Newton Laws of Motion

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Applied Physics

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- Newtonian Mechanics/ Classical Mechanics
- Newton's Laws
- Inertial Reference frames
- Particular Forces(Gravitational Force, Weight, Normal Force, Tension, Frictional Force)
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Classical Mechanics(CM)

- The field of study in which we study the causes of motion is called “DYNAMICS”
- The approach to dynamics we consider in this chapter and ahead known as “CLASSICAL MECHANICS”.
- Often referred to as “Newtonian Mechanics”

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Causes of Motion(some examples)

Table : Some accelerated Motions and their Causes		
Object	*Change in Motion*	*Major Cause (Environment)*
Apple	Falls from tree	Earth's Gravity
Billiard Ball	Bounces off another	Other ball, table, gravity(earth)
Skier	Slides down hill	Earth's gravity, friction(snow), air resistance
Beam of Electrons	Focusing and deflection	EM fields(Magnets & Voltage Differences)
Comet Halley	Round trip through solar system	Sun's Gravity

Newtonian Mechanics

- Classical Mech ~ Newtonian Mech,
- The study of relationship between a Force and the Acceleration it causes is called Newtonian Mechanics.
- We shall focus on its three primary laws of motion

1. First Law of Motion : a qualitative analysis
2. Second Law of Motion: a quantitative analysis
3. Third Law of Motion

Limitation of Newtonian Mech.

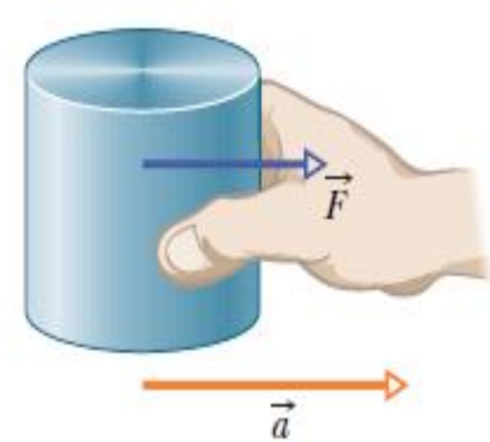
- It does not apply to all situations.
- If the speeds are quite high or very large say the body moves with the speed of light then **we will replace Newtonian mechanics by Einstein's special theory of relativity**, which holds for any speed, including those near the speed of light.
- If the interacting bodies are on the scale of atomic structure(might be electrons in an atom) we must replace **Newtonian mechanics by Quantum mechanics.**

Introduction to Force

- Physics is the study of motion
- Physics is also the study of those causes that produces motion in an object.
- That cause is known as FORCE
- A Force is defined generally as a "pull or a push" on the object.
- The force is said to ***act*** on the object to change its velocity.
- Examples(car slams on a pole, a Force from the pole causes a car to stop)

Introduction to Force

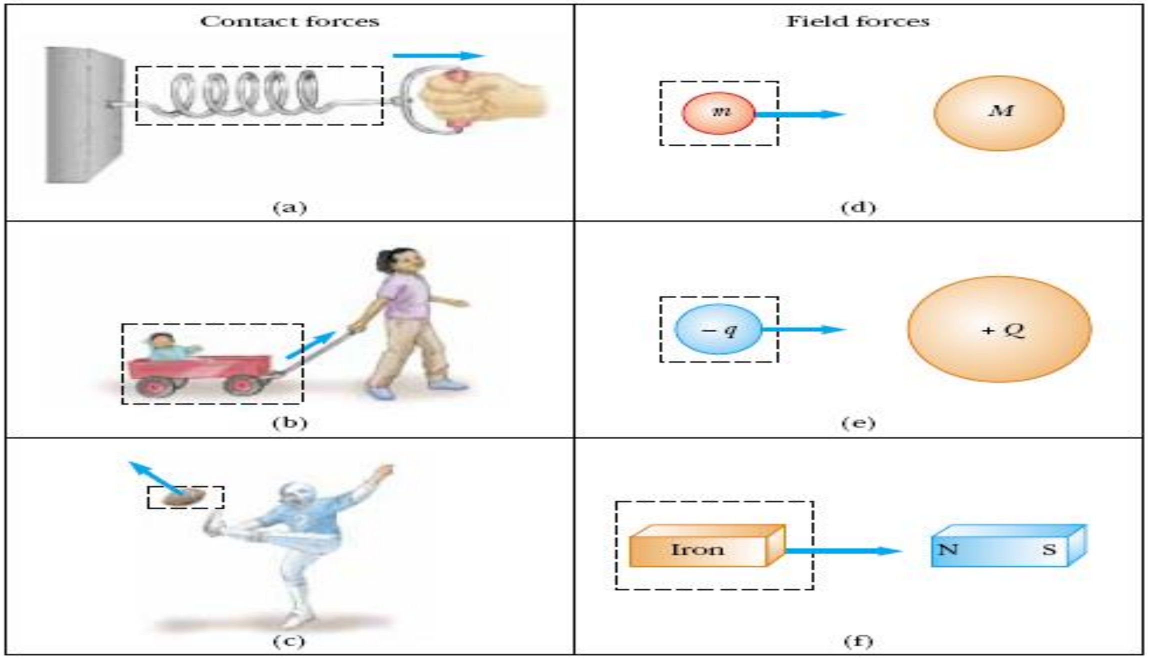
- Force is measured by the acceleration it produces.
- However, acceleration is a vector quantity, with both magnitude and direction.
- To find force we should have the mass of the object and acceleration produced.



