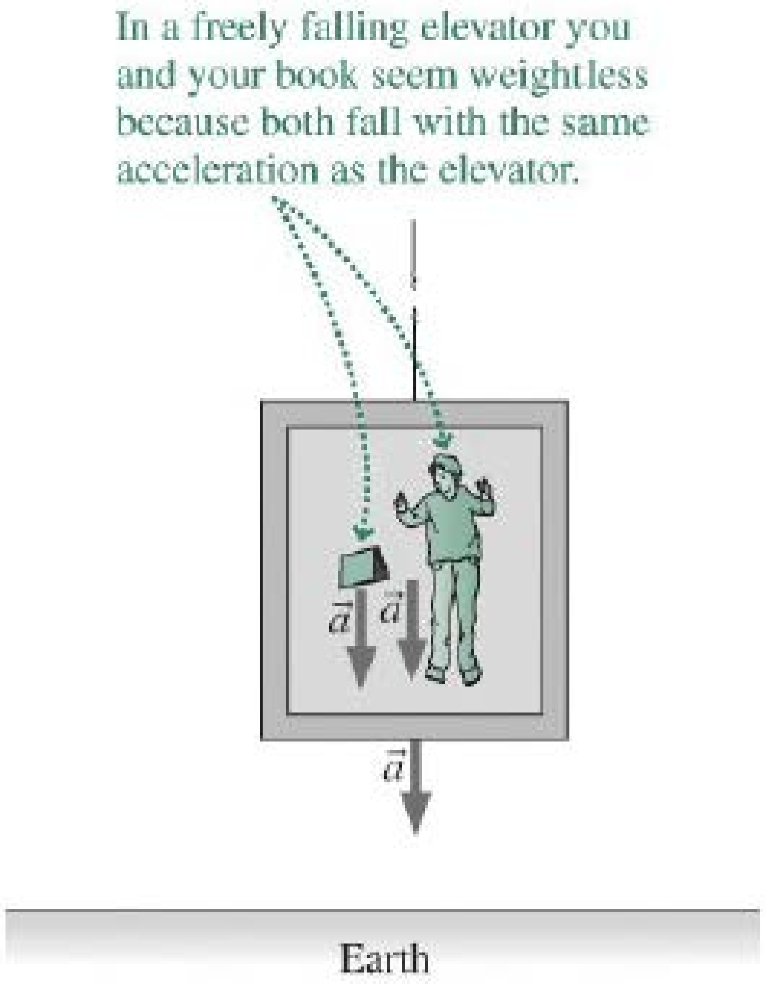
Weight is the force of gravity on an object:

Mass doesn't depend on the presence or strength of gravity.

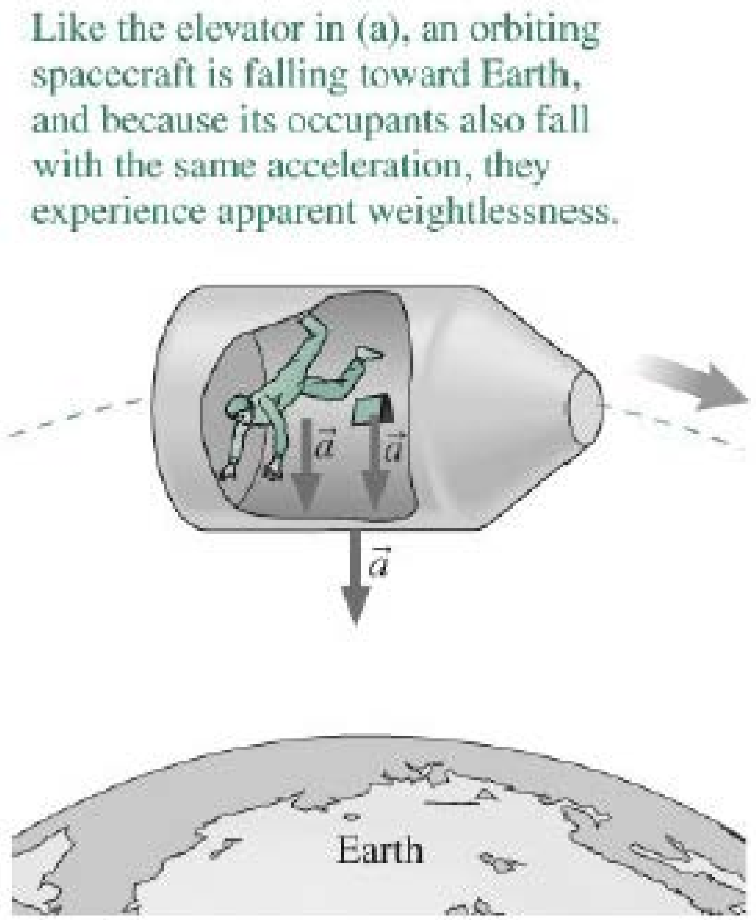
- Weight depends on gravity, so varies with location: Weight is different on different planets.

- Near Earth's surface, g has magnitude 9.8 m/s^2 or 9.8 N/kg, and is directed downward.

- All objects experience the same gravitational acceleration, regardless of mass.
- Therefore objects in free fall—under the influence of gravity alone—appear “weightless” because they share a common accelerated motion.


In a freely falling elevator you and your book seem weightless because both fall with the same acceleration as the elevator.
$\vec{a}$
$\vec{a}$
$\vec{a}$
Earth

(a)

