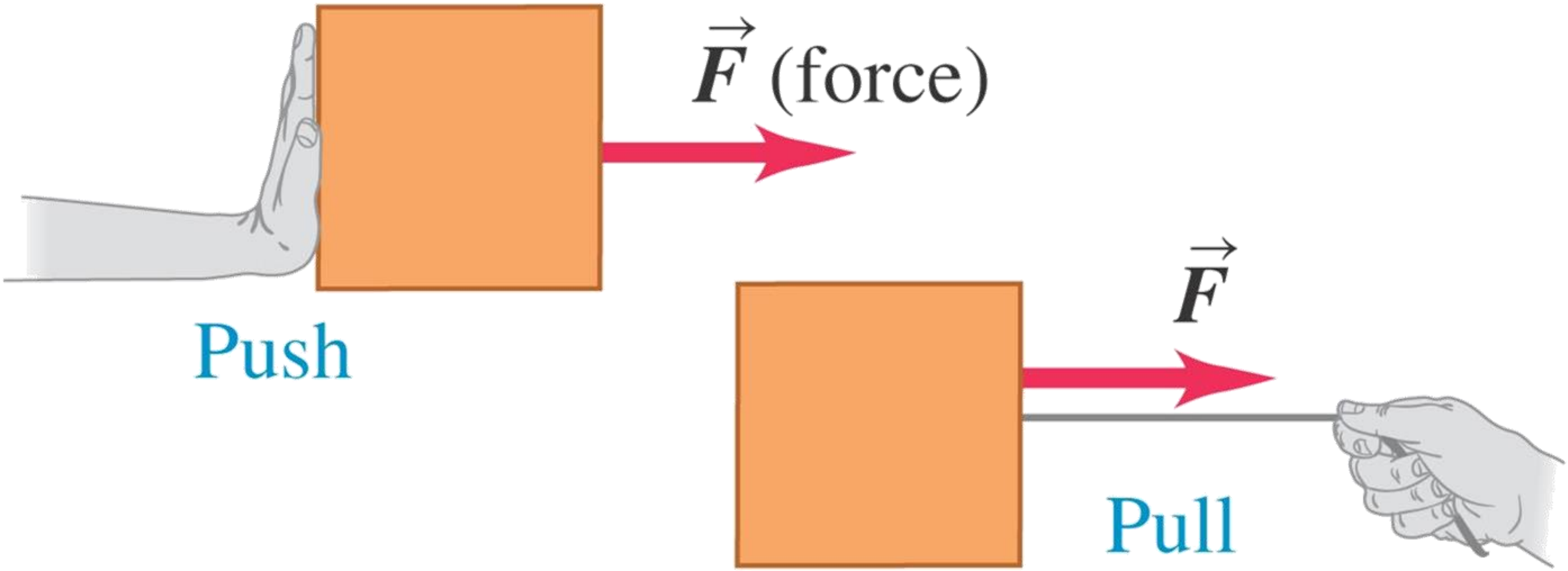
Chapter 4

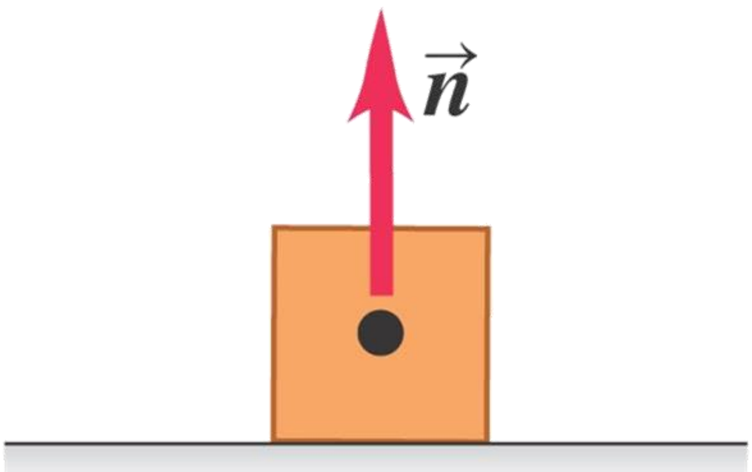
Newton's laws of motion

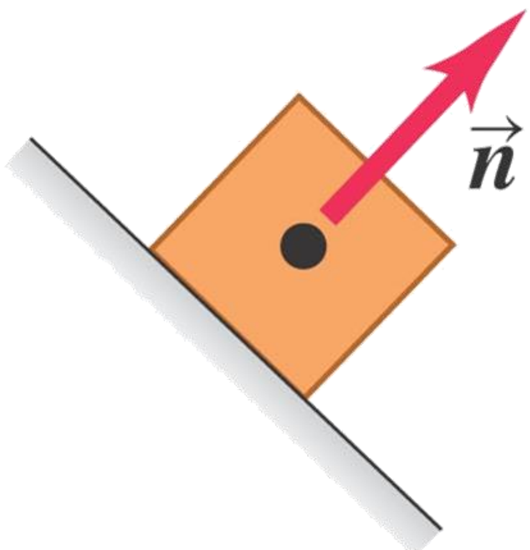
Force and Interactions



Common Types of Forces

NORMAL FORCE

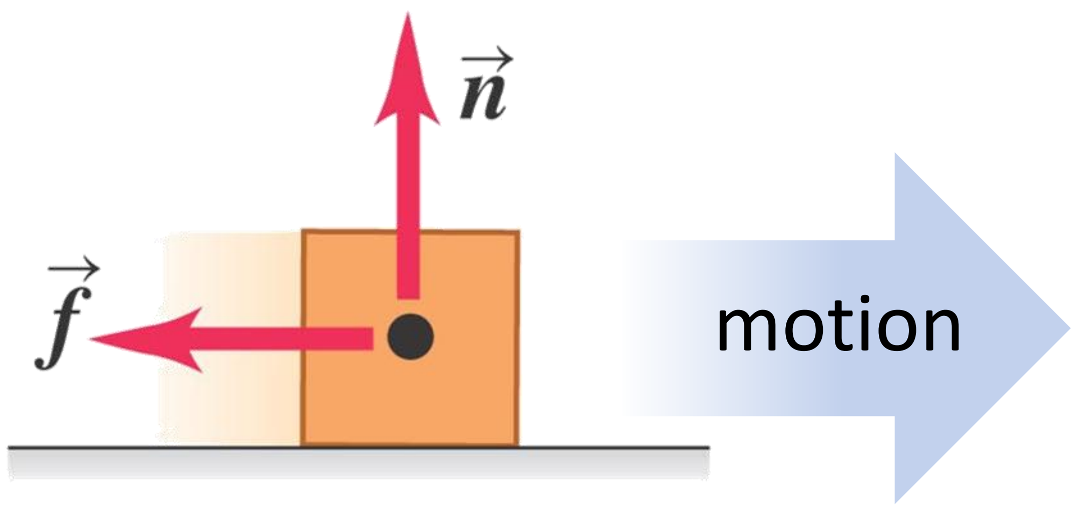




perpendicular to the surface

Common Types of Forces

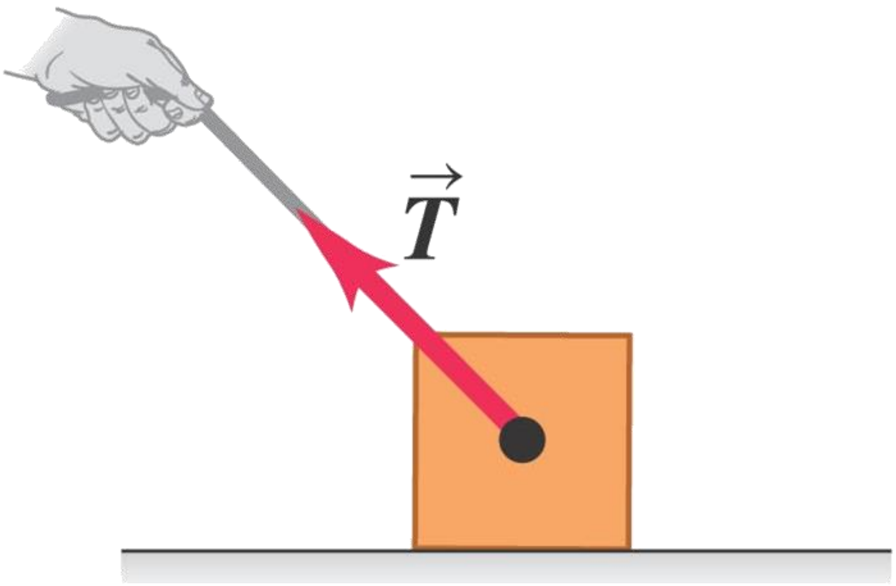
FRICTION FORCE



parallel to the surface (against motion)

Common Types of Forces

TENSION FORCE

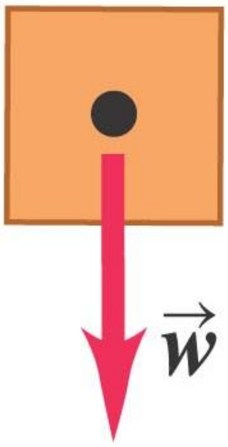


along a rope, cord, chain, etc.

Common Types of Forces

WEIGHT

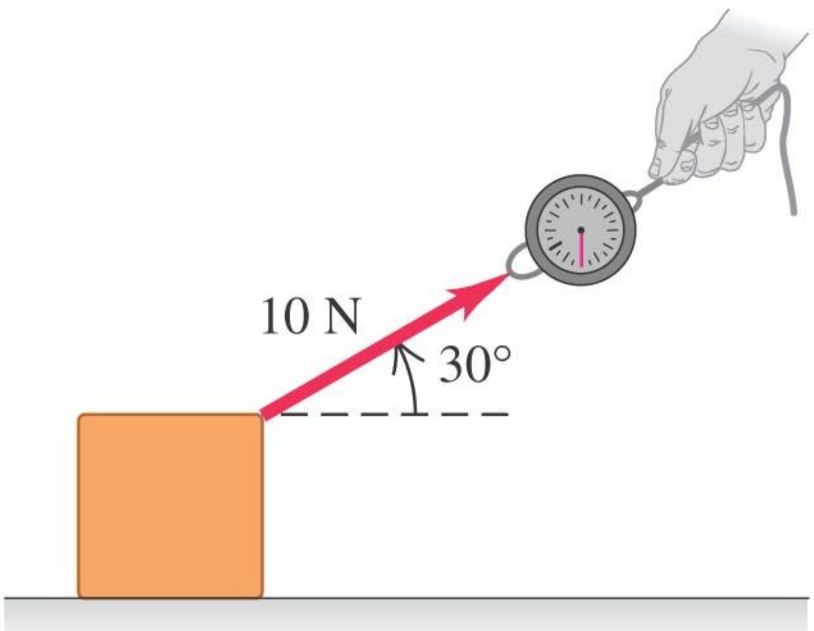
the *pull of gravity* on an object



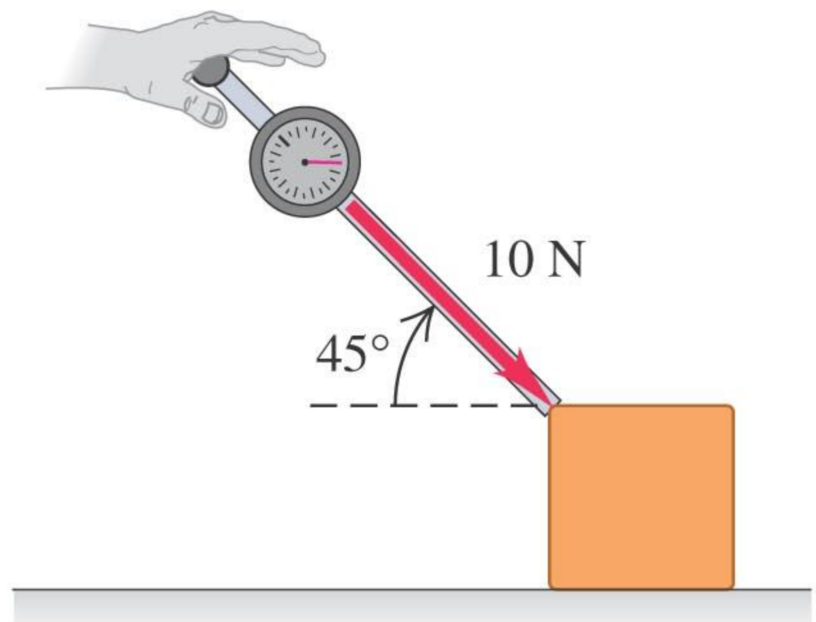
Force is a Vector!

Unit of force is the **newton (N)**.