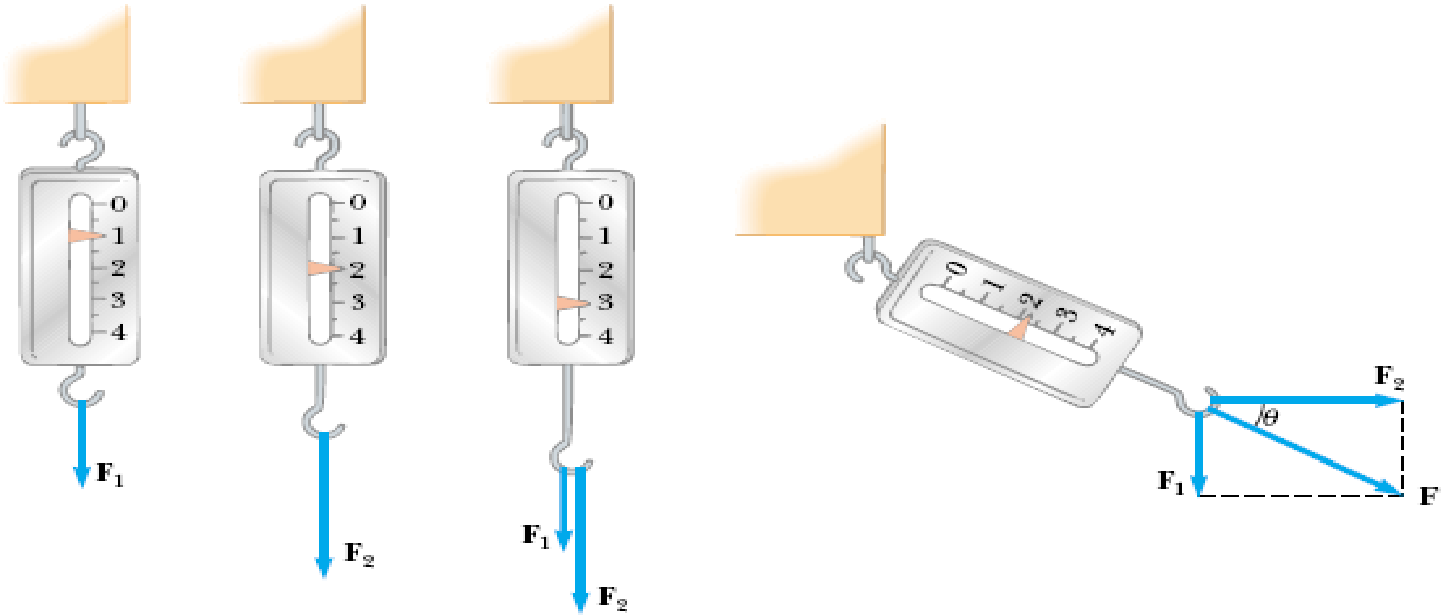
A force $\vec{F}$ on the standard kilogram gives that body an acceleration $\vec{a}$.

The Concept of Force

- The net force acting on an object is defined as the vector sum of all forces acting on the object. (We sometimes refer to the net force as the *total force*, *the resultant force*, *or the unbalanced force.)*
- If the net force exerted on an object is zero, the acceleration of the object is zero and its velocity remains constant.
- When the velocity of an object is constant (including when the object is at rest), the object is said to be in equilibrium.



Measuring the Strength of a Force



Because forces are vector quantities, you must use the rules of vector addition to obtain the net force acting on an object.

Reference Frames

- A "**frame of reference**" is just a set of coordinates: something you use to measure the things that matter in Newtonian problems, that is to say, positions and velocities, so we also need a clock.
- An **inertial frame** is defined as one in which Newton's law of inertia holds—that is, any body which isn't being acted on by an outside force stays at rest if it is initially at rest, or continues to move at a constant velocity if that's what it was doing to begin with.
- In other words we can say that Newton's First law is not true in all reference frames.

Newton's First Law and Inertial Frames

Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame.

Newton 1st Law of Motion

"In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line)".

Mass

Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity.

Mass is an inherent property of an object and is independent of the object's surroundings and of the method used to measure it. Also, mass is a scalar quantity and thus obeys the rules of ordinary arithmetic.

Note: Mass and weight are two different quantities

Newton's Second Law

"When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass" .

$$\boxed{\sum \mathbf{F} = m\mathbf{a}}$$

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

Unit of Force

The SI unit of force is the **newton**, which is defined as the force that, when acting on an object of mass 1 kg, produces an acceleration of 1 m/s^2. From this definition and Newton's second law, we see that the newton can be expressed in terms of the following fundamental units of mass, length, and time:

$$1\,\mathrm{N} \equiv 1\,\mathrm{kg \cdot m/s^2}$$

Example Problem

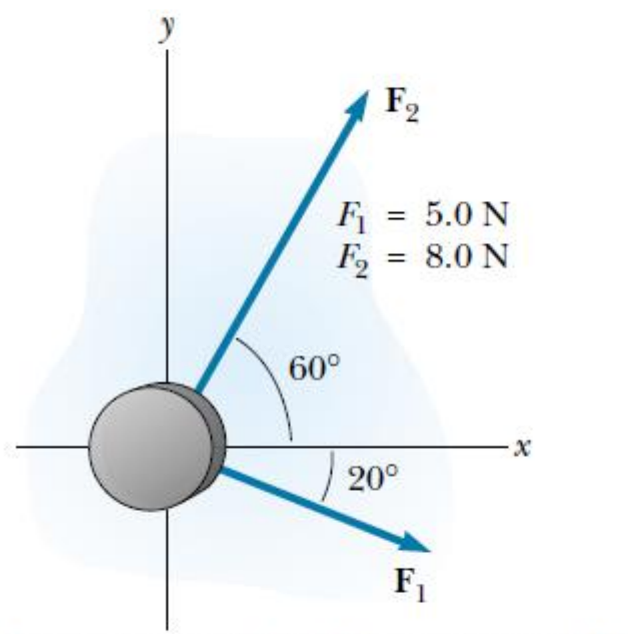
A hockey puck having a mass of 0.30 kg slides on the horizontal, frictionless surface of an ice rink. Two forces act on the puck, as shown in Figure . The force $\mathbf{F}_1$ has a magnitude of 5.0 N, and the force $\mathbf{F}_2$ has a magnitude of 8.0 N. Determine both the magnitude and the direction of the puck's acceleration.

Solution The resultant force in the x direction is

$$\sum F_x = F_{1x} + F_{2x} = F_1 \cos(-20°) + F_2 \cos 60°$$
$$= (5.0\text{ N})(0.940) + (8.0\text{ N})(0.500) = 8.7\text{ N}$$

The resultant force in the y direction is

$$\sum F_y = F_{1y} + F_{2y} = F_1 \sin(-20°) + F_2 \sin 60°$$
$$= (5.0\text{ N})(-0.342) + (8.0\text{ N})(0.866) = 5.2\text{ N}$$



A hockey puck moving on a frictionless surface accelerates in the direction of the resultant force $\mathbf{F}_1 + \mathbf{F}_2$.

Solution cont'd

Now we use Newton's second law in component form to find the x and y components of acceleration:

$$a_x = \frac{\sum F_x}{m} = \frac{8.7\ \text{N}}{0.30\ \text{kg}} = 29\ \text{m/s}^2$$

$$a_y = \frac{\sum F_y}{m} = \frac{5.2\ \text{N}}{0.30\ \text{kg}} = 17\ \text{m/s}^2$$

The acceleration has a magnitude of

$$a = \sqrt{(29)^2 + (17)^2}\ \text{m/s}^2 = \boxed{34\ \text{m/s}^2}$$

and its direction relative to the positive x axis is

$$\theta = \tan^{-1}\left(\frac{a_y}{a_x}\right) = \tan^{-1}\left(\frac{17}{29}\right) = \boxed{30°}$$

The Gravitational Force and Weight

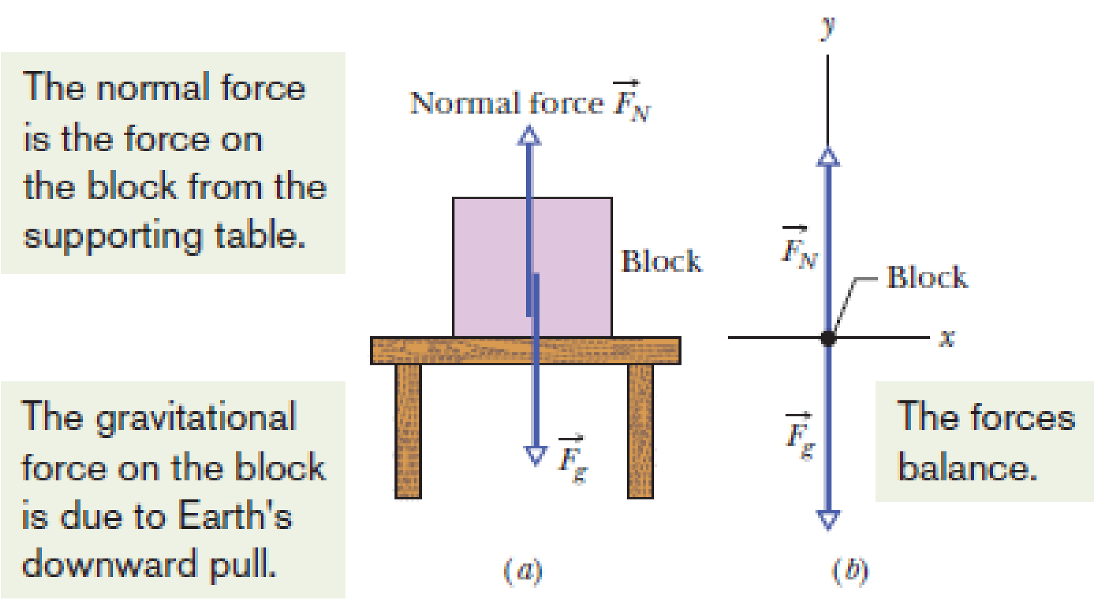
We are well aware that all objects are attracted to the Earth. The attractive force exerted by the Earth on an object is called the gravitational force F*g* . *This force is directed* toward the center of the Earth, and its magnitude is called the weight of the object.

$$\mathbf{F}_g = m\mathbf{g}$$

The Normal Force

When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force that is perpendicular to the surface

Note: To solve problems with Newton's second law, we often draw a free-body diagram in which the only body shown is the one for which we are summing forces.



How Much Do You Weigh in an Elevator?

You have most likely had the experience of standing in an elevator that accelerates upward as it moves toward a higher floor. In this case, you feel heavier. In fact, if you are standing on a bathroom scale at the time, the scale measures a force magnitude that is greater than your weight. Thus, you have tactile and measured evidence that leads you to believe you are heavier in this situation. *Are* you heavier?

