NEWTON’S LAWS OF MOTION

Pre-class Assignment: Newton’s laws

Instruction: Complete each statement by filling in the blanks from the given *list of words/phrases.

1. Newton’s second law states that the acceleration of an object is <u>directly proportional</u> to the net force acting on the object.
2. A car rounds a curve while maintaining a constant speed. The net force on the car as it rounds the curve is <u>nonzero</u>.
3. A <u>free-body</u> diagram represents the object as a particle at the origin of a coordinate system. Force

vectors that act on the object are drawn with their tails on the particle.

4. Weight is the force upon an object due to gravity.
5. After your sports car breaks down, you start to push it to the nearest repair shop. While the car is starting to move, the force you exert on the car compared to the force the car exerts on you is equal in magnitude.

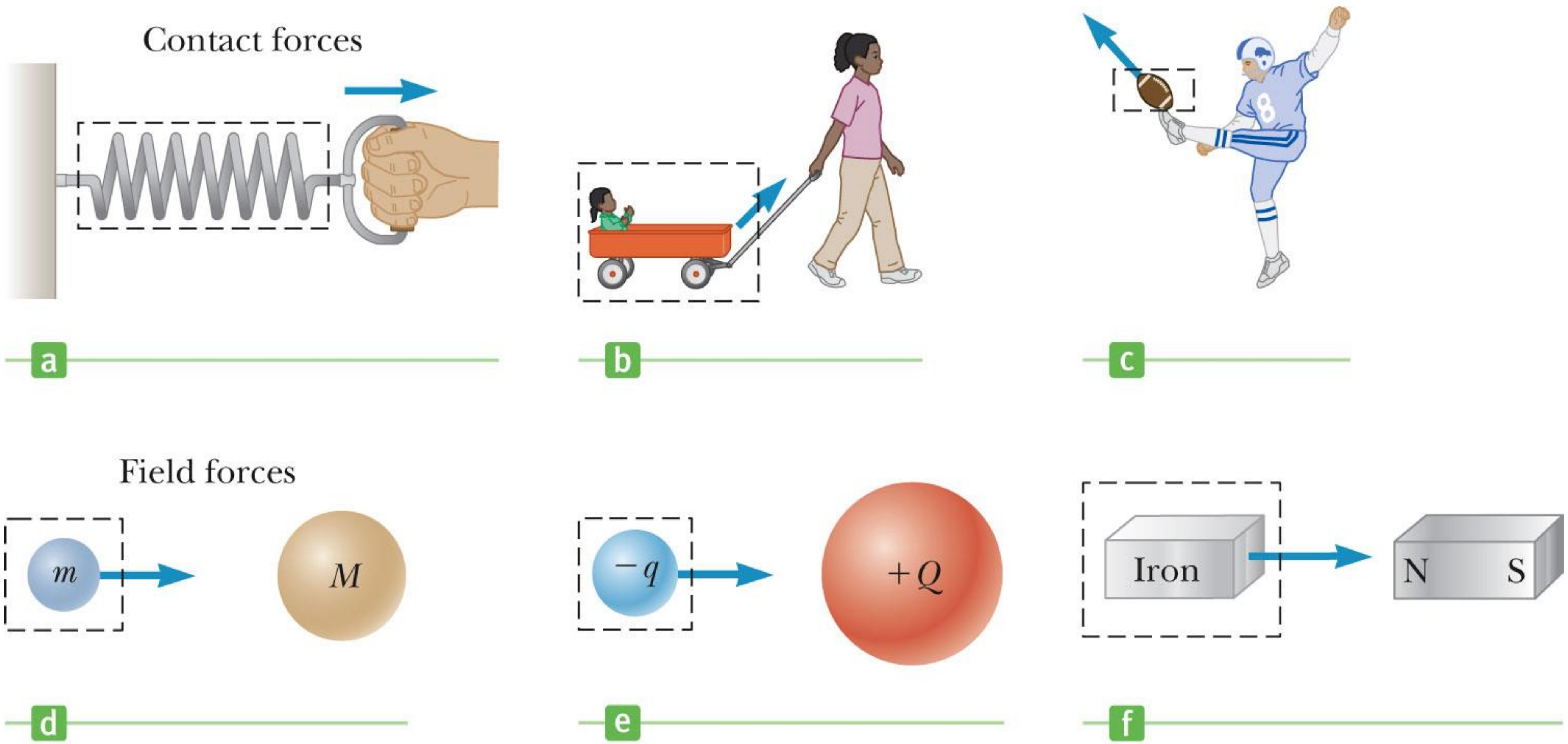
* tension, directly proportional, lesser, friction, nonzero, greater, motion, weight, newton, free-body, inversely proportional, zero, inertia, mass, equal

A. Force

A force (SI unit: newton, N) is a quantitative measure of the interaction between two objects or between an object and its environment. It is represented by a vector.

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

1. Two Class of Forces:
   a. Contact forces arise from the physical contact between two objects.
   b. Field forces are forces in which two objects or an object and its environment exert forces on one another even though they are not touching.


Contact forces
a
b
c
Field forces
m
M
d
−q
+Q
e
Iron
N
S
f

The known fundamental forces in nature are all field forces. These are, in order of decreasing strength:

i. strong nuclear force between subatomic particles,
ii. electromagnetic forces between electric charges,
iii. weak nuclear force, which arises in certain radioactive decay processes, and
iv. gravitational force between objects or an object and its environment.

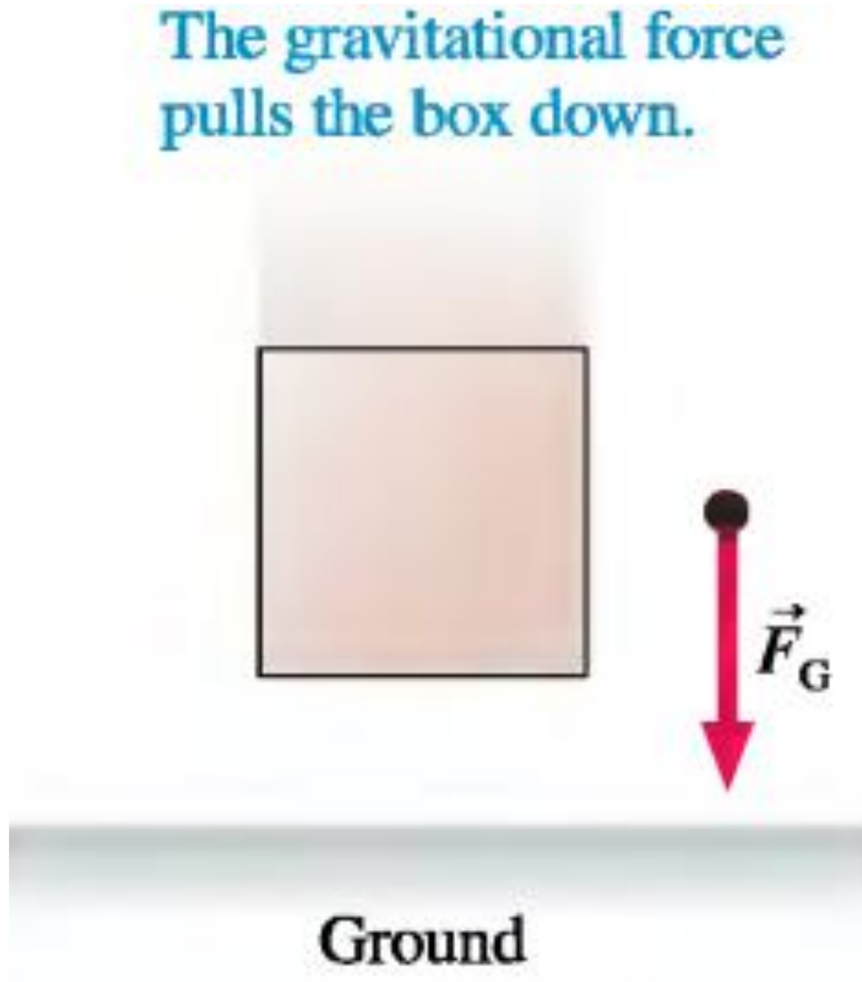
Checkpoint Questions:

