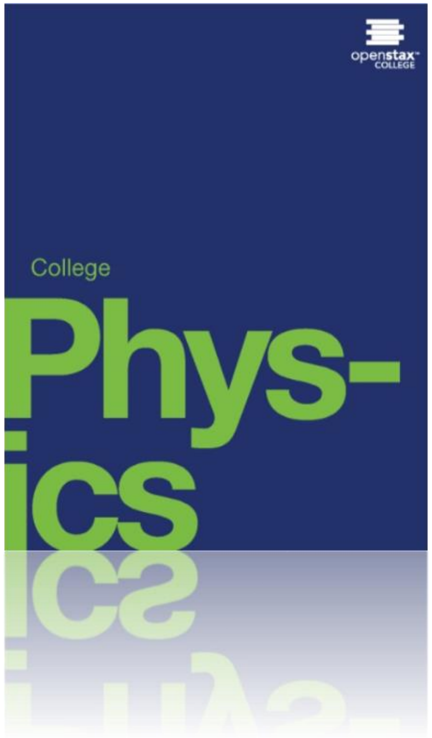
COLLEGE PHYSICS

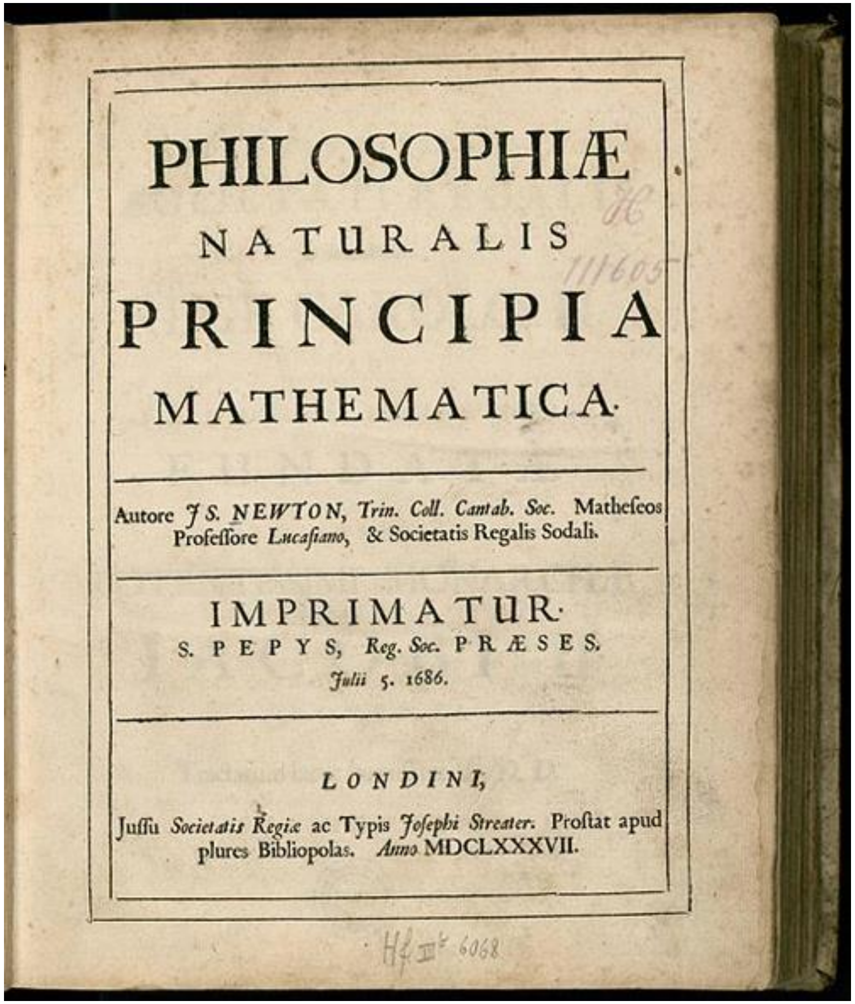
Chapter 4 DYNAMICS: FORCE AND NEWTON'S LAWS OF MOTION

PowerPoint Image Slideshow



Chapter 4

- Force
- Newton’s First, Second, and Third Law of Motion
- Weight (Mass) – the Force of Gravity
- Solving Problems with Newton’s Laws: Free-Body Diagrams
- Applications Involving Friction, Inclines



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, *Trin. Coll. Cantab. Soc.* Mathefeos Profeffore *Lucafiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

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Juffu *Societatis Regiæ* ac Typis *Jofephi Streater*. Proftat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Issac Newton’s monumental work, *Philosophiae Naturalis Principia Mathematica*, was published in 1687. It proposed scientific laws that are still used today to describe the motion of objects.

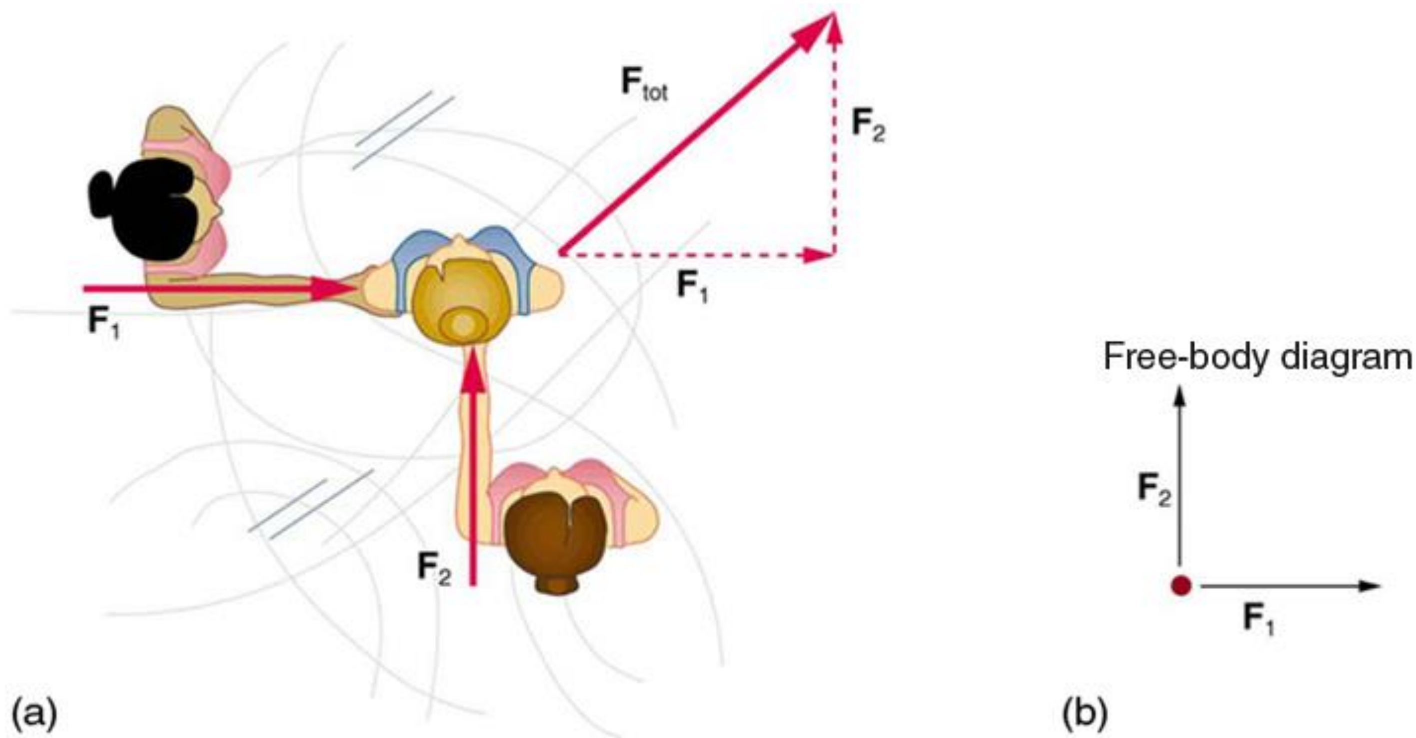
Development of Force Concept

- **Dynamics** is the study of how forces affect the motion of objects.
- **Force** is a push or pull and it is a vector having both magnitude and direction.
- **External forces** are any outside forces that act on a body. A **free-body diagram** is a drawing of all external forces acting on a body.