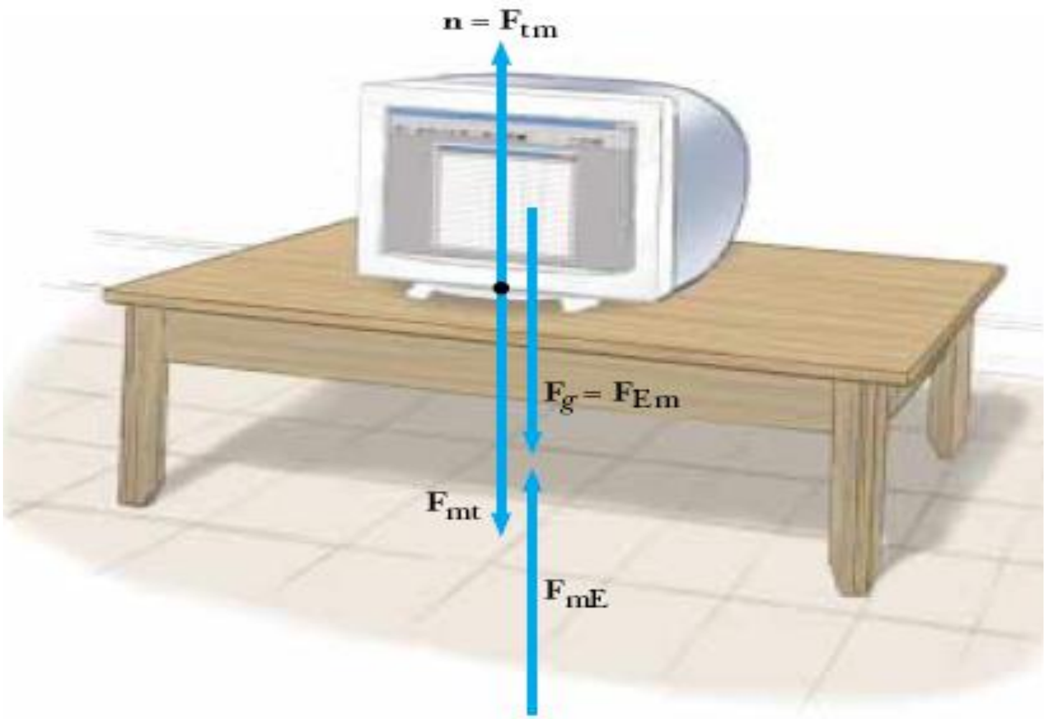
The Answer is: NO

No, your weight is unchanged. To provide the acceleration upward, the floor or scale must exert on your feet an upward force that is greater in magnitude than your weight. It is this greater force that you feel, which you interpret as feeling heavier. The scale reads this upward force, not your weight, and so its reading increases.

Newton's Third Law

If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force F_{21} exerted by object 2 on object 1:

$$\mathbf{F}_{12} = -\mathbf{F}_{21}$$



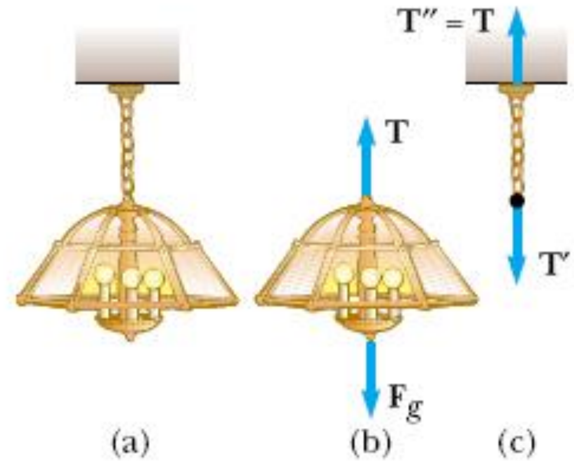
This is equivalent to stating that a single isolated force cannot exist.

Application of Newton's Laws

- In this section we apply Newton's laws to objects that are either in equilibrium ($a= 0$) or accelerating along a straight line under the action of constant external forces
- We assume that the objects behave as particles so that we need not worry about rotational motion.
- We also neglect the effects of friction in those problems involving motion; this is equivalent to stating that the surfaces are *frictionless.*
- Finally, we usually neglect the mass of any ropes involved.

Tension:

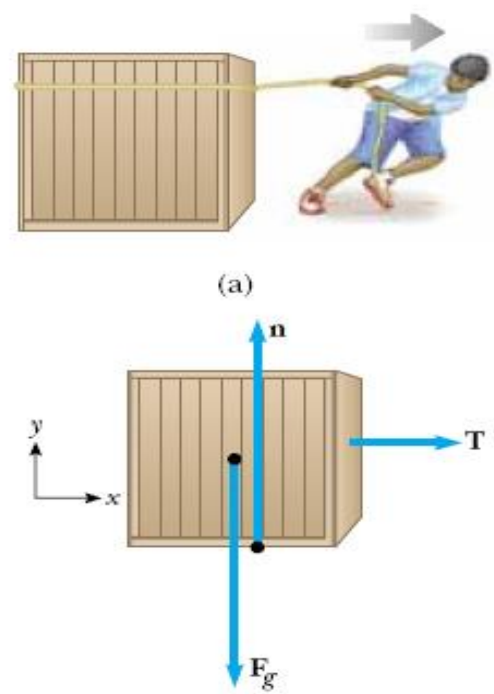
When a rope attached to an object is pulling on the object, the rope exerts a force T on the object, and the magnitude of that force is called the tension in the rope.



