Chapter 5. Force and Motion

In this chapter we study causes of motion: Why does the windsurfer blast across the water in the way he does? The combined forces of the wind, water, and gravity accelerate him according to the principles of dynamics.

Chapter Goal: To establish a connection between force and motion.

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Chapter 5. Force and Motion

Topics:

- Force
- A Short Catalog of Forces
- Identifying Forces
- What Do Forces Do?
- Newton's Second Law
- Newton's First Law
- Free-Body Diagrams

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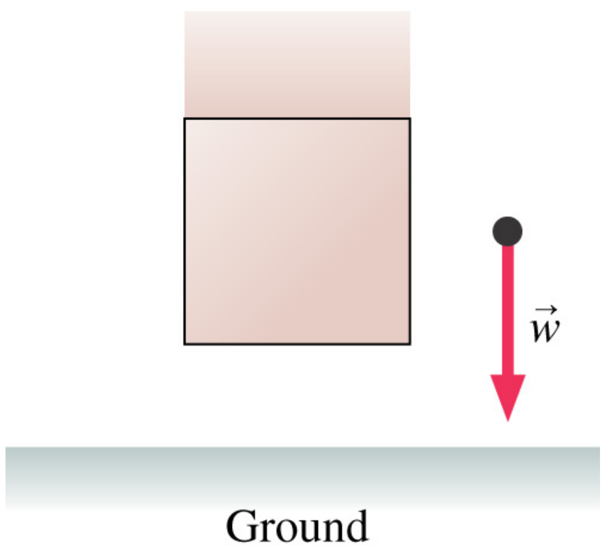
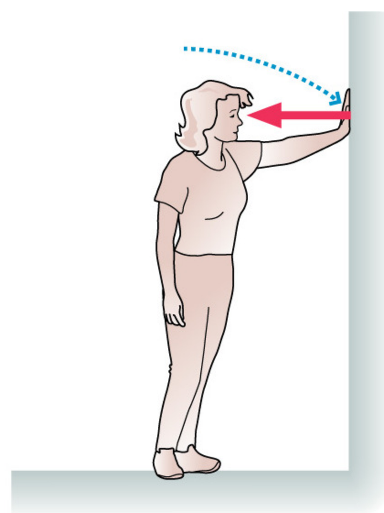
Force: Properties

1. Push or Pull
2. Acts on an object
3. Force is a vector
4. Force is either a contact force or long range force





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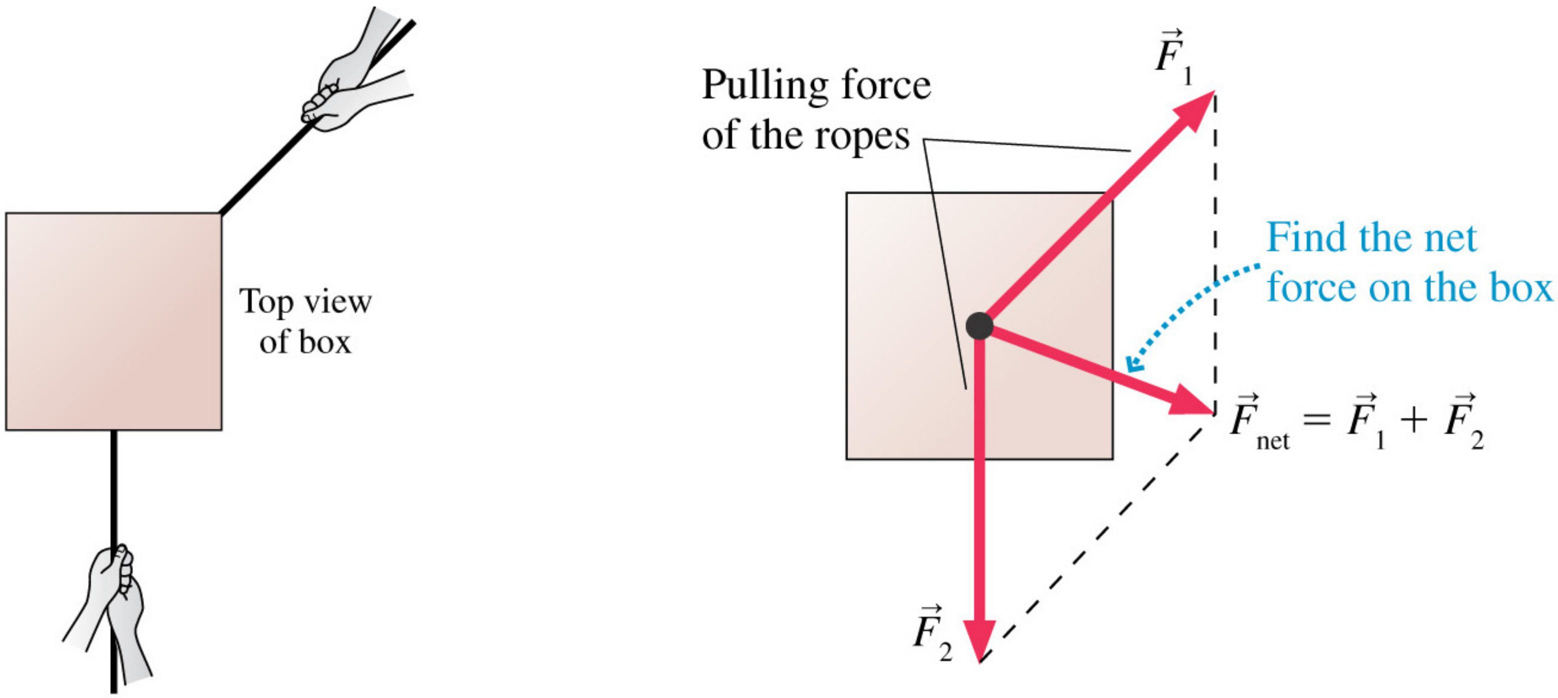
Force: Properties

Force is a vector – The net force is the vector sum of the individual forces



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How can we find the individual force?

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Major Forces:

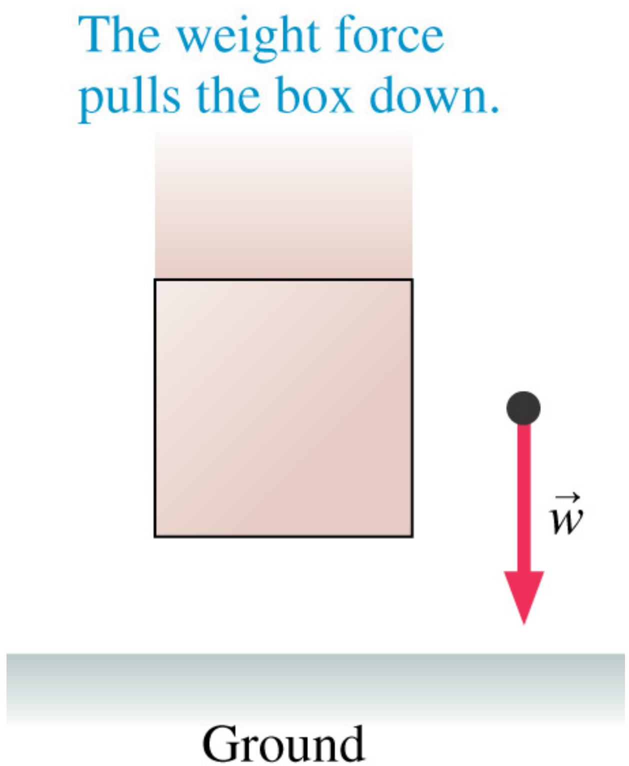
1. **Weight – gravitational force**

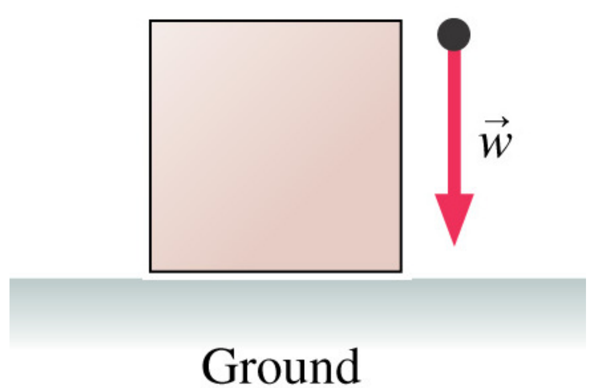
pulls the objects down – determines its direction

magnitude: $$\vec{w} = m\vec{g}$$

m **- Mass of the object**

$$g = 9.8\frac{m}{s^2}$$ **- free-fall acceleration**





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Major Forces:

1. **Weight – gravitational force** $$\vec{w} = m\vec{g}$$

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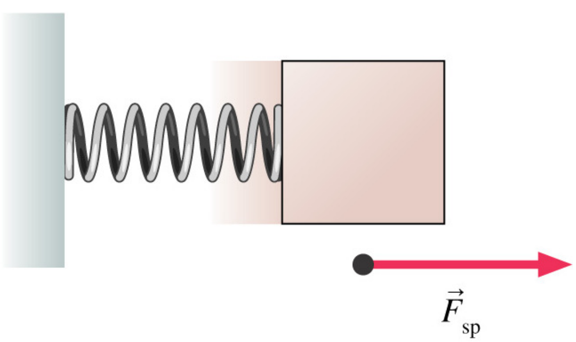
2. **Spring Force** $$F_{sp} = kx$$

k - **coefficient, which depends only on geometric parameters of the spring**

$x = |\Delta l|$ - **change in the length of the spring**

A compressed spring exerts a pushing force on an object.



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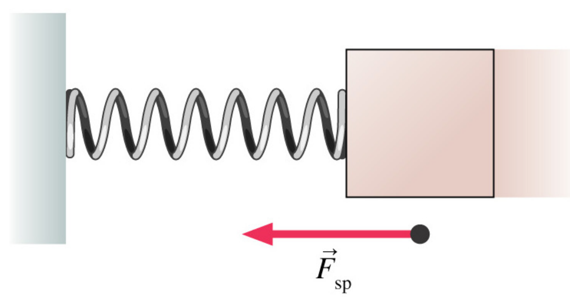
A stretched spring exerts a pulling force on an object.



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Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$

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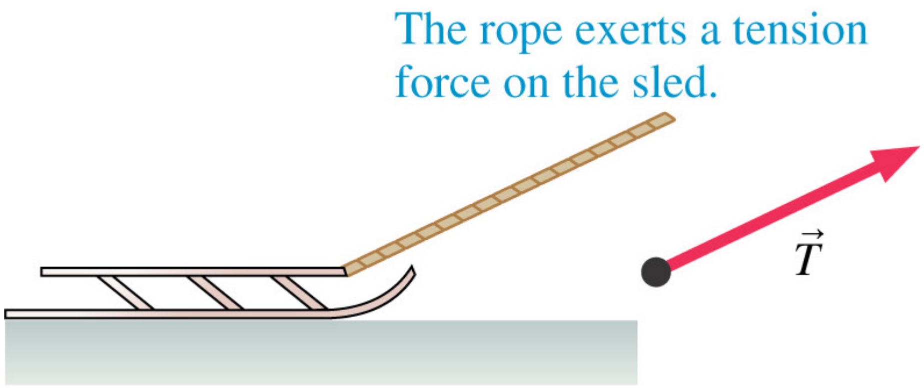
3. Tension Force $\vec{T}$

   direction is always in the direction of the rope

   magnitude - usually found from the condition of equilibrium



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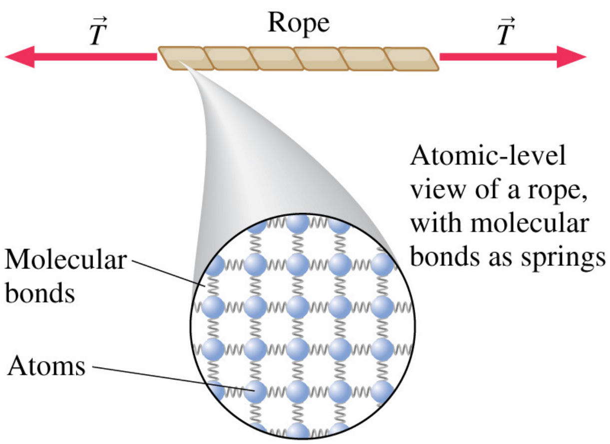

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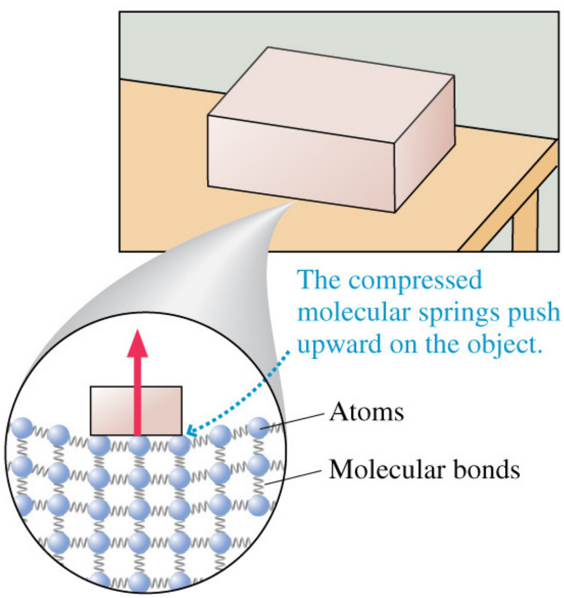
Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$
3. Tension Force $\vec{T}$
4. Normal Force $\vec{n}$

direction is always perpendicular to the surface

magnitude - usually found from the condition of equilibrium



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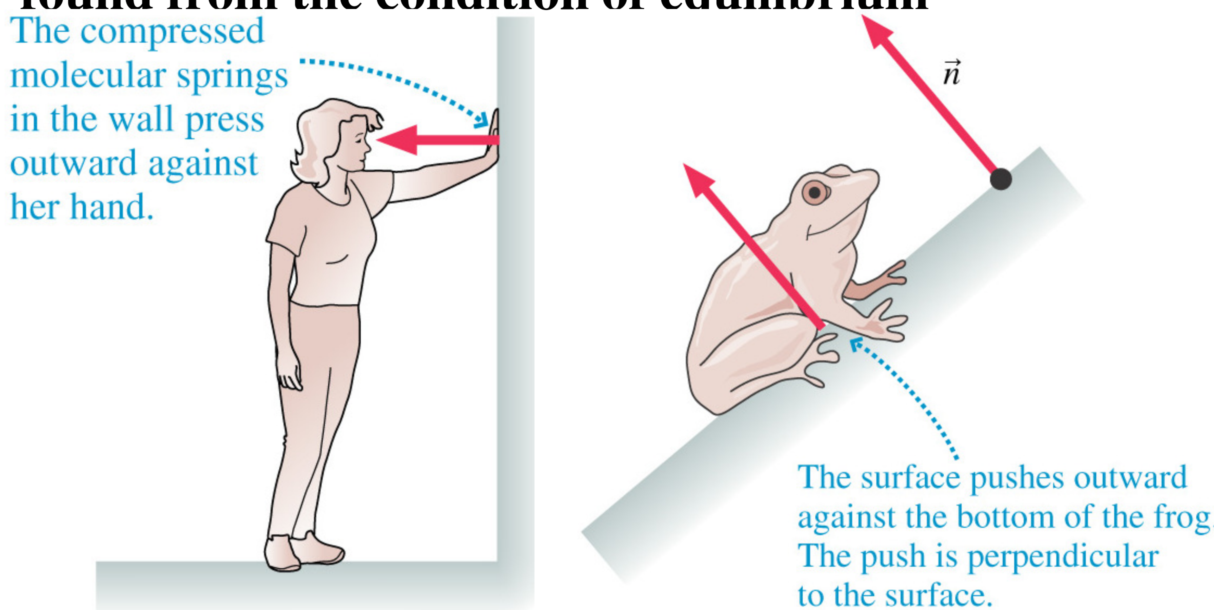