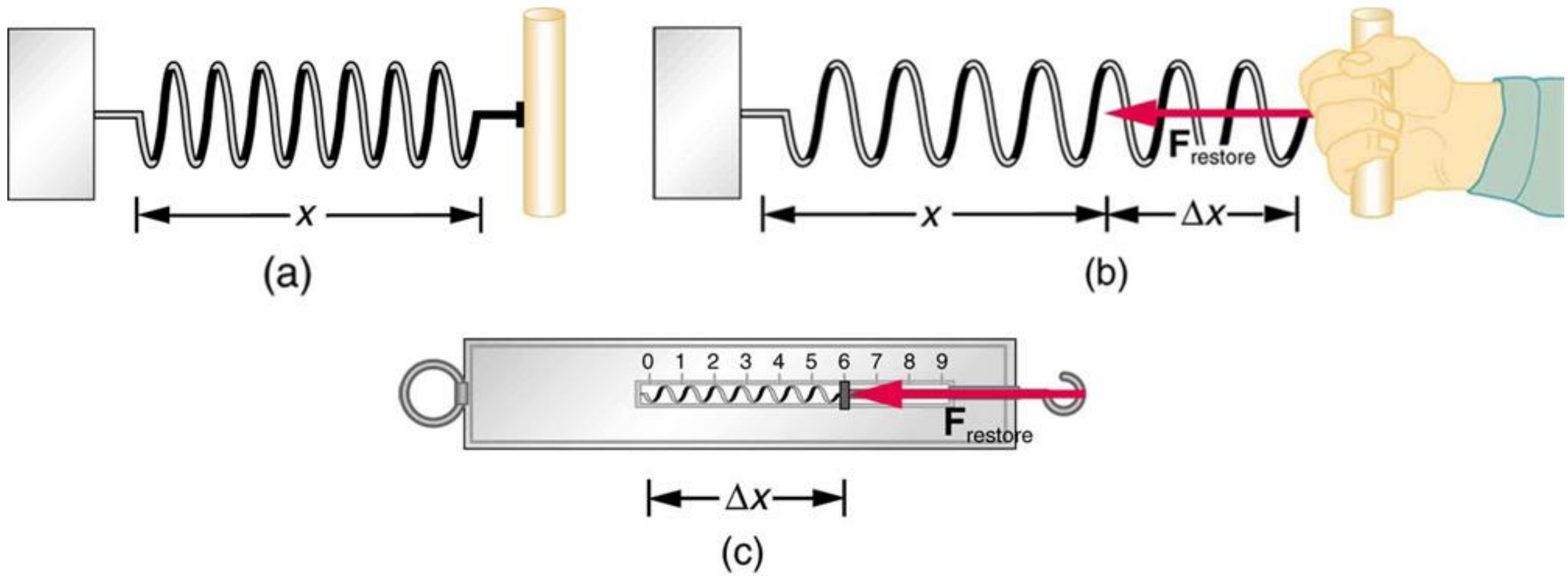
Other forces: tension, friction, weight, normal force, restoring force, buoyant force, electric, thrust reaction force, …

Newton’s First Law of Motion: Inertia

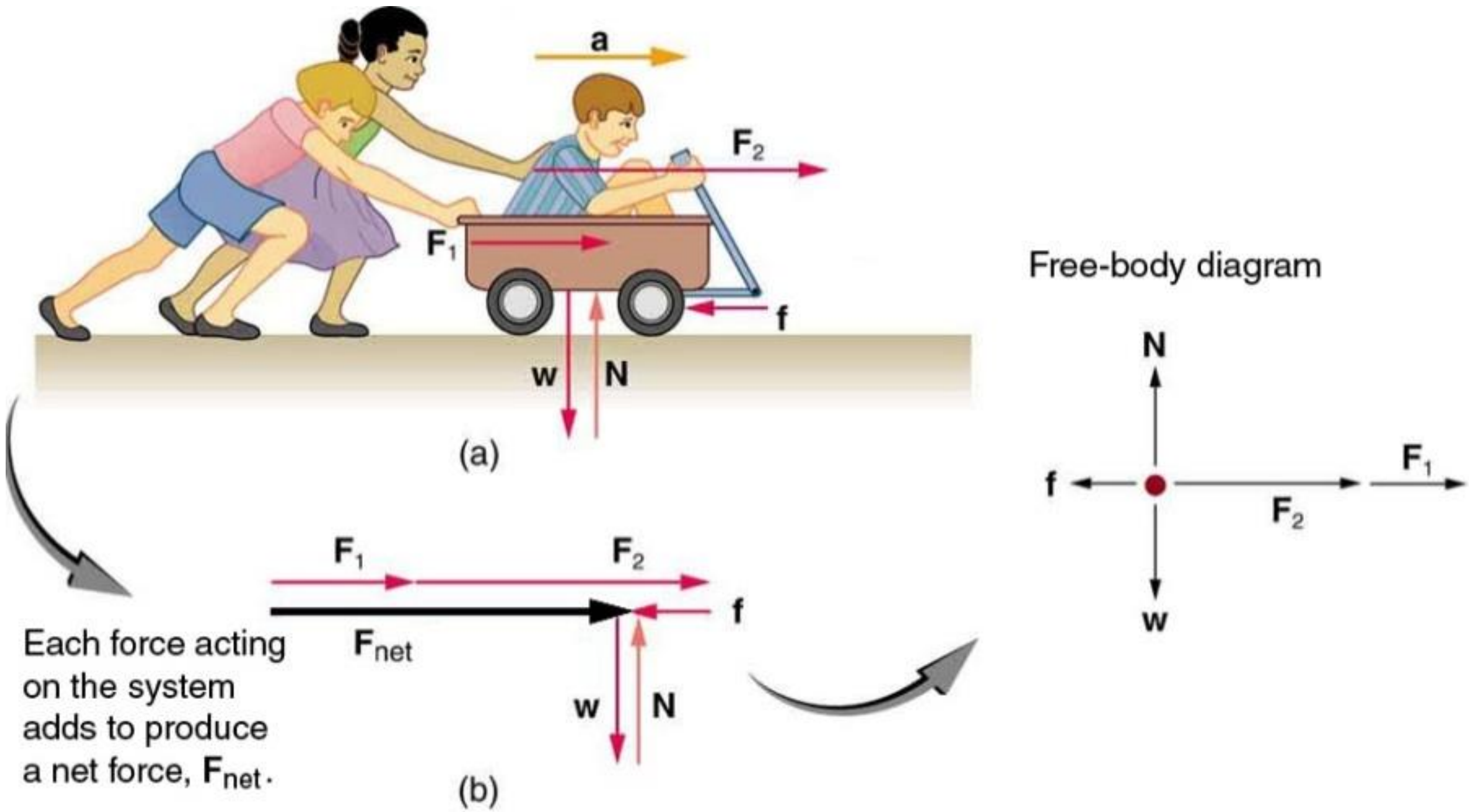
- **Newton’s first law of motion** states that a body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force. This is also known as the **law of inertia**.
- **Inertia** is the tendency of an object to remain at rest or remain in motion. Inertia is related to an object’s mass.
- **Mass** is the quantity of matter in a substance.



Part (a) shows an overhead view of two ice skaters pushing on a third. Forces are vectors and add like other vectors, so the total force on the third skater is in the direction shown. In part (b), we see a free-body diagram representing the forces acting on the third skater.



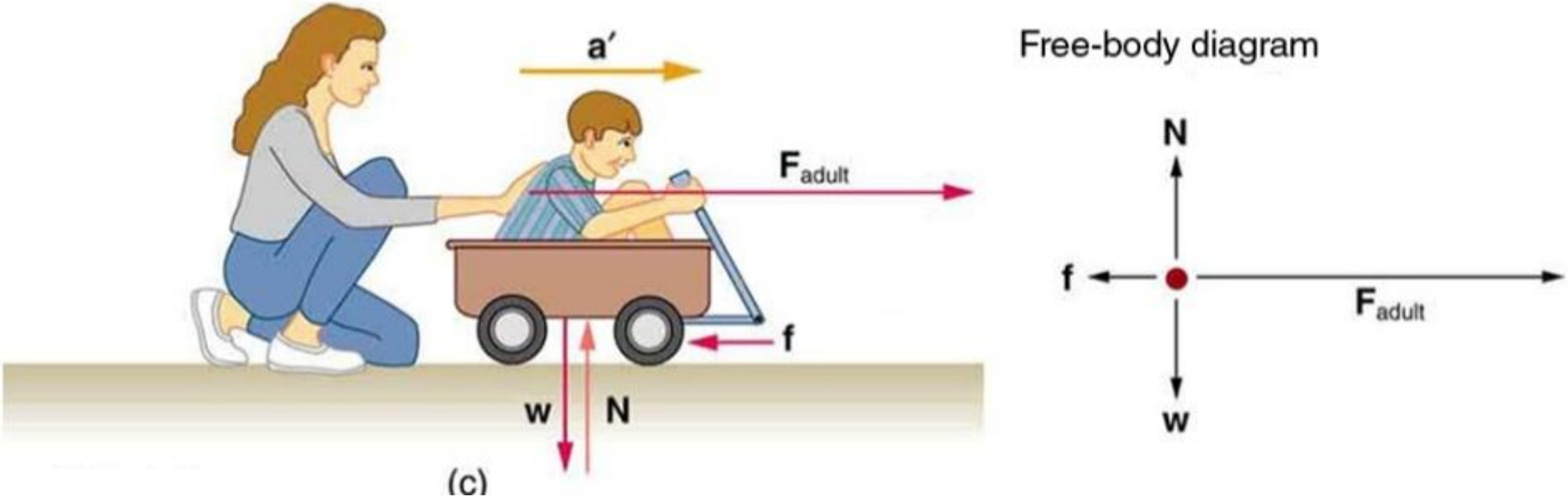
The force exerted by a stretched spring can be used as a standard unit of force. (a) This spring has a length x when undistorted. (b) When stretched a distance Δx , the spring exerts a restoring force, $\mathbf{F}_{\text{restore}}$, which is reproducible. (c) A spring scale is one device that uses a spring to measure force. The force $\mathbf{F}_{\text{restore}}$ is exerted on whatever is attached to the hook. Here $\mathbf{F}_{\text{restore}}$ has a magnitude of 6 units in the force standard being employed.



Different forces exerted on the same mass produce different accelerations.