Objects in Equilibrium

$$\sum F_y = T - F_g = 0 \qquad \text{or} \qquad T = F_g$$

Objects Experiencing a Net Force



$$\sum F_x = T = ma_x \qquad \text{or} \qquad a_x = \frac{T}{m}$$

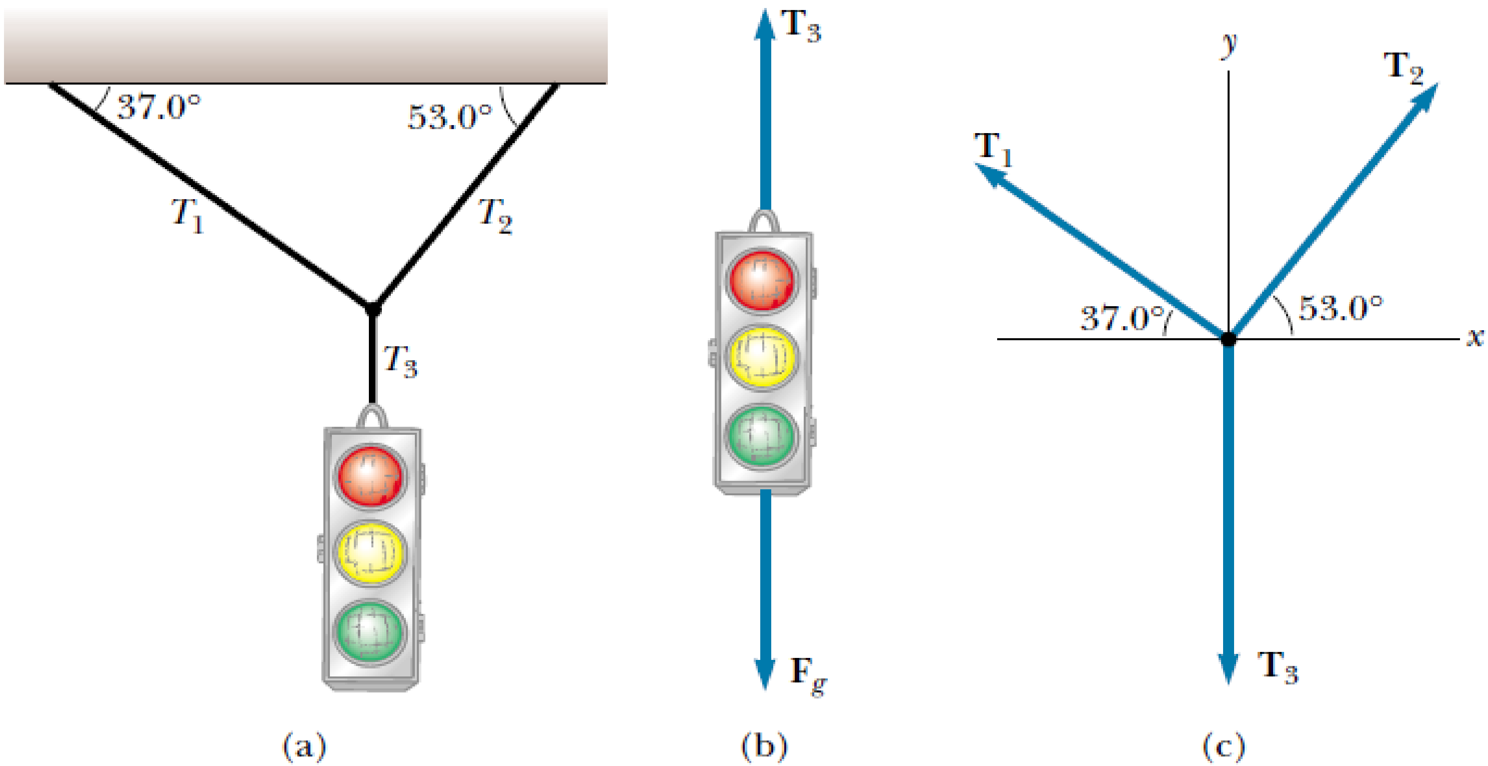
$$n + (-F_g) = 0 \qquad \text{or} \qquad n = F_g$$

$$v_{xf} = v_{xi} + \left(\frac{T}{m}\right)t$$

$$x_f = x_i + v_{xi}t + \frac{1}{2}\left(\frac{T}{m}\right)t^2$$

Example Problem

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0° and 53.0° with the horizontal. Find the tension in the three cables.