1) The SI unit of force is the ________.
2) These forces act at a distance. An example is the gravitational force.
3) _______ is the weakest among the four fundamental forces of nature.

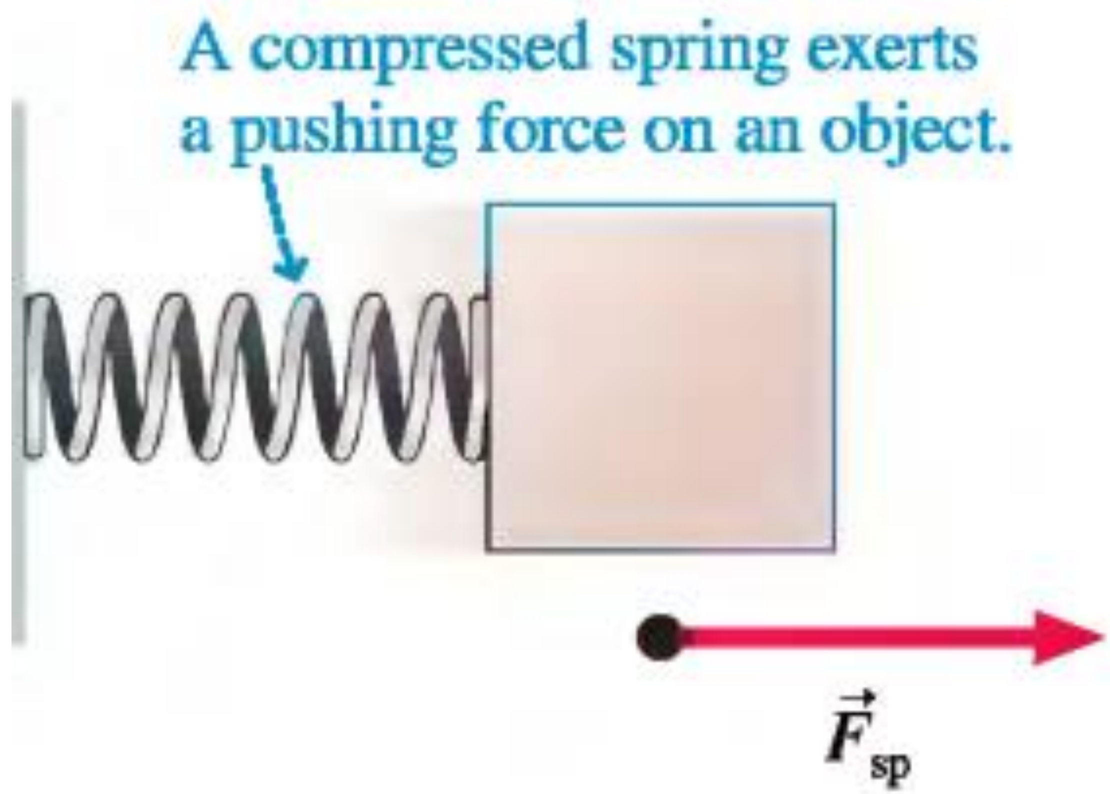
2. Catalog of forces:

a. Tension ($\vec{T}$) is the contact force that arises when a string/rope/wire/cable pulls on an object.

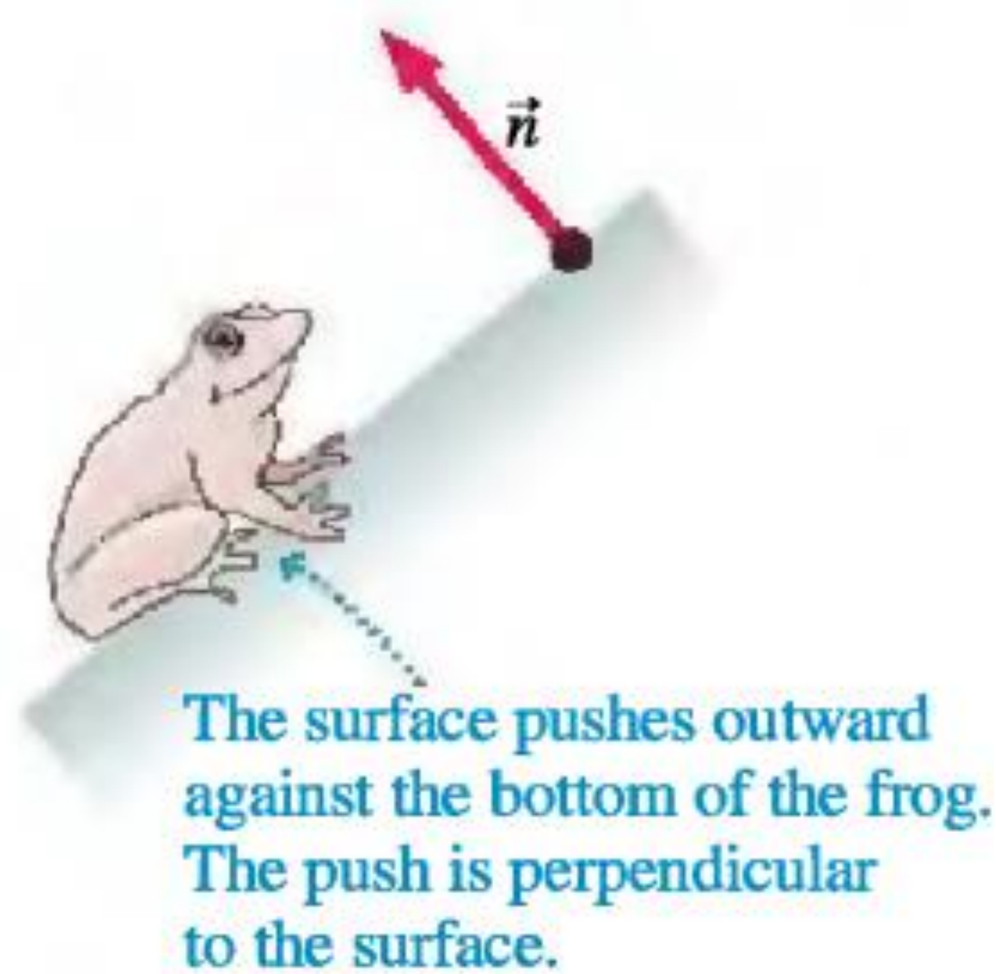
b. Gravity ($\vec{F}_g$) is the gravitational pull of a planet on an object on or near the surface.