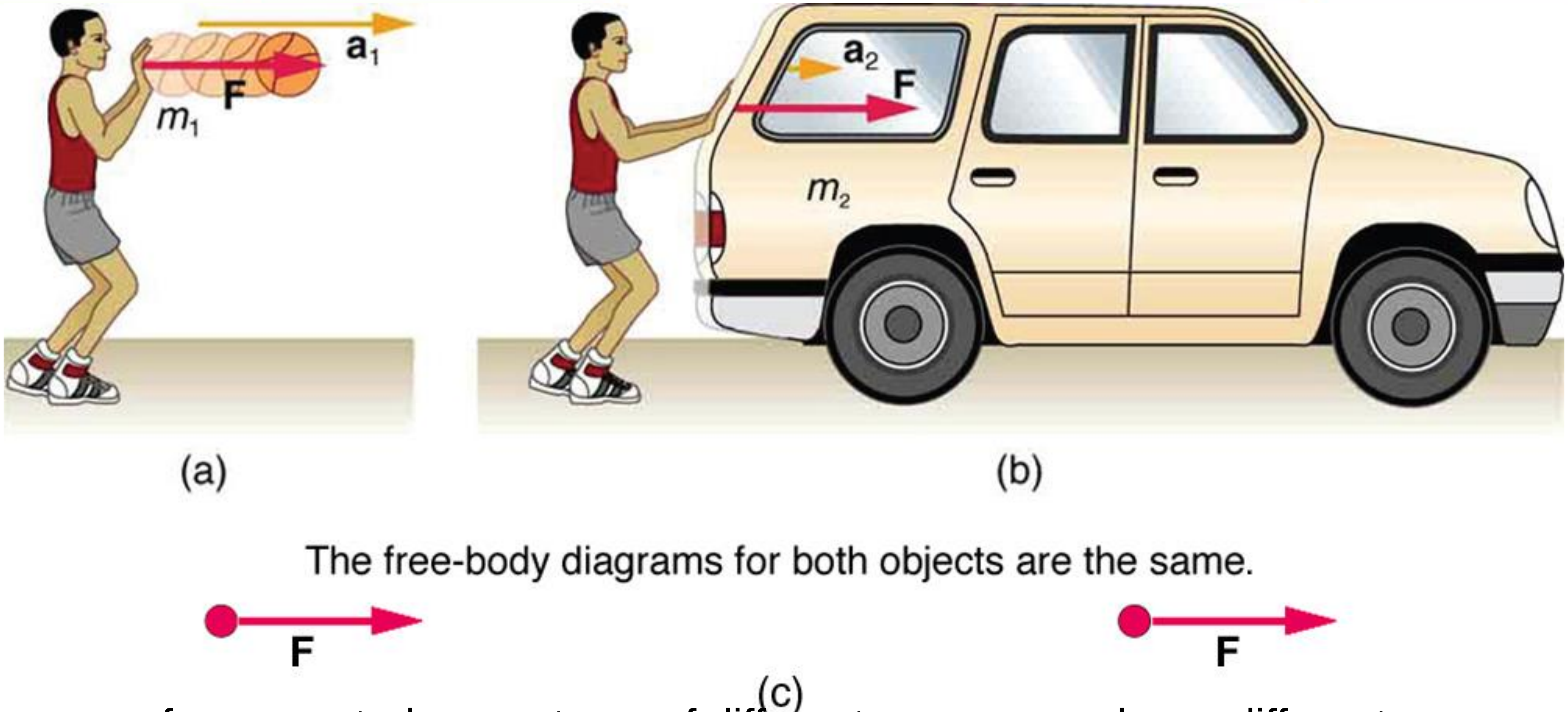
(a) Two children push a wagon with a child in it. The weight **w** of the system and the support of the ground **N** are also shown for completeness and are assumed to cancel. The vector **f** represents the friction acting on the wagon.

(b) All of the external forces acting on the system add together to produce a net force, $\mathbf{F}_{net}$. The free-body diagram shows all of the forces acting on the system of interest. The dot represents the center of mass of the system. Each force vector extends from this dot. Because there are two forces acting to the right, we draw the vectors collinearly.



Different forces exerted on the same mass produce different accelerations.

(c) A larger net external force produces a larger acceleration (**a′** > **a**) when an adult pushes the child.



The same force exerted on systems of different masses produces different accelerations.

(a) A basketball player pushes on a basketball to make a pass. (The effect of gravity on the ball is ignored.)

(b) The same player exerts an identical force on a stalled SUV and produces a far smaller acceleration (even if friction is negligible).

(c) The free-body diagrams are identical, permitting direct comparison of the two situations. A series of patterns for the free-body diagram will emerge as you do more problems.

Newton's Second Law of Motion: Concept of a System

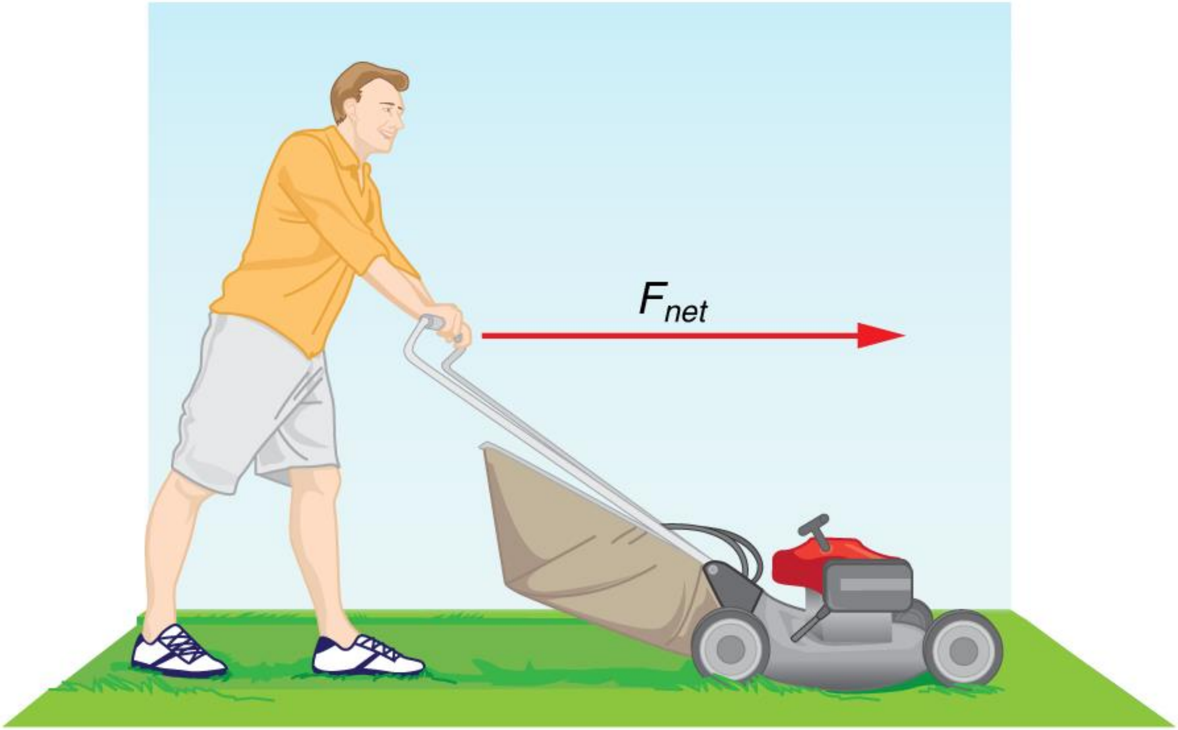
- Acceleration, **a** , is defined as a change in velocity, meaning a change in its magnitude or direction, or both.
- An external force is one acting on a system from outside the system, as opposed to internal forces, which act between components within the system.
- Newton's second law of motion states that the acceleration of a system is directly proportional to and in the same direction as the net external force acting on the system, and inversely proportional to its mass.
- In equation form, Newton's second law of motion is $\mathbf{a} = \mathbf{F}_{net}/m$. This is often written in the more familiar form:

$$\mathbf{F}_{net} = m\mathbf{a}.$$

- The **weight** **w** of an object is defined as the force of gravity acting on an object of mass *m*. The object experiences an acceleration due to gravity **g** :

$$\mathbf{w} = m\mathbf{g}$$

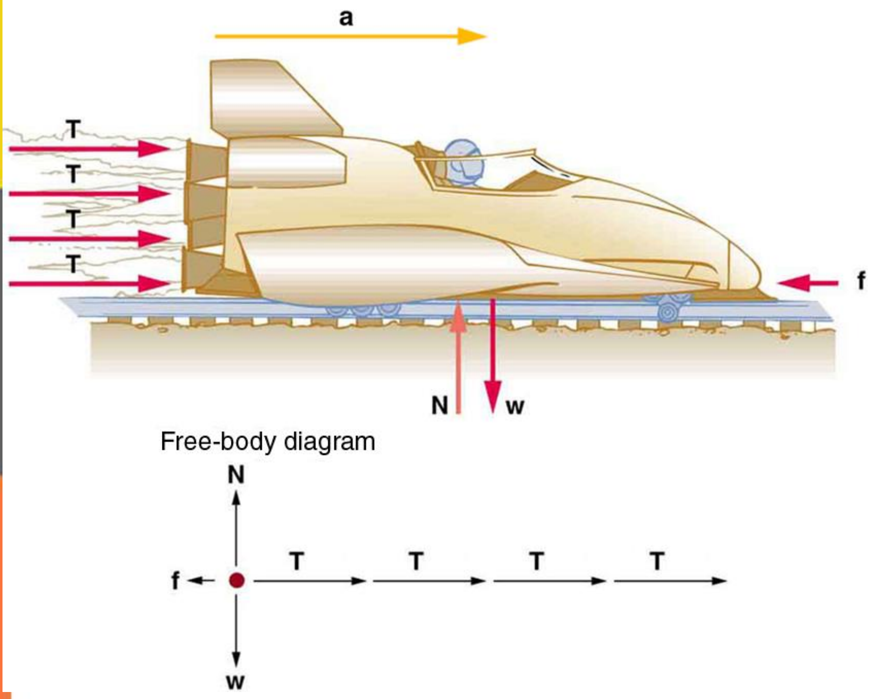
- If the only force acting on an object is due to gravity, the object is in free fall.
- **Friction** is a force that opposes the motion past each other of objects that are touching.