(a) A 10-N pull directed 30° above the horizontal

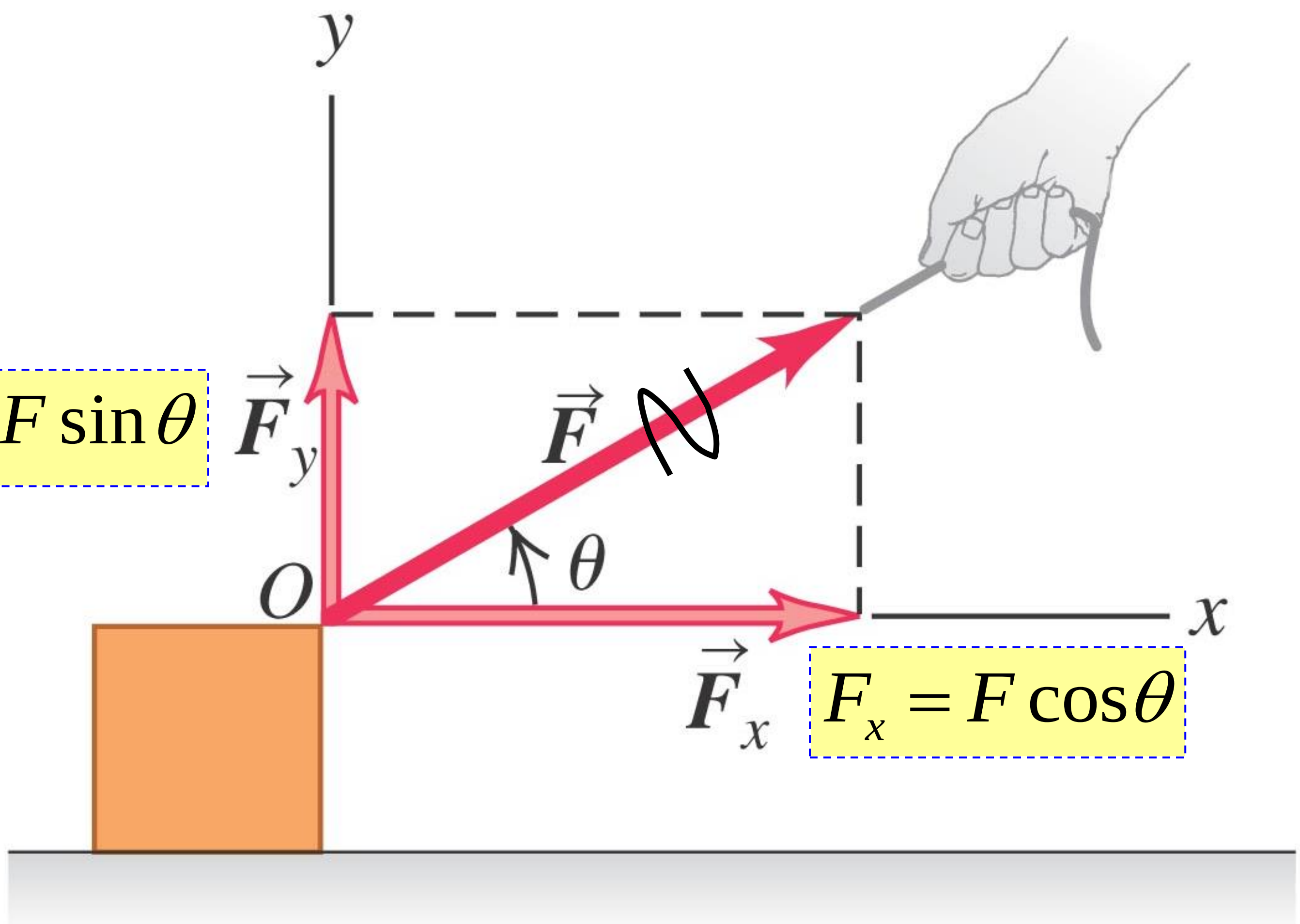


(b) A 10-N push directed 45° below the horizontal



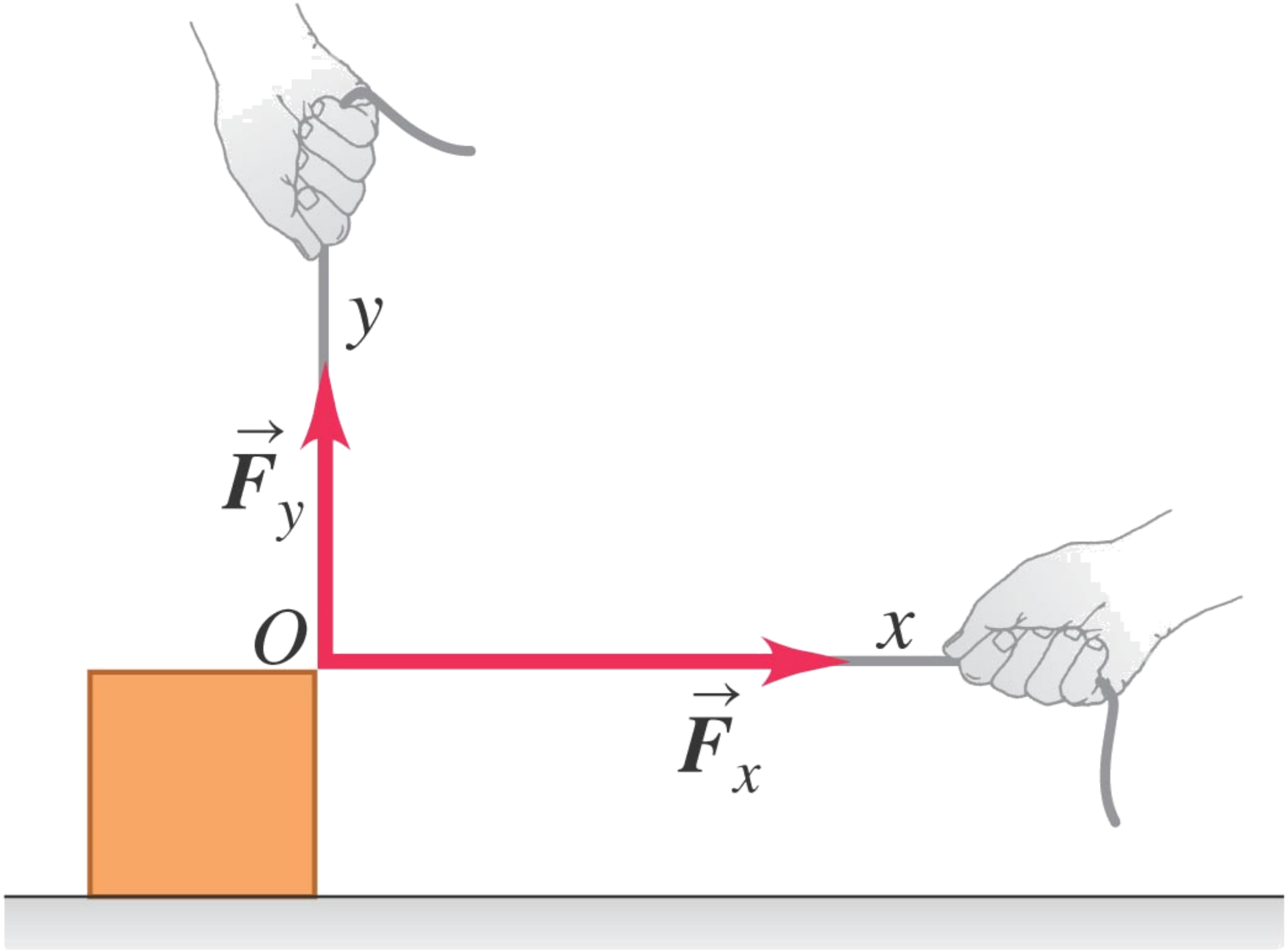
Force is a Vector!

$$F_y = F\sin\theta$$



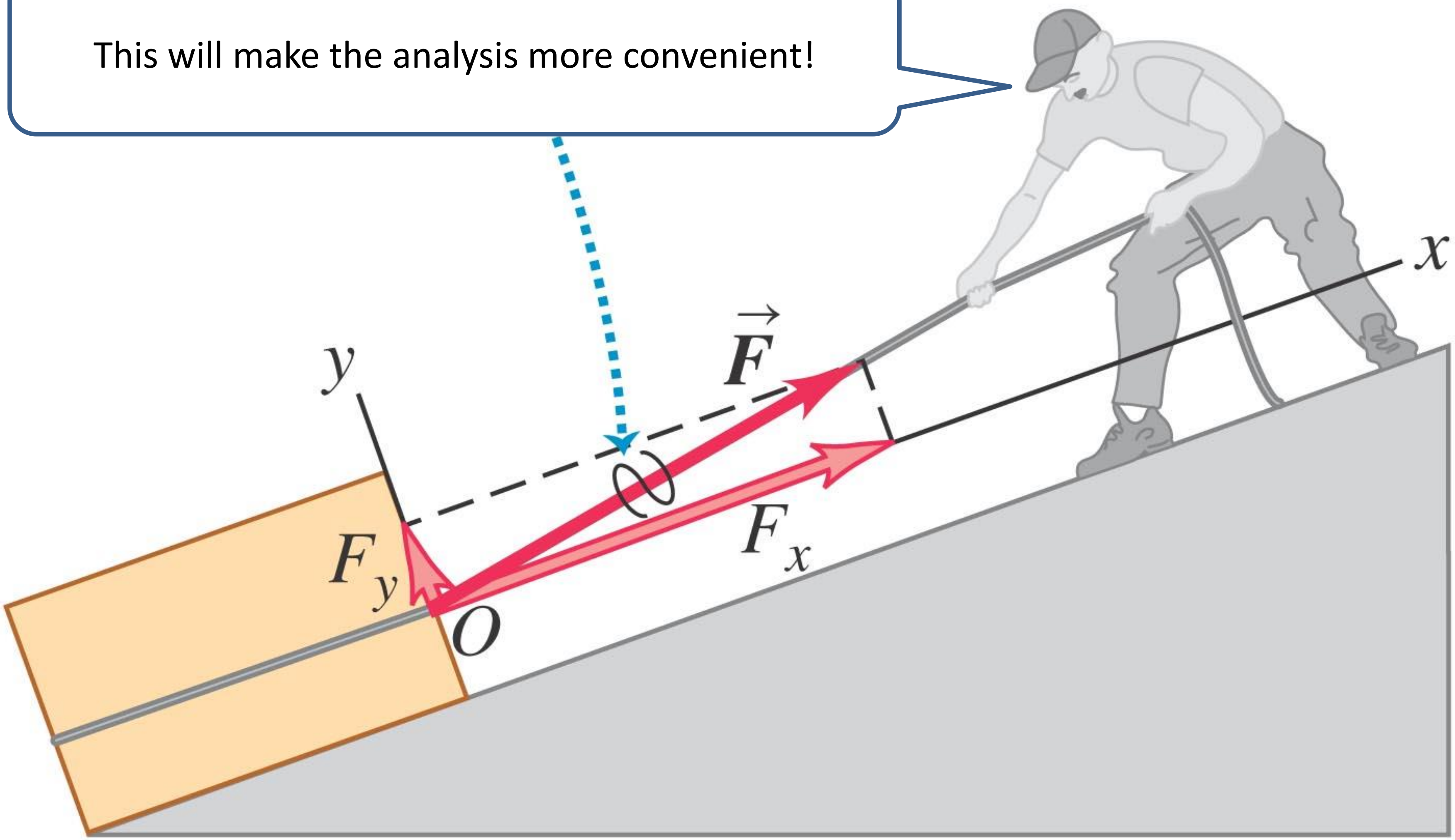
$$F_x = F\cos\theta$$

Force is a Vector!

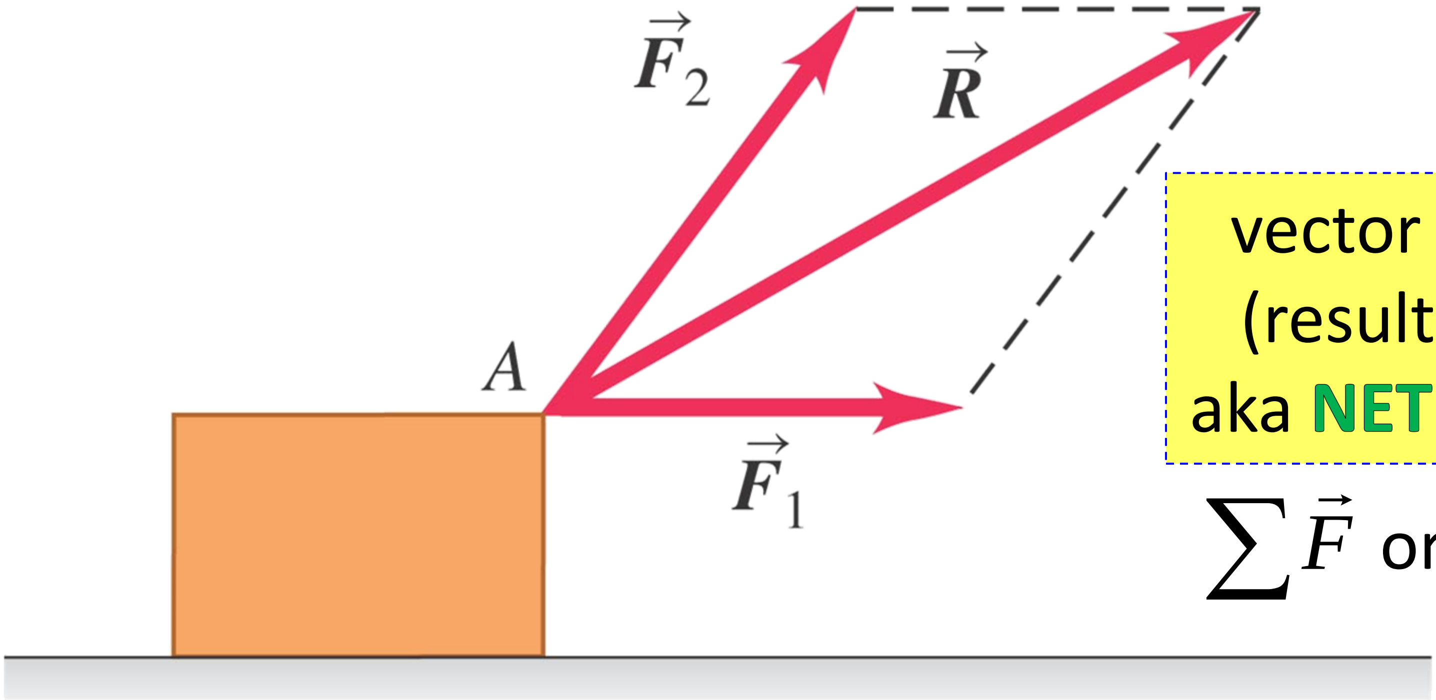


Coordinate axes need not to be vertical and horizontal!

This will make the analysis more convenient!