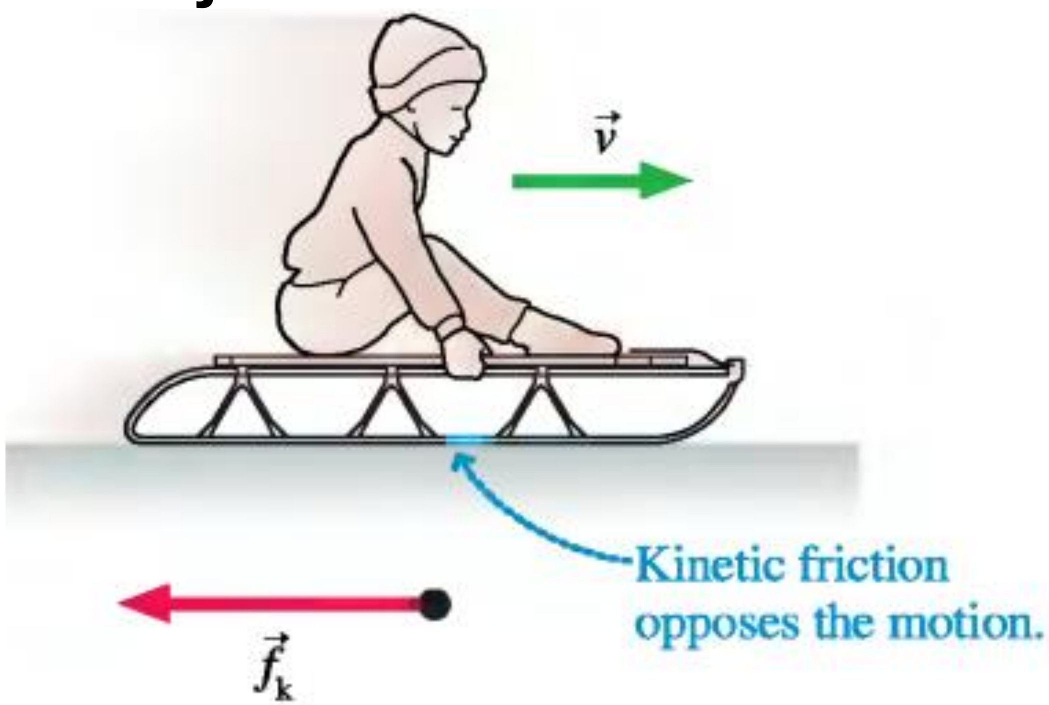
c. Spring force ($\vec{F}_s$) arises from a spring which can either push (when compressed) or pull (when stretched).

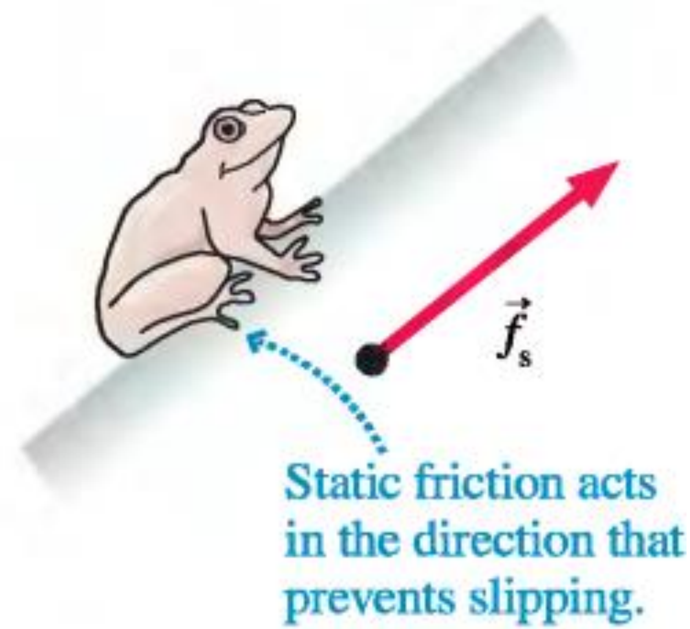


d. Normal force ($\vec{n}$) is the component of a contact force between two objects that is perpendicular to their common surface.



e. Friction ($\vec{f}$) is the component of a contact force between two objects that is parallel to their common surface. Friction forces often act to oppose the motion or resist the sliding of an object.





Kinds of frictional forces:

i. Static friction is the force on an object that keeps it from slipping or sliding. It points in the direction necessary to prevent motion.

$$f_s \leq \mu_s n$$

ii. Kinetic friction is a force that opposes the motion of an object relative to a surface. It points in a direction opposite the object's velocity.

$$f_k = \mu_k n$$

Coefficients of static μ_s and kinetic μ_k friction are found in the table below.

Coefficients of Friction[a]

	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.25–0.5	0.2
Glass on glass	0.94	0.4
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

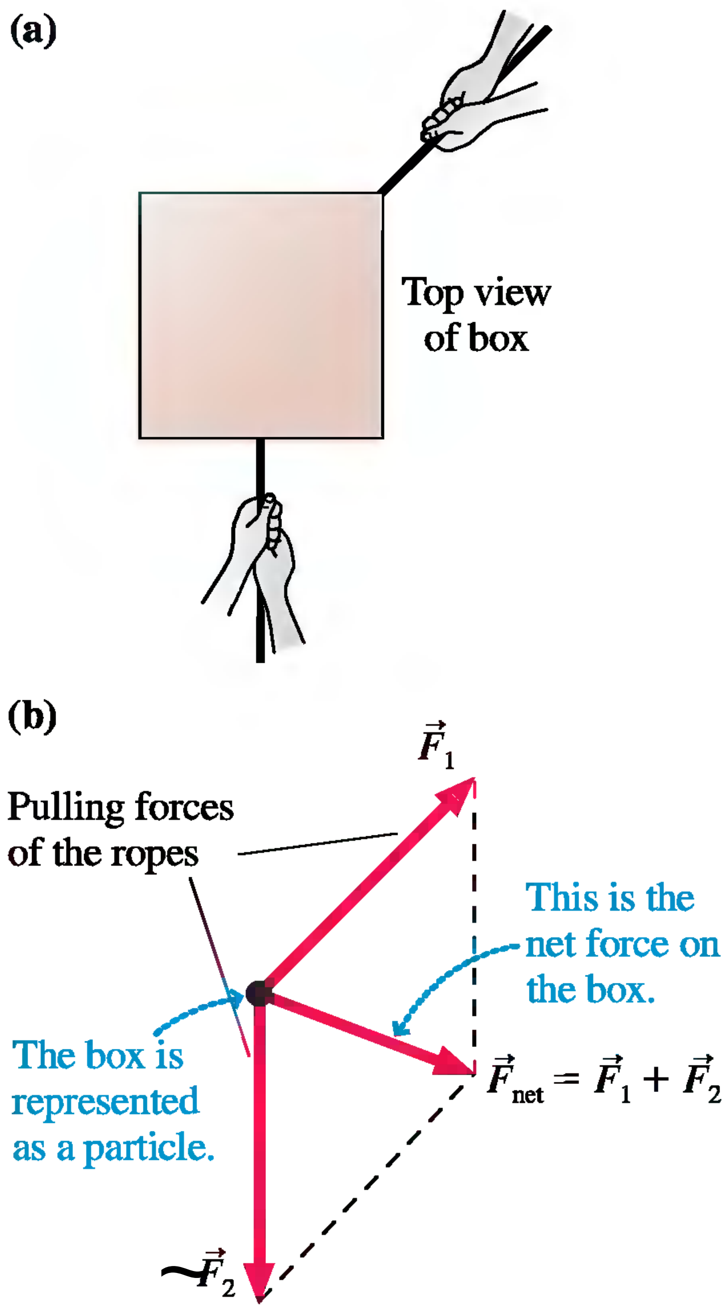
[a]All values are approximate.