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Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$
3. Tension Force $\vec{T}$
4. Normal Force $\vec{n}$
5. Friction $\vec{f}_k$

   - Kinetic friction – opposes the motion $\vec{f}_s$

direction – opposite the velocity vector

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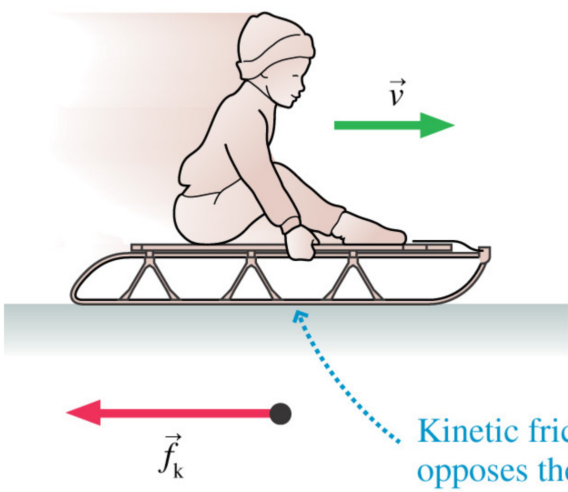

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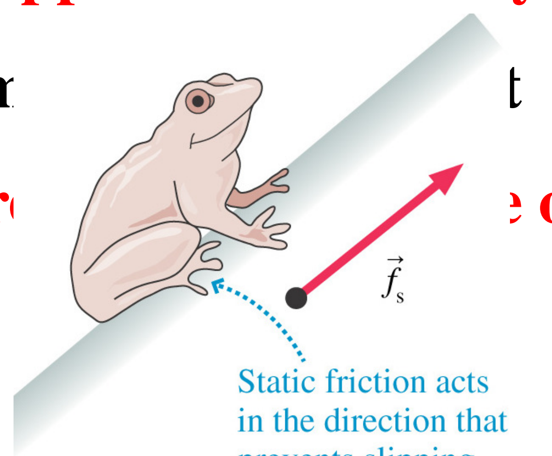

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Major Forces:

1. Weight – gravitational force $\vec{w} = m\vec{g}$
2. Spring Force $F_{sp} = kx$
3. Tension Force $\vec{T}$
4. Normal Force $\vec{n}$
5. Friction
   - kinetic friction $\vec{f}_k$
   - static friction $\vec{f}_s$

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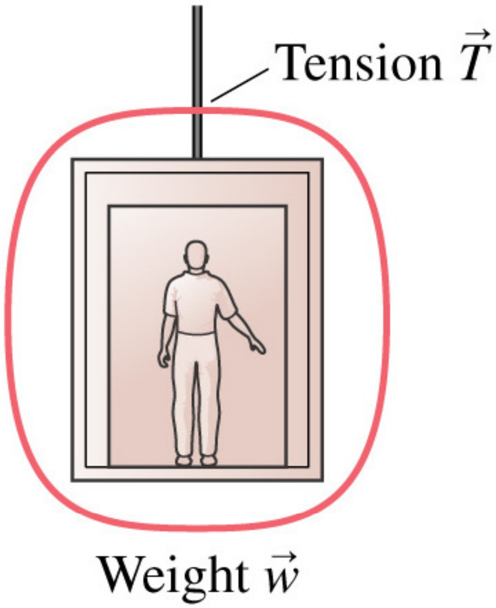
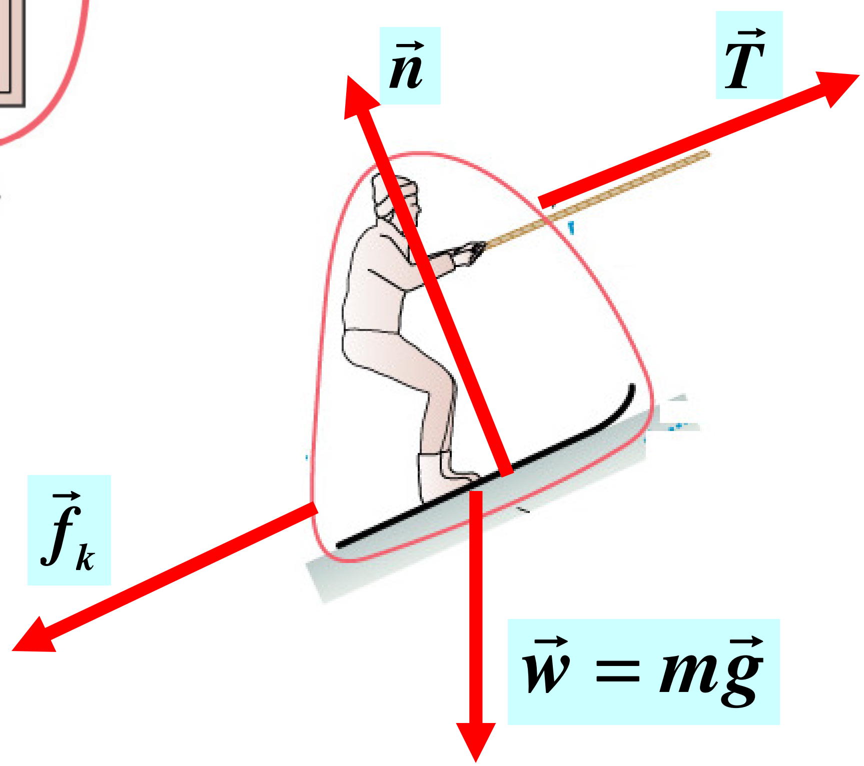
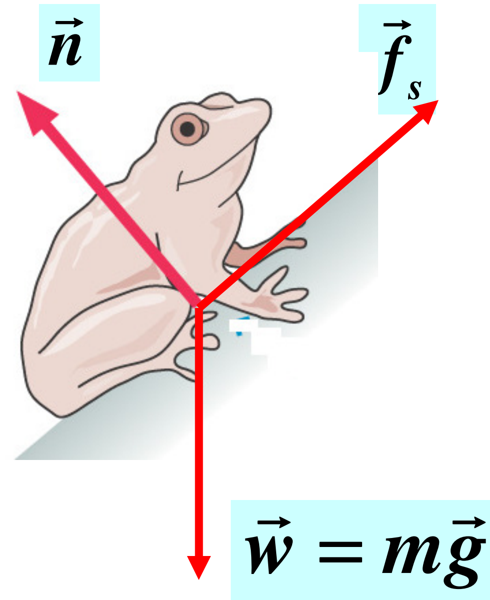
Force Identification