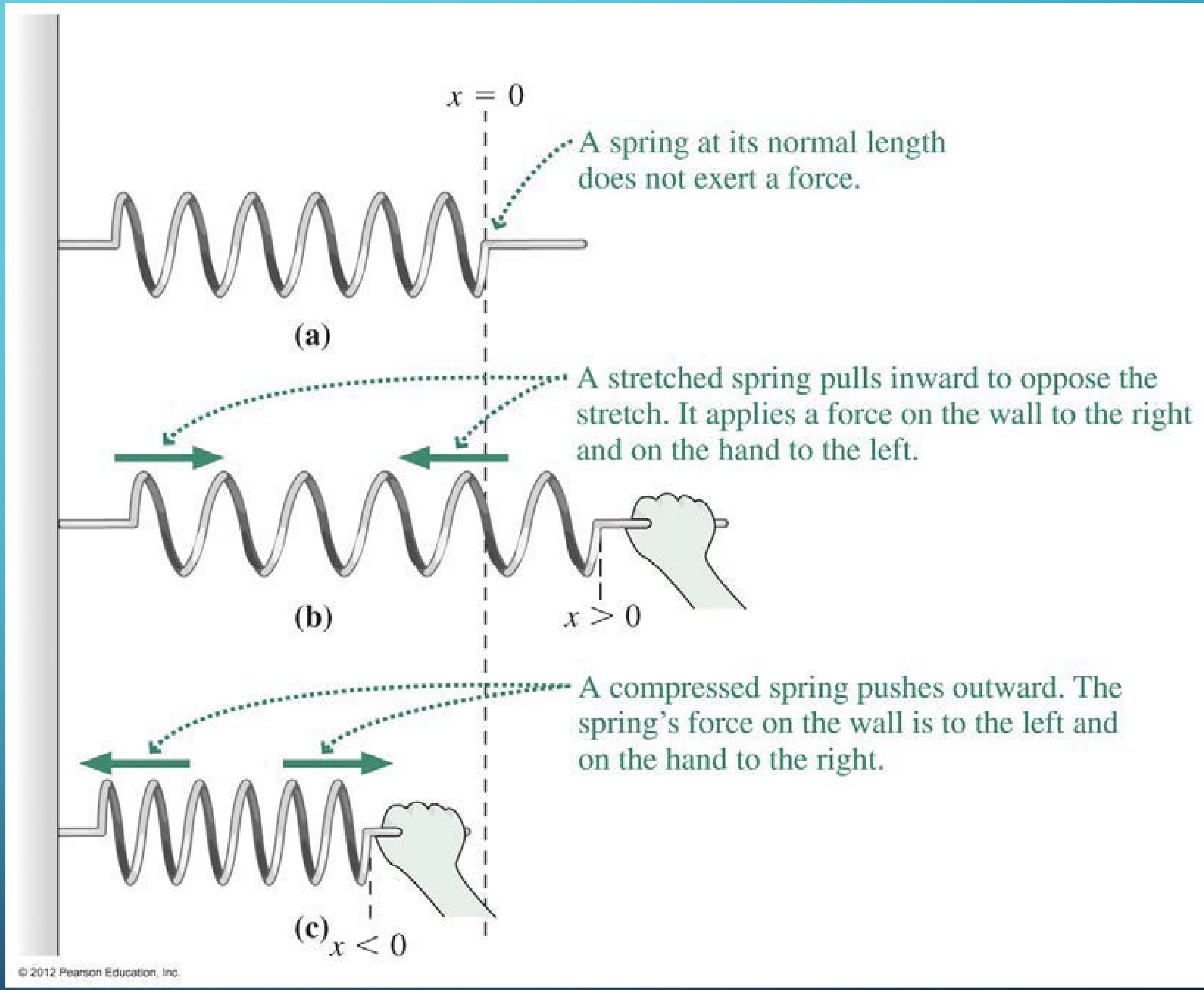

Like the elevator in (a), an orbiting spacecraft is falling toward Earth, and because its occupants also fall with the same acceleration, they experience apparent weightlessness.
$\vec{a}$
$\vec{a}$
$\vec{a}$
Earth

(b)

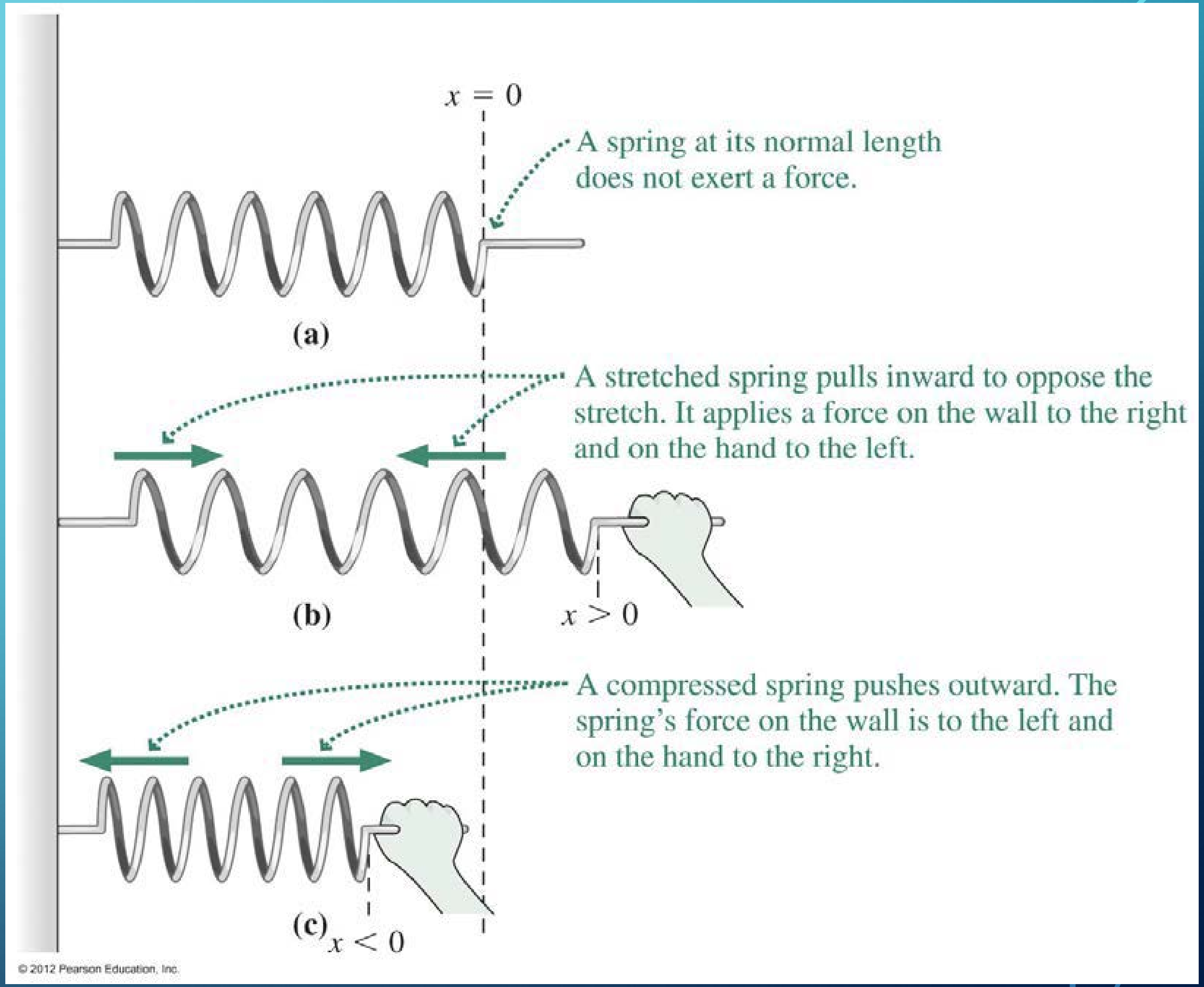
SPRING FORCE

A stretched or compressed spring produces a force proportional to the stretch or compression from its equilibrium configuration:

$$F_{sp} = -k\,x$$

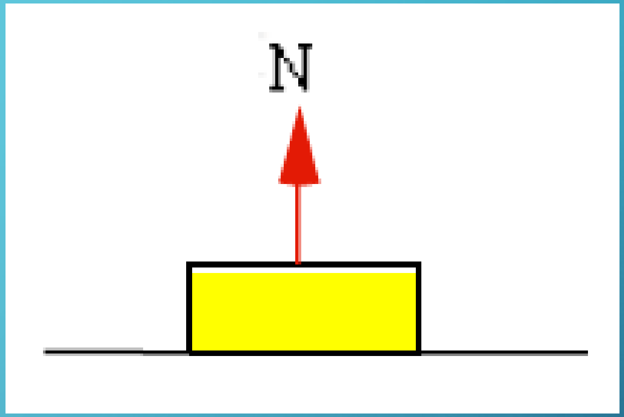


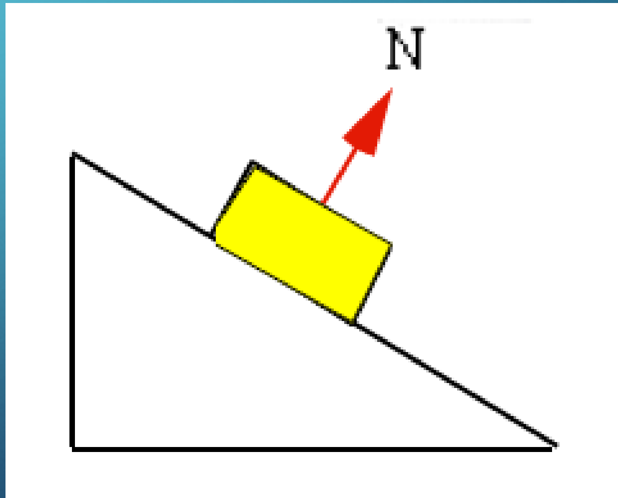
- The spring force is a restoring force because its direction is opposite that of the stretch or compression.
- Springs provide convenient devices for measuring force.