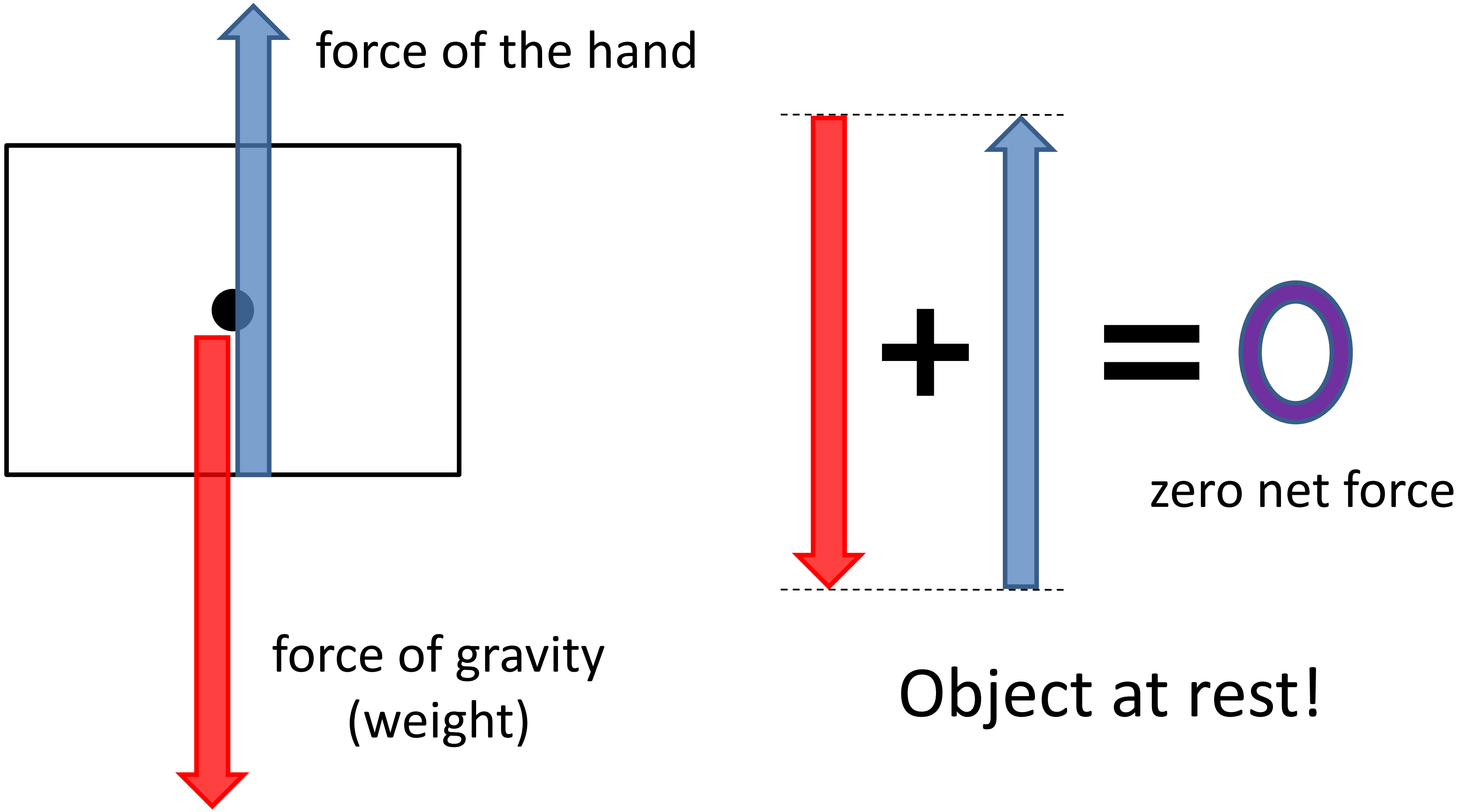
Superposition of Forces



vector sum
(resultant)
aka **NET force**

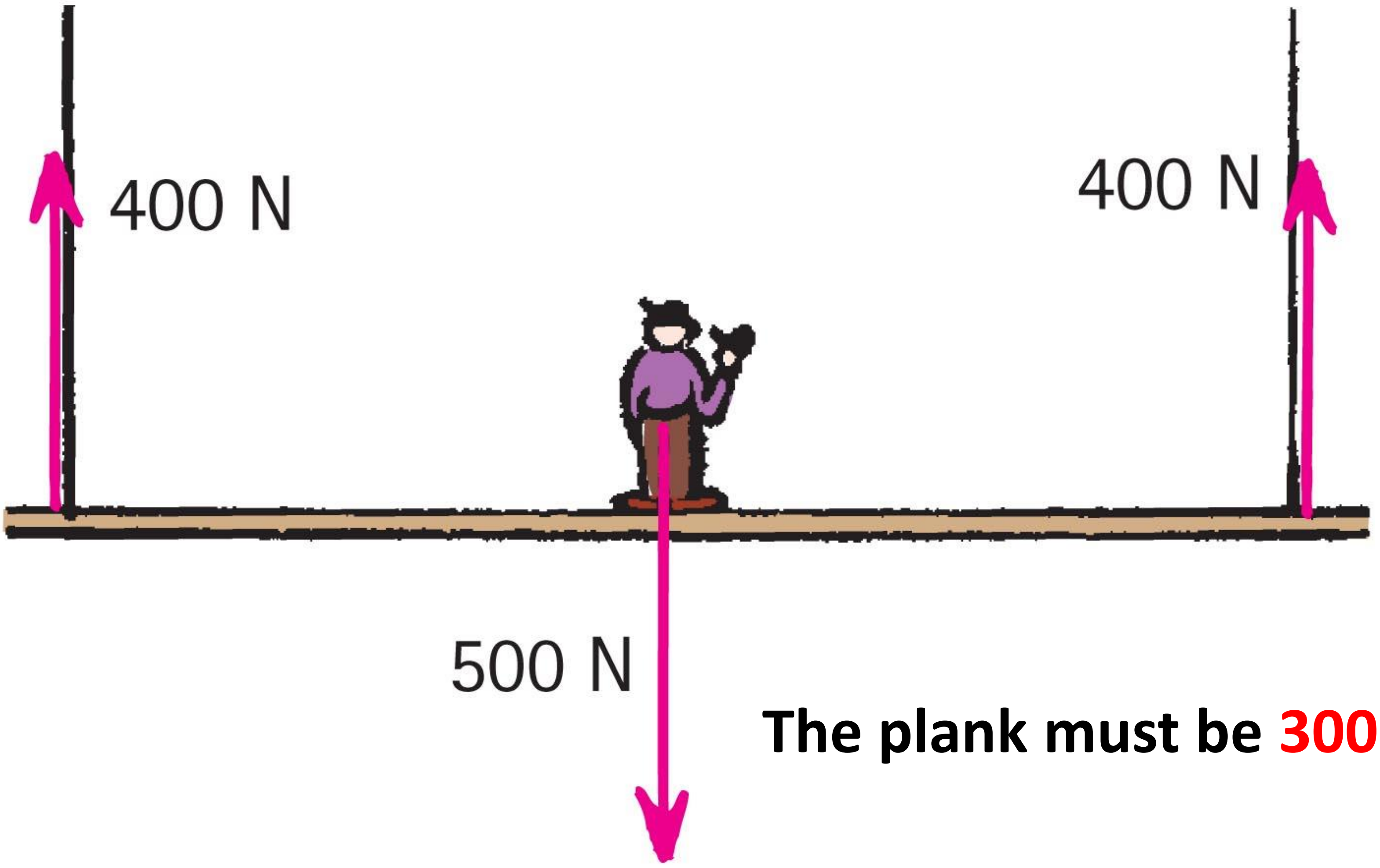
$$\sum \vec{F} \text{ or } \vec{F}_{\text{net}}$$

Equilibrium of Forces



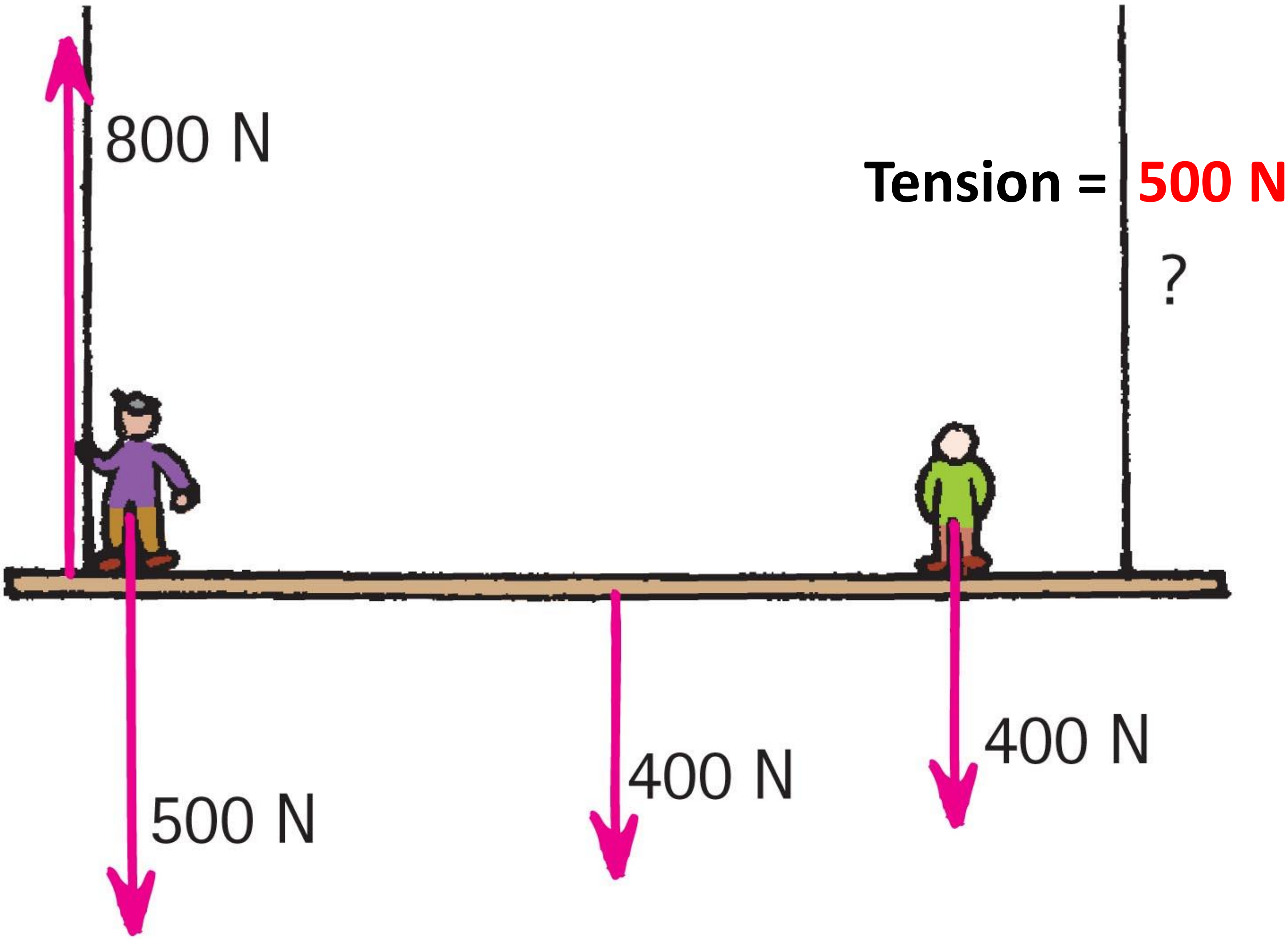
Object at rest!

Equilibrium of Forces

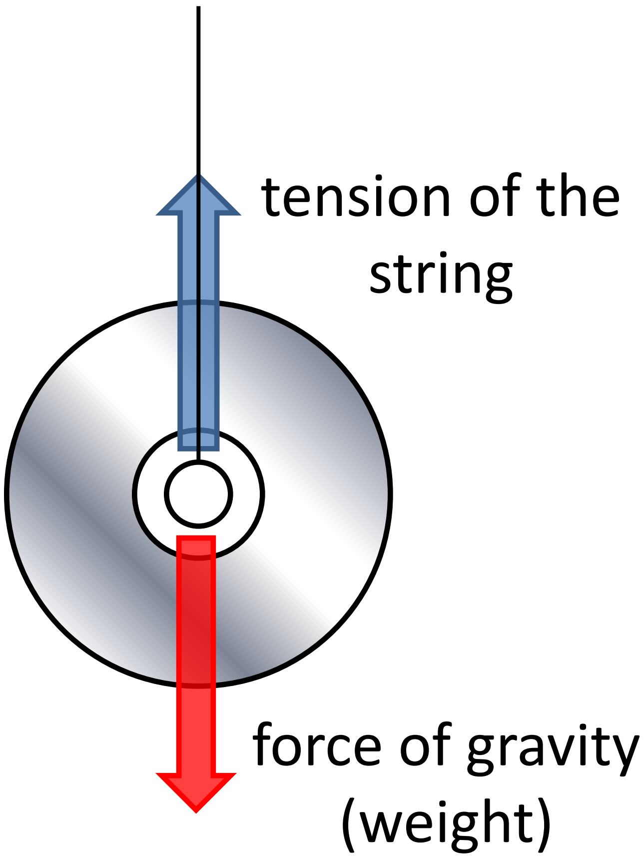


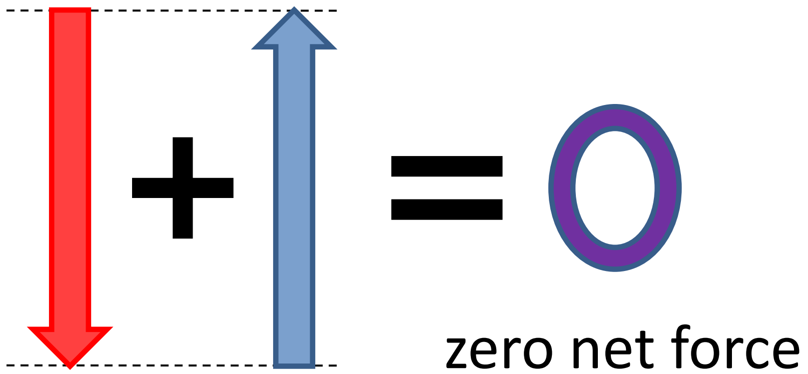
The plank must be 300 N.