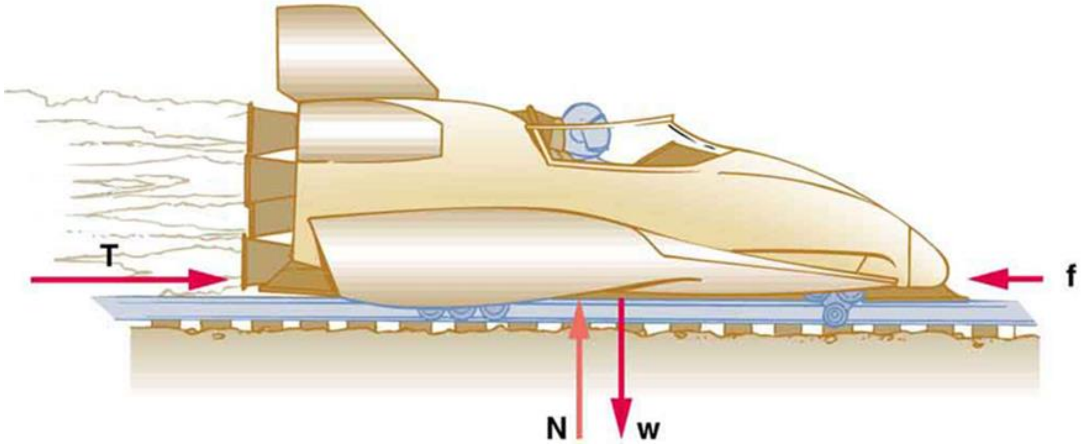
The mass of the mower is 24 kg.

The net force on a lawn mower is 51 N to the right. At what rate does the lawn mower accelerate to the right?

The magnitude of the acceleration a is $a = F_{net}/m$. Entering known values gives $a = 51\text{ N} / 24\text{ kg}$. Substituting the units $\text{kg} \cdot \text{m/s}^2$ for N yields $a = 51\text{ kg} \cdot \text{m/s}^2 / 24\text{ kg} = 2.1\text{ m/s}^2$.



A sled experiences a rocket thrust that accelerates it to the right. Each rocket creates an identical **thrust T**. As in other situations where there is only horizontal acceleration, the vertical forces cancel. The ground exerts an **upward force N** on the system that is equal in magnitude and opposite in direction to its **weight w** . The system here is the sled, its rockets, and rider, so none of the forces *between* these objects are considered. The arrow representing **friction f** is drawn larger than scale.



Calculate the magnitude of force exerted by each rocket, called its thrust **T** , for the four-rocket propulsion system shown in **figure**. The sled's initial acceleration is 49 m/s^2, the mass of the system is 2100 kg, and the force of friction opposing the motion is known to be 650 N.

Substituting this into Newton's second law gives $F_{\text{net}} = ma = 4T - f$

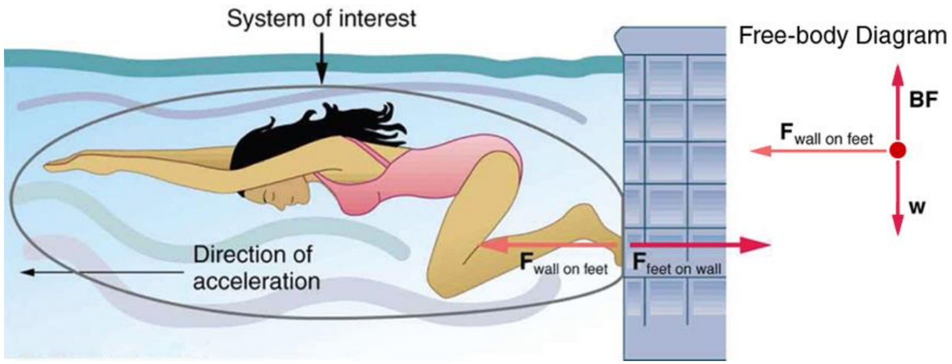
Using a little algebra, we solve for the total thrust: $4T = ma + f.$

Substituting known values yields

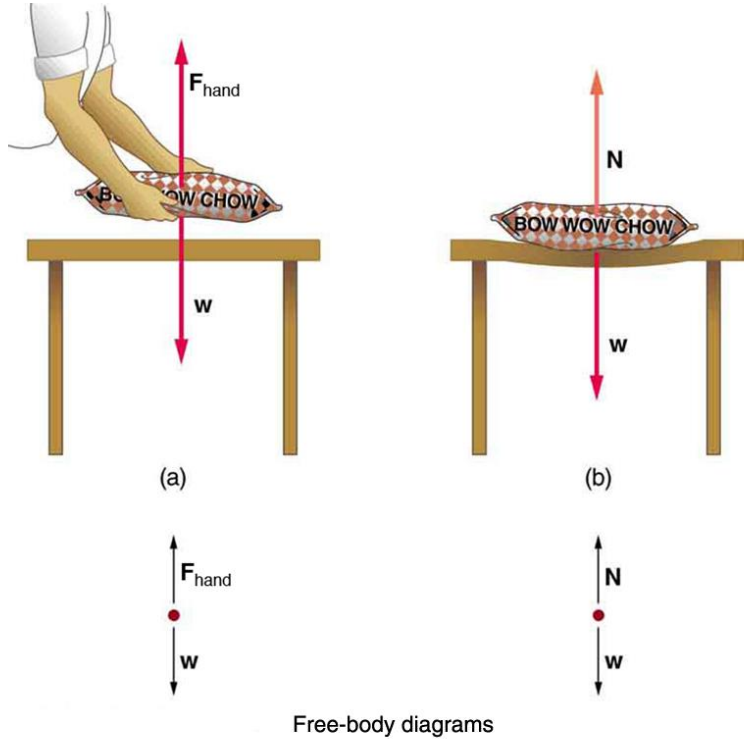
$$4T = ma + f = (2100\ \text{kg})(49\ \text{m/s}^2) + 650\ \text{N}.$$

So the total thrust is $4T = 1.0\times10^5$ N, and the individual thrusts are

$$T = 1.0\times10^5\ \text{N}/4 = 2.6\times10^4\ \text{N}.$$

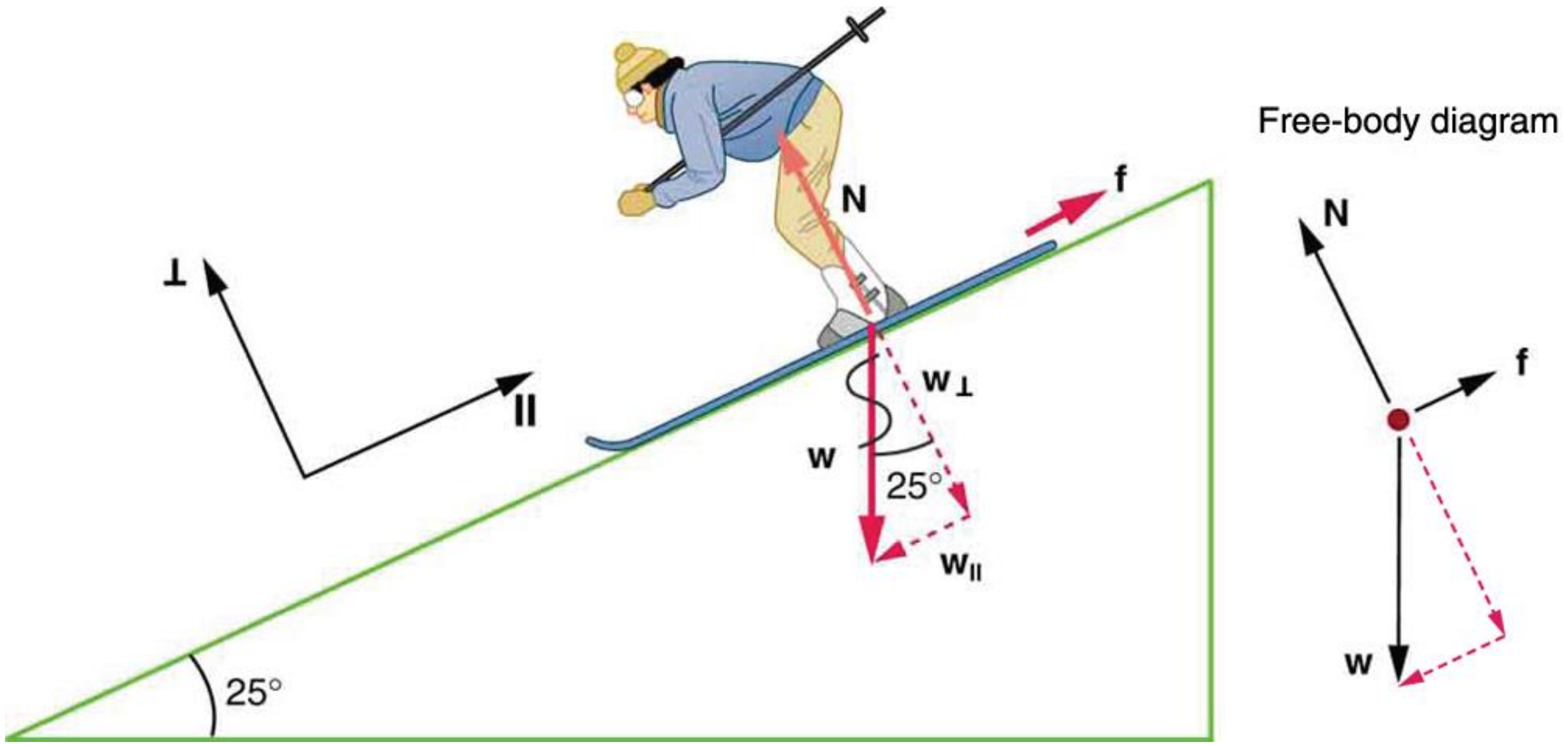


When the swimmer exerts a force $\mathbf{F}_{\text{feet on wall}}$ on the wall, she accelerates in the direction opposite to that of her push. This means the net external force on her is in the direction opposite to $\mathbf{F}_{\text{feet on wall}}$. This opposition occurs because, in accordance with Newton's third law of motion, the wall exerts a force $\mathbf{F}_{\text{wall on feet}}$ on her, equal in magnitude but in the direction opposite to the one she exerts on it. The line around the swimmer indicates the system of interest. Note that $\mathbf{F}_{\text{feet on wall}}$ does not act on this system (the swimmer) and, thus, does not cancel $\mathbf{F}_{\text{wall on feet}}$. Thus the free-body diagram shows only $\mathbf{F}_{\text{wall on feet}}$ **w** the **gravitational force**, and **BF**, the **buoyant force** of the water supporting the swimmer's weight. The vertical forces **w** and **BF** cancel since there is no vertical motion.