NORMAL REACTION FORCE

- A mass at rest on a table top is compressing it slightly and the restoring force of the compressed table top is what is holding the mass up.
- In this case, the restoring force is the normal force of contact; the force of support when one body rests on another.
- Always perpendicular to the surface.





Block on an incline

NORMAL FORCE

In the figure, forces F_g and F_N and are the only two forces on the block and they are both vertical. Thus, for the block we can write Newton's second law for a positive-upward *y axis, ($F_{net,\,y} = ma_y$), as:*

$$F_N - F_g = ma_y.$$

$$F_N - mg = ma_y.$$

$$F_N = mg + ma_y = m(g + a_y)$$

for any vertical acceleration a_y *of the table and block*

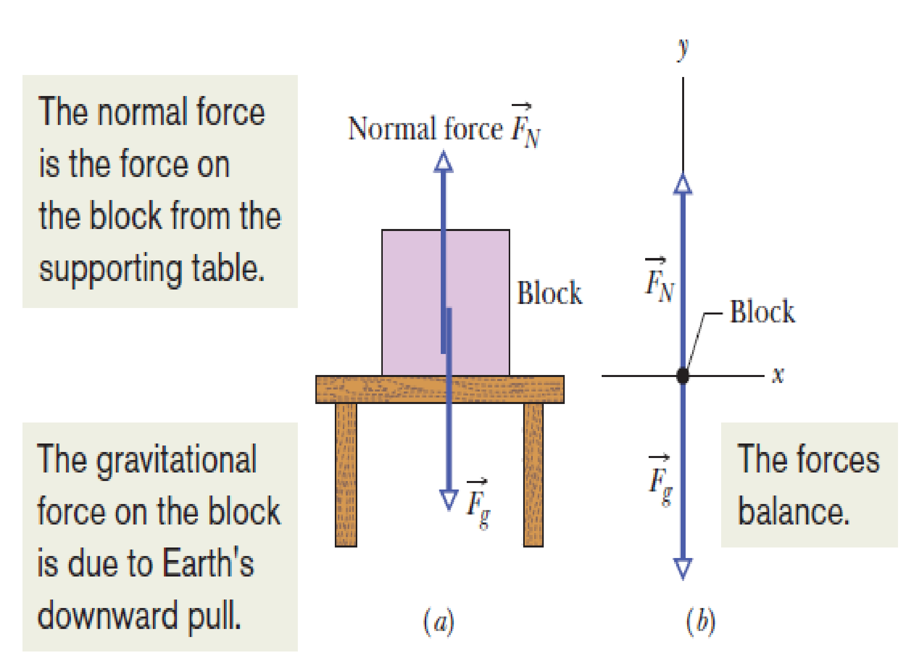


Fig. 5-7 (a) A block resting on a table experiences a normal force perpendicular to the tabletop. (b) The free-body diagram for the block.

TENSION

When a cord is attached to a body and pulled taut, the cord pulls on the body with a force *T directed away from the* body and along the cord.

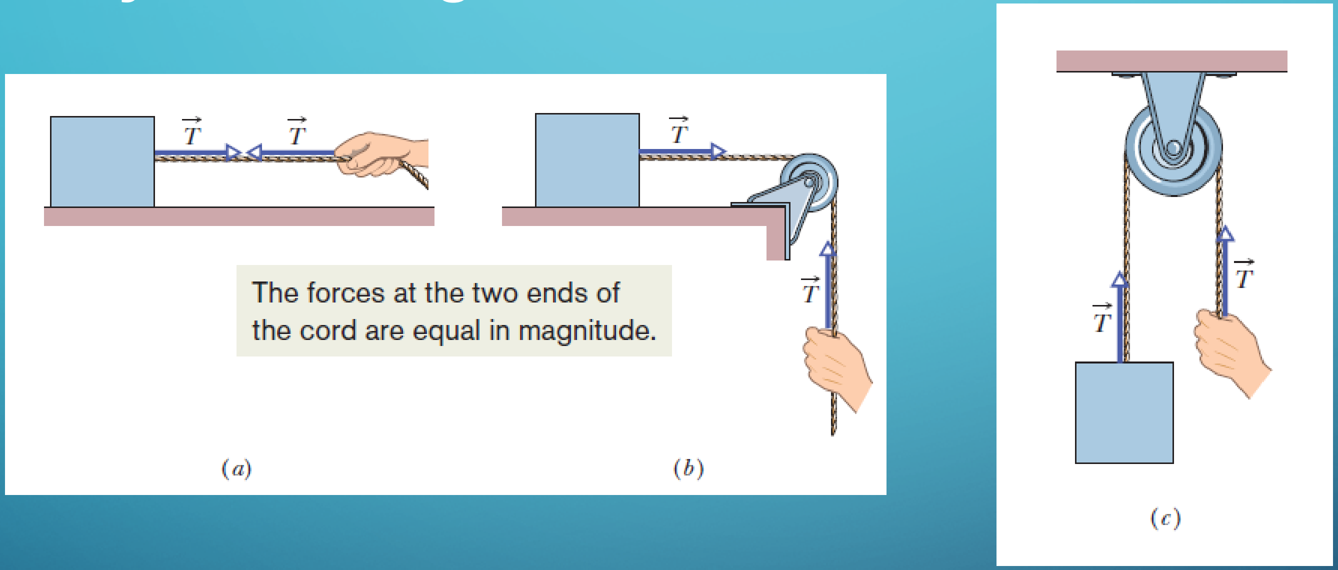


Fig. *(a) The cord, pulled taut, is* under tension. If its mass is negligible, the cord pulls on the body and the hand with force **T**, even if the cord runs around a massless, frictionless pulley as in *(b) and (c).*

FRICTION

If we either slide or attempt to slide a body over a surface, the motion is resisted by a bonding between the body and the surface.

The resistance is considered to be single force called the frictional force, *f*. This force is directed along the surface, opposite the direction of the intended motion.

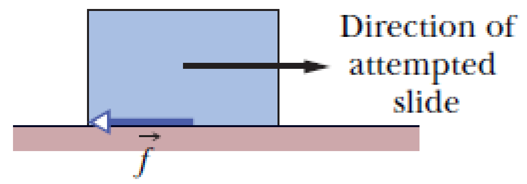
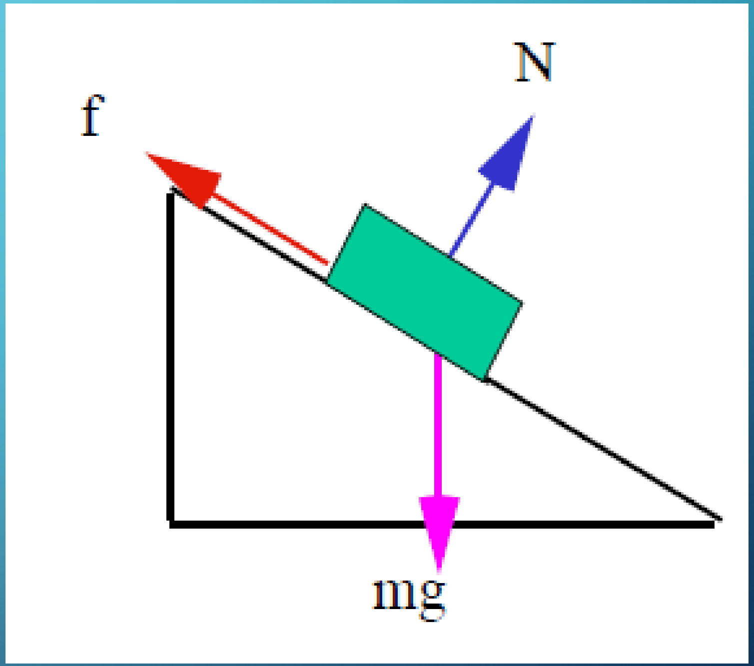


Fig. 5-8 A frictional force $\vec{f}$ opposes the attempted slide of a body over a surface.

