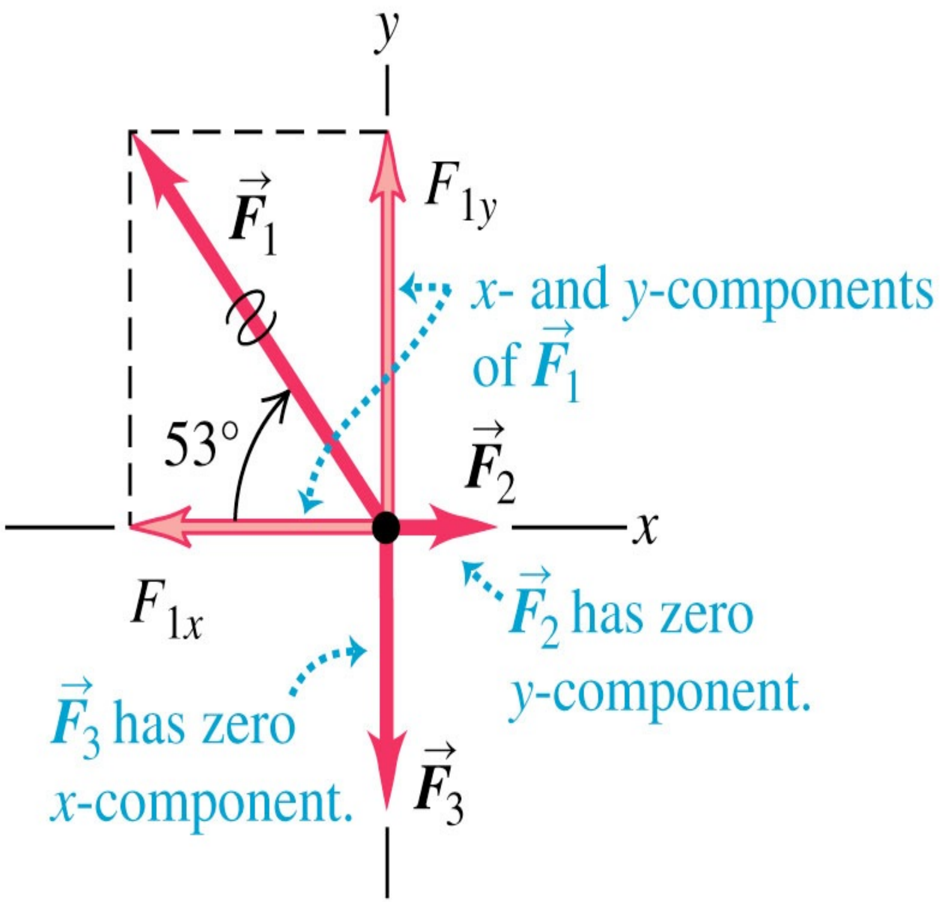
Example: Adding 3 Forces



$F_1 = 250$ N, $\theta_1 = 127°$

$F_2 = 50$ N, $\theta_2 = 0°$

$F_3 = 120$ N, $\theta_3 = 270°$

$R_x = F_{1x} + F_{2x} + F_{3x}$

$R_y = F_{1y} + F_{2y} + F_{3y}$

Newton's first law

…is actually a special case of Newton's second law. If no force acts on an object or all applied forces compensate:

$$\sum \vec{F} = m\vec{a} = 0 \rightarrow \vec{a} = \frac{\Delta \vec{v}}{\Delta t} = 0$$

If there is no effective force, the object's velocity does not change.

An object moves with a velocity that is constant in magnitude and direction unless a non-zero net force acts on it.

Let's look at some consequences of Newton's first law…..

Newton’s first law

With no outside forces,
this object will
never move

With no outside forces,
this object will
never stop

Consequences of Newton’s first law

When you ride a car, you and the car are moving at the same speed.

If you do not use the seat belts and the car breaks, a force will act on the car to decelerate it, but it will not act on you.

Thus, you continue to move at the original speed according to Newton’s 1st law.

In space there is no friction and (except weak gravity) no forces.

Thus, once accelerated in one direction an object will continue moving in this direction forever.