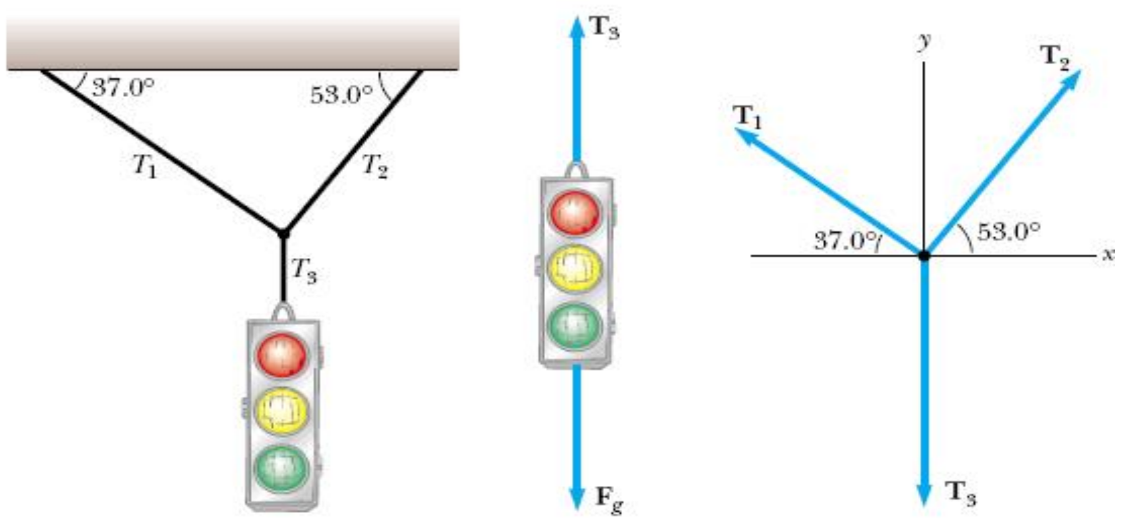


(a) A traffic light suspended by cables. (b) Free-body diagram for the traffic light. (c) Free-body diagram for the knot where the three cables are joined.

Solution:

In Figure (b) the force $\mathbf{T}_3$ exerted by the vertical cable supports the light, and so $T_3 = F_g =$ 125 N. Next, we choose the coordinate axes shown in Figure (c) and resolve the forces acting on the knot into their components:

Force	x Component	y Component
$\mathbf{T}_1$	$-T_1 \cos 37.0°$	$T_1 \sin 37.0°$
$\mathbf{T}_2$	$T_2 \cos 53.0°$	$T_2 \sin 53.0°$
$\mathbf{T}_3$	0	-125 N



Solution:

Knowing that the knot is in equilibrium ($\mathbf{a} = 0$) allows us to write

$$(1) \qquad \sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0$$

$$(2) \qquad \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-125\ N) = 0$$

From (1) we see that the horizontal components of $\mathbf{T}_1$ and $\mathbf{T}_2$ must be equal in magnitude, and from (2) we see that the sum of the vertical components of $\mathbf{T}_1$ and $\mathbf{T}_2$ must balance the weight of the light. We solve (1) for T_2 in terms of T_1 to obtain

$$T_2 = T_1\left(\frac{\cos 37.0°}{\cos 53.0°}\right) = 1.33 T_1 \longrightarrow \textbf{(3)}$$

This value for T_2 is substituted into (2) to yield

$$T_1 \sin 37.0° + (1.33 T_1)(\sin 53.0°) - 125\text{ N} = 0$$

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

$$T_2 = 1.33 T_1 = 99.9\text{ N}$$

What If? **Suppose the two angles in Figure (a) are equal. What would be the relationship between T_1 and T_2?**

Answer We can argue from the symmetry of the problem that the two tensions T_1 and T_2 would be equal to each other. Mathematically, if the equal angles are called θ, Equation (3) becomes

$$T_2 = T_1\left(\frac{\cos\theta}{\cos\theta}\right) = T_1$$

which also tells us that the tensions are equal. Without knowing the specific value of θ, we cannot find the values of T_1 and T_2. However, the tensions will be equal to each other, regardless of the value of θ.

The Runaway Car

Suppose a car is released from rest at the top of the incline, and the distance from the front edge of the car to the bottom is *d*. *How long does it take the front edge to reach the bottom, and what is its speed just as it gets there?*

Because a_x = constant,

we can apply

$x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2$,

to analyze the car's motion

replace displacement by $x_f - x_i = d$

Put, $v_{xi} = 0$, we get

$$d = \frac{1}{2}a_x t^2$$

$$(1) \qquad \sum F_x = mg\sin\theta = ma_x$$

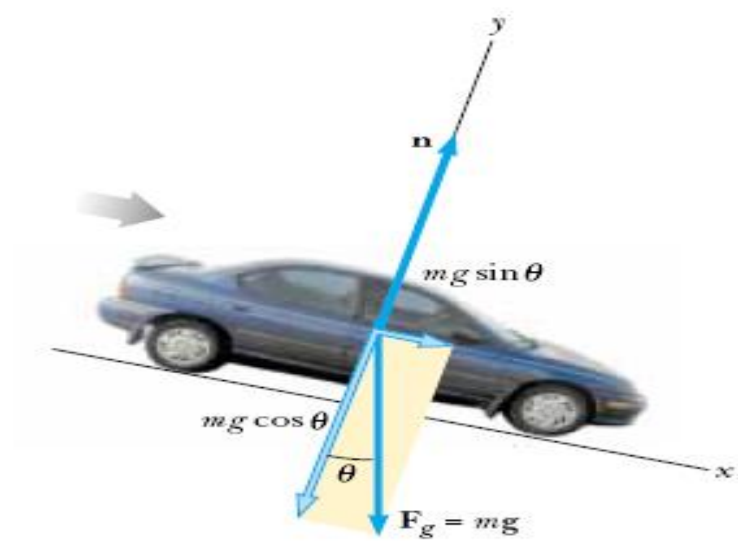
$$(2) \qquad \sum F_y = n - mg\cos\theta = 0$$