FRICTION

Another example: if we sit a block on an incline it will not necessarily slide down. This is because the incline exerts a force, *the frictional force*, equal and opposite to the component of the gravitational force acting on the body down the incline.

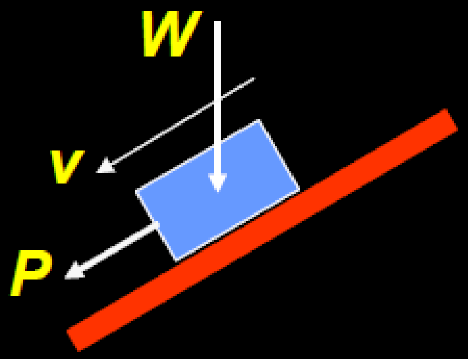


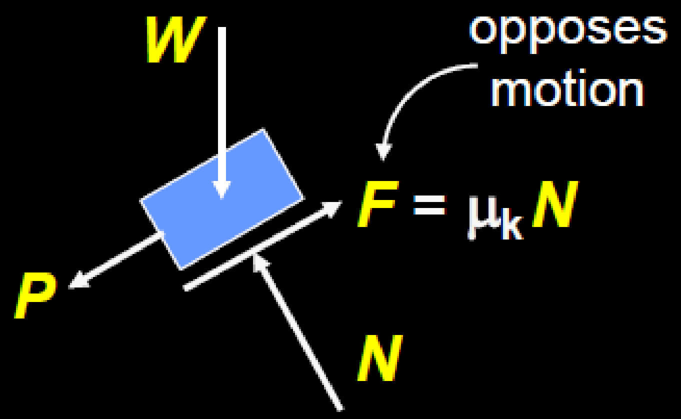
The direction of frictional force will always be opposite to the direction in which the motion would take place if there is no friction.

The *frictional force* is parallel to the contact surfaces.

Weight, $W = mg$
($g = 9.81\ m/s^2$)

Free Body Diagram:





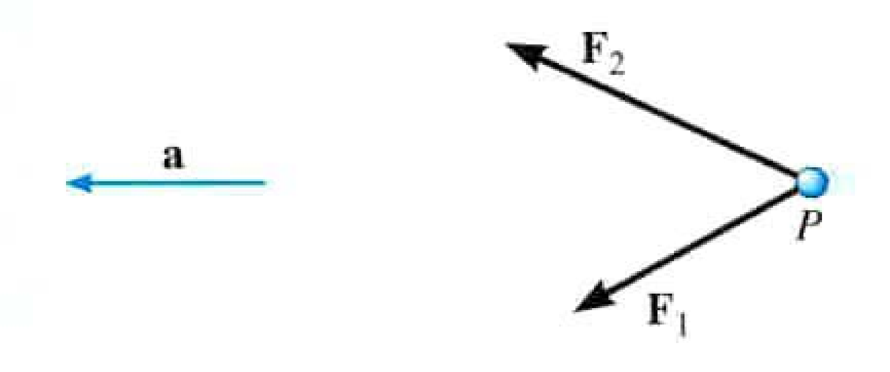
μ_k = Kinetic coefficient of friction

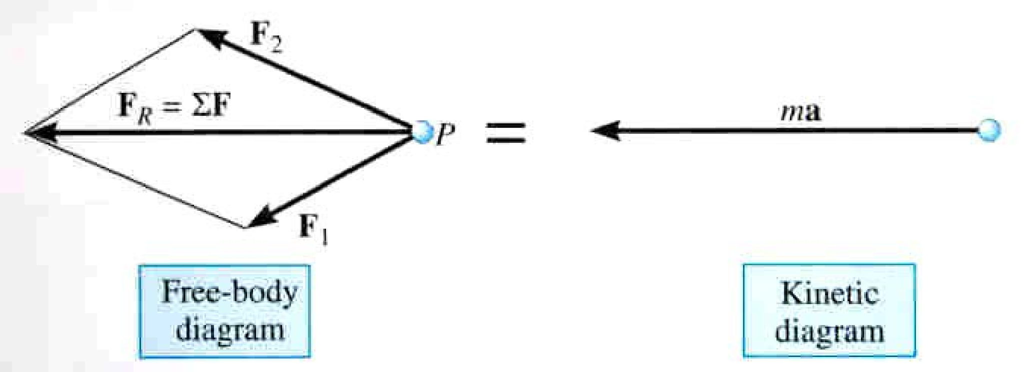
For static case (impending motion): $F = \mu_s N$

μ_s = Static coefficient of friction

$\mu_k \approx$ 75 to 85% of μ_s

- Motion of a particle is governed by Newton's second law, relating unbalanced forces on a particle to its acceleration. If more than one force acts on a particle, equation of motion can be written:
  - $\Sigma F = F_R = ma$
- where F_R is resultant force = vector summation of all forces.





- Equation of motion, being a vector equation, may be expressed in terms of its three components in the Cartesian (rectangular) coordinate system as:

$$\Sigma \boldsymbol{F} = m\boldsymbol{a}$$

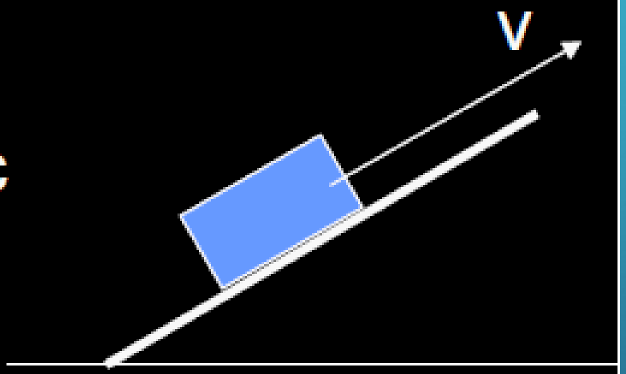
or

$$\Sigma F_x \boldsymbol{i} + \Sigma F_y \boldsymbol{j} + \Sigma F_z \boldsymbol{k} = ma_x \boldsymbol{i} + ma_y \boldsymbol{j} + ma_z \boldsymbol{k}$$

OR, in scalar form:

$$\Sigma F_x = ma_x \;,\; \Sigma F_y = ma_y \;,\; \Sigma F_z = ma_z$$

1. The block (mass = m) is moving upward with a speed v. Draw the FBD if the kinetic friction coefficient is μ_k.



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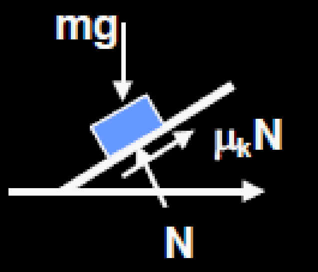

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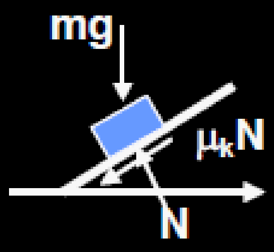
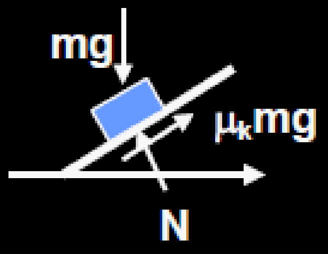


C)



D) None of the above.