The equations of friction provide a model that assumes:

- coefficients of friction are nearly independent of the area of contact between the surfaces
- kinetic friction is independent of the object’s speed

3. Superposition of forces

The principle of superposition of forces states that the effect of any number of forces applied at a point on an object/body is the same as the effect of a single force equal to the vector sum of the forces. The vector sum of forces acting on an object is also called net force or resultant force.



$$\vec{R} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots = \sum \vec{F}$$

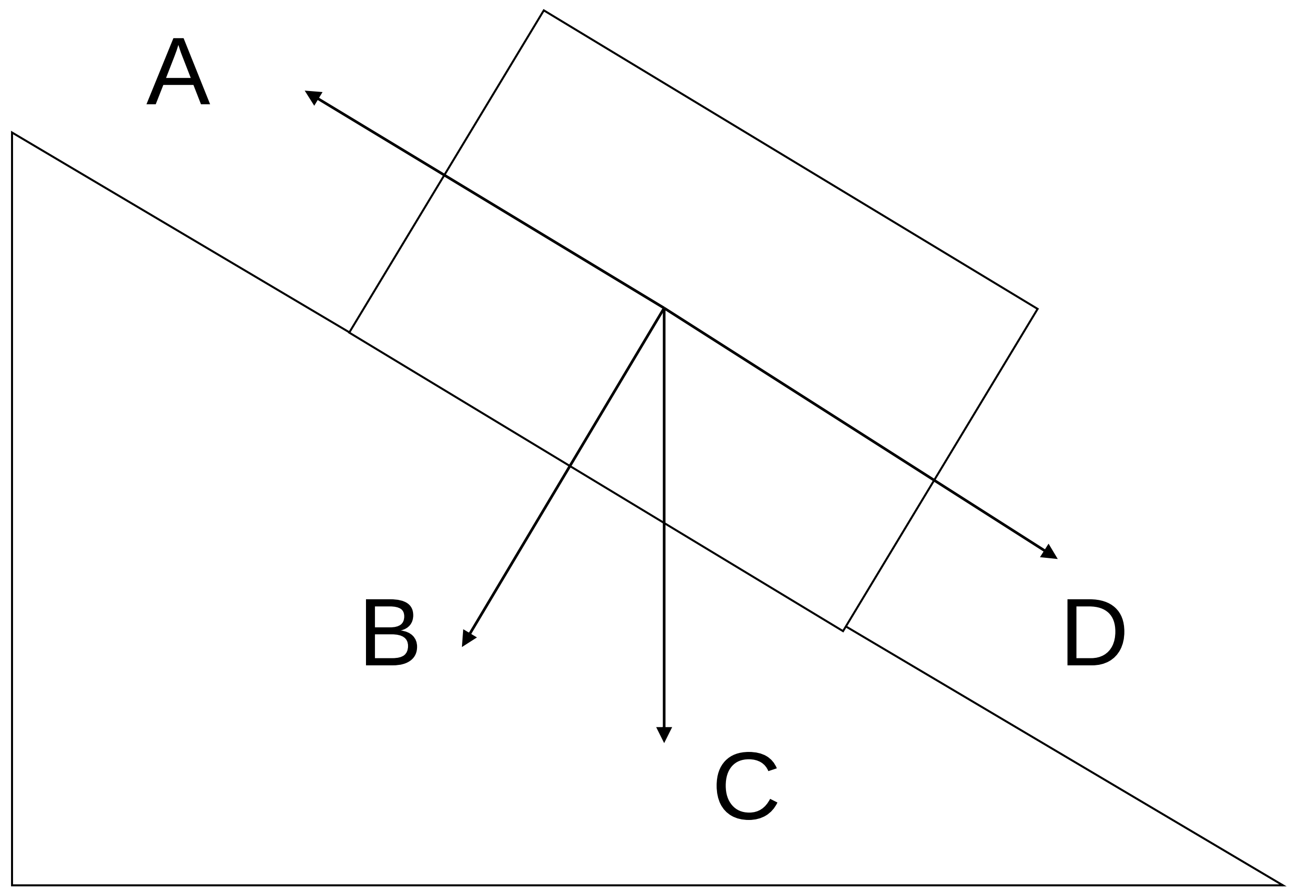
In component form,

$$R_x = \sum F_x \qquad\qquad R_y = \sum F_y$$

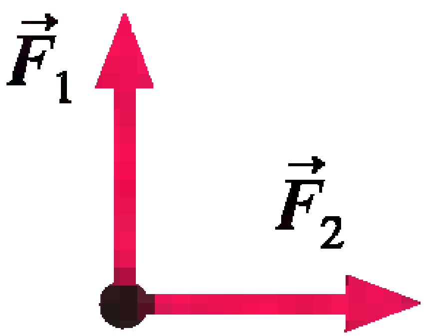
Checkpoint Questions:

1) _______ is one component of the force that a surface exerts on an object with which it is in contact. Its direction is perpendicular to the surface.
2) Does a force cause an object to move? Why?
3) You’ve just kicked a rock, and it is now sliding across the ground about 2 meters in front of you. Which of these forces does not act on the rock: gravity, normal force, force of kick, friction?

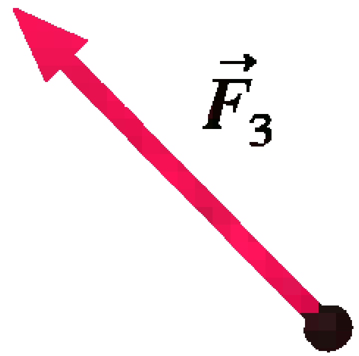
4) Which one of the following represents gravity?
5) Which one of the following represents friction if the block is at rest?