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Free-Body Diagram

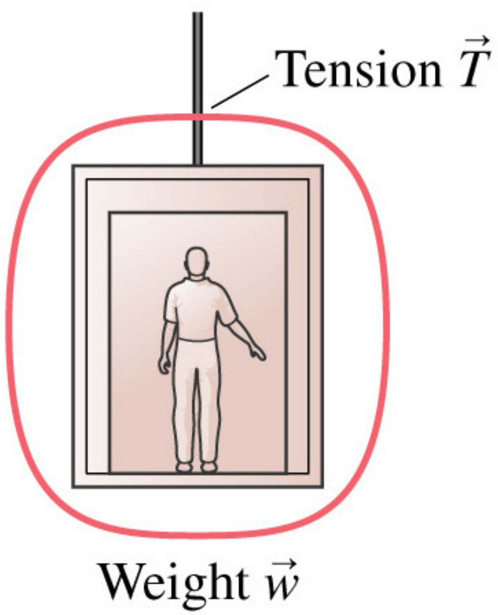
1) Object – as a particle

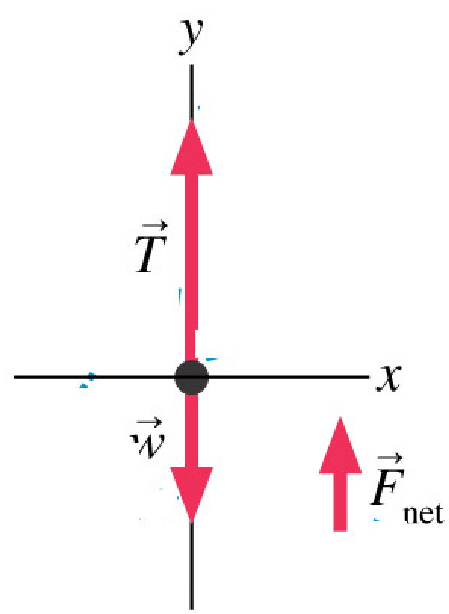
2) Identify all the forces

3) Find the net force (vector sum of all individual forces)

4) Find the acceleration of the object (second Newton's law)

5) With the known acceleration find kinematics of the object





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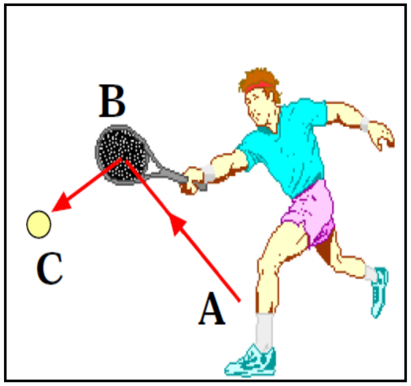
Newton's Laws of Motion

It was Isaac Newton (1642-1727) who realized the importance of force and its connection with motion.

Three Laws of motion

- **1st Law: inertia**
- **2nd Law: change in motion**
- **3rd Law: action and reaction pairs**



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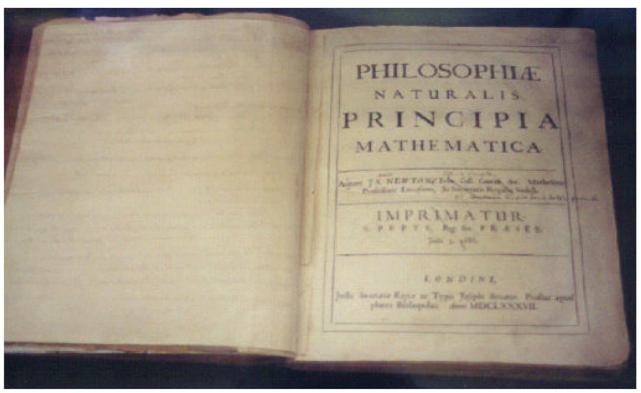
About Newton

In 1665, shortly after getting a bachelor's degree at Cambridge, Newton was forced to return to his home because of the Great Plague. During the next 18 months he formulated most of his scientific discoveries: including, the development of his three Laws of motion, the Law of gravitation, the invention of the calculus, the dispersion of light, the building of a reflecting telescope, and so on. That short period was probably the most creative period in the history of man ... and it will never be repeated!



Newton's book of 1687:
the Principia Mathematica

Today, an apple tree stands on the lawn between the Great Gate and the Chapel at Trinity College, Cambridge; the rooms Newton occupied overlook the tree. The tree was grown from seeds taken from an old apple tree at Newton's birthplace, Woolsthorpe, Lincolnshire.

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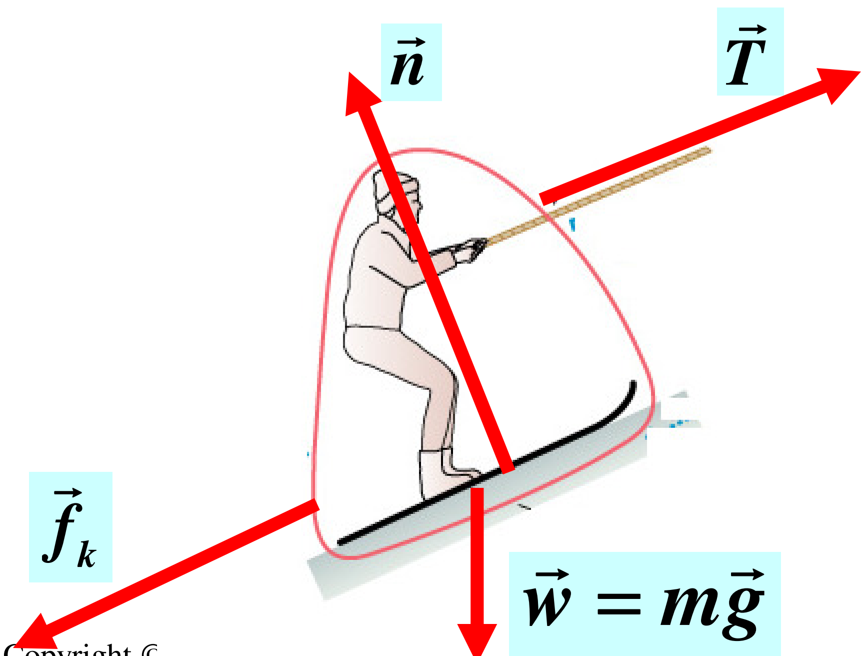
Newton's Second Law

An object of mass m subject to forces $\vec{F}_1, \vec{F}_2, \ldots$ undergo an acceleration given by

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$



$$\vec{a} = \frac{\vec{w} + \vec{n} + \vec{T} + \vec{f}_k}{m}$$

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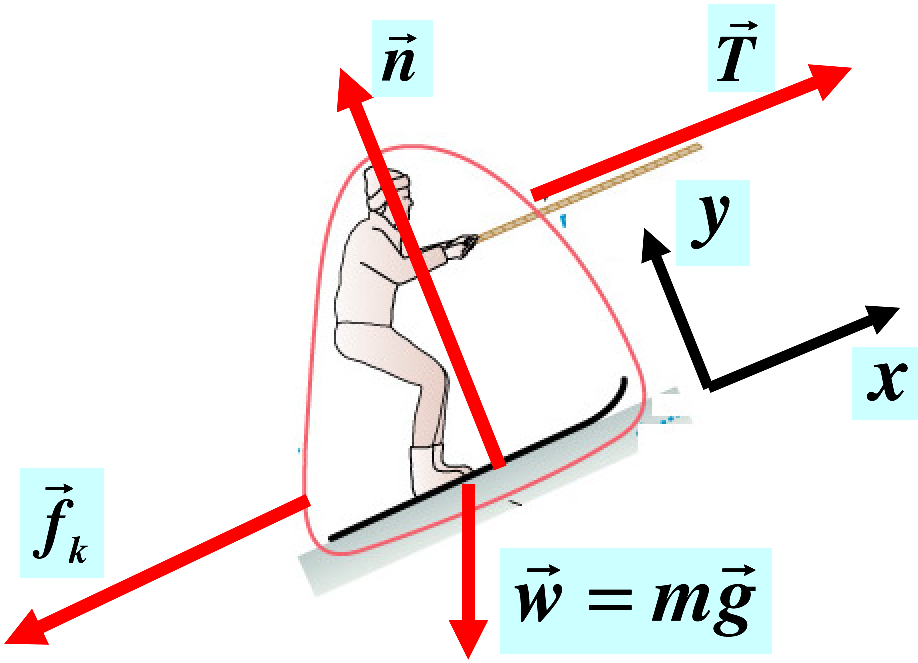
Newton's Second Law