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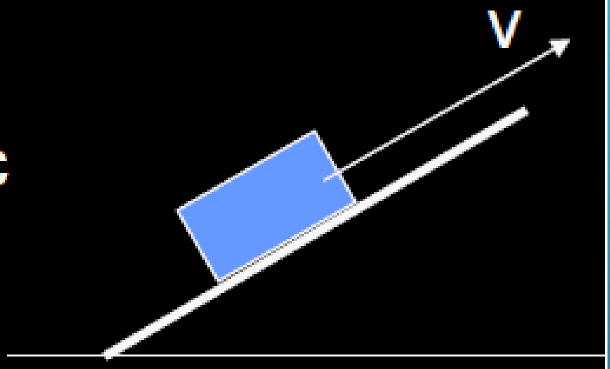
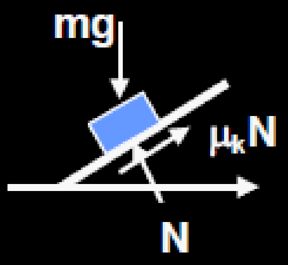
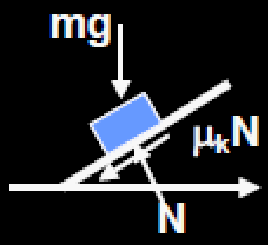
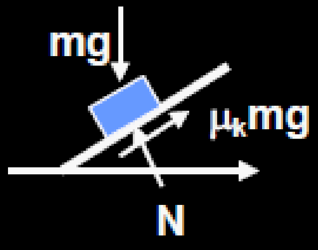


A) 

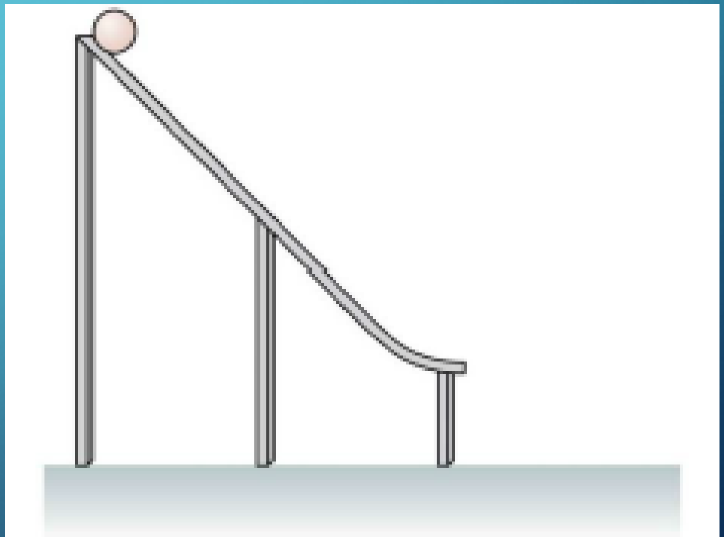
B) 

C) 

D) None of the above.

3- A ball rolls down an incline and off a horizontal ramp. Ignoring air resistance, what force or forces act on the ball as it moves through the air just after leaving the horizontal ramp?

a. The weight of the ball acting vertically down.
b. A horizontal force that maintains the motion.
c. A force whose direction changes as the direction of motion changes.
d. The weight of the ball and a horizontal force.
e. The weight of the ball and a force in the direction of motion.



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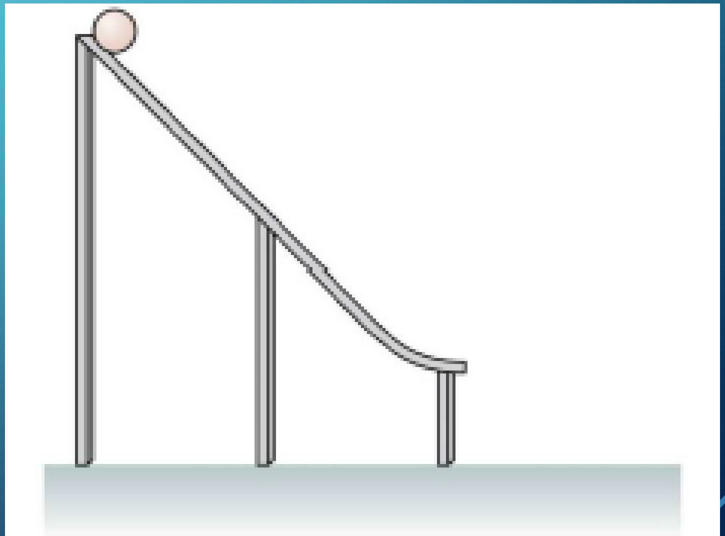

4 - A steel beam hangs from a cable as a crane lifts the beam. What forces act on the beam?

a. Gravity
b. Gravity and tension in the cable
c. Gravity and a force of motion
d. Gravity and tension and a force of motion

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5 - A bobsledder pushes her sled across horizontal snow to get it going, then jumps in. After she jumps in, the sled gradually slows to a halt. What forces act on the sled just after she's jumped in?