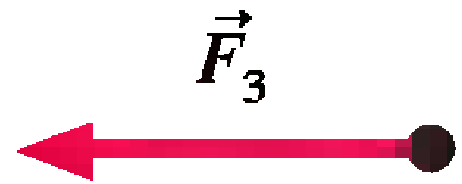
6) Two of the three forces exerted on an object are shown. The net force points to the left. Which is the missing third force?



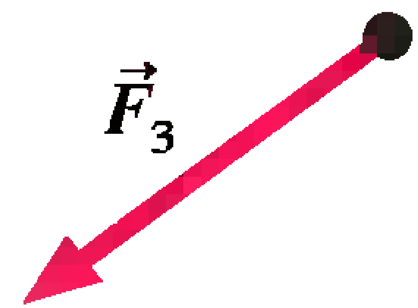
Two of the three forces exerted on an object



(a)



(b)



(c)

B. Newton's Laws of Motion

1. 1st Law (law of inertia):

   An object acted on by no net force moves in constant velocity (or remains at rest) with zero acceleration.

   Important points about the 1st law:

   a. An object on which the net force is zero is said to be in static (at rest) or dynamic (moving with constant velocity) equilibrium.
   b. No net force is needed for motion because uniform motion is the "natural state" of an object.

c. Inertia is the property of an object to resist changes in motion. The mass of an object is a quantitative measure of inertia.
d. A frame of reference in which Newton’s first law is valid is called an inertial frame of reference. Accelerating reference frames are not inertial reference frames.

2. 2nd Law (law of acceleration):

If a net external force acts on an object, the object accelerates. The net force vector is equal to the mass of the object times the acceleration of the object.

Important points about the 2nd law:

a. A net force causes an object to accelerate or change the object's velocity. The direction of acceleration is the same as the direction of the net force.

b. For any given object, the magnitude of the acceleration is directly proportional to the magnitude of the net force acting on the object and inversely proportional to the object’s mass.

c. Mass (SI unit: kg) and weight (SI unit: N) are two different quantities. The relationship between mass m and weight w is reflected in the 2nd law:

$$w = mg$$

where g = 9.8 m/s^2 (near the Earth’s surface).

i. Mass is a measure of the amount of matter an object contains. It is the property that determines how an object accelerates in response to an applied force.
ii. Weight is the magnitude of the gravitational force exerted on an object by the earth (or another astronomical body). The weight acts downward, toward the center of the earth.

3. 3rd Law (law of action and reaction):

If object *A* exerts a force on object *B* (an "action"), then object *B* exerts a force on object *A* (a "reaction"). These two forces have the same magnitude but are opposite in direction.

Important points about the 3rd law:

a. The two forces in an action-reaction pair act on different objects not on a single object.
b. Newton's 3rd law may apply to both contact and field forces.

C. Application of Newton's Laws

A free-body diagram shows the object as a particle and identifies all of the external forces acting on the object or system. It is a useful pictorial representation of a situation when applying Newton's laws.

1. Objects in Equilibrium

For objects in static or dynamic equilibrium, Newton's 1st law states that:

$$\sum \vec{F} = 0$$

In component form,

$$\sum F_x = 0 \qquad \sum F_y = 0$$

2. Accelerating Objects

When a net force acts on an object, the object accelerates. Hence Newton's 2nd law states that:

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

In component form,

$$\sum F_x = ma_x \qquad \sum F_y = ma_y$$

Checkpoint Questions:

1) If you are inside a vehicle and it suddenly stops, is there a force that is pushing you forward? Explain your answer.
2) The net external force acting on an object is zero. Thus, the object can only be stationary. True or False?
3) No force is needed to keep an object moving. True or False?
4) Can a moving object be in equilibrium?

5) The purpose served when a net force acts on an object is not to sustain the object's velocity, but rather, to change it. True or False?

6) Newton's first law is also known as the law of ______.

7) A ball is kicked, and it rolls on the ground, slows down, and eventually stops. You conclude that the ball has a natural tendency to be at rest. True or False?

8) An object is moving straight downward with a constant speed of 9.8 m/s. The net force on the object is ______. Zero or Nonzero?

9) An object is moving straight downward with a constant acceleration of 9.8 m/s^2. The net force on the object is ______. Zero or Nonzero?

10) When a body is moved from sea level to the top of a mountain, what changes, mass or weight?

11) A stone and a feather fall from the same height in a vacuum chamber. Gravity is greater on the stone. True or False?

12) A book rests on top of a table. The action-reaction pair consists of the normal force and gravity. True or False?

13) Give an example of an action-reaction pair of forces.

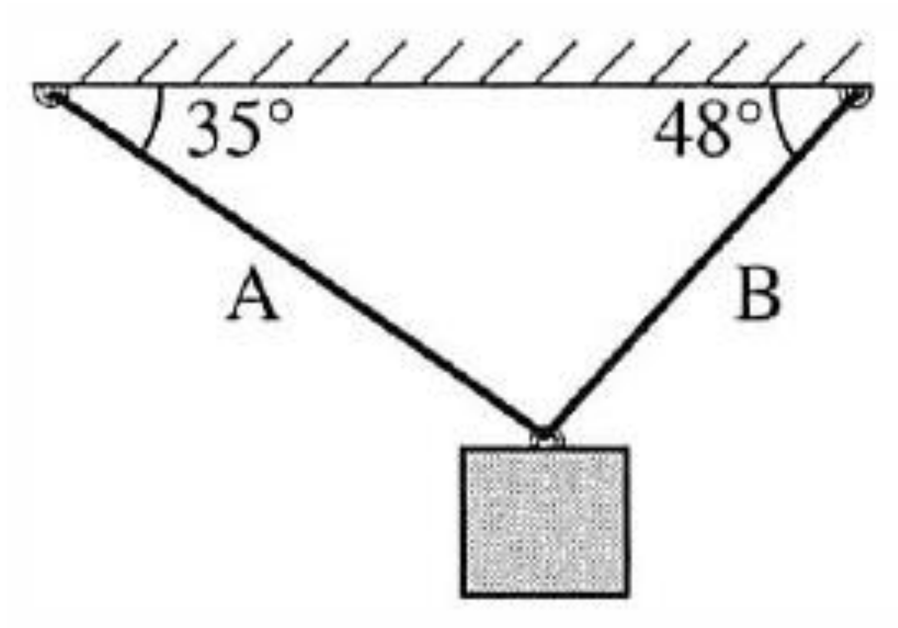
14) It is easier to keep an object moving than to start it moving. Hence the coefficient of kinetic friction is usually ______ (less than, greater than, or equal to) the coefficient of static friction for any given pair of surfaces.

15) Consider two identical blocks, one resting on a flat surface and the other resting on an incline. For which case is the normal force greater?