$$\vec{a} = \frac{\vec{F}_{net}}{m}$$

$$\vec{a} = \frac{\vec{w} + \vec{n} + \vec{T} + \vec{f}_k}{m}$$



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It is convenient to introduce coordinate system and write the Newton's second law in terms of vector components

No motion in y-direction:

$$a_y = 0$$

$$w_y + n = 0$$

For motion in x-direction:

$$ma_x = w_x + T - f_k$$

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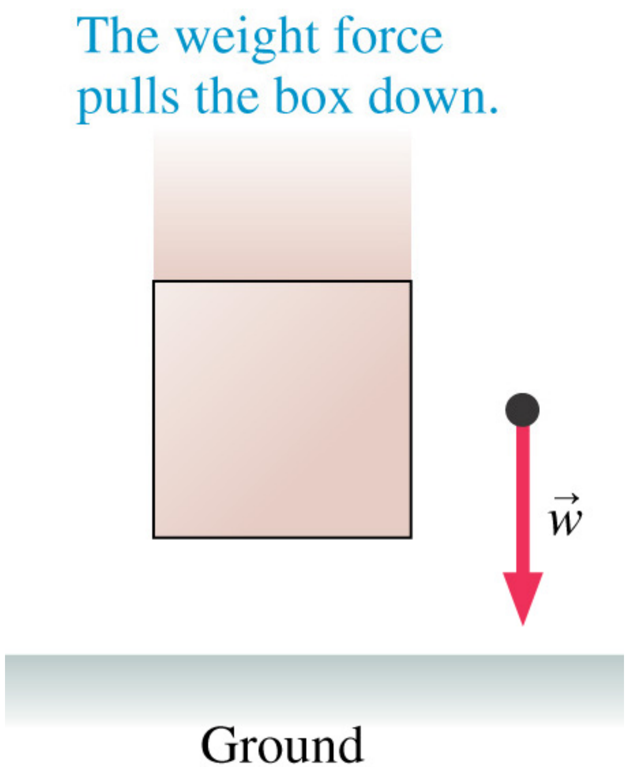
Free-fall motion



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

Then from the second
New

$$\vec{a} = \frac{\vec{w}}{m} = \frac{m\vec{g}}{m} = \vec{g}$$

$$g = 9.8\frac{m}{s^2}$$

The acceleration is the same for all objects (does not depend on the mass of the object)

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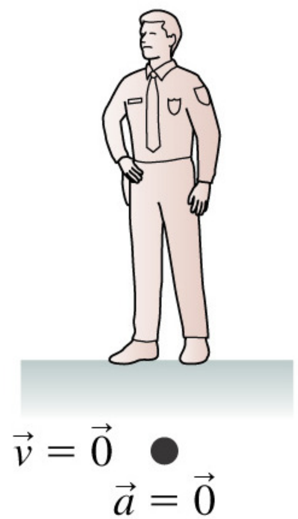
Newton's First Law

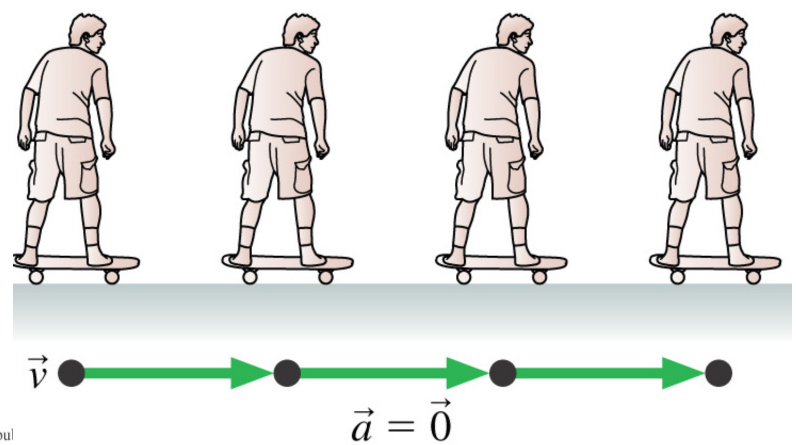
An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

$\vec{F}_{net} = 0$ **then** $\vec{a} = 0$ **velocity is constant**

Static equilibrium



Dynamic equilibrium



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Inertial reference frames

Inertial reference frame is the coordinate system in which Newton's laws are valid.

The earth is an inertial reference frame

Any other coordinate systems, which are traveling with constant velocity with respect to the earth is an inertial reference frame

Car traveling with constant velocity is an inertial reference frame

Car traveling with acceleration is NOT an inertial reference frame (violation of Newton's law)

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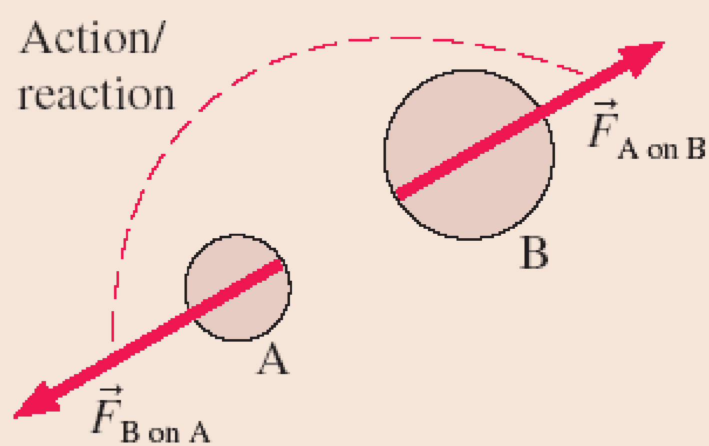
Newton's Third Law

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.
- Are equal in magnitude but opposite in direction:

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$



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Chapter 5. Summary

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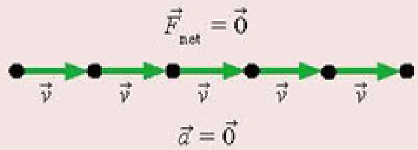
Newton's First Law

An object at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force on the object is zero.



The first law tells us that no "cause" is needed for motion. Uniform motion is the "natural state" of an object.

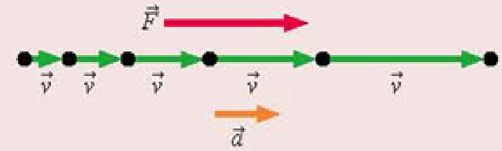
Newton's laws are valid only in inertial reference frames.