Inertia, mass, and weight

Inertia is the tendency of an object to continue in its original state of motion.

Mass is a measure of the object's resistance to changes in its motion due to a force.

$$\vec{F} = m\vec{a} = m\frac{\Delta\vec{v}}{\Delta t}$$

The higher the mass, the smaller the acceleration for a given force.

Weight is the magnitude of the gravitational force acting on an object of mass, m.

$$w = mg$$

The weight depends on the gravitational constant, g, that is different for different planets.

Example: Application of Newton's Laws

An 80 kg movie stuntman jumps from a window of a building situated 30 m above a catching net. Assuming air resistance exerts a 100-N force on the stuntman as he falls, determine his velocity just before he hits the net.

Summary

- A force is the product of an object's mass and acceleration. Forces are the reason why objects change their velocity. Newton's second law:

$$\vec{F} = m\vec{a} = m\frac{\Delta \vec{v}}{\Delta t}$$

Unit: 1 N = 1 kg m/s^2

- Forces are vector quantities, since they have magnitude and direction.

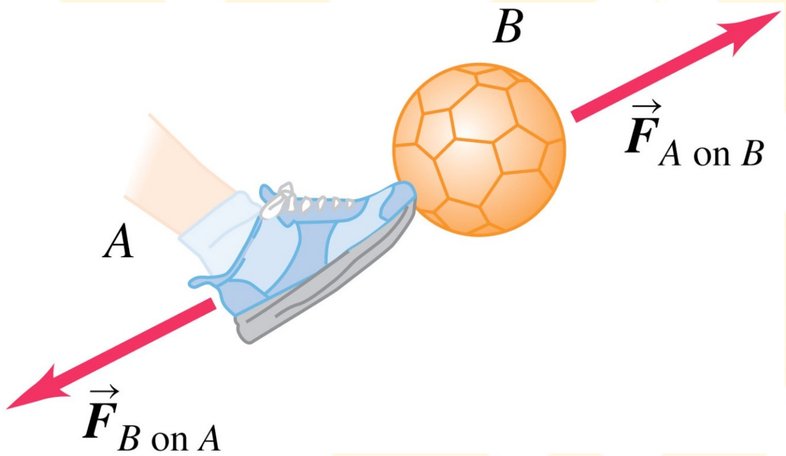
- An effective force changes an object's velocity (magnitude and/or direction). A circular motion is an accelerated motion.

- Newton's first law is a special case of Newton's second law (F = 0):

An object moves with a velocity that is constant in magnitude and direction unless a non-zero net force acts on it.

- *Inertia* is the tendency of an object to continue in its original state of motion.
  Mass is a measure of the object's resistance to changes in its motion due to a force.
  Weight is the magnitude of the gravitational force acting on an object of mass, m: $w = mg$

Newton’s 3rd law



Action = - Reaction

If object A exerts a force on object B (Action Force), object B will always exert a force on object A that is equal in magnitude, but opposite in direction (Reaction Force)

Important: - Forces in nature always exist in pairs (Action, Reaction).
- The action and reaction forces always act on different objects.

Is Newton's third law correct?

Let's say $F = 20$ N, $m_A = 5$ kg, and $m_B = 15$ kg. What is the acceleration of both blocks?

Newton's 2nd law: $F = 20\ \text{N} = (m_A + m_B)\, a = 20\ \text{kg} \cdot a \quad \rightarrow \quad a = 1\ \text{m/s}^2$ (for both blocks!)