Imagine that you are holding a book weighing 4 N at rest on the palm of your hand. Complete the following sentences: (a) A downward force of magnitude 4 N is exerted on the book by ________. (b) An upward force of magnitude ________ is exerted on ________ by your hand. (c) Is the upward force in part (b) the reaction to the downward force in part (a)? (d) The reaction to the force in part (a) is a force of magnitude ________, exerted on ________ by ________. Its direction is ________. (e) The reaction to the force in part (b) is a force of magnitude ________, exerted on ________ by

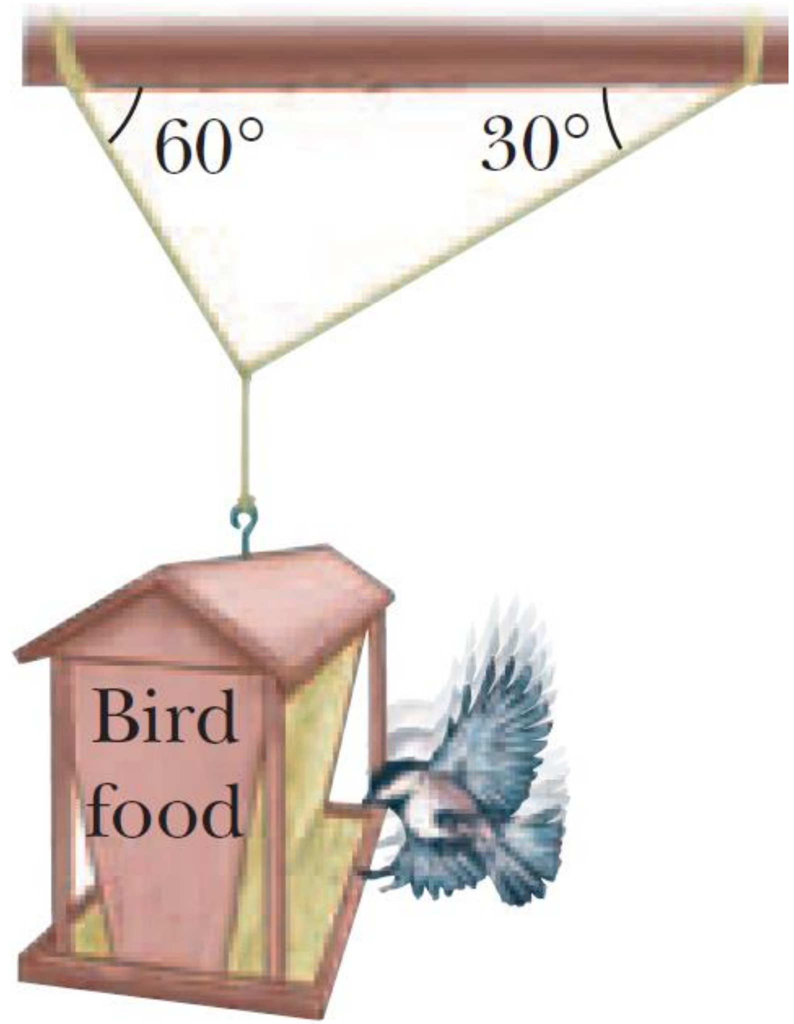
________. Its direction is ________. (f) The forces in parts (a) and (b) are equal and opposite because of Newton's ________ law. (g) The forces in parts (b) and (e) are equal and opposite because of Newton's ________ law. Now suppose that you exert an upward force of magnitude 5 N on the book. (h) Does the book remain in equilibrium? (i) Is the force exerted on the book by your hand equal and opposite to the force exerted on the book by the earth? (j) Is the force exerted on the book by the earth equal and opposite to the force exerted on the earth by the book? (k) Is the force exerted on the book by your hand equal and opposite to the force exerted on your hand by the book? Finally, suppose you snatch your hand away while the book is moving upward. (l) How many forces then act on the book (assume we can neglect air resistance)? (m) Is the book in equilibrium?

* A 322 kg block hangs from two cables as shown below. Find the tension in cables A and B.

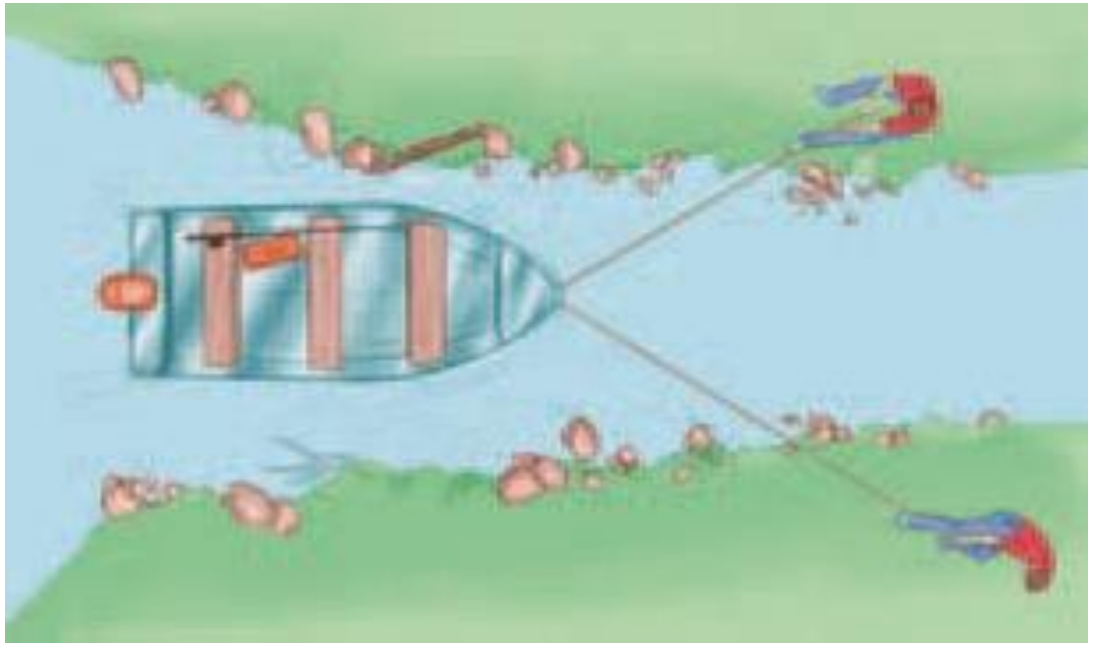


** The distance between two telephone poles is 50.0 m. When a 1.00-kg bird lands on the telephone wire midway between the poles, the wire sags 0.200 m. Draw a free-body diagram of the bird. How much tension does the bird produce in the wire? Ignore the weight of the wire.

* A 150-N bird feeder is supported by three cables as shown in the figure. Find the tension in each cable.