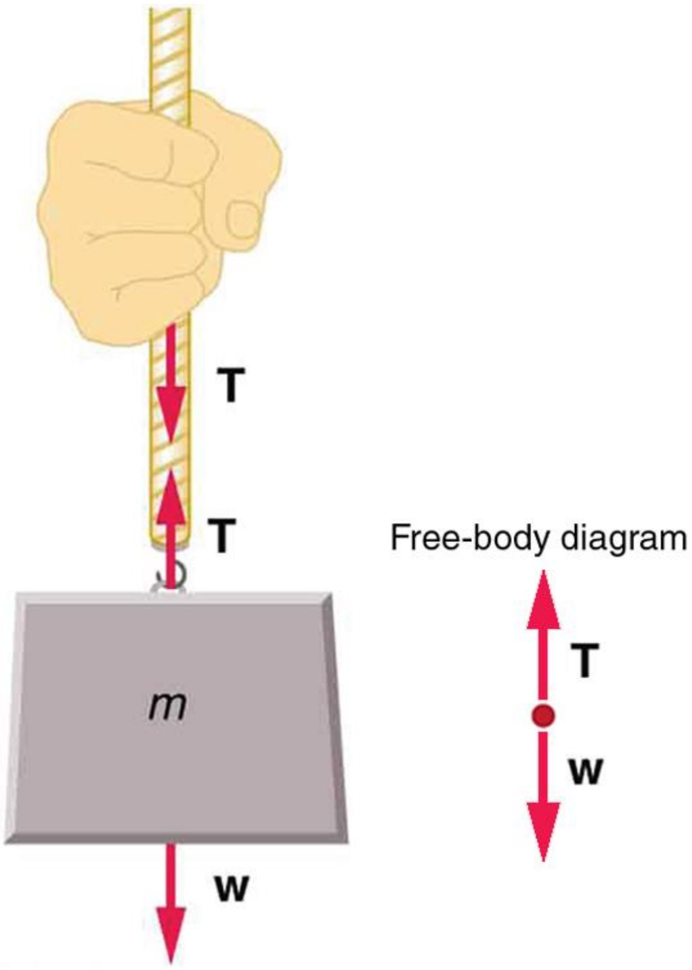


(a) The person holding the bag of dog food must supply an upward force $\mathbf{F}_{\text{hand}}$ equal in magnitude and opposite in direction to the weight of the food **w** .

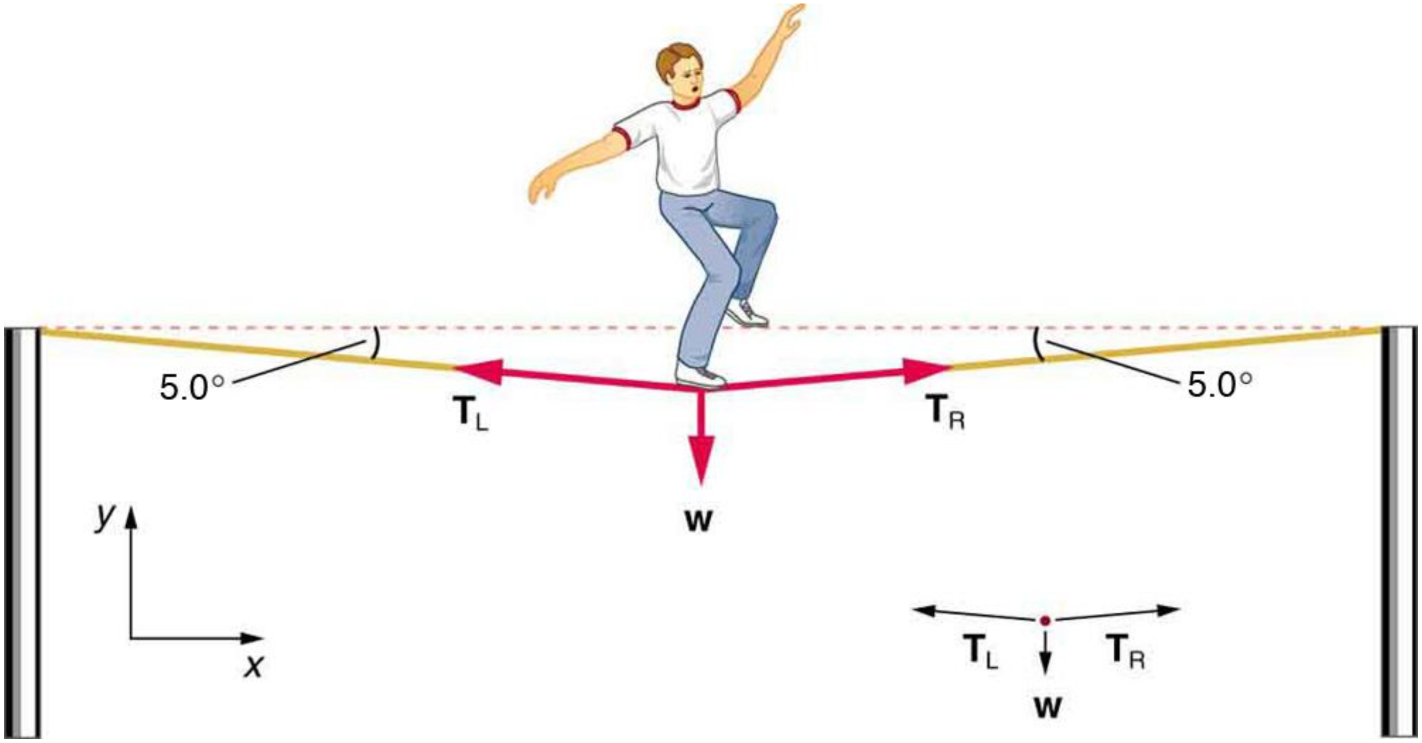
(b) The card table sags when the dog food is placed on it, much like a stiff trampoline. **Elastic restoring forces** in the table grow as it sags until they supply a force **N** equal in magnitude and opposite in direction to the weight of the load.



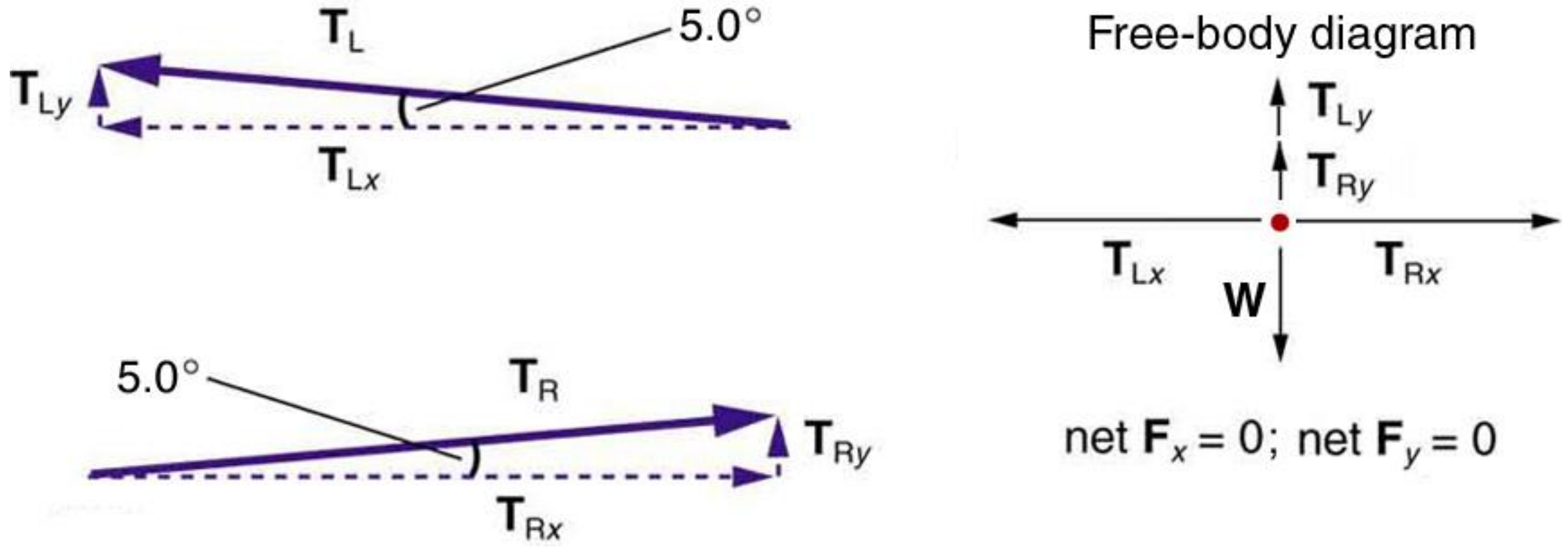
Since motion and friction are parallel to the slope, it is most convenient to project all forces onto a coordinate system where one axis is parallel to the slope and the other is perpendicular (axes shown to left of skier). **N** is perpendicular to the slope and **f** is parallel to the slope, but **w** has components along both axes, namely $\mathbf{w}_{\perp}$ and $\mathbf{w}_{\parallel}$. **N** is equal in magnitude to $\mathbf{w}_{\perp}$, so that there is no motion perpendicular to the slope, but *f* is less than $w_{\parallel}$, so that there is a downslope acceleration (along the parallel axis).