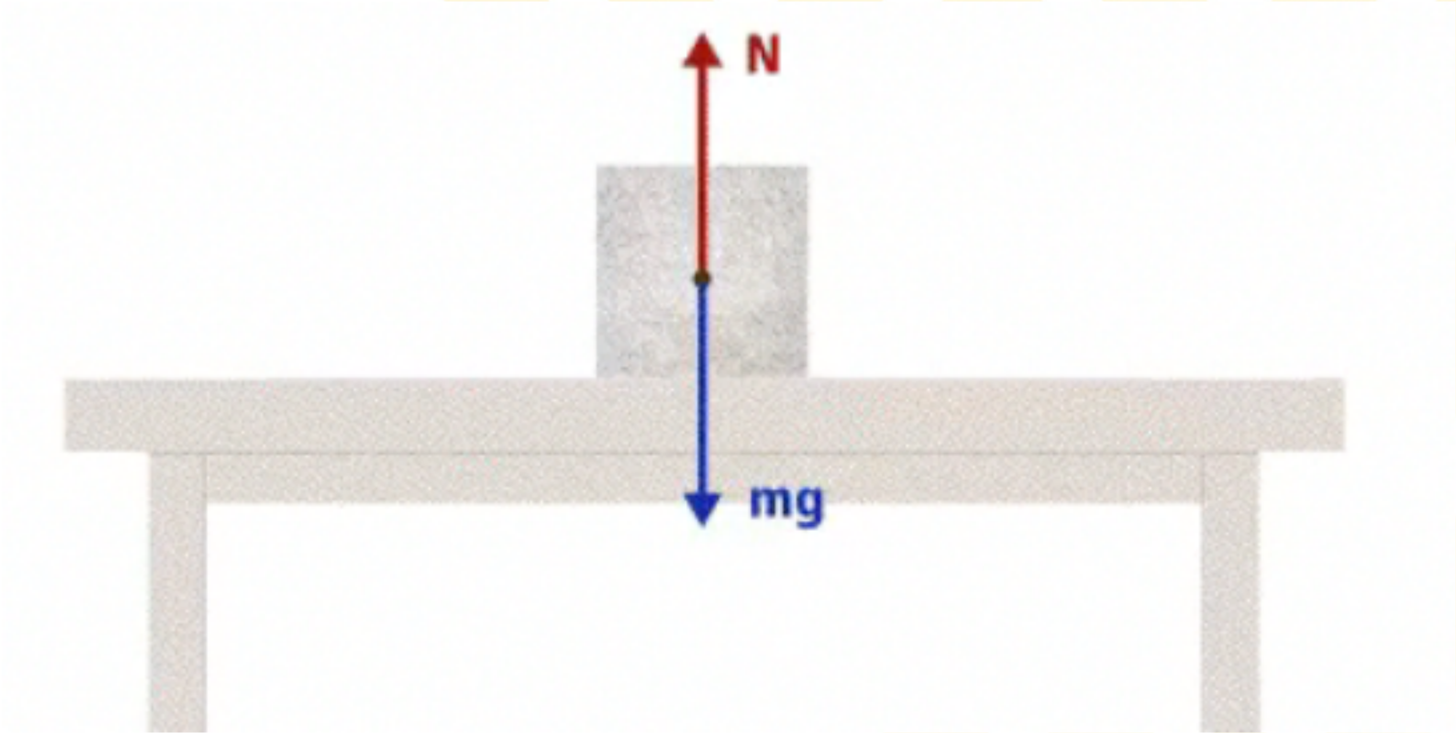
Now, let's look at block B only. What must be the force of block A on B so that $a = 1\ \text{m/s}^2$?

$F_{AB} = m_B \cdot 1\ \text{m/s}^2 = 15\ \text{kg} \cdot 1\ \text{m/s}^2 = 15\ \text{N}$