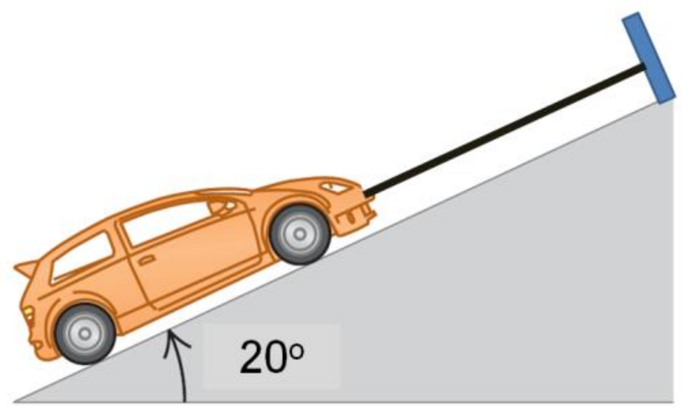


* Two people are pulling a boat through the water as shown in the figure. Each exerts a force of 600 N directed at a 30.0^{o} angle relative to the forward motion of the boat. If the boat moves with constant velocity, find the magnitude of the resistive force exerted by the water on the boat.



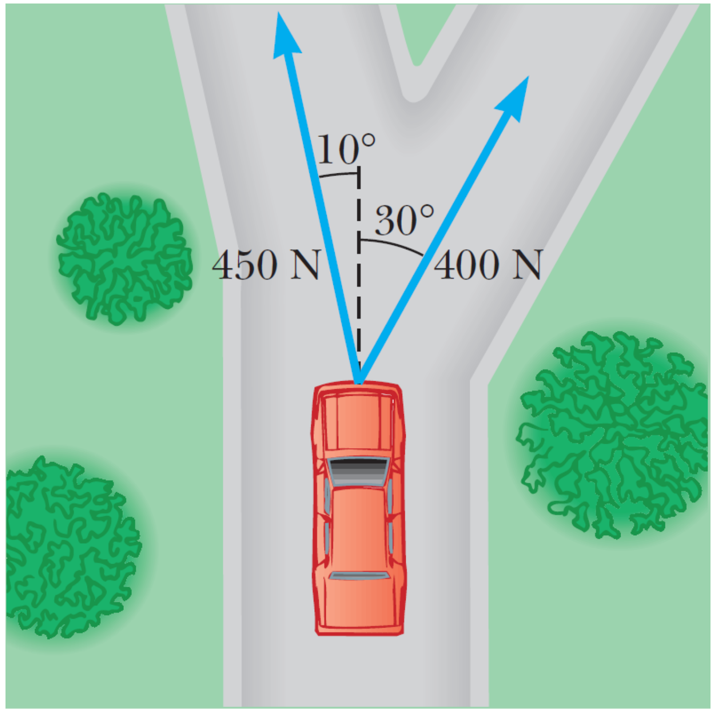
** Three forces act on a moving object. One force has a magnitude of 80.0 N and is directed due north. Another has a magnitude of 60.0 N and is directed due west. What must be the magnitude and direction of the third force, such that the object continues to move with a constant velocity?

* A 16 200-N car is held in place by a light cable on a very smooth (frictionless) ramp. The cable and ramp makes an angle of 20^{o} above the horizontal. The forces acting on the car are tension, normal force, and the force of weight, but no friction. (a) Find the tension in the cable. (b) How hard does the surface of the ramp push on the car (normal force)?



* 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.

** Two forces are applied to a car in an effort to move it as shown in the figure. a) What is the resultant force (magnitude and direction) of these two forces? b) If the car has a mass of 3 000 kg, what acceleration (magnitude and direction) does it have? Ignore friction.

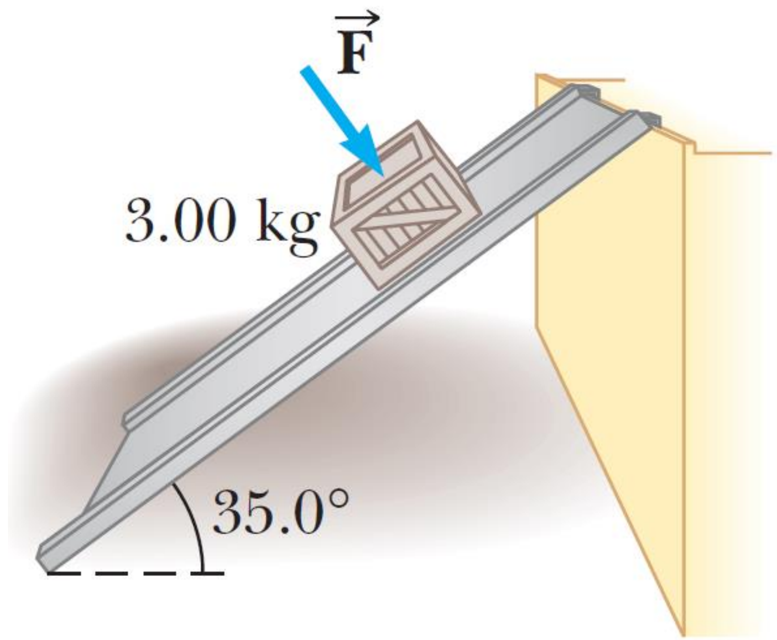


** At an instant when a soccer ball is in contact with the foot of a player kicking it, the horizontal or x component of the ball's acceleration is 810 m/s^2 and the vertical or y component of its acceleration is 1100 m/s^2. The ball's mass is 0.43 kg. What is the magnitude of the net force acting on the soccer ball at this instant?

** An astronaut's weight while standing on Earth is 800 N. What is his weight on Mars, where g = 3.76 m/s^2?

** a) If the coefficient of kinetic friction between tires and dry pavement is 0.80, what is the shortest distance in which you can stop an automobile by locking the brakes when travelling at 28.7 m/s? b) On wet pavement the coefficient of kinetic friction may be only 0.25. How fast should you drive on wet pavement in order to be able to stop in the same distance in part (a)? (Note: Locking the brakes is not the safest way to stop.)

* The coefficient of static friction between the 3-kg crate and the 35º incline of the figure is 0.3. What minimum force $\vec{F}$ must be applied to the crate perpendicular to the incline to prevent the crate from sliding down the incline?



**(a) $\Sigma F = ma$

$-f_k = ma$

$-\mu_k n = ma$

$-\mu_k \cancel{m} g = \cancel{m} a$

$-\mu_k g = a$

$\cancel{v^2}^{\,0} = v_0^2 + 2a\Delta x$

$\Delta x = \dfrac{-v_0^2}{2a} = \dfrac{-v_0^2}{2(-\mu_k g)}$

$\Delta x = \dfrac{-(28.7)^2}{2(-0.80)(9.8)} \approx \boxed{52.5\text{ m}}$

(b) $\cancel{v^2}^{\,0} = v_0^2 + 2a\Delta x$

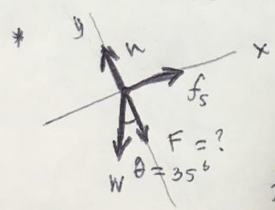
$v_0 = \sqrt{-2a\Delta x}$

$= \sqrt{-2(-\mu_k g)\Delta x}$

$= \sqrt{-2(-0.25)(9.8)(52.5)}$

$v_0 \approx \boxed{16.0\text{ m/s}}$

*



$\Sigma F_x = 0$

$f_s - mg\sin\theta = 0$

$f_s = mg\sin\theta$

$\mu_s n = mg\sin\theta$

$\Sigma F_y = 0$

$n - mg\cos\theta - F = 0$

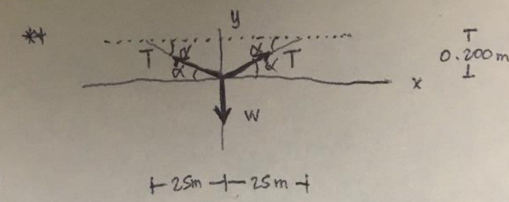
$n = F + mg\cos\theta$

$\mu_s(F + mg\cos\theta) = mg\sin\theta$

$F = \dfrac{mg\sin\theta}{\mu_s} - mg\cos\theta$

$F = \dfrac{(3)(9.8)\sin 35^\circ}{0.3} - (3)(9.8)\cos 35^\circ \approx \boxed{32.1\text{ N}}$