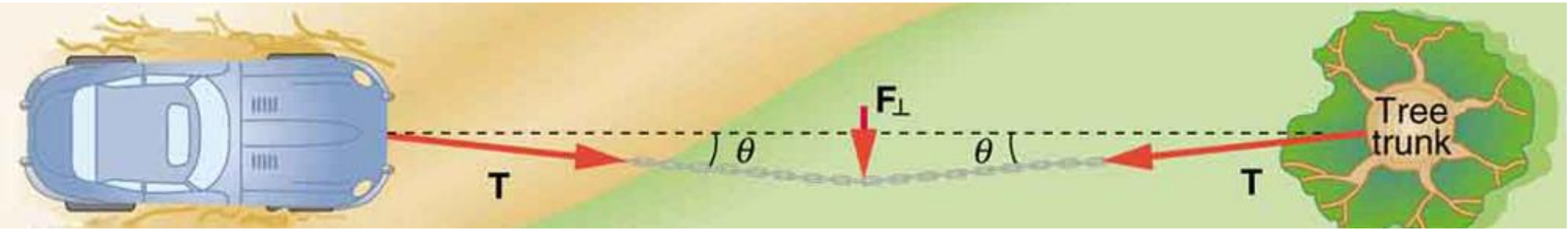
When a perfectly flexible connector (one requiring no force to bend it) such as this rope transmits a force **T**, that force must be parallel to the length of the rope, as shown. The pull such a flexible connector exerts is a tension. Note that the rope pulls with equal force but in opposite directions on the hand and the supported mass (neglecting the weight of the rope). This is an example of Newton's third law. The rope is the medium that carries the equal and opposite forces between the two objects. The tension anywhere in the rope between the hand and the mass is equal. Once you have determined the tension in one location, you have determined the tension at all locations along the rope.



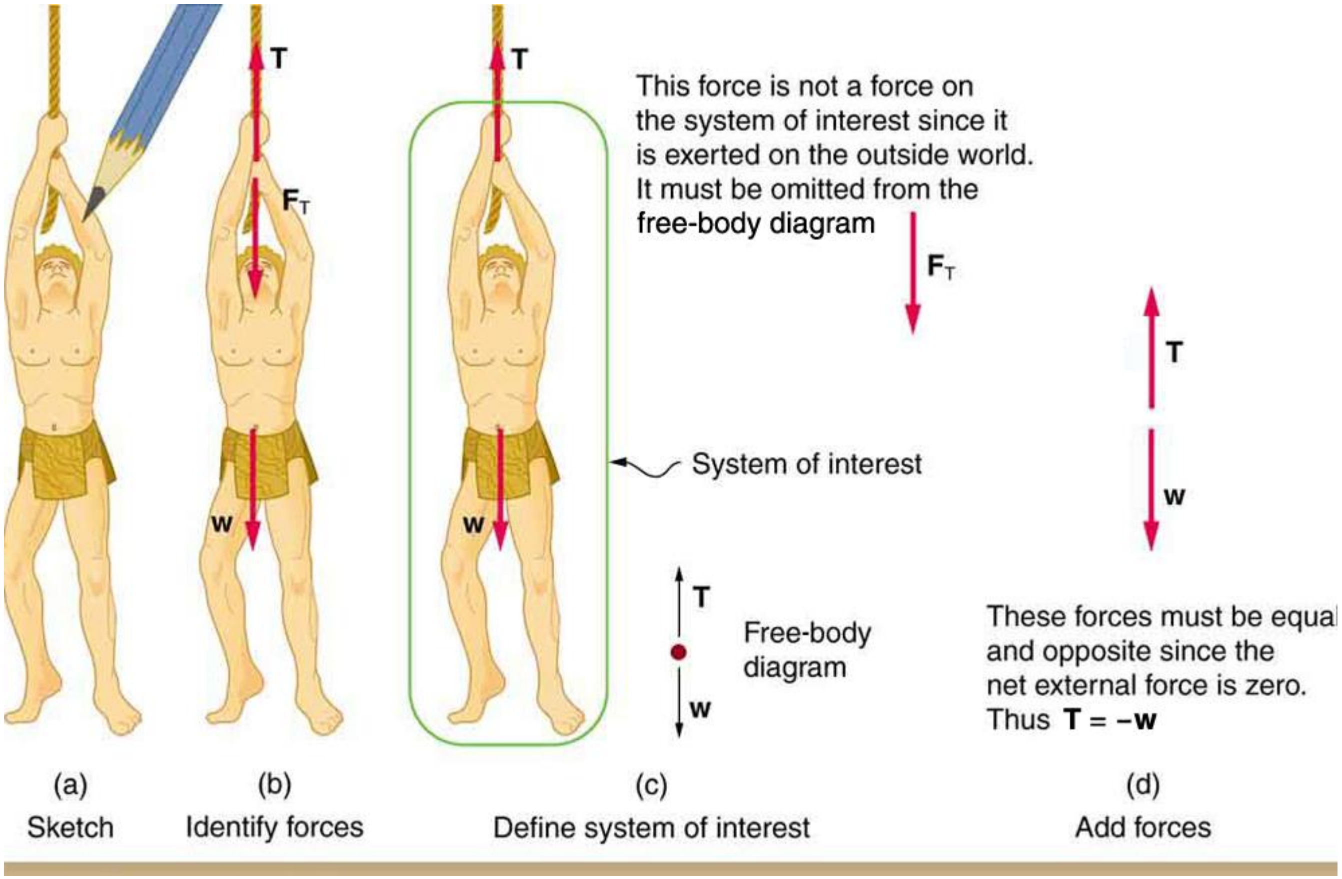
The weight of a tightrope walker causes a wire to sag by 5.0 degrees. The system of interest here is the point in the wire at which the tightrope walker is standing.



When the vectors are projected onto vertical and horizontal axes, their components along those axes must add to zero, since the tightrope walker is stationary. The small angle results in *T* being much greater than *w* .



We can create a very large tension in the chain by pushing on it perpendicular to its length, as shown. Suppose we wish to pull a car out of the mud when no tow truck is available. Each time the car moves forward, the chain is tightened to keep it as nearly straight as possible. The tension in the chain is given by $T = \frac{F_{\perp}}{2\,sin(\theta)}$ sin (θ); since θ is small, T is very large. This situation is analogous to the tightrope walker, except that the tensions shown here are those transmitted to the car and the tree rather than those acting at the point where $\mathbf{F}_{\perp}$ is applied.

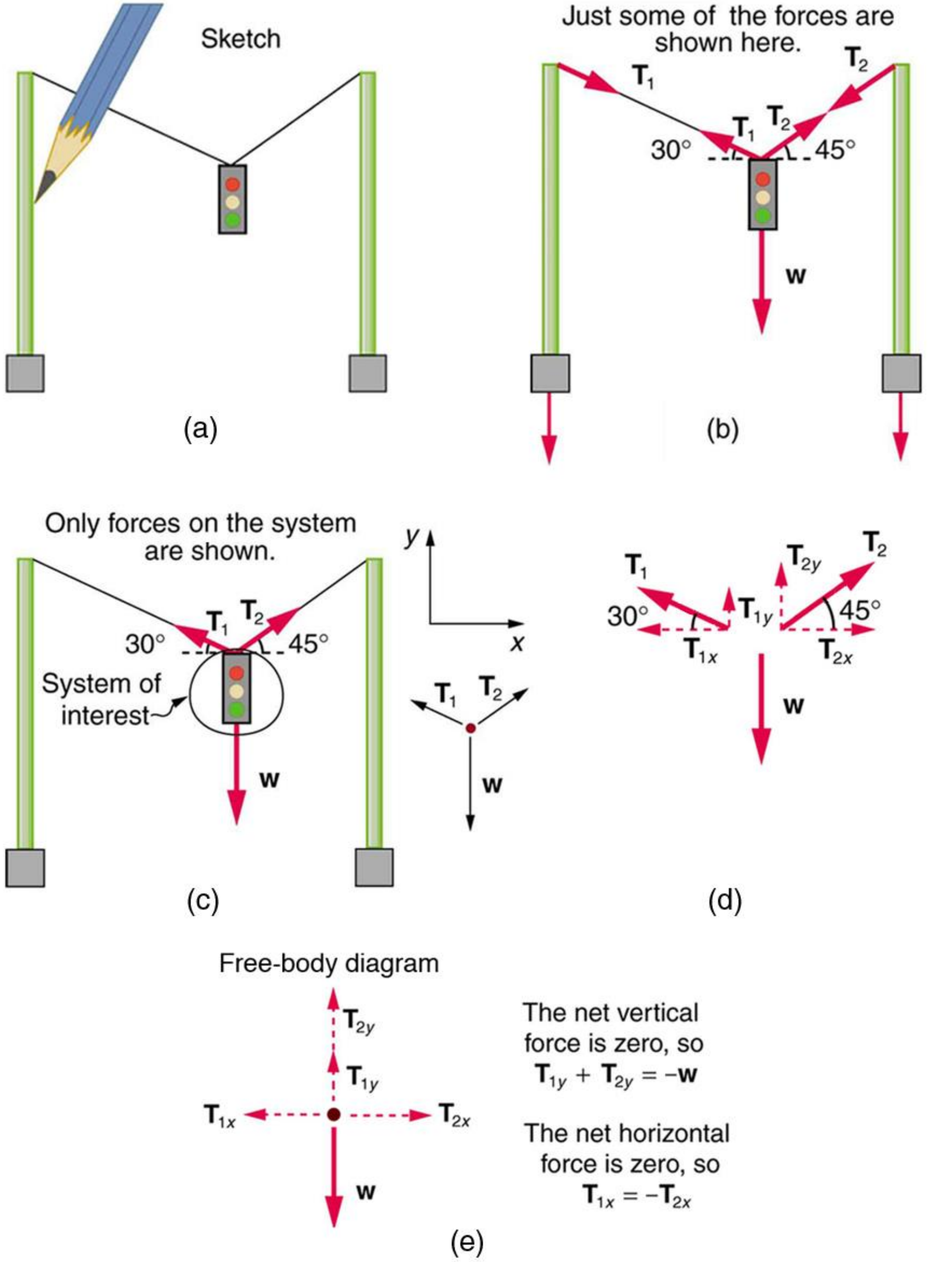


(a) A sketch of Tarzan hanging from a vine.