Equilibrium of Forces

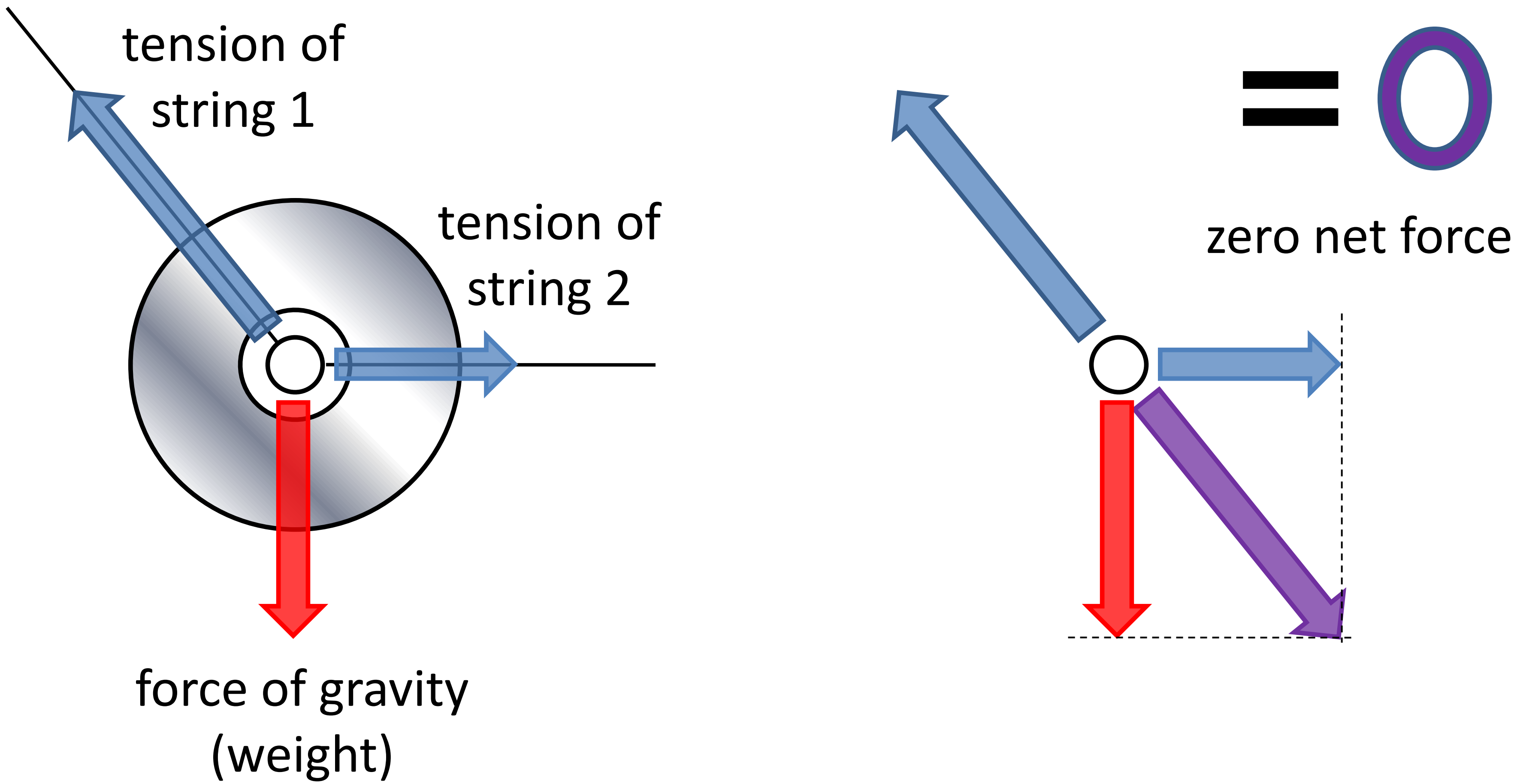


Equilibrium of Forces

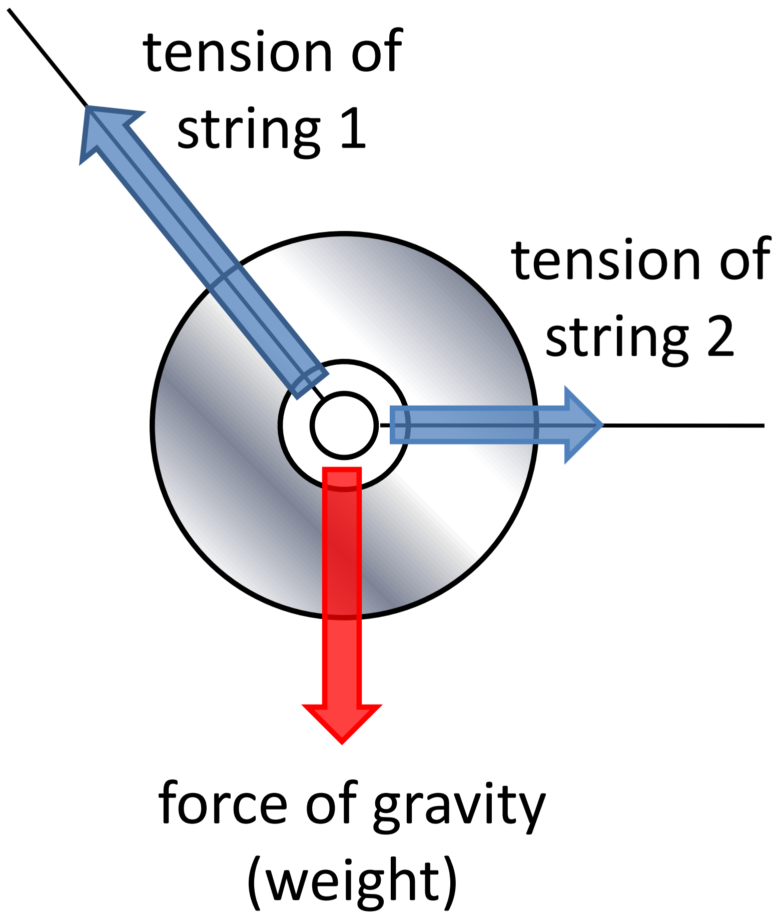


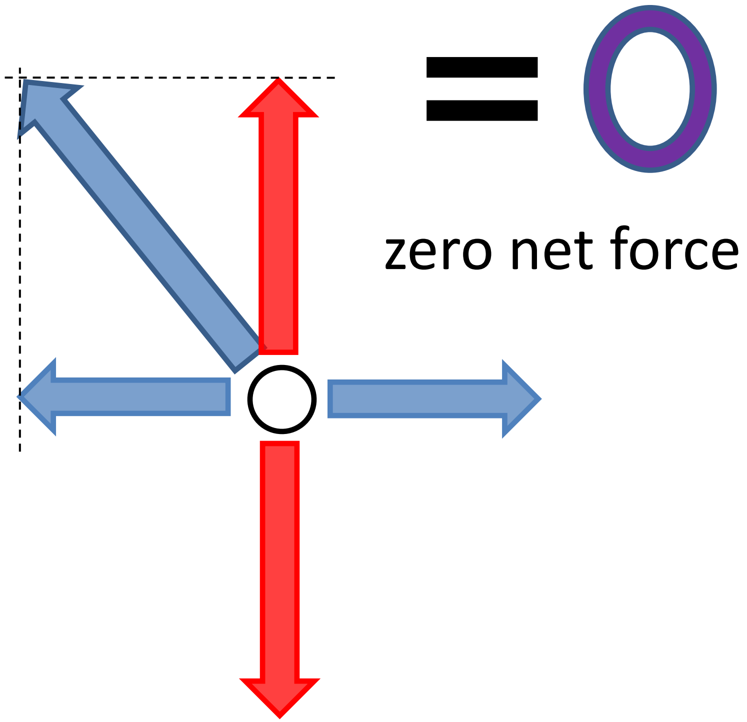


Equilibrium of Forces



Equilibrium of Forces

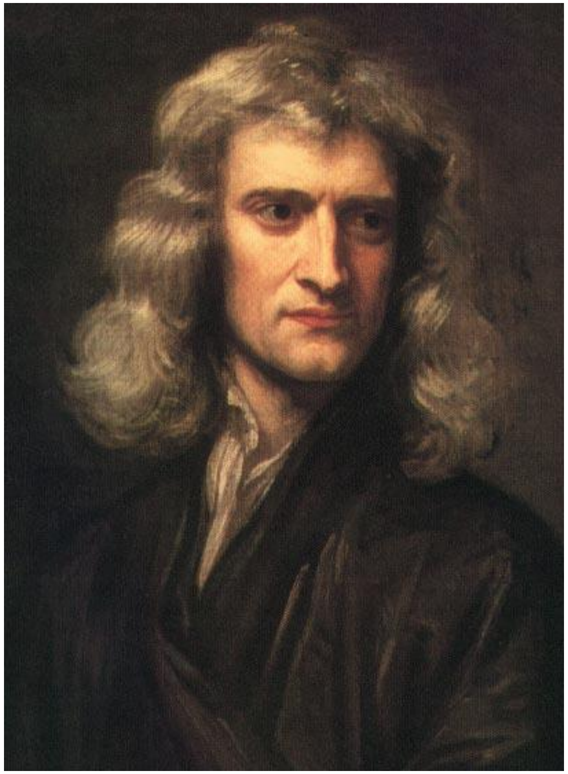




Absence of a Force?

Is it possible for objects to be in motion even when forces are zero?

Newton's First Law



An object tends to remain in its state of motion (at rest or moving with constant velocity) unless acted upon by an outside net force.

Law of **Inertia**

Inertial Frame of Reference

where Newton's 1st Law is valid

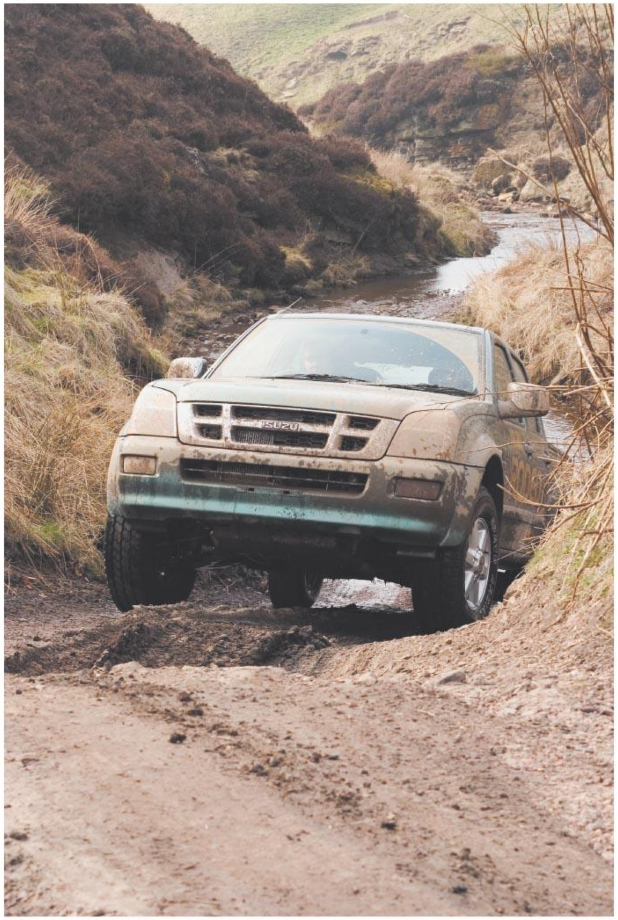
Is the net force zero???

An airplane flying due north at a steady 120 m/s at a constant altitude…

YES!

Is the net force zero???

A car driving straight up a hill with a 30° slope at a constant 20 km/h...



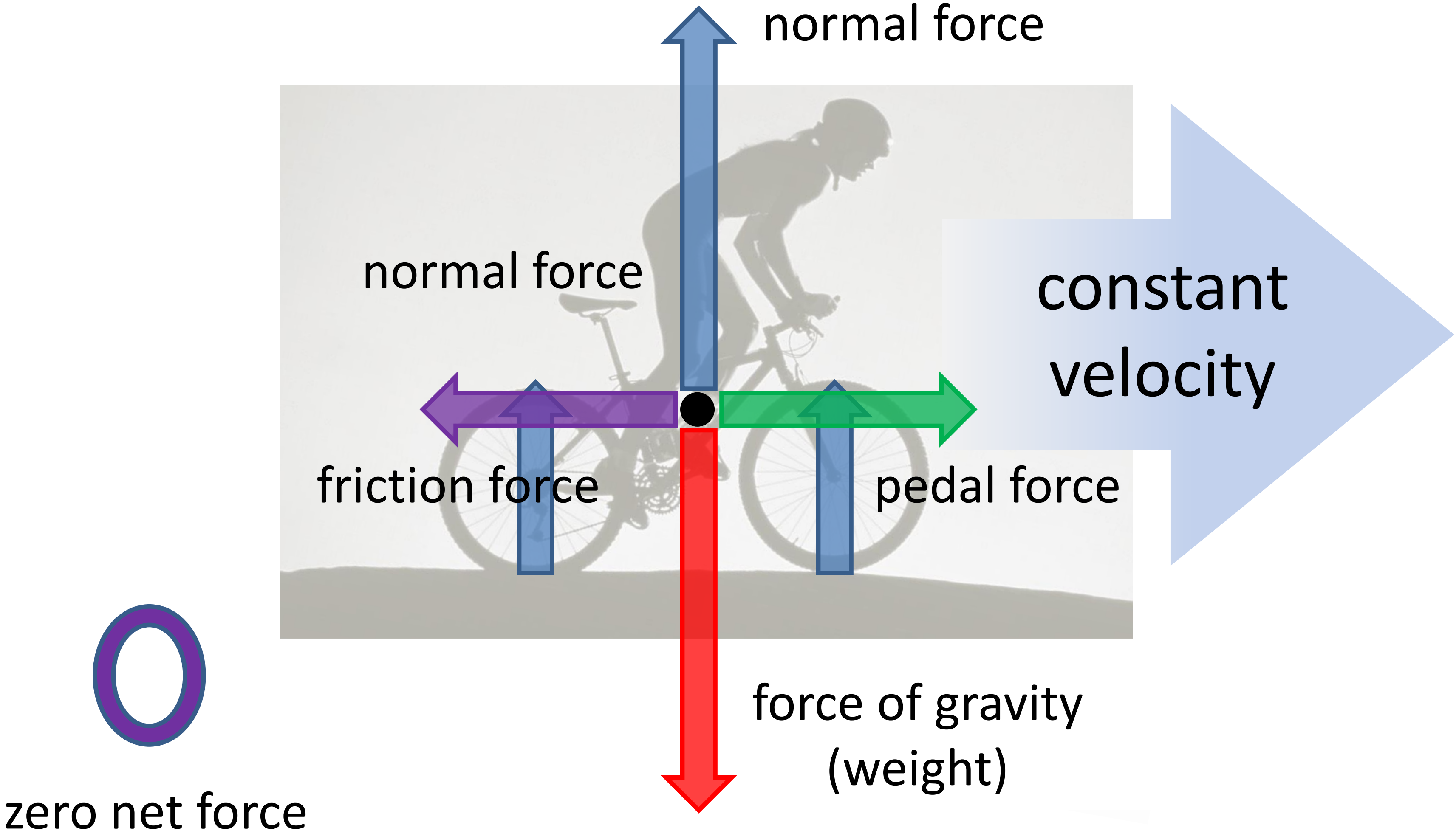
YES!