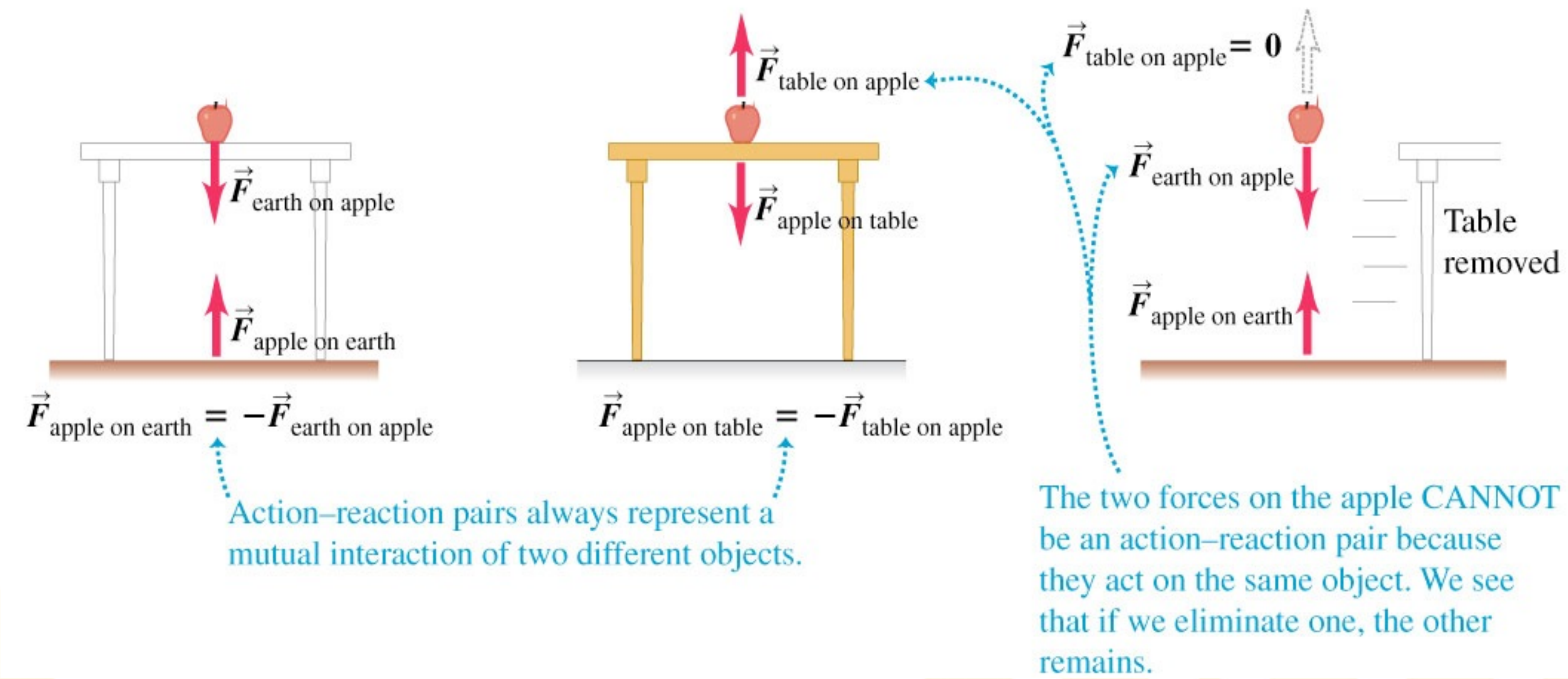
Now, let's look at block A only. What must be the force of block B on A so that $a = 1\ \text{m/s}^2$?

$F_A = F + F_{BA} \qquad F_A = m_A \cdot 1\ \text{m/s}^2 = 5\ \text{kg} \cdot 1\ \text{m/s}^2 = 5\ \text{N} \quad \rightarrow \quad \boxed{F_{BA} = -15\ \text{N} = -F_{AB}}$

Normal forces

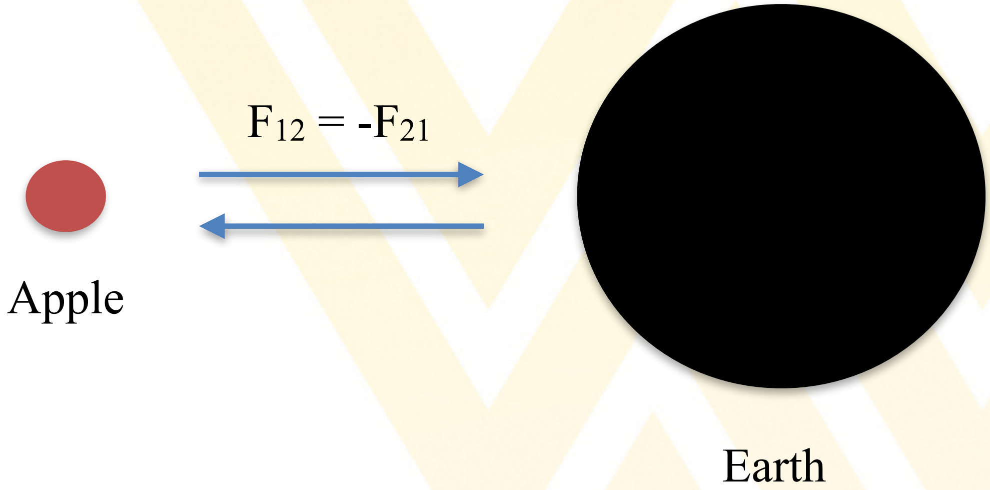


Applying Newton's third law



The force exerted by the table on the apple is called a normal force, since it acts perpendicular to the surface of the table.