Newton's Second Law

An object with mass m will undergo acceleration

$$\vec{a} = \frac{1}{m}\vec{F}_{net}$$

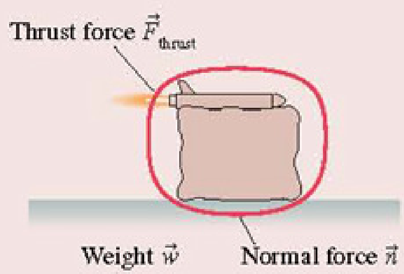
where $\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$ is the vector sum of all the individual forces acting on the object.



The second law tells us that a net force causes an object to accelerate. This is the connection between force and motion that we are seeking.

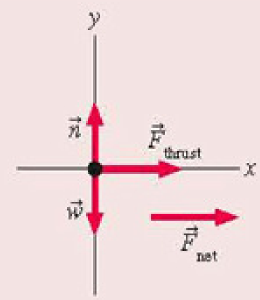
Identifying Forces

Forces are identified by locating the points where the environment touches the system. These are points where contact forces are exerted. In addition, objects with mass feel a long-range weight force.



Free-Body Diagrams

A free-body diagram represents the object as a particle at the origin of a coordinate system. Force vectors are drawn with their tails on the particle. The net force vector is drawn beside the diagram.



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Chapter 5. Questions

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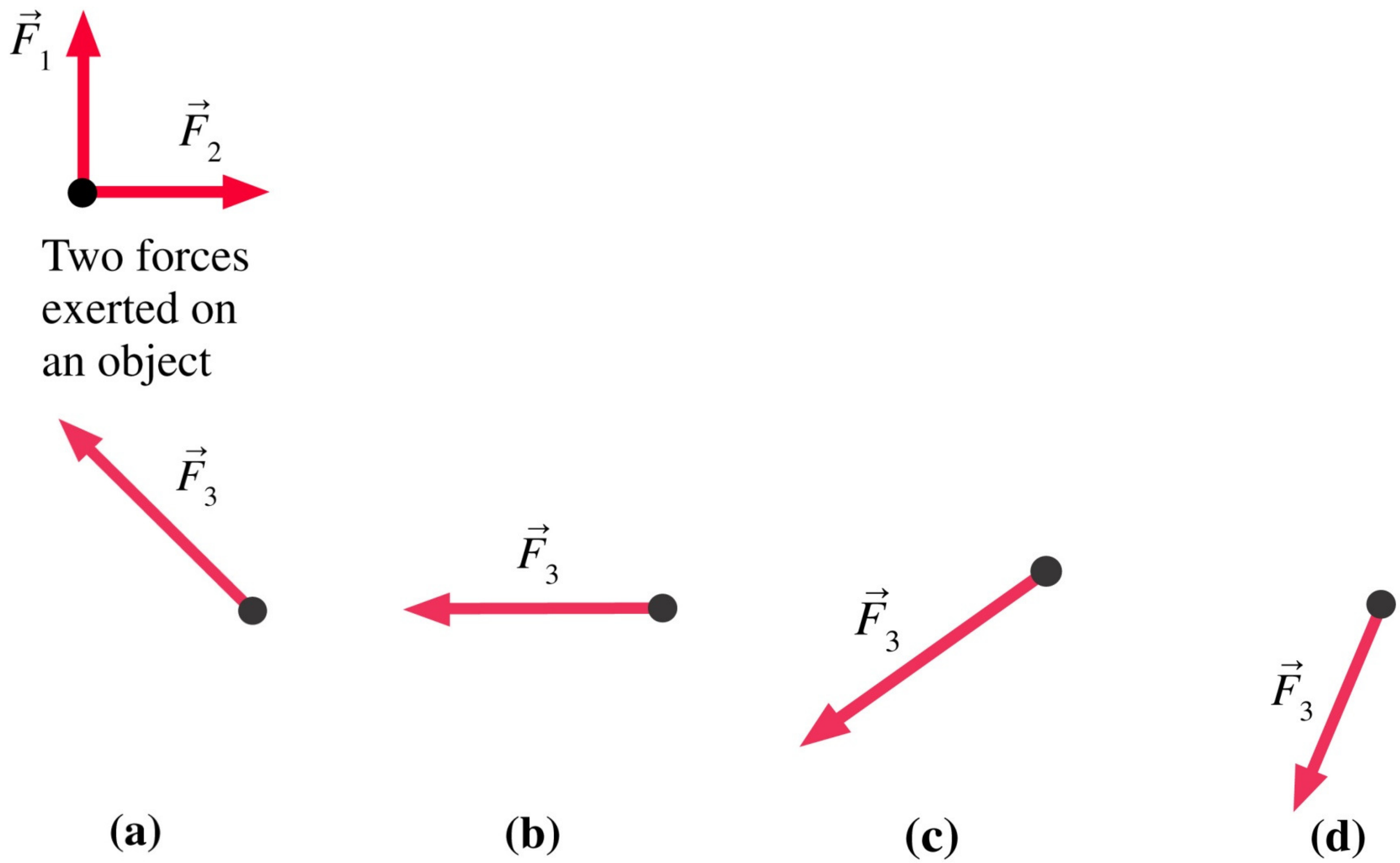
Two of three forces exerted on an object are shown. The net force points to the left. What is the missing third force?



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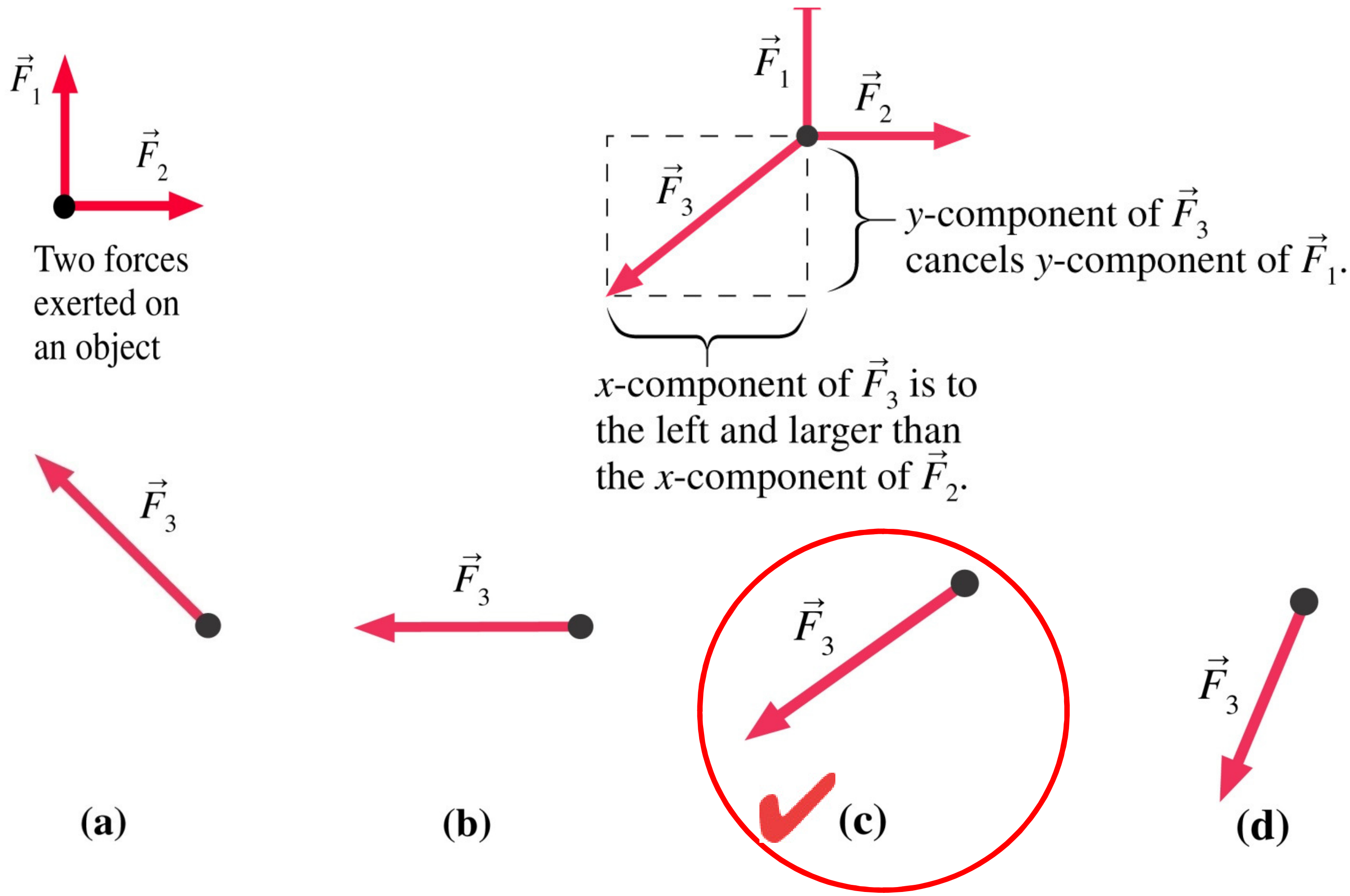