Solving (1) for a_x $\boxed{a_x = g\sin\theta}$

put the value of a_x in $d = \frac{1}{2}a_x t^2$ and find time, as follows

$$t = \sqrt{\frac{2d}{a_x}}$$

$$t = \sqrt{\frac{2d}{g\sin\theta}}$$



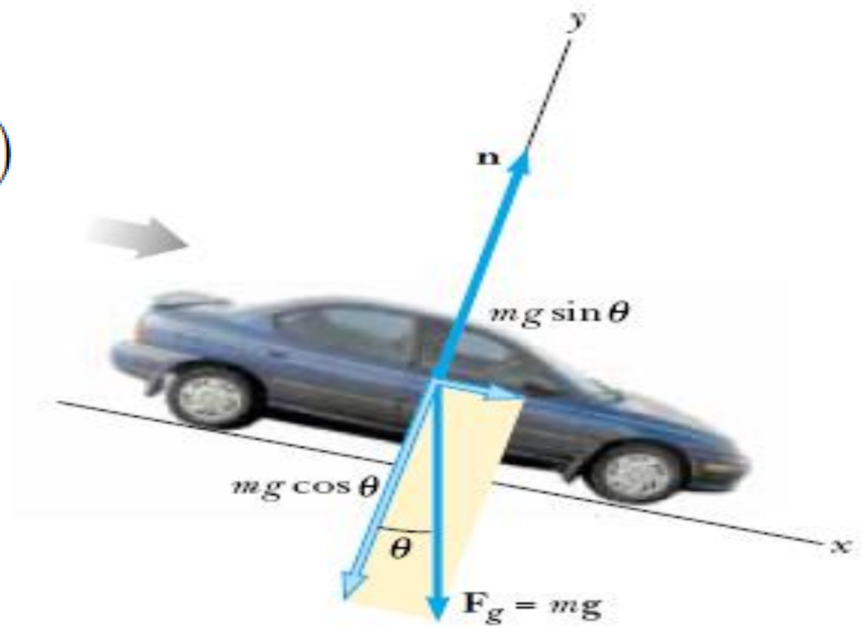
Calculation for Final Velocity

Using $v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$

with $v_{xi} = 0, \quad x_f - x_i = d$

$$v_{xf}^2 = 2a_x d$$

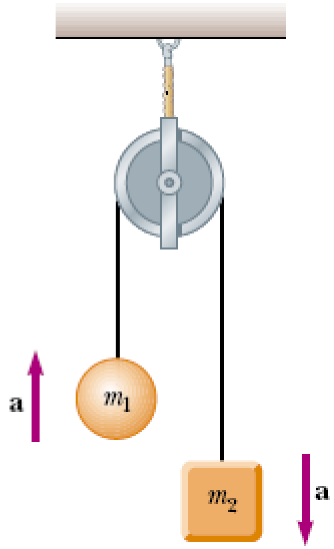
$$v_{xf} = \boxed{\sqrt{2gd \sin \theta}}$$

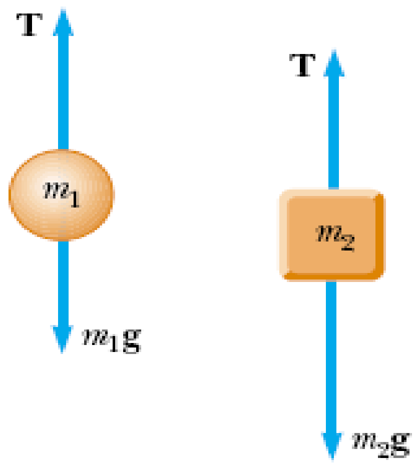


Conclusion

We see that the time t needed to reach the bottom and the speed v_{xf}, are independent of the car's mass.

The Atwood Machine





$$\sum F_y = T - m_1 g = m_1 a_y$$

$$\sum F_y = m_2 g - T = m_2 a_y$$

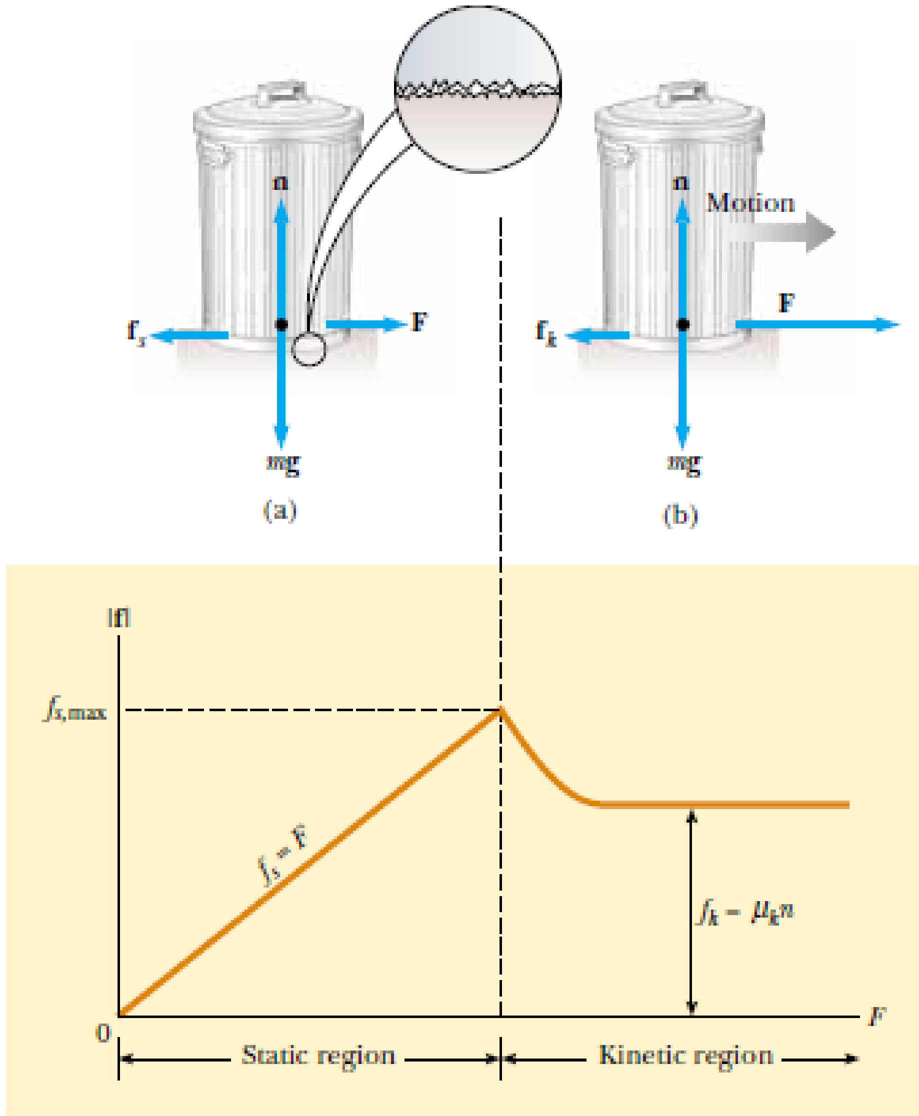
$$a_y = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g$$