Is the net force zero???

A bird circling at a constant 20 km/h at a constant height of 15 m above an open field…

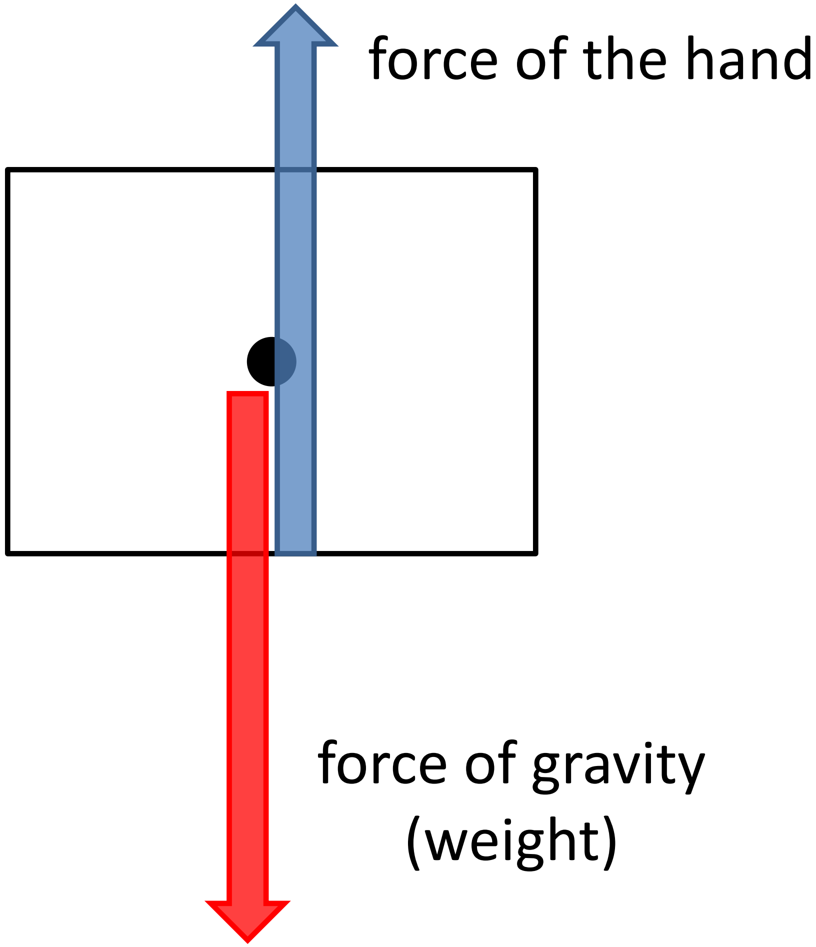
NO

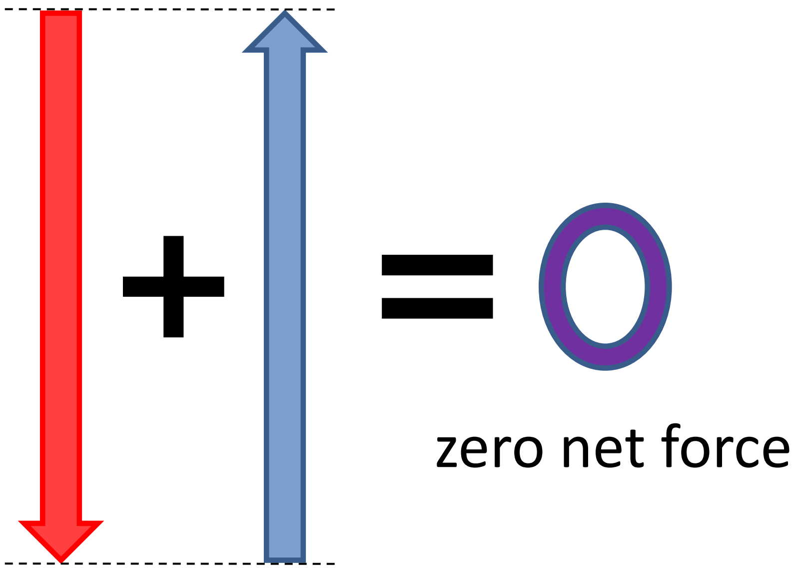
Newton's First Law



Newton's First Law

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

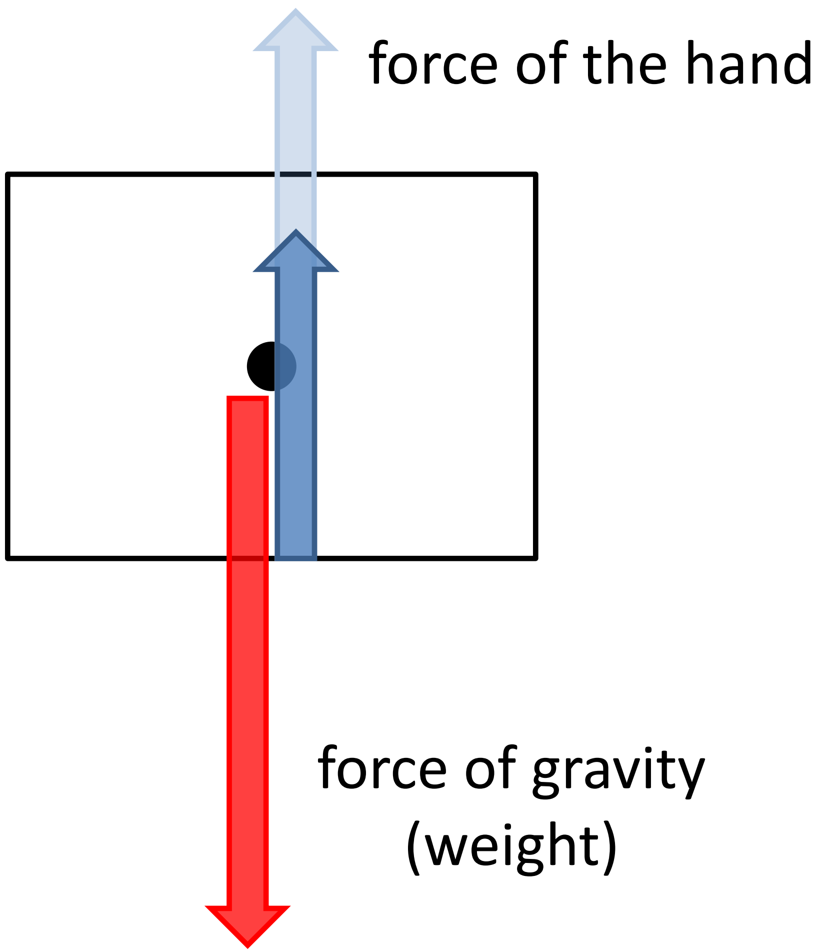


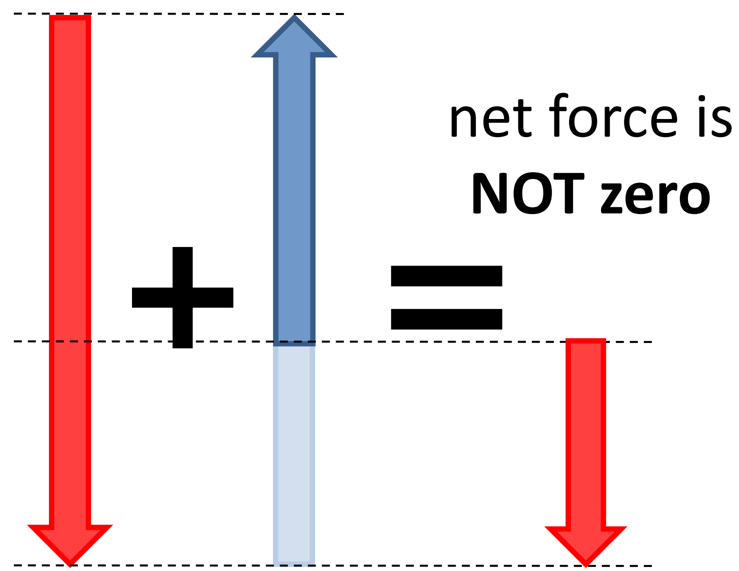


Object at rest!

Newton's ~~First~~ Law

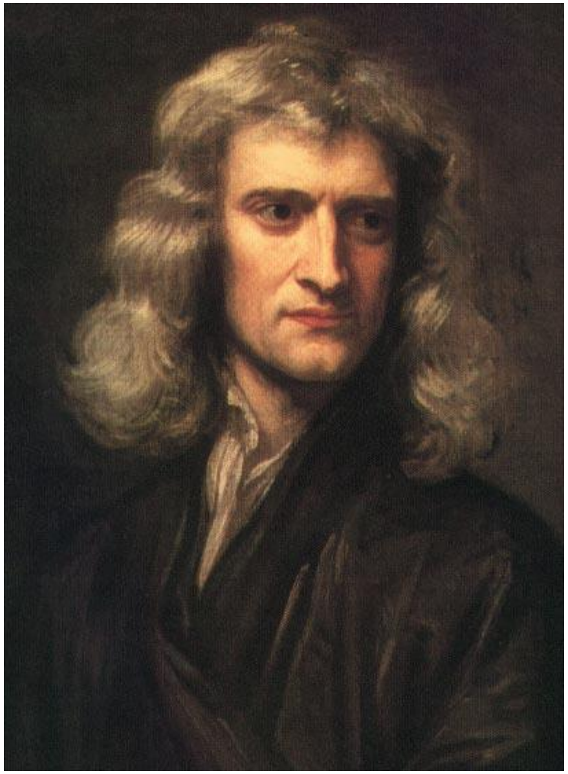
$$\sum \vec{F} \neq 0$$



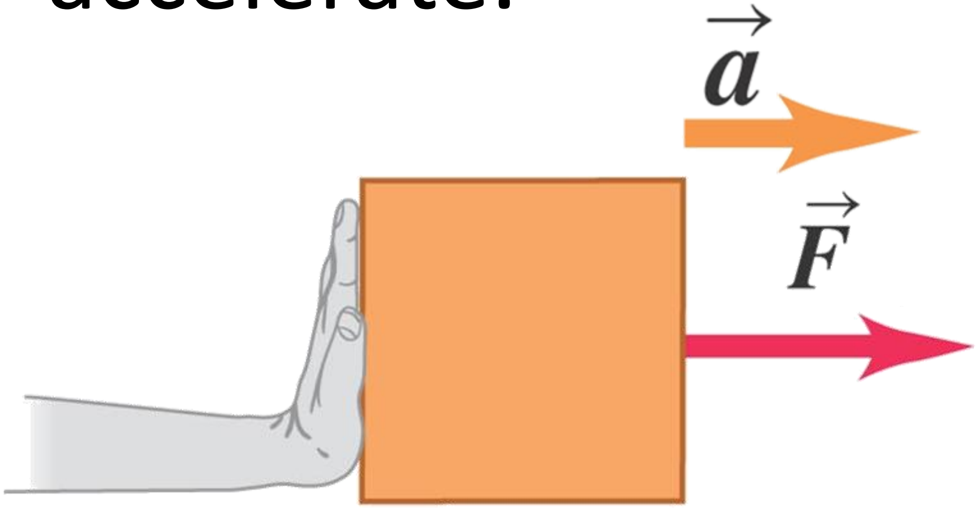


Object
accelerates!