Does the earth move towards the apple?



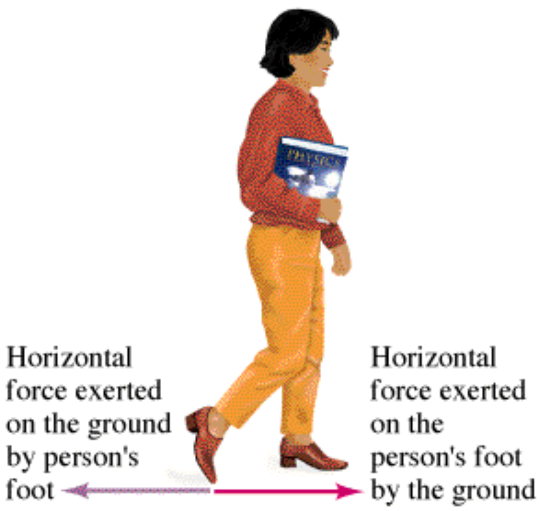
The force exerted by the apple on earth has the same magnitude as the force exerted by earth on the apple. However, the mass of the apple, m_a, is much smaller than the mass of earth, m_e.

$F_{12} = m_a \cdot a_a \quad \rightarrow \quad a_a = F_{12}/m_a$ is high, since m_a is small.

$F_{21} = -F_{12} = m_e \cdot a_e \quad \rightarrow \quad a_e = -F_{12}/m_e$ is small, since m_e is high.

$s = 1/2\ a\ t^2 \quad \rightarrow$ During a given time, t, the apple moves a longer distance than the earth. The latter is so small that it cannot be measured.

Walking - a consequence of Newton's 3rd law

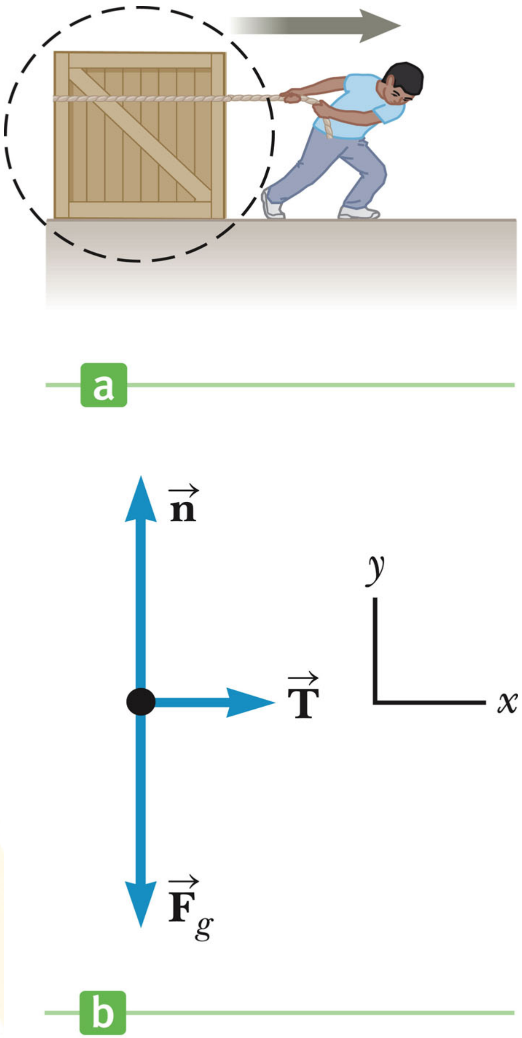


When we walk, we exert a force, F_{GP}, on the ground. This forces pushes earth, but not ourselves!