a. Gravity and kinetic friction

b. Gravity and a normal force

c. Gravity and the force of the push

d. Gravity, a normal force, and kinetic friction

e. Gravity, a normal force, kinetic friction, and the force of the push

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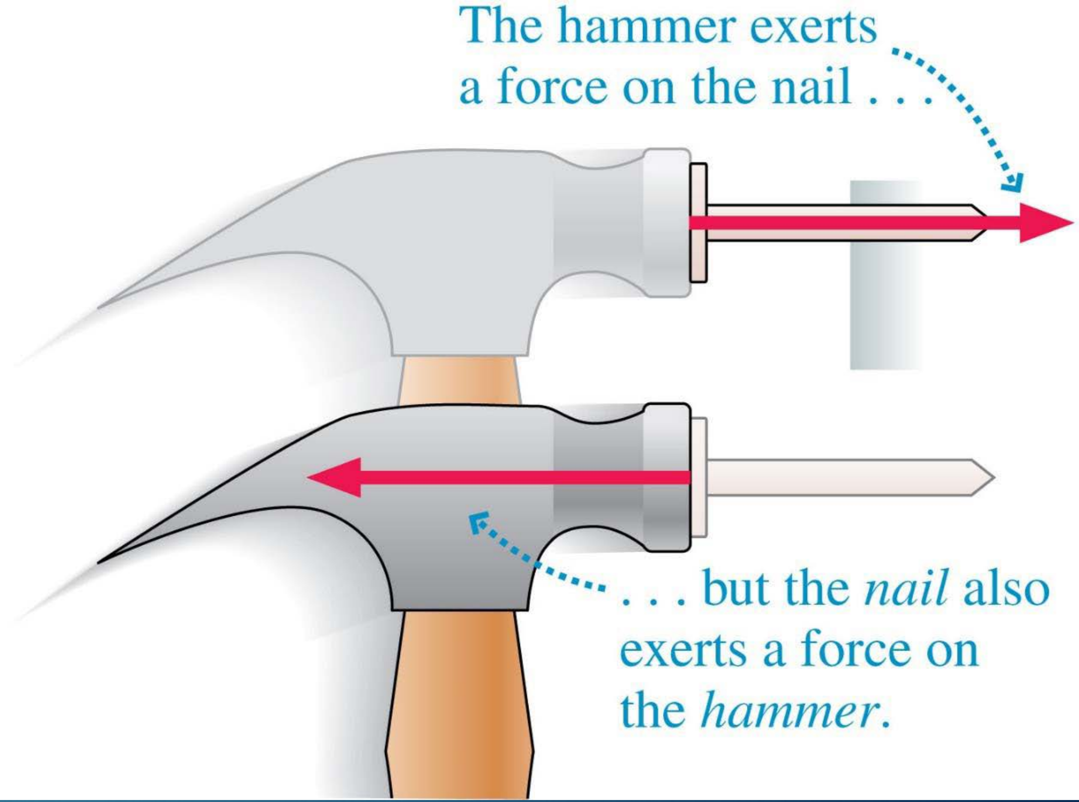
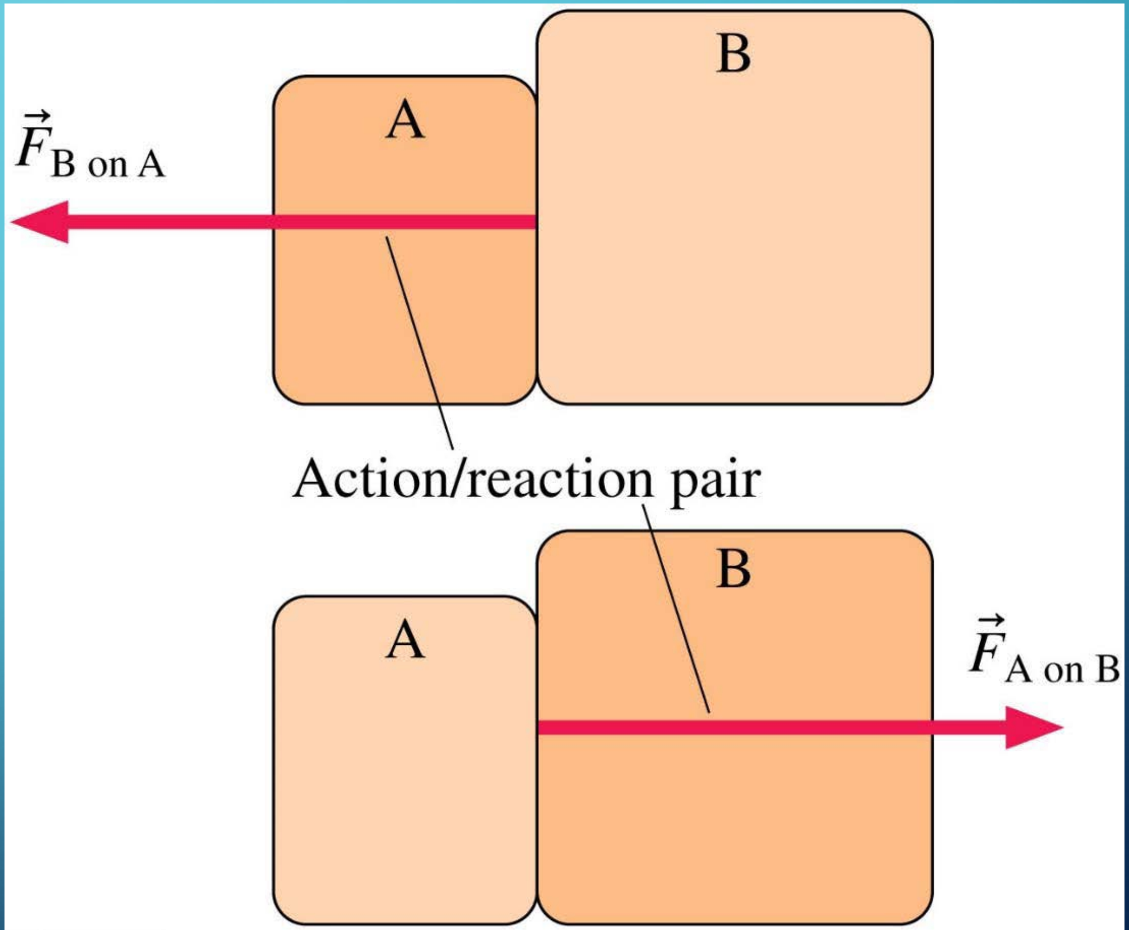
QUICK REMINDER - NEWTON'S THIRD LAW

Motion often involves two or more objects *interacting* with each other. As the hammer hits the nail, the nail pushes back on the hammer. A bat and a ball, your foot and a soccer ball, and the earth-moon system are other examples of interacting objects.



INTERACTING OBJECTS

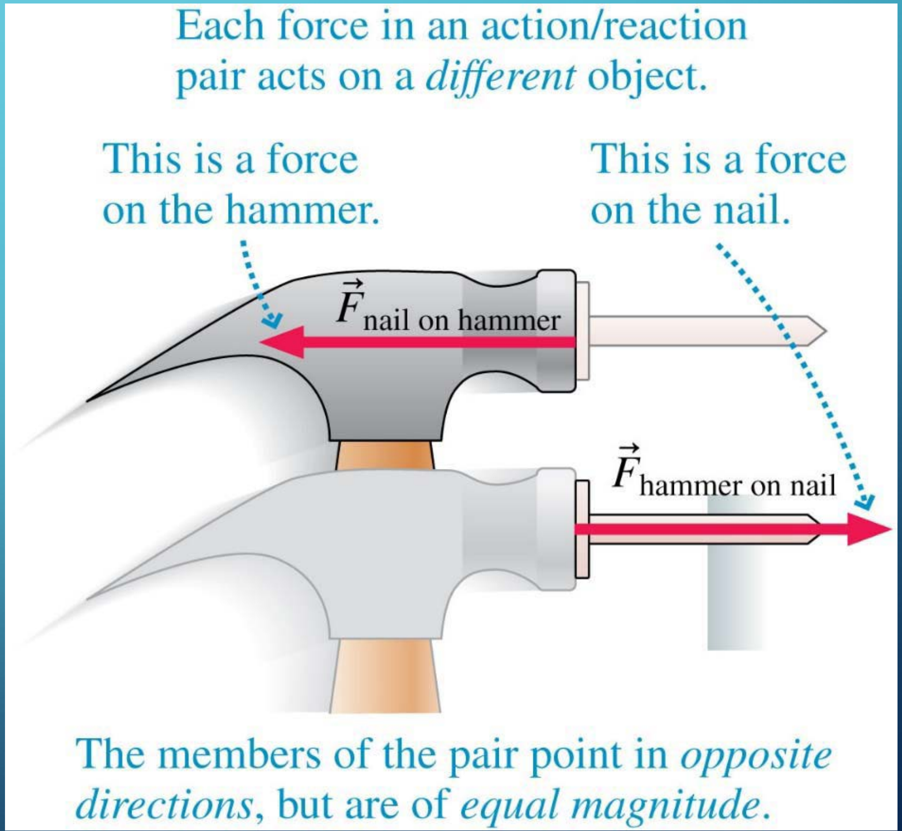
An interaction is the mutual influence of two objects on each other. The pair of forces shown in the figure is called an action/reaction pair. Action/reaction pair of forces exists as a pair, or not at all.



Newton's third law Every force occurs as one member of an action/reaction pair of forces.