(b) Arrows are used to represent all forces. **T** is the tension in the vine above Tarzan, $\mathbf{F}_T$ is the force he exerts on the vine, and **w** is his weight. All other forces, such as the nudge of a breeze, are assumed negligible.

(c) Suppose we are given the ape man's mass and asked to find the tension in the vine. We then define the system of interest as shown and draw a free-body diagram. $\mathbf{F}_T$ is no longer shown, because it is not a force acting on the system of interest; rather, $\mathbf{F}_T$ acts on the outside world.

(d) Showing only the arrows, the head-to-tail method of addition is used. It is apparent that **T** = - **w** , if Tarzan is stationary.



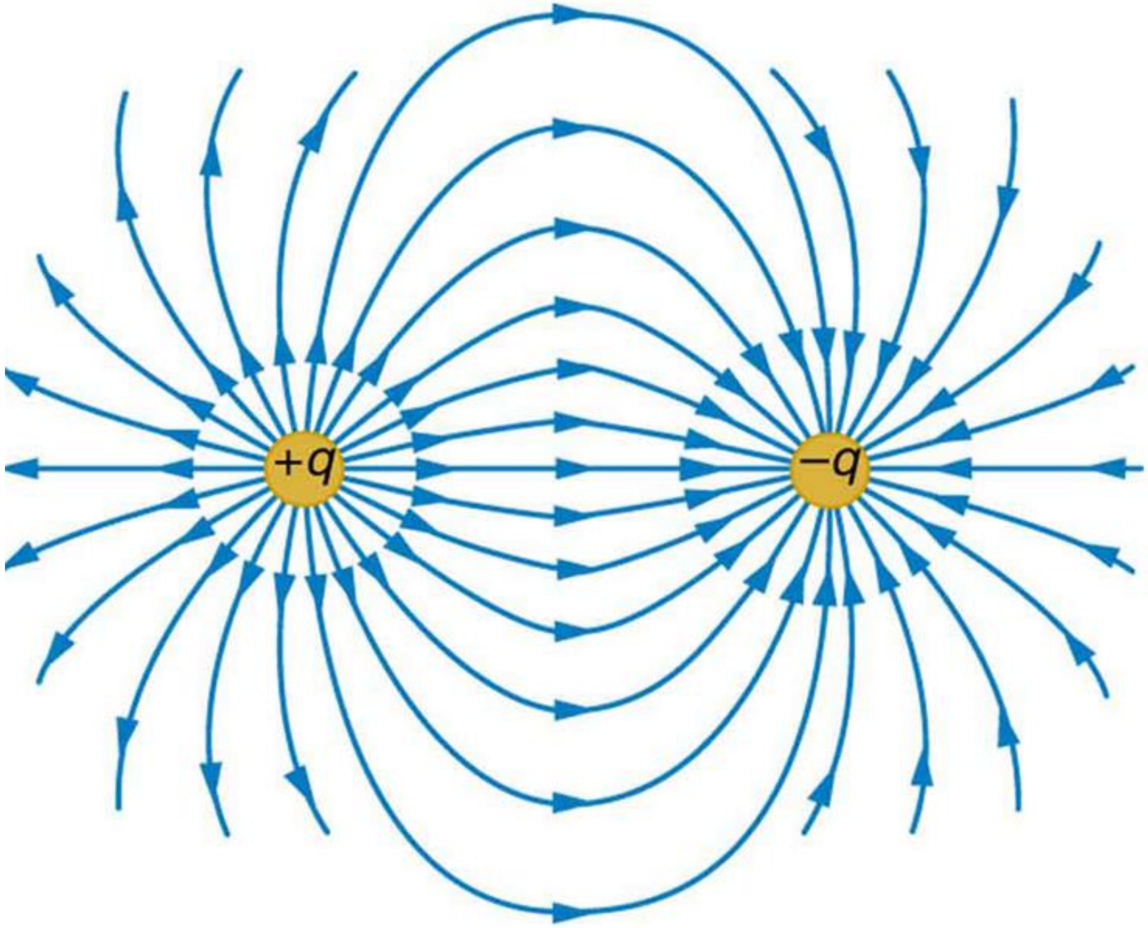
(a) A traffic light is suspended from two wires.

(b) Some of the forces involved.

(c) Only forces acting on the system are shown here. The free-body diagram for the traffic light is also shown.

(d) The forces projected onto vertical (y) and horizontal (x) axes. The horizontal components of the tensions must cancel, and the sum of the vertical components of the tensions must equal the weight of the traffic light.

(e) The free-body diagram shows the vertical and horizontal forces acting on the traffic light.



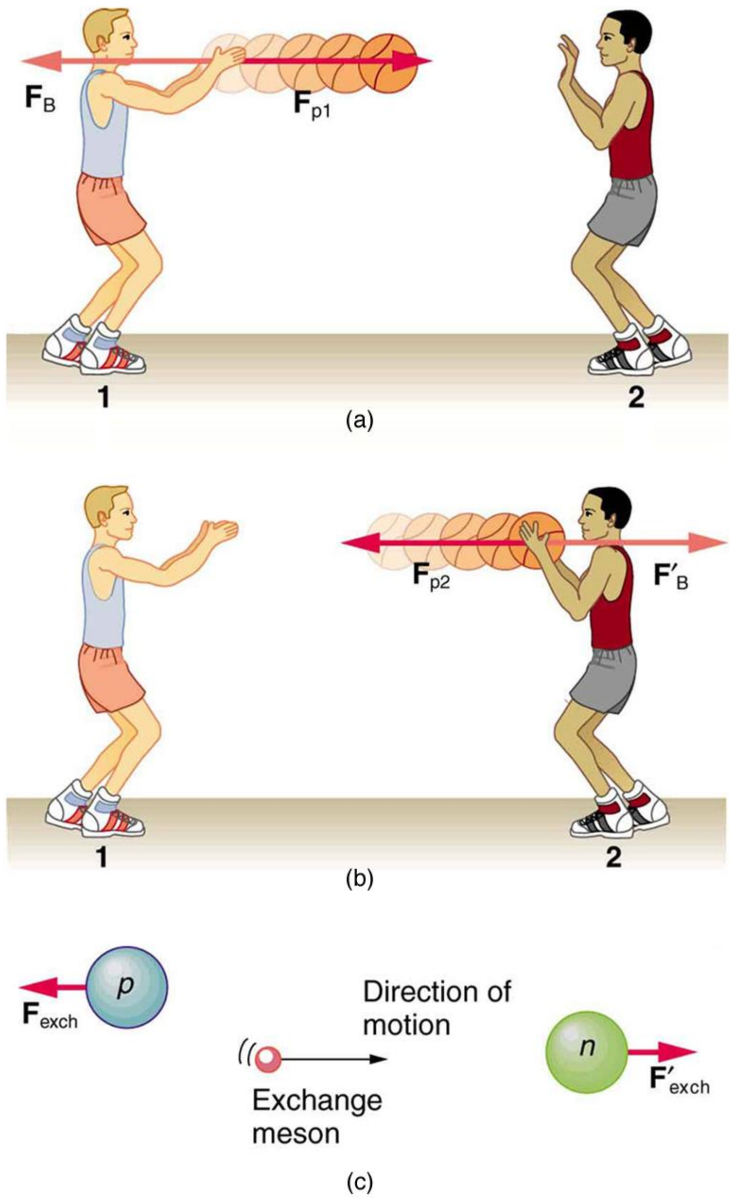
The electric force field between a positively charged particle and a negatively charged particle. When a positive test charge is placed in the field, the charge will experience a force in the direction of the force field lines.