Newton's Second Law

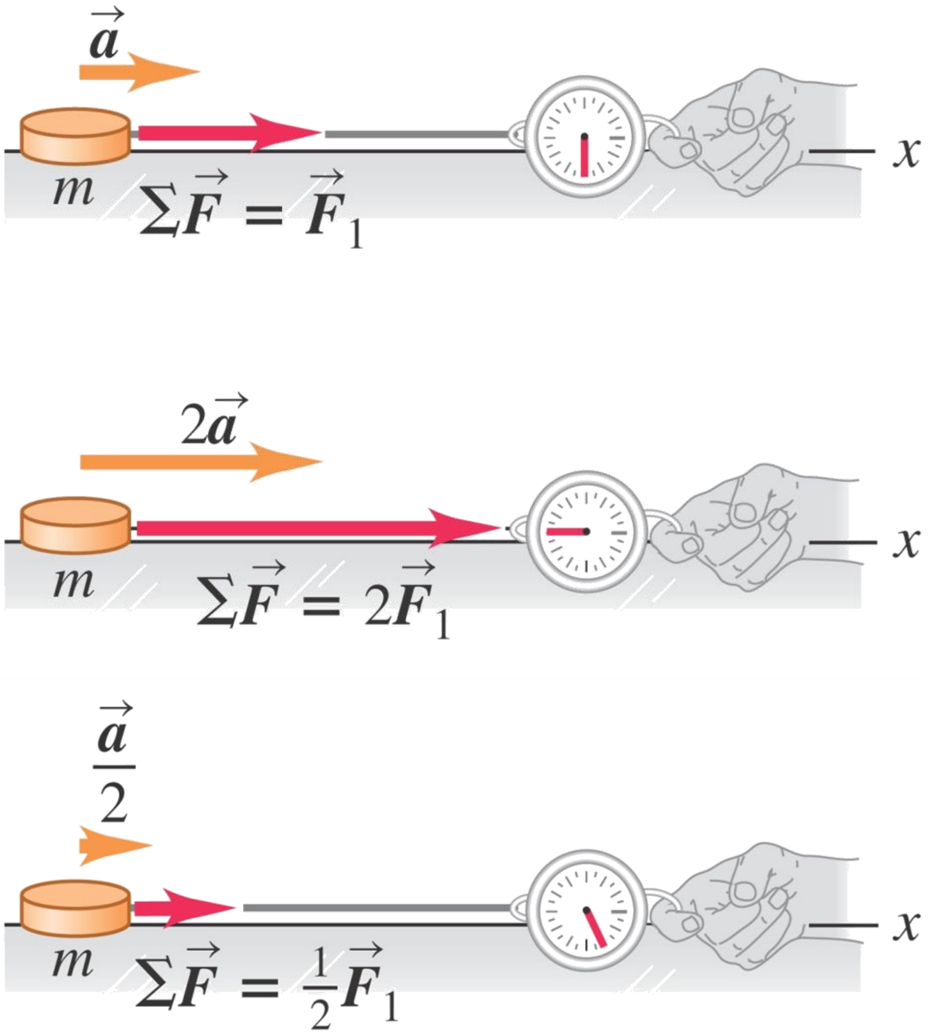


An external net force causes an object to accelerate.

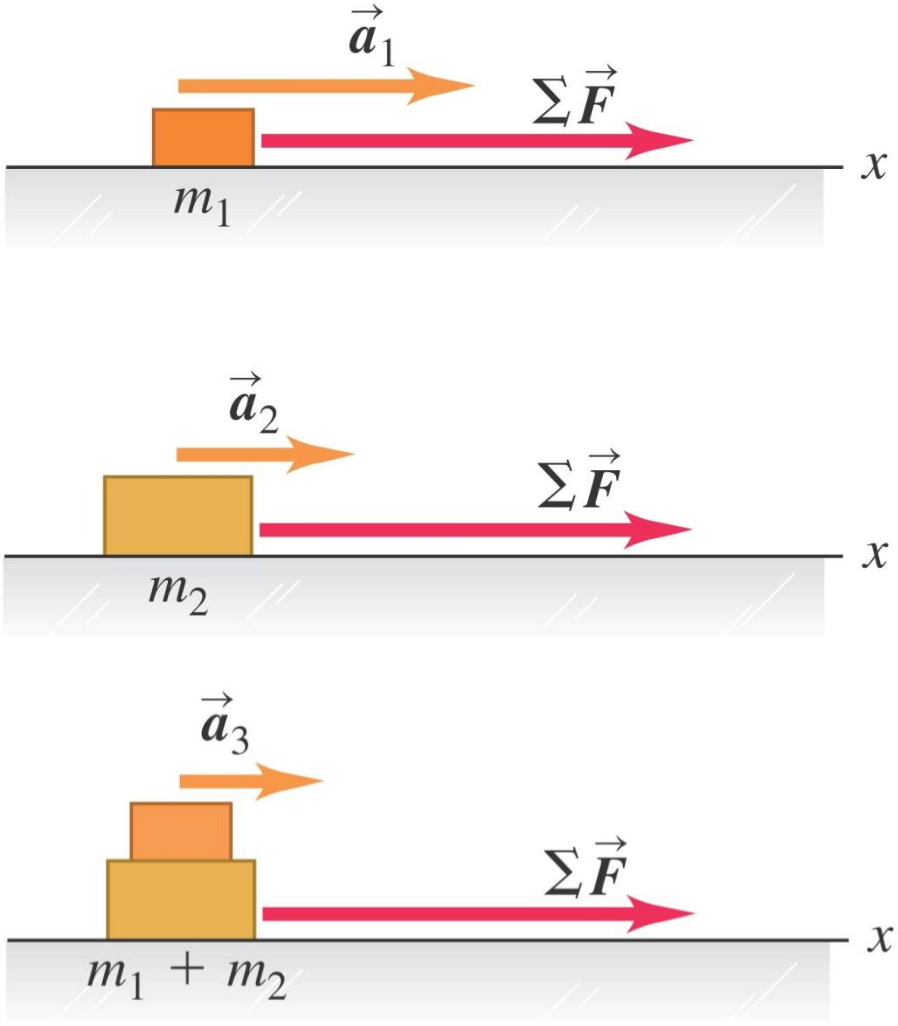


Law of **Acceleration**

Acceleration is proportional to the net force…



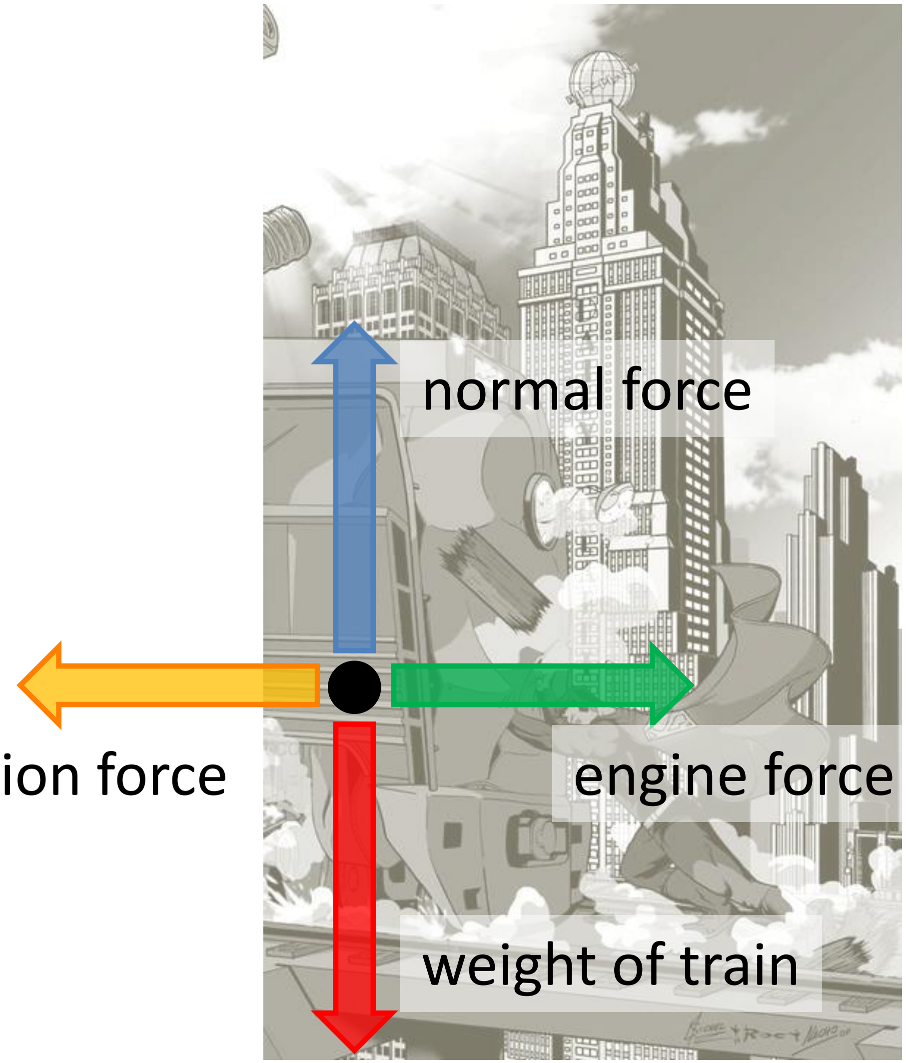
…and inversely proportional to mass



Acceleration and net force have the same direction

$\vec{v}_{\text{train}}$

Acceleration and net force have the same direction



$\vec{v}_{\text{train}}$

Acceleration and net force have the same direction

$\vec{a}$

$\vec{F}_{\text{Superman}}$

applied force

NET FORCE

$\vec{v}_{\text{train}}$

magnitude of velocity decreases!

Newton's Second Law

$$\vec{a} \propto \vec{F}_{\text{net}}$$

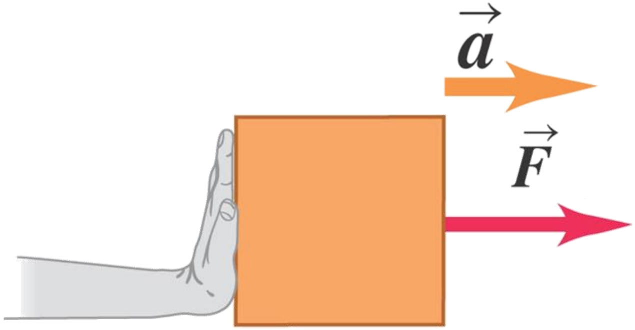
$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m}$$

$$\vec{a} \propto \frac{1}{m}$$

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

Newton's Second Law

The direction of acceleration is the same direction as the direction of the net force.



The mass of the body times the acceleration of the body equals the net force vector.

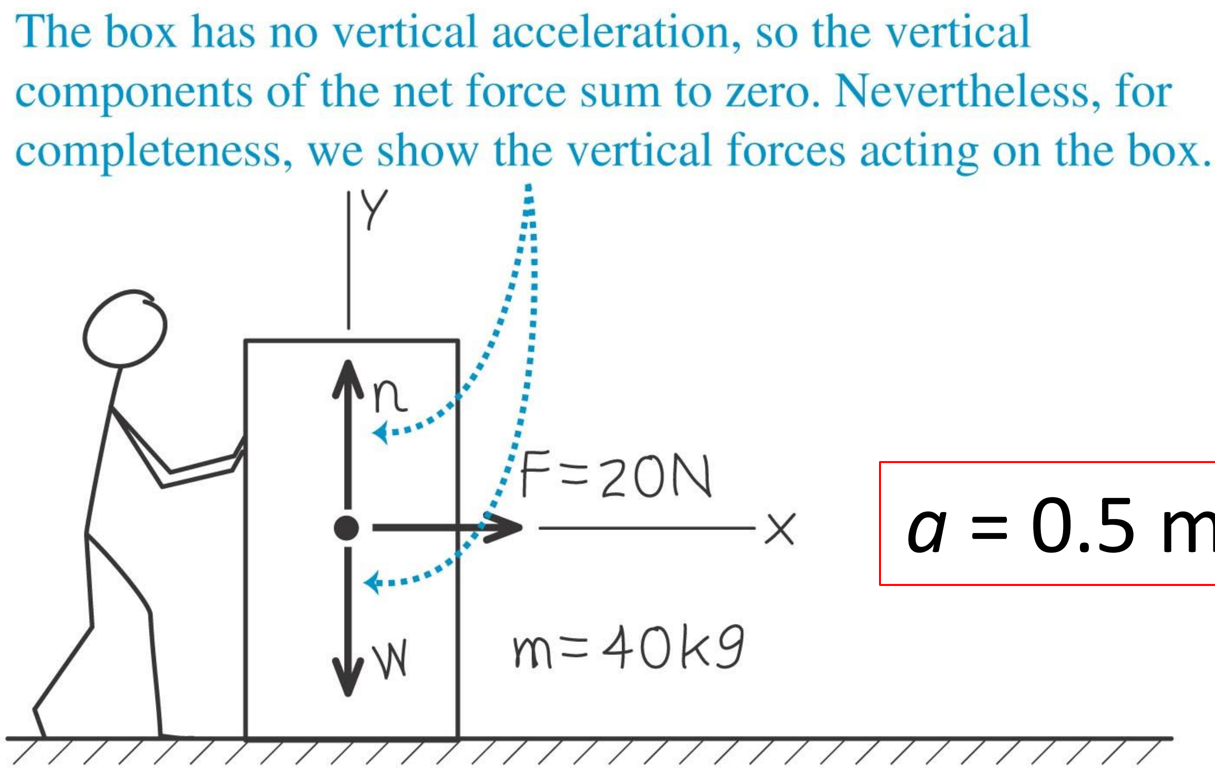
$$\vec{F}_{\text{net}} = m\vec{a}$$

Units of force, mass, and acceleration

System of Units	Force	Mass	Acceleration
SI	newton (N)	kilogram (kg)	m/s^2
cgs	dyne (dyn)	gram (g)	cm/s^2
British	pound (lb)	slug	ft/s^2

Newton's Second Law: Determining acceleration from force

A worker applies a constant horizontal force with magnitude 20 N to a box with mass 40 kg resting on a level floor with negligible friction. What is the acceleration of the box?

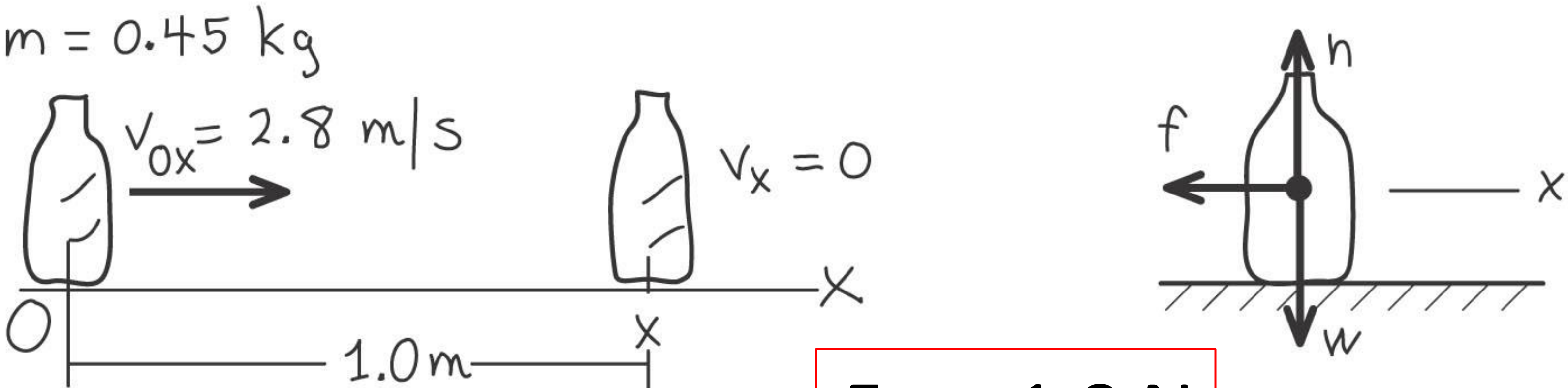


$$\boxed{a = 0.5\ \mathrm{m/s^2}}$$

Newton's Second Law: Determining force from acceleration

A waitress shoves a ketchup bottle with mass 0.45 kg to the right along a smooth, level lunch counter. The bottle leaves her hand moving at 2.8 m/s, then slows down as it slides because of the constant horizontal friction force exerted on it by the counter top. It slides a distance of 1.0 m before coming to rest. What are the magnitude and direction of the friction force acting on the bottle?