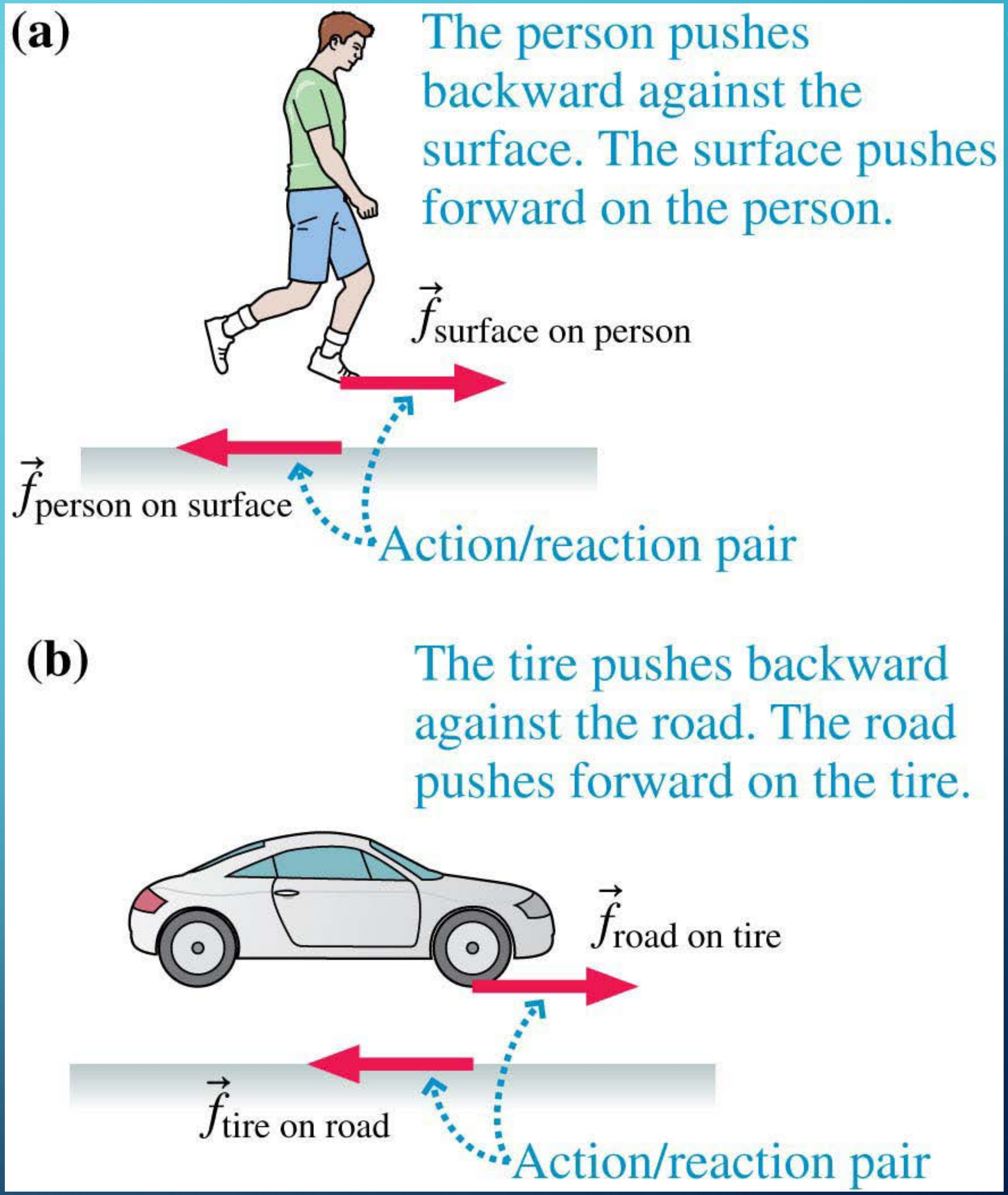
- The two members of an action/reaction pair act on two *different* objects.
- The two members of an action/reaction pair point in *opposite* directions and are *equal in magnitude*.

If two objects are interacting via a force and no other forces are involved, then *both* objects will accelerate ---in opposite directions!

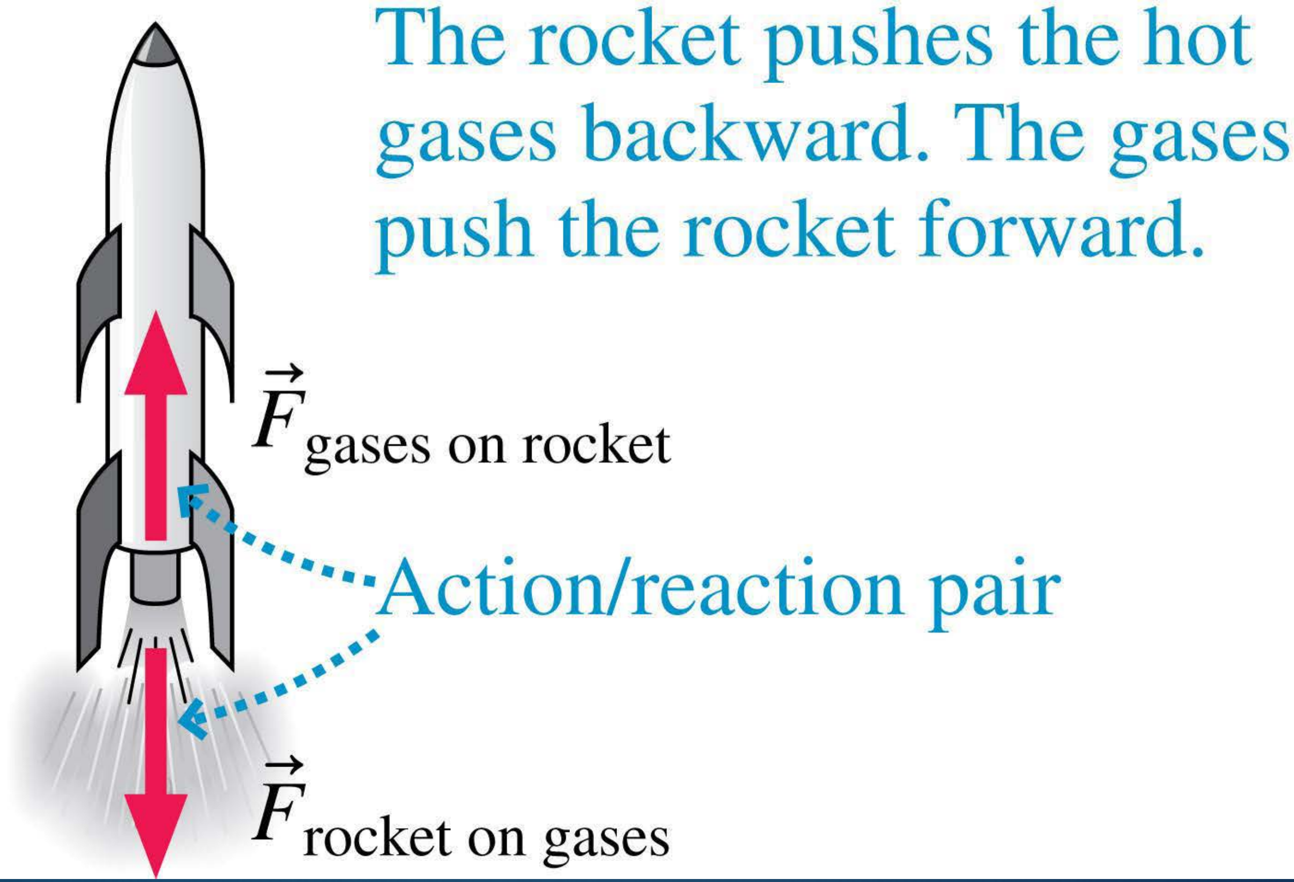


RUNNERS AND ROCKETS

- In order for you to walk, the floor needs to have friction so that your foot sticks to the floor as you straighten your leg, moving your body forward.
- The friction that prevents slipping is *static* friction.
- The static friction has to point in the forward direction to prevent your foot from slipping.



The rocket pushes hot gases out the back, and this results in a forward force (*thrust*) on the rocket.



6 - 10-year-old Sarah stands on a skateboard. Her older brother Jack starts pushing her backward and she starts speeding up. The force of Jack on Sarah is:

a. Greater than the force of Sarah on Jack.

b. Equal to the force of Sarah on Jack.

c. Less than the force of Sarah on Jack.

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7- A mosquito runs head-on into a truck. Splat! Which is true during the collision?

a) The mosquito exerts more force on the truck than the truck exerts on the mosquito.

b) The truck exerts more force on the mosquito than the mosquito exerts on the truck.

c) The mosquito exerts the same force on the truck as the truck exerts on the mosquito.

d) The truck exerts a force on the mosquito but the mosquito does not exert a force on the truck.