**



$\alpha = \tan^{-1}\left(\dfrac{0.200\text{ m}}{25.0\text{ m}}\right) \approx 0.458^\circ$

$\Sigma F_x = 0$

$T\cos\alpha - T\cos\alpha = 0$

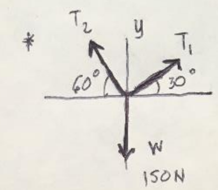
$\Sigma F_y = 0$

$T\sin\alpha + T\sin\alpha - mg = 0$

$2T\sin\alpha = mg$

$T = \dfrac{9.8}{2\sin\alpha} \approx \boxed{613\text{ N}}$

*



$\Sigma F_x = 0$

$T_1\cos 30^\circ - T_2\cos 60^\circ = 0$

$T_2 = \dfrac{T_1\cos 30^\circ}{\cos 60^\circ}$

$\Sigma F_y = 0$

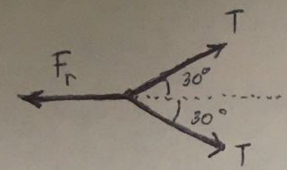
$T_1\sin 30^\circ + T_2\sin 60^\circ - 150 = 0$

$T_1\sin 30^\circ + \left(\dfrac{T_1\cos 30^\circ}{\cos 60^\circ}\right)\sin 60^\circ - 150 = 0$

$T_1 = \boxed{75.1\text{N}}$

$T_2 \approx \boxed{130\text{ N}}$

*



$\Sigma F_x = 0$ $\Sigma F_y = 0$

$T\cos\theta + T\cos\theta - F_r = 0$

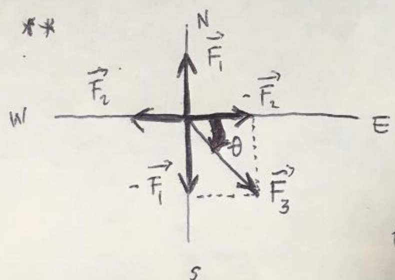
$T = 600\ N$

$\theta = 30.0°$

$2T\cos\theta = F_r$

$F_r \approx \boxed{1039\ N}$

**

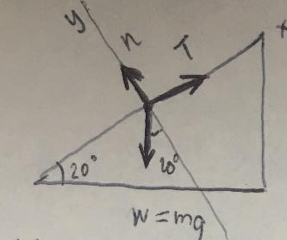


Third force $\vec{F_3}$ must be equal in magnitude but opposite in direction to the vector sum $\vec{F_1} + \vec{F_2}$

$F_3 = \sqrt{80^2 + 60^2} \approx \boxed{100\ N}$

$\theta = \tan^{-1}\left(\frac{-80}{60}\right) \approx \boxed{-53.1° \text{ or } 53.1 \text{ south of east}}$

*



(a) $\Sigma F_x = 0$

$T - mg\sin 20° = 0$

$T = mg\sin 20$

$T = (16\ 200)\sin 20° \approx \boxed{5\ 540.7\ N}$

(b) $\Sigma F_y = 0$

$n - mg\cos 20° = 0$

$n = mg\cos 20°$

$n = (16\ 200)\cos 20° \approx \boxed{15\ 223\ N}$

*

$\Sigma F_y = ma_y$

$T - mg = ma_y$

$T = m(a_y + g)$

$T = 5(3 + 9.8)$

$T \approx \boxed{64\ N}$

* (a) $\Sigma F_x = 400 \sin 30^\circ - 450 \sin 10^\circ$

$\Sigma F_x = 122N$

$\Sigma F_y = 400 \cos 30^\circ + 450 \cos 10^\circ$

$\Sigma F_y = 789 N$

$F_R = \sqrt{\Sigma F_x^2 + \Sigma F_y^2}$

$F_R \simeq \boxed{798 N}$

$\theta = \tan^{-1}\left(\frac{\Sigma F_y}{\Sigma F_x}\right) \simeq \boxed{81.21^\circ}$

(b) $a = \frac{F_R}{m} = \frac{798 N}{3000 Kg} \simeq \boxed{0.27 \ m/s^2}$

** $a = \sqrt{a_x^2 + a_y^2}$

$a = \sqrt{810^2 + 1100^2} \simeq 1366.05 \ m/s^2$

$F = ma = (0.43)\ 1366.05$

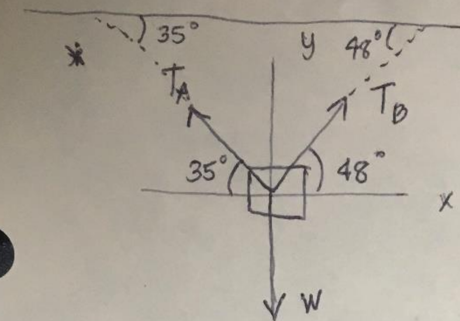
$F \simeq \boxed{587.40 N}$

** $W_E = mg_E$

$$m = \frac{W_E}{g_E} = \frac{800N}{9.8\,m/s^2} \simeq 81.63\ kg$$

$$W_M = mg_M = (81.63)\ 3.76$$

$$W_M \simeq \boxed{307\ N}$$



$$\Sigma F_x = 0$$

$$T_B \cos 48° - T_A \cos 35° = 0$$

$$\Sigma F_y = 0$$

$$T_B \sin 48° + T_A \sin 35° - mg = 0$$

$$T_B = T_A \frac{\cos 35°}{\cos 48°}$$

$$T_A \frac{\cos 35°}{\cos 48°} \sin 48° + T_A \sin 35° - mg = 0$$

$$T_A (\cos 35° \tan 48° + \sin 35°) = mg$$

$$T_A = \frac{mg}{(\cos 35° \tan 48° + \sin 35°)} = \frac{(322 Kg)\ 9.8\,m/s^2}{\cos 35° \tan 48° + \sin 35°}$$

$$T_A \simeq \boxed{2130\ N}$$

$$T_B = T_A \frac{\cos 35°}{\cos 48°} = 2130N \frac{\cos 35°}{\cos 48°} = \boxed{2600\ N}$$