We draw one diagram for the bottle's motion and one showing the forces on the bottle.

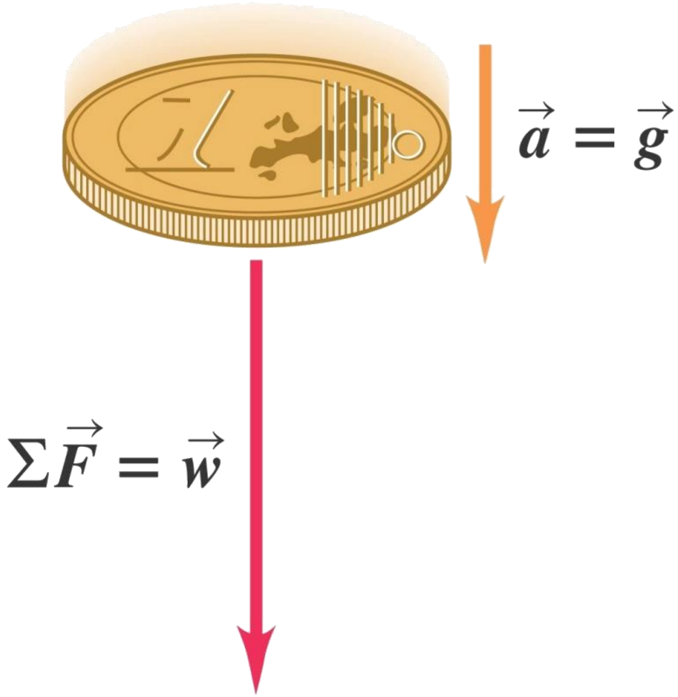


$$\boxed{F_f = -1.8 \text{ N}}$$

Difference between Mass and Weight

Mass → Inertia

Weight → Force of Gravity



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

Newton’s Second Law: Mass and weight

A 2.49×10^4 N Rolls-Royce Phantom traveling in the + x-direction makes a fast stop; the x-component of the net force acting on it is -1.83×10^4 N. What is its acceleration?

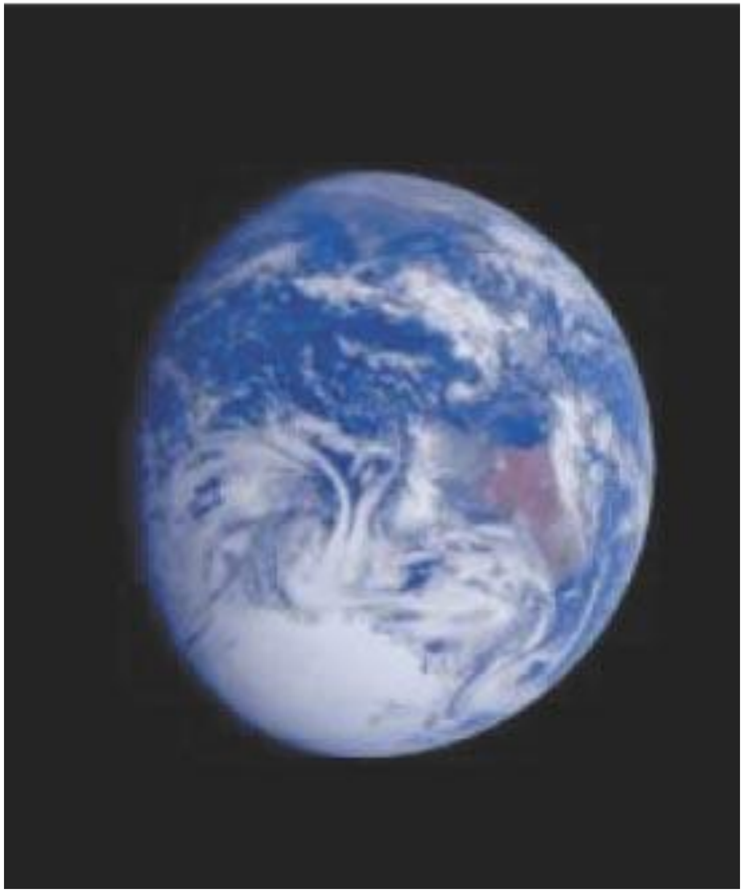
$m = 2540$ kg

$$\boxed{a = -7.20 \text{ m/s}^2}$$

g varies with location

9.78 to 9.82 m/s^2

Slightly larger in the poles!



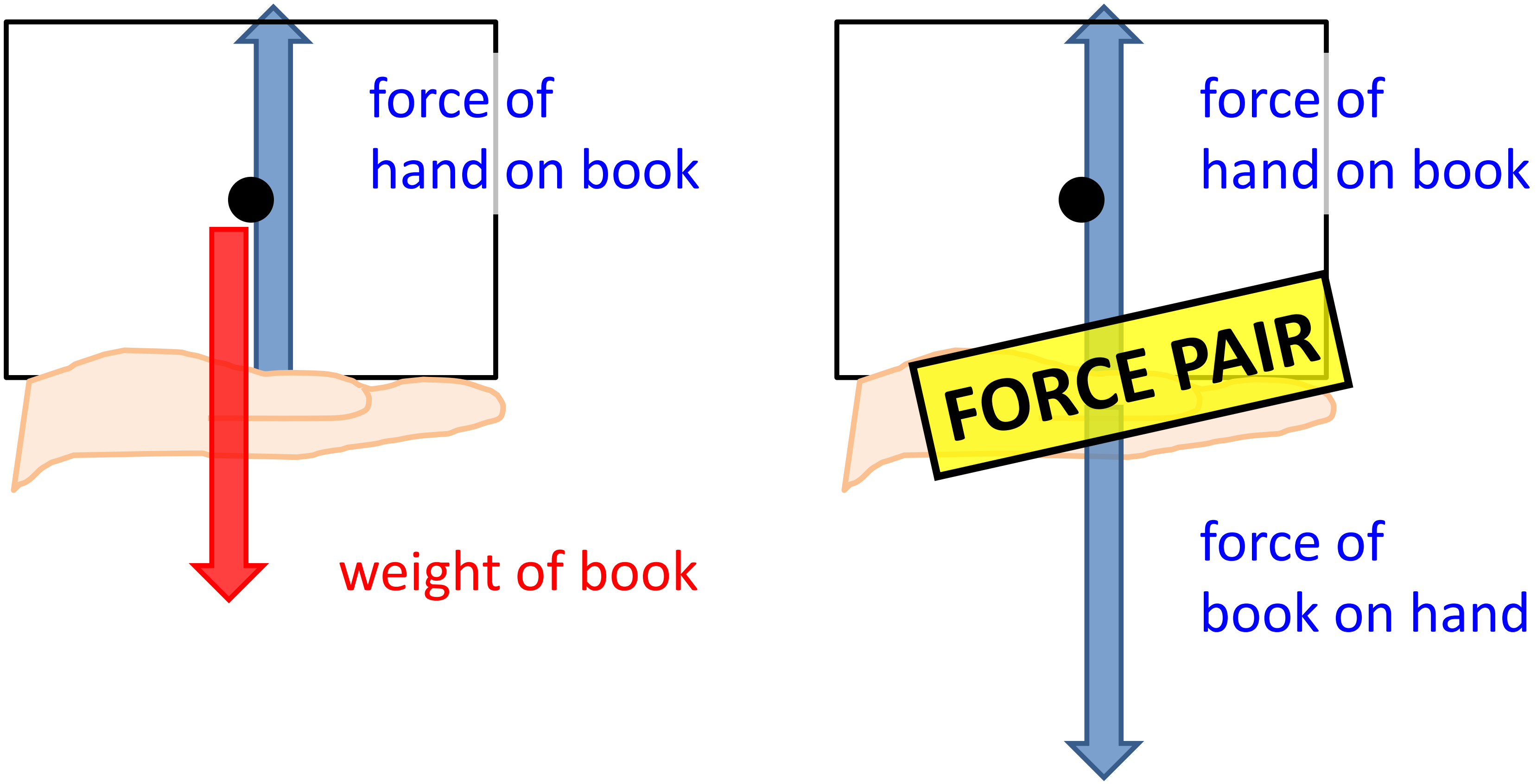
Forces come in pairs!

Force → an interaction between two objects

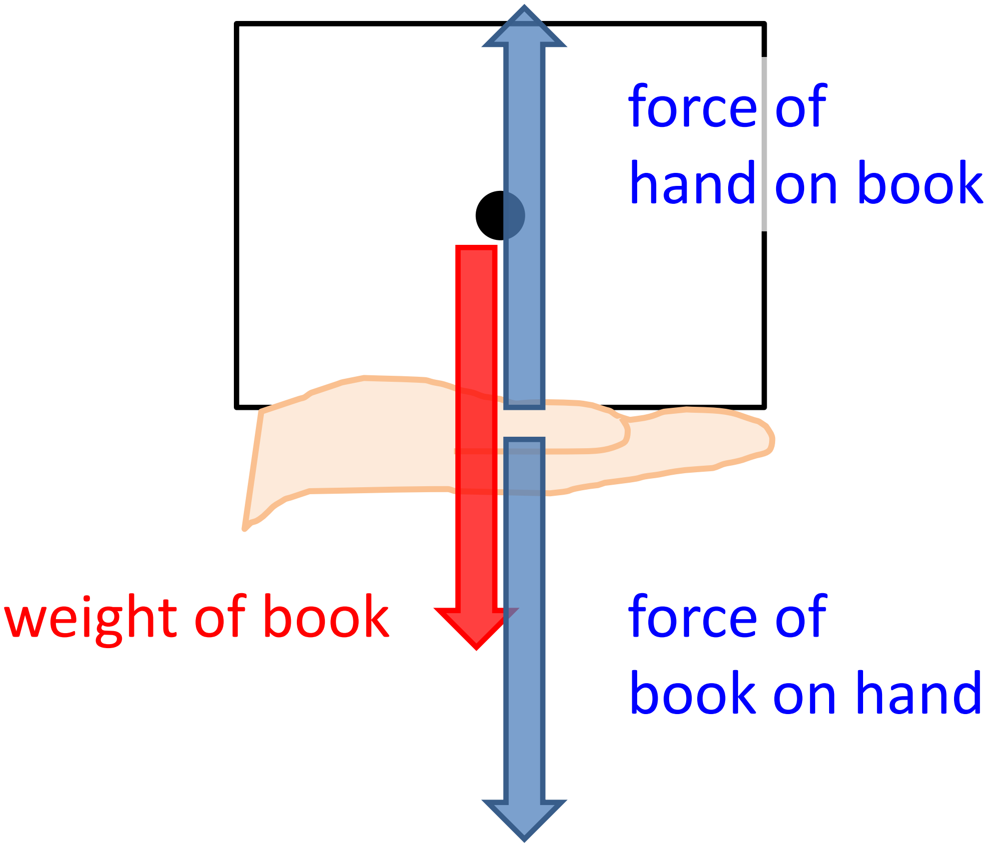
force of **ball** on **foot**

force of **foot** on **ball**

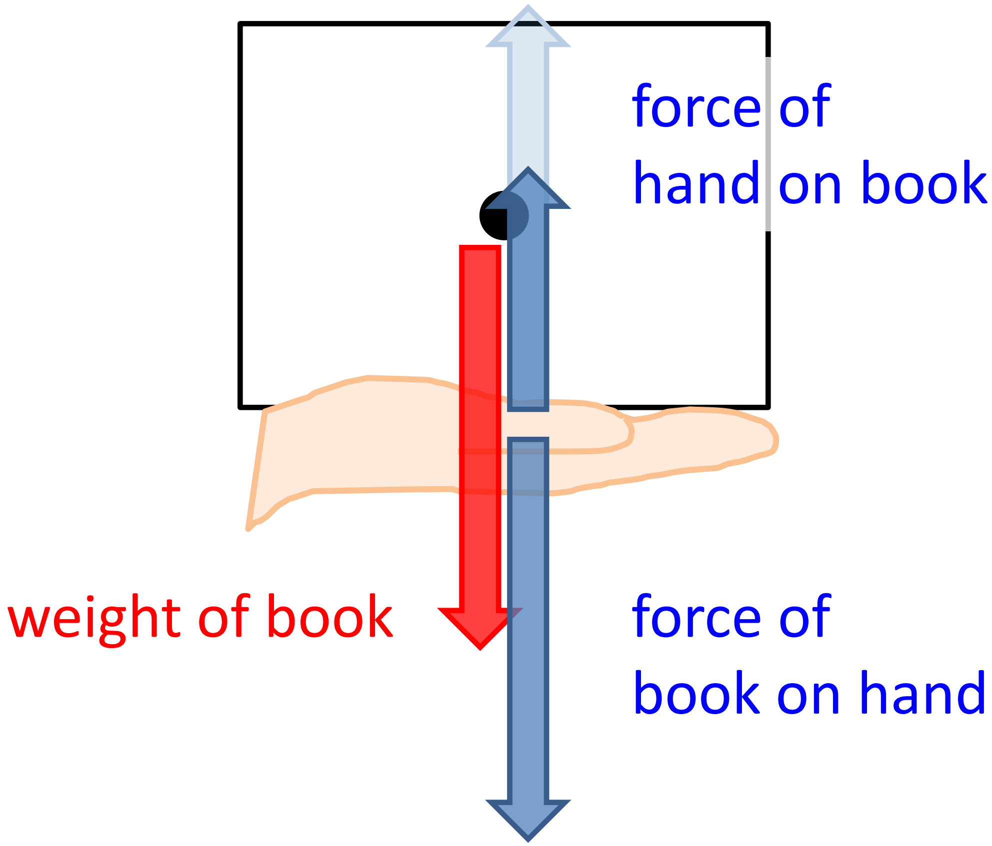
Action and Reaction (Force pairs)