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You've just kicked a rock, and it is now sliding across the ground about 2 meters in front of you. Which of these forces act on the ball?

A. Gravity, acting downward
B. The normal force, acting upward
C. The force of the kick, acting in the direction of motion
D. Friction, acting opposite the direction of motion
E. A, B, and D but not C.

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D. Friction, acting opposite the direction of motion

✔ **E. A, B, and D but not C.**

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Two rubber bands stretched the standard distance cause an object to accelerate at 2 m/s^2. Suppose another object with twice the mass is pulled by four rubber bands stretched the standard length. The acceleration of this second object is

A. 16 m/s^2.

B. 8 m/s^2.

C. 4 m/s^2.

D. 2 m/s^2.

E. 1 m/s^2.

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A. 16 m/s^2.

B. 8 m/s^2.

C. 4 m/s^2.

✔ **D. 2 m/s^2.**

E. 1 m/s^2.

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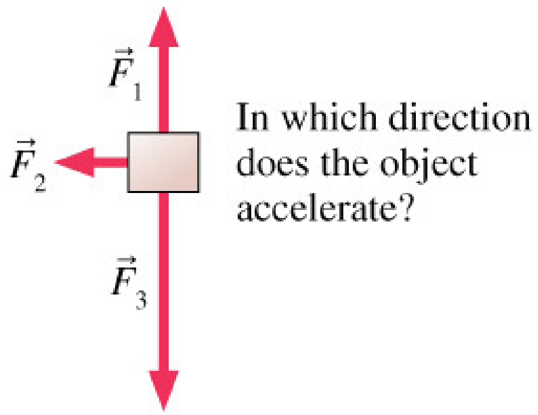
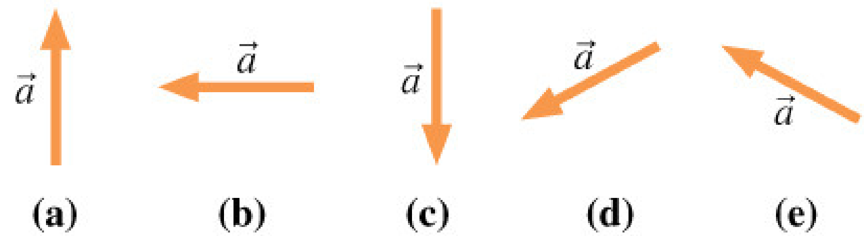
Three forces act on an object. In which direction does the object accelerate?





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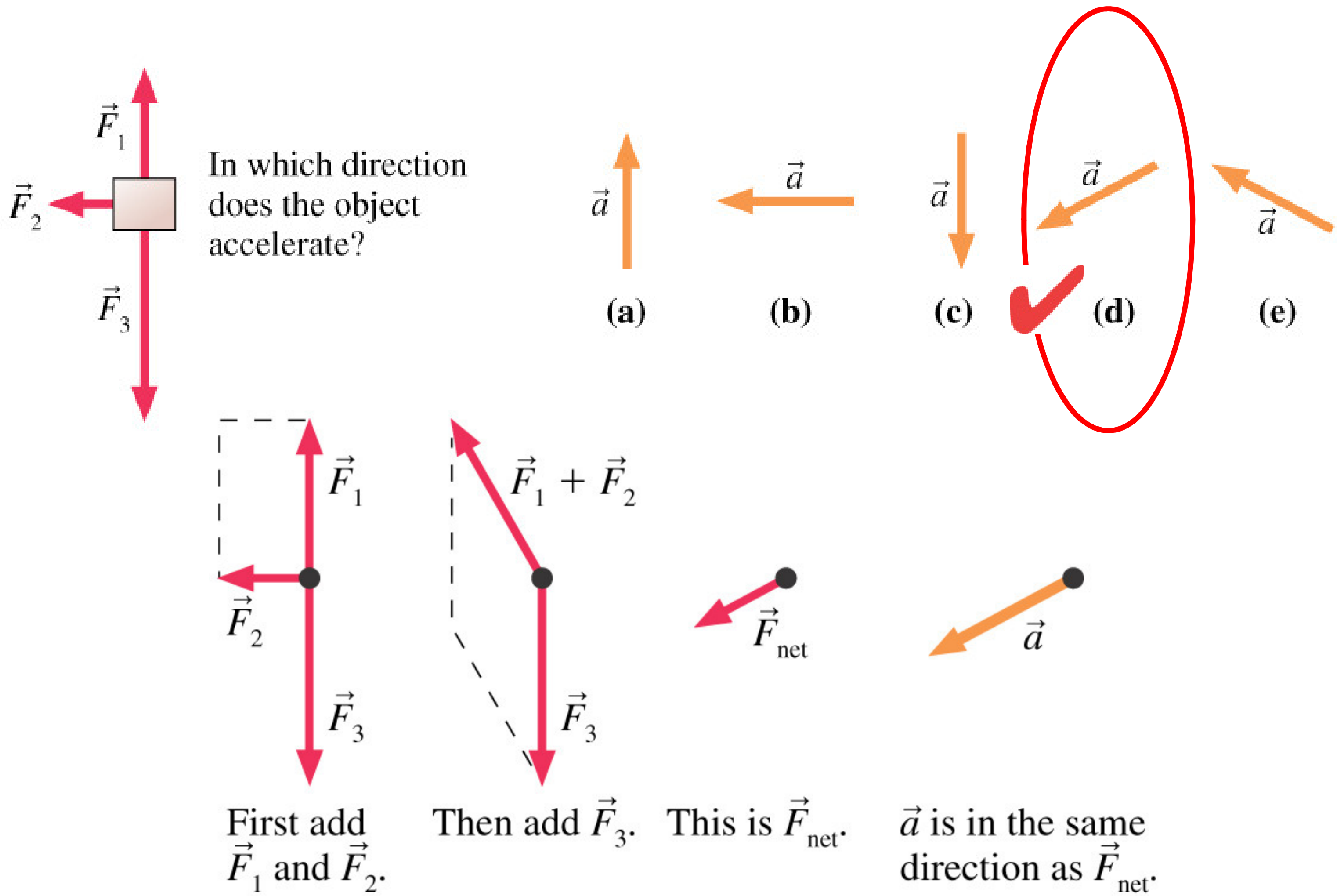