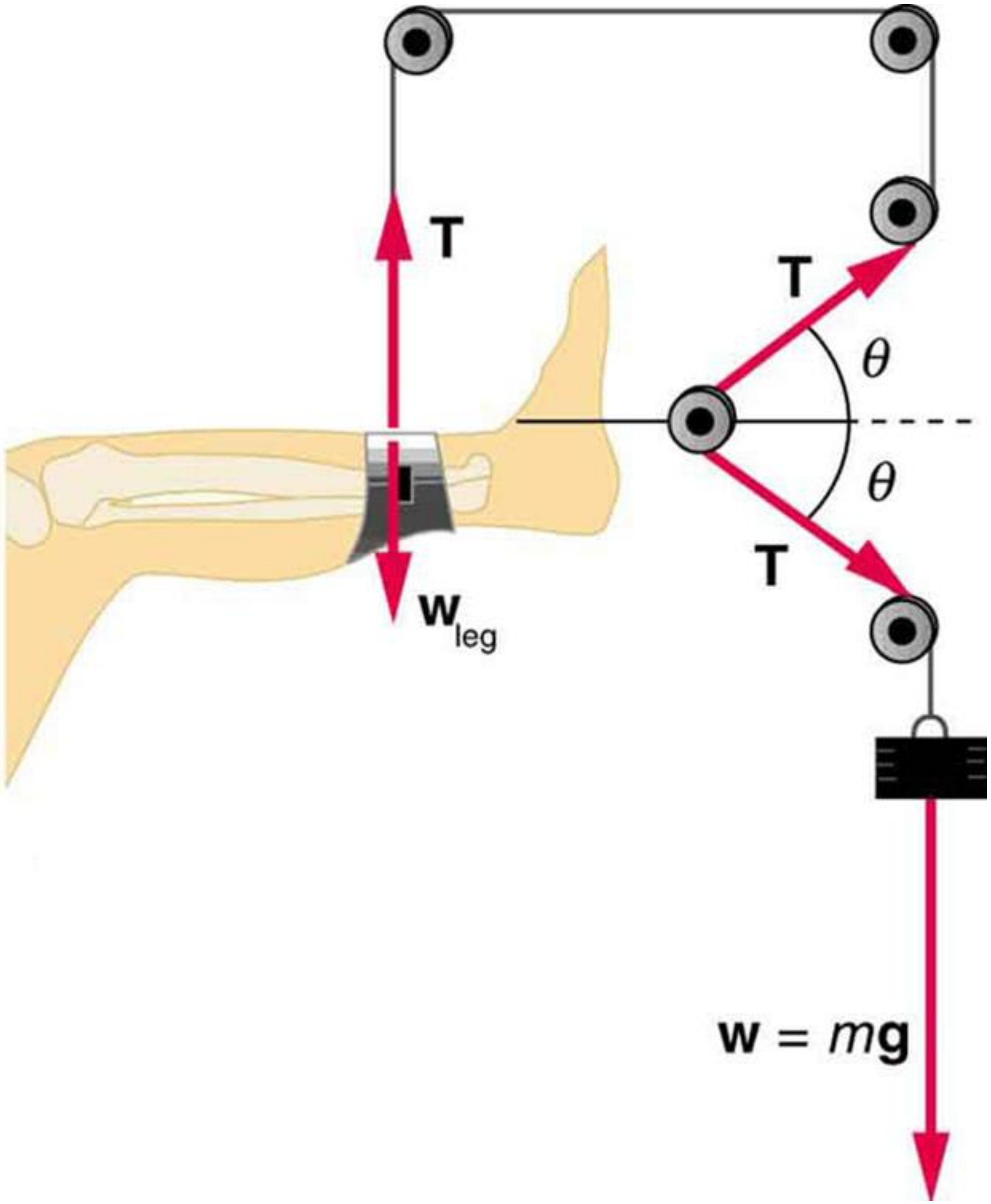
The exchange of masses resulting in repulsive forces.

(a) The person throwing the basketball exerts a force $\mathbf{F}_{p1}$ on it toward the other person and feels a reaction force $\mathbf{F}_B$ away from the second person.

(b) The person catching the basketball exerts a force $\mathbf{F}_{p2}$ on it to stop the ball and feels a reaction force $\mathbf{F'}_B$ away from the first person.

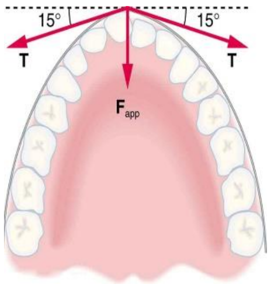
(c) The analogous exchange of a meson between a proton and a neutron carries the strong nuclear forces $\mathbf{F}_{exch}$ and $\mathbf{F'}_{exch}$ between them. An attractive force can also be exerted by the exchange of a mass—if person 2 pulled the basketball away from the first person as he tried to retain it, then the force between them would be attractive.





A leg is suspended by a traction system in which wires are used to transmit forces. Frictionless pulleys change the direction of the force *T* without changing its magnitude.

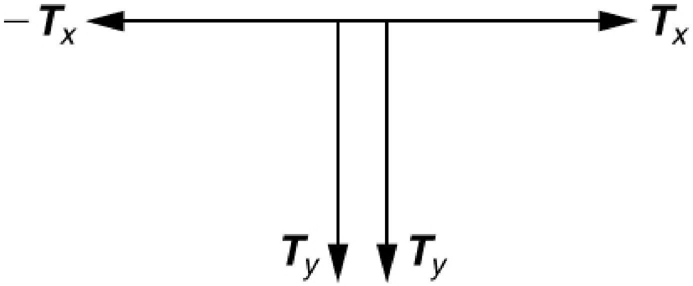
What force is exerted on the tooth in Figure if the tension in the wire is 25.0 N? Note that the force applied to the tooth is smaller than the tension in the wire, but this is necessitated by practical considerations of how force can be applied in the mouth. Explicitly show how you follow steps in the Problem-Solving Strategy for Newton's laws of motion.



Braces are used to apply forces to teeth to realign them. Shown in this figure are the tensions applied by the wire to the protruding tooth. The total force applied to the tooth by the wire, $\mathbf{F}_{app}$, points straight toward the back of the mouth.

Solution Step 1: Use Newton's laws since we are looking for forces.

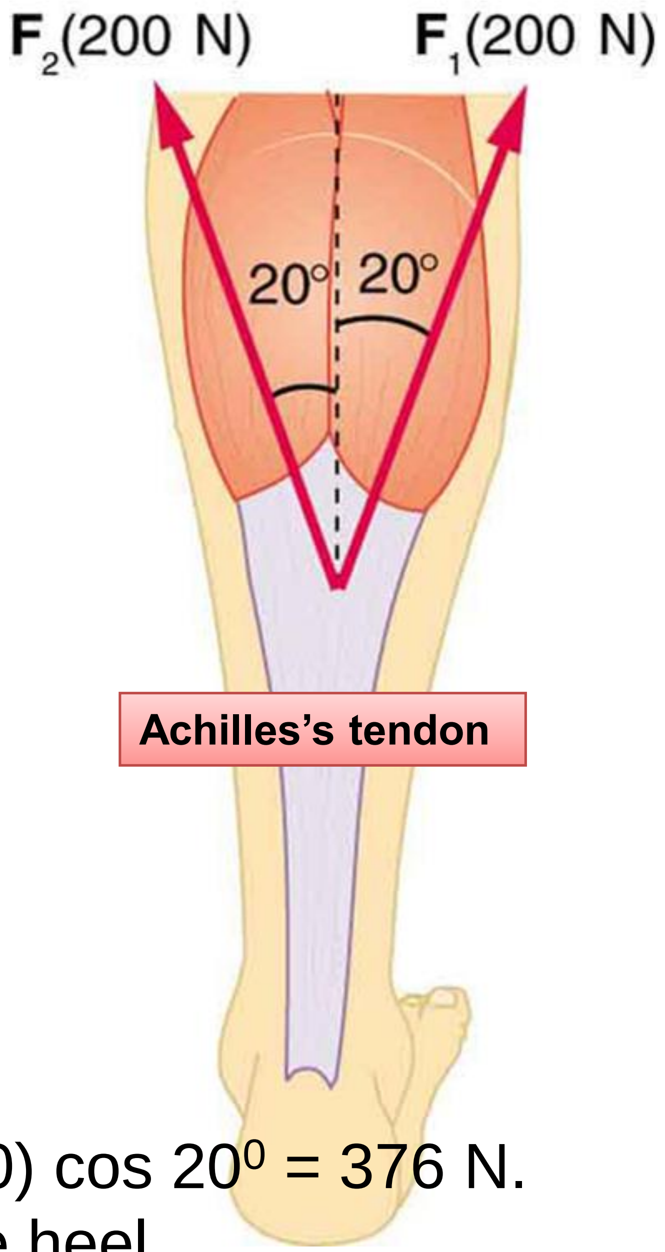
Step 2: Draw a force diagram:



Step 3: Given $T = 25.0\ \text{N}$, find F_{app}. Using Newton's laws gives $\Sigma F_x = T_x + (-T_x) = 0$, so that the applied force is due to the y-components of the two tensions:

$$F_{\text{app}} = 2T\sin\theta = 2(25.0\ \text{N})\sin 15° = \underline{12.9\ \text{N}}$$

Two muscles in the back of the leg pull upward on the Achilles tendon, as shown in Figure. (These muscles are called the medial and lateral heads of the gastrocnemius muscle.) Find the magnitude and direction of the total force on the Achilles tendon. What type of movement could be caused by this force?



Force on Achilles tendon $F = 2\ (200) \cos 20^0 = 376$ N.
Force used to raise heel.

Newton’s Third Law of Motion: Symmetry in Forces

- **Newton’s third law of motion** represents a basic symmetry in nature. It states: Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that the first body exerts.
- A **thrust** is a reaction force that pushes a body forward in response to a backward force. Rockets, airplanes, and cars are pushed forward by a thrust reaction force.

Force	Approximate Relative Strengths	Range	Attraction/Repulsion	Carrier Particle
Gravitational	10^{-38}	∞	attractive only	Graviton
Electromagnetic	10^{-2}	∞	attractive and repulsive	Photon
Weak nuclear	10^{-13}	$< 10^{-18}$ m	attractive and repulsive	W^+, W^-, Z^0
Strong nuclear	1	$< 10^{-15}$ m	attractive and repulsive	gluons

Chapter 4

- Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.

- Newton's second law: $\Sigma \vec{\mathbf{F}} = m\vec{\mathbf{a}}$

- Newton's third law: $\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}$

- Weight is the gravitational force on an object.

- The frictional force can be written: $F_{fr} = \mu_k F_N$

(kinetic friction) or $F_{fr} \leq \mu_s F_N$ (static friction)

- Free-body diagrams are essential for problem-solving