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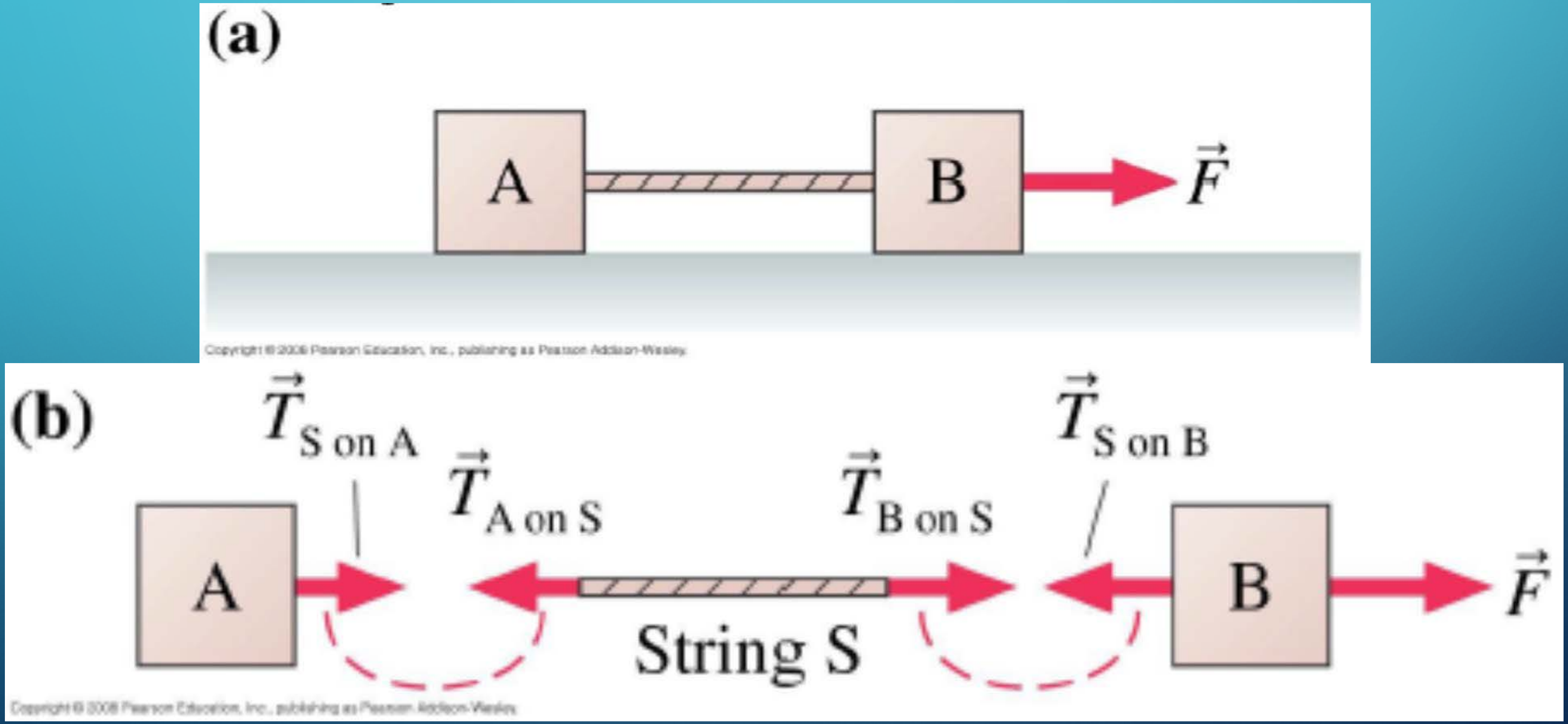
The tension is constant throughout a string that is in equilibrium. What happens to a string that is not in equilibrium, that is accelerating?

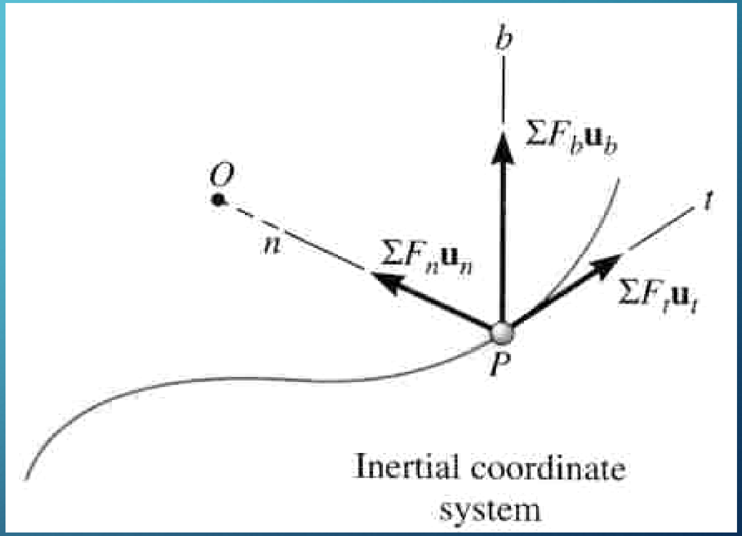


The tension in a string pulls in both directions. The tension in a string is constant throughout the string if it is:

- massless (i.e. *Mass* of string is negligible compared to the other objects being considered. We will assume this in most questions, unless it says otherwise).
- or in equilibrium.

NORMAL & TANGENTIALCOORDINATES

- When particle moves along curved path, it may be more convenient to write equation of motion in terms of normal and tangential coordinates.
- Normal direction (n) *always* points toward path's centre of curvature. In a circle, the centre of curvature is centre of the circle.
- Tangential direction (t) is tangent to path, usually set as positive in direction of motion of particle.
- Binormal direction (b) is perpendicular to n-t plane.



$\sum \boldsymbol{F} = m\boldsymbol{a}$

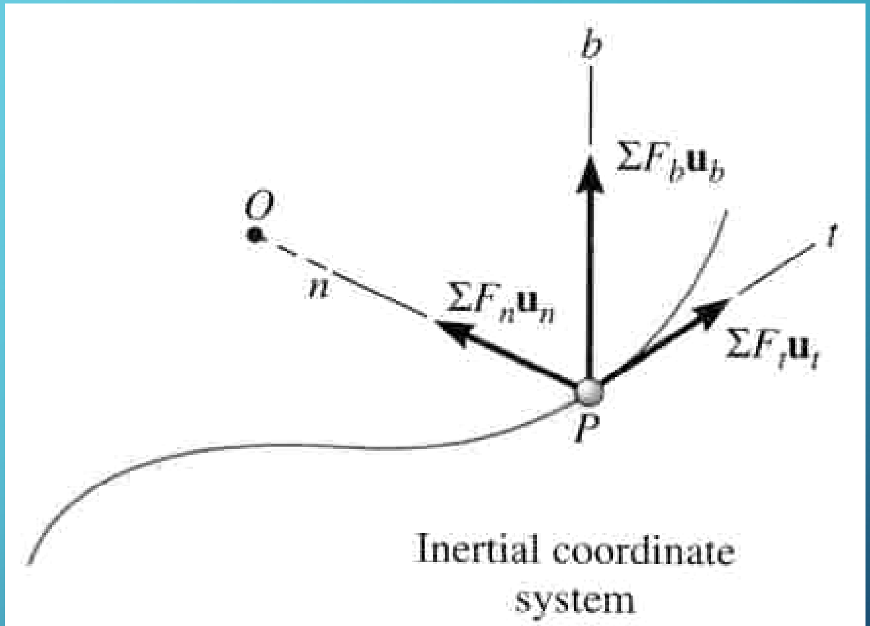
$\sum F_t \boldsymbol{u}_t + \sum F_n \boldsymbol{u}_n = m\boldsymbol{a}_t + m\boldsymbol{a}_n$

$\sum F_b = 0$ (no motion in binormal direction)

Scalar form:
$\sum F_t = ma_t$ and
$\sum F_n = ma_n$ (called Centripetal Force, always directed towards centre of curvature)

$a_t = dv/dt$ or $v\ dv/ds$

$a_n = v^2/\rho$



CYLINDRICALCOORDINATES

- Equilibrium equations or “Equations of Motion” in cylindrical coordinates (using r, θ and z coordinates)

- 2D: Polar Coordinates (r, θ)