$$T = \left(\frac{2 m_1 m_2}{m_1 + m_2}\right) g$$

Forces of Friction

When an object is in motion either on a surface or in a viscous medium such as air or water, there is resistance to the motion because the object interacts with its surroundings. We call such resistance a force of friction.
Forces of friction are very important in our everyday lives. They allow us to walk or run and are necessary for the motion of wheeled vehicles.

Static and Kinetic Friction



• The magnitude of the force of static friction between any two surfaces in contact can have the values.

$$f_s \leq \mu_s n$$

• The magnitude of the force of kinetic friction acting between two surfaces is

$$f_k = \mu_k n$$

• The values of μ_s and μ_k depend on the nature of the surfaces, but μ_k is generally less than μ_s .

• The direction of the friction force on an object is parallel to the surface with which the object is in contact and opposite to the actual motion (kinetic friction) or the impending motion (static friction) of the object relative to the surface.

Experimental Determination of μ_s and μ_k

The following is a simple method of measuring coefficients of friction: Suppose a block is placed on a rough surface inclined relative to the horizontal, as shown in Figure 5.19. The incline angle is increased until the block starts to move. Show that by measuring the critical angle θ_c at which this slipping just occurs, we can obtain μ_s.

Solution *Conceptualizing* from the free body diagram in Figure 5.19, we see that we can *categorize* this as a Newton's second law problem. To *analyze* the problem, note that the only forces acting on the block are the gravitational force $m\mathbf{g}$, the normal force $\mathbf{n}$, and the force of static friction $\mathbf{f}_s$. These forces balance when the block is not moving. When we choose x to be parallel to the plane and y perpendicular to it, Newton's second law applied to the block for this balanced situation gives

$$(1) \qquad \sum F_x = mg\sin\theta - f_s = ma_x = 0$$

$$(2) \qquad \sum F_y = n - mg\cos\theta = ma_y = 0$$

We can eliminate mg by substituting $mg = n/\cos\theta$ from (2) into (1) to find

$$(3) \qquad f_s = mg\sin\theta = \left(\frac{n}{\cos\theta}\right)\sin\theta = n\tan\theta$$

When the incline angle is increased until the block is on the verge of slipping, the force of static friction has reached its maximum value $\mu_s n$. The angle θ in this situation is the critical angle θ_c, and (3) becomes

$$\mu_s n = n\tan\theta_c$$

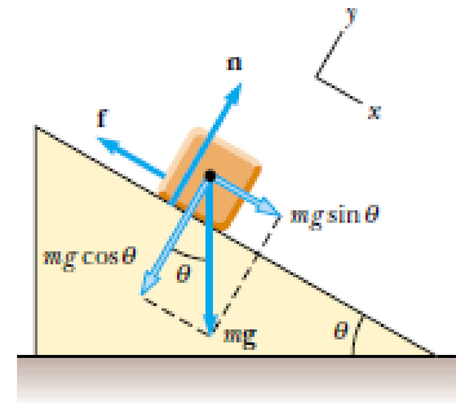


Figure 5.19 (Example 5.12) The external forces exerted on a block lying on a rough incline are the gravitational force $m\mathbf{g}$, the normal force $\mathbf{n}$, and the force of friction $\mathbf{f}$. For convenience, the gravitational force is resolved into a component along the incline $mg\sin\theta$ and a component perpendicular to the incline $mg\cos\theta$.

$$\mu_s = \tan\theta_c$$

For example, if the block just slips at $\theta_c = 20.0°$, then we find that $\mu_s = \tan 20.0° = 0.364$.

To *finalize* the problem, note that once the block starts to move at $\theta \geq \theta_c$, it accelerates down the incline and the force of friction is $f_k = \mu_k n$. However, if θ is reduced to a value less than θ_c, it may be possible to find an angle θ_c' such that the block moves down the incline with constant speed ($a_x = 0$). In this case, using (1) and (2) with f_s replaced by f_k gives

$$\mu_k = \tan\theta_c'$$

where $\theta_c' < \theta_c$.