Due to Newton's 3rd law, earth exerts a force, $F_{PG} = -F_{GP}$, on us. This force pushes us forward!

Rocket propulsion - a consequence of Newton’s 3rd law

Free body diagrams



A free body diagram is a schematic that shows all forces acting on a given body (no other forces).

The forces are represented by vectors indicating each force's magnitude and direction.

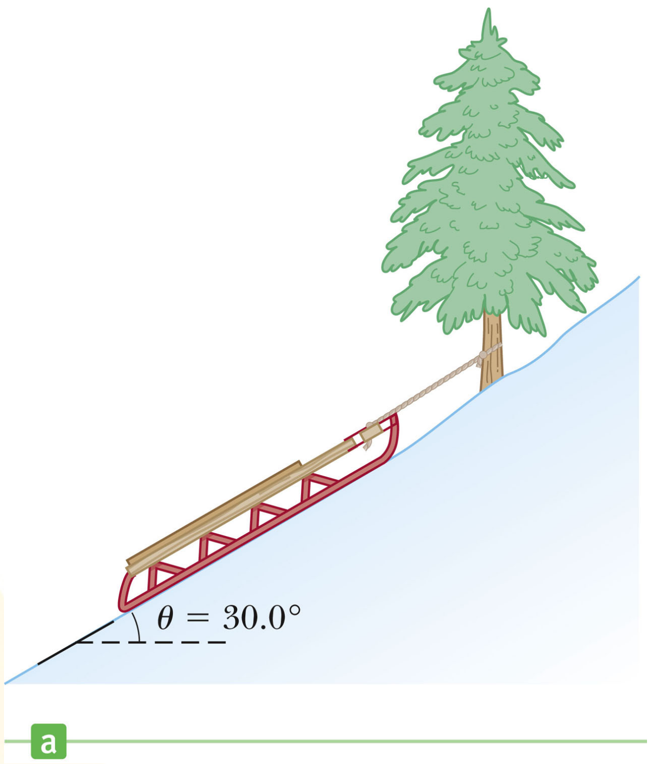
It is called free body diagram, because the environment is replaced by a series of forces on an otherwise free body.

A free body diagram is very useful to determine the resulting forces on an object.

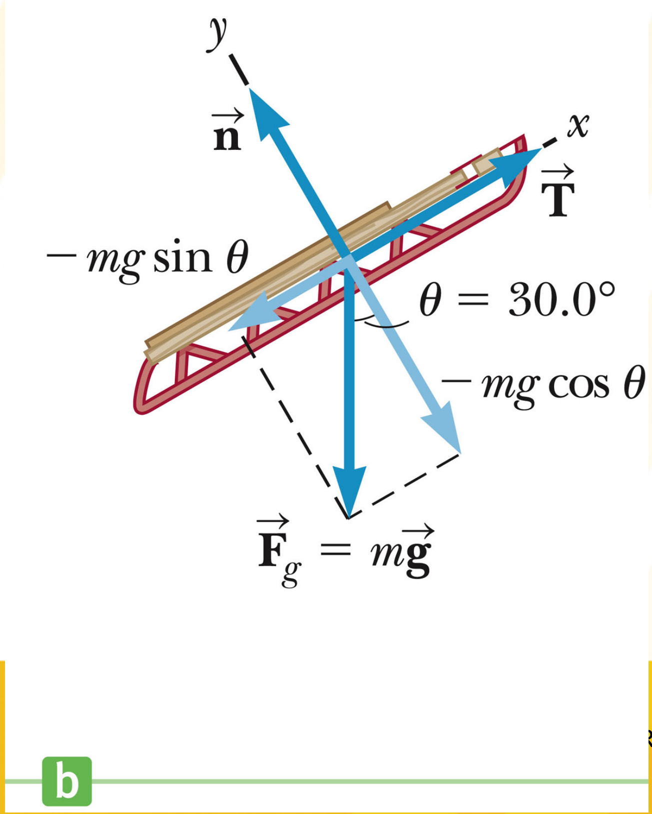
Draw a free body diagram, whenever you face a problem related to forces!