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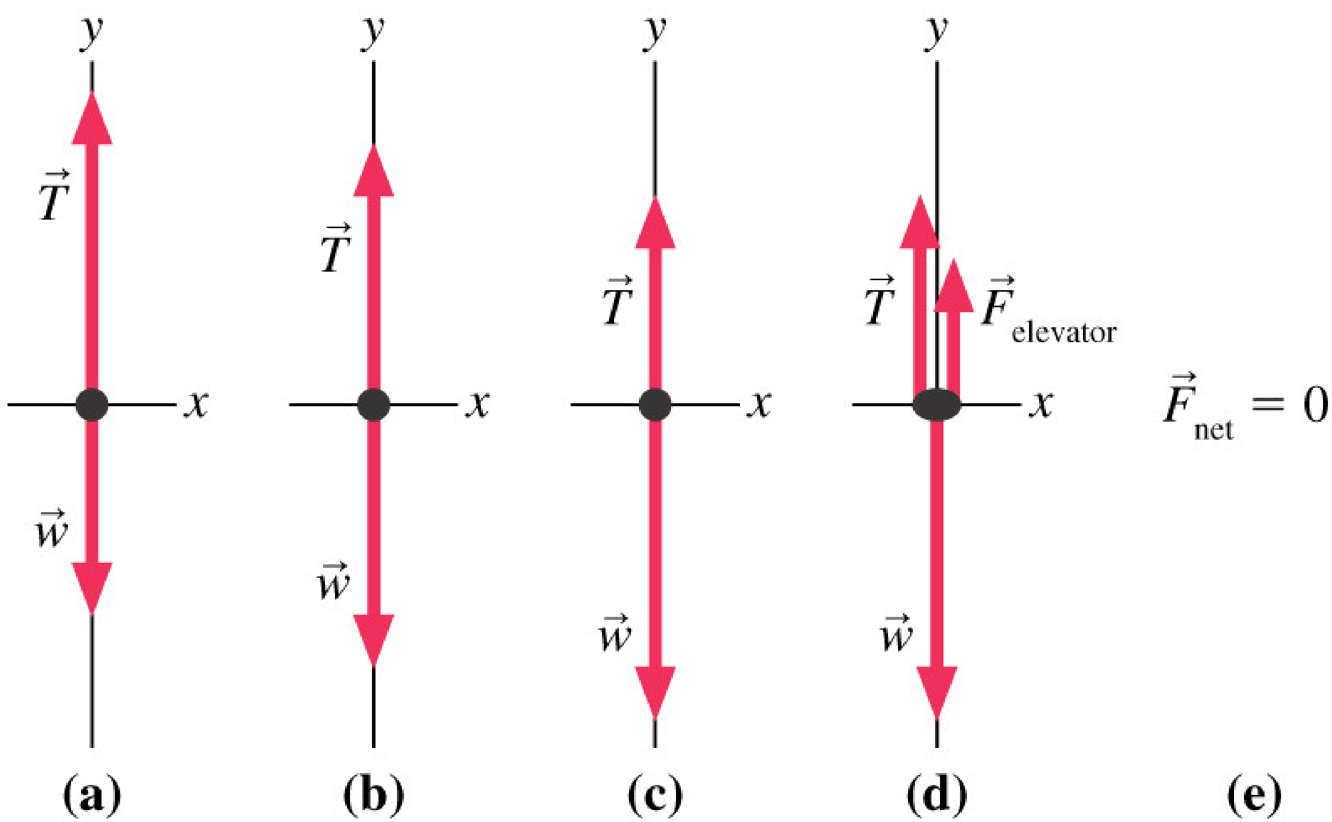
An elevator suspended by a cable is moving upward and slowing to a stop. Which free-body diagram is correct?



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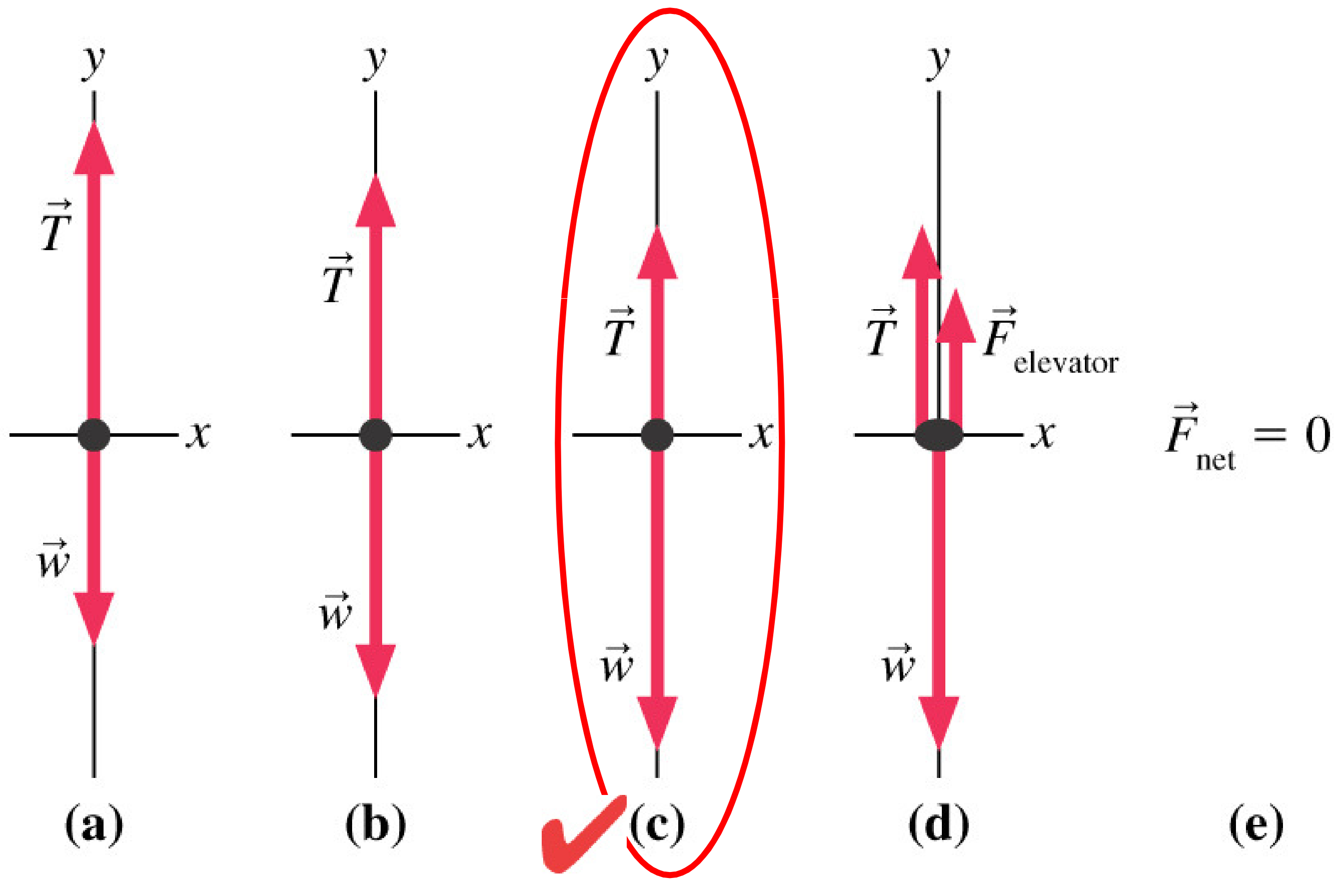

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