Example problem

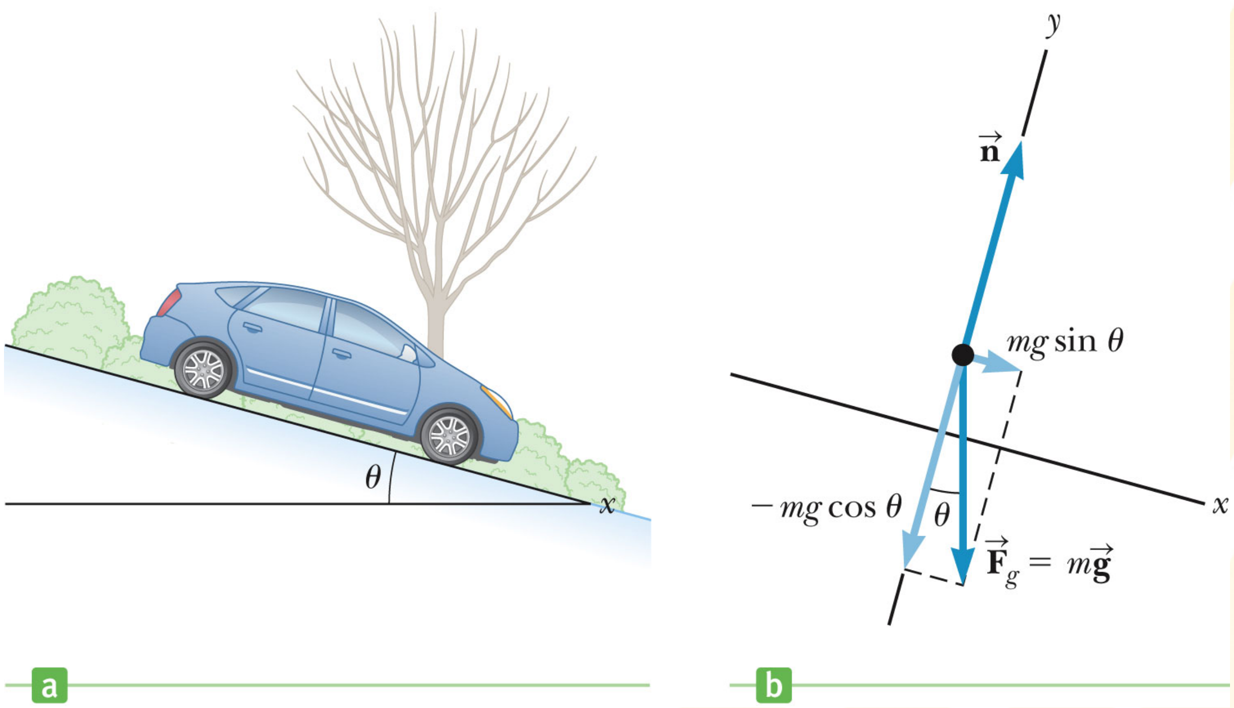
A sled is tied to a tree on a frictionless (snow covered) hill. If the sled weighs 77 N, find the magnitude of the tension force exerted by the rope on the sled and that of the normal force exerted by the hill on the sled.



1st step: Draw the free body diagram. Which forces act on the sled (dark blue arrows)?



The runaway car



A car of mass m is on an icy driveway inclined at an angle of 20º.

A. Determine the acceleration of the car (no friction)
B. If the length of the driveway is 25 m and the car starts from rest at the top, how long does it take to travel to the bottom?
C. What is the car’s speed at the bottom?

Summary

- Newton's 3rd law: If object A exerts a force on object B (Action Force), object B will always exert a force on object A that is equal in magnitude, but opposite in direction (Reaction Force)

Action = - Reaction

- If an objects is located on a surface at rest, at least two forces will act on it: (i) The gravitational force (downwards) and (ii) the normal force (upwards) exerted by the surface on the object to compensate gravitation.

- A free body diagram is a schematic that shows all forces acting on a given body (no other forces). Always draw such a diagram, when facing a problem related to forces.

- In problems about inclined planes, calculate all forces parallel and perpendicular to the inclined plane.