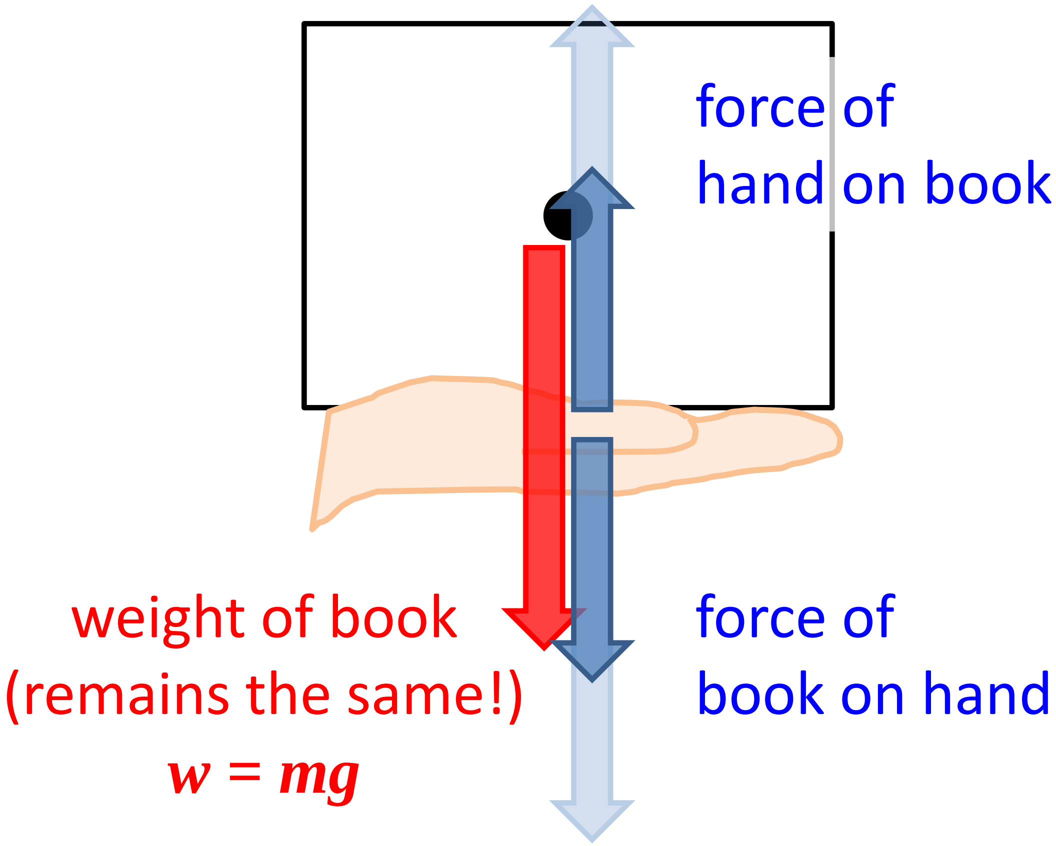
Think of this…



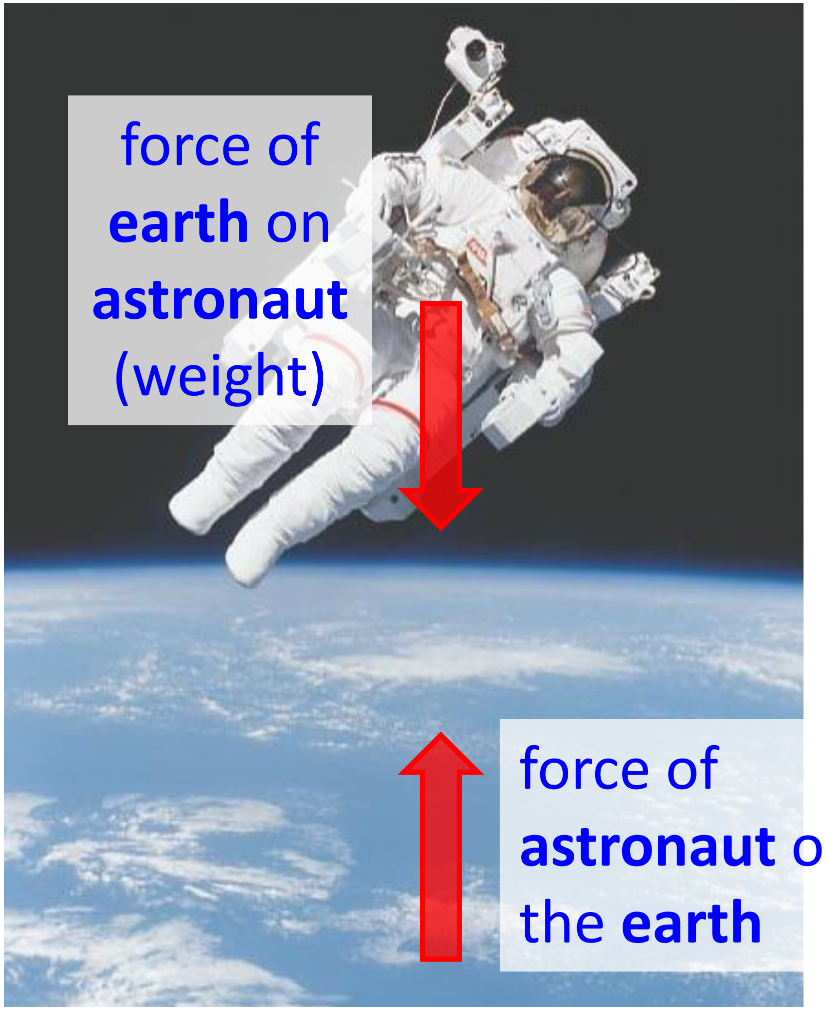
If we lessen the support on the book…



…then we feel that the book is lighter!



Forces ALWAYS come in pairs!

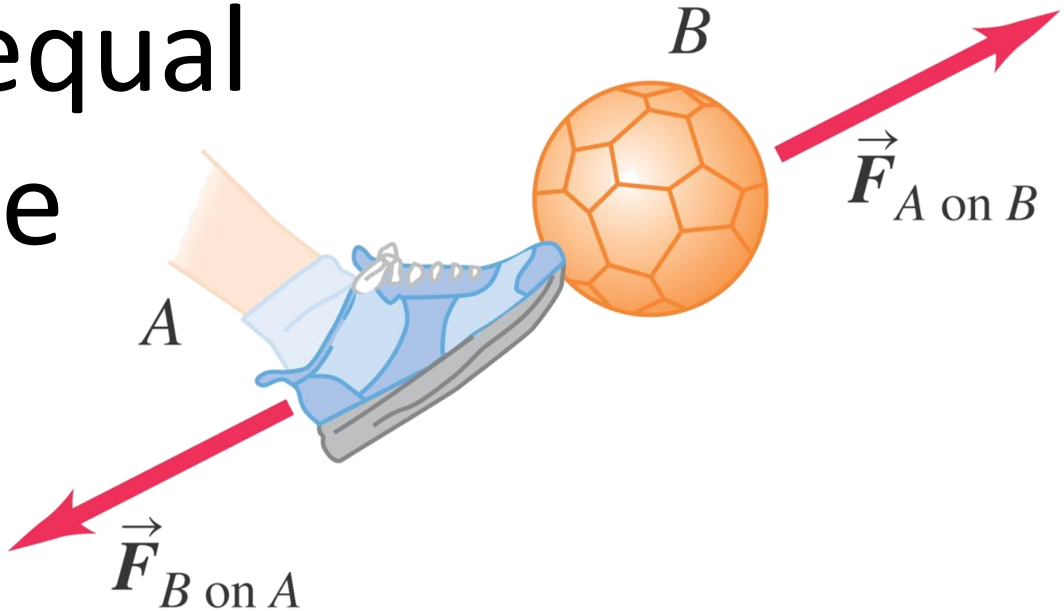


But why can't we see the earth move towards the astronaut?

Newton's Third Law

For every action, there is an equal and opposite reaction.

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



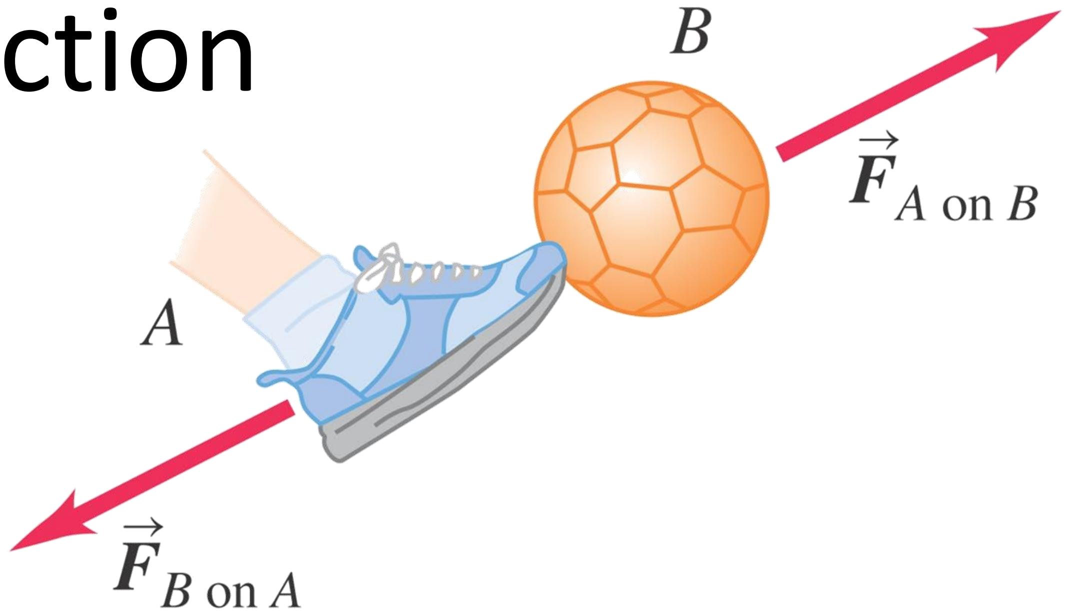
Law of Action and Reaction

Newton’s Third Law

Newton’s Third Law

The forces in an action – reaction pair **act on different bodies**!

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



Law of **Action and Reaction**

Remember: Forces come in pairs!

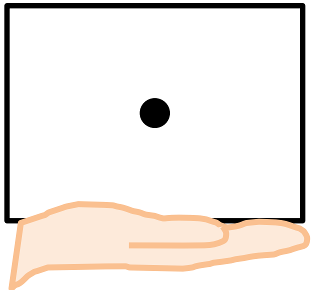
Newton's Third Law

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 **the earth**.

b) An upward force of magnitude **4 N** is exerted on **the book** by your hand.

c) Is the upward force in part (b) the reaction to the downward force in part (a)? **NO**



Newton's Third Law

d) The reaction to the force in part (a) is a force of magnitude **4 N**, exerted on **the earth** by **the book**. Its direction is **upward**.

e) The reaction to the force in part (b) is a force of magnitude **4 N** exerted on **your hand** by **the book**. Its direction is **downward**.

f) The forces in parts (a) and (b) are equal and opposite because of Newton's **first** law.

g) The forces in parts (b) and (e) are equal and opposite because of Newton's **third** law.

Newton’s Third Law

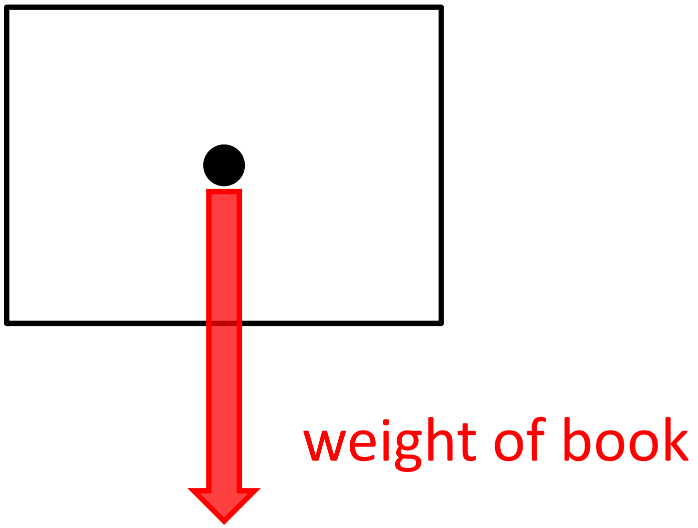
Now suppose that you exert an upward force of magnitude 5 N on the book.

h) Does the book remain in equilibrium? **NO**
i) Is the force exerted on the book by your hand equal and opposite to the force exerted on the book by the earth? **NO**
j) Is the force exerted on the book by the earth equal and opposite to the force exerted on the earth by the book? **YES**
k) Is the force exerted on the book by your hand equal and opposite to the force exerted on your hand by the book? **YES**

Newton's Third Law

Finally, suppose you snatch your hand away while the book is moving upward.

l) How many forces then act on the book? **ONE**



m) Is the book in equilibrium?

NO

Review

A 12.0-kg object undergoes an acceleration of 3.0 m/s^2. What is the magnitude of the resultant force acting on it? If this same force is applied to a 9.0-kg object, what acceleration is produced?

a) 36 N; 4.0 m/s^2
b) 4.0 N; 36 m/s^2
c) 4.0 N; 4.0 m/s^2
d) 36 N; 36 m/s^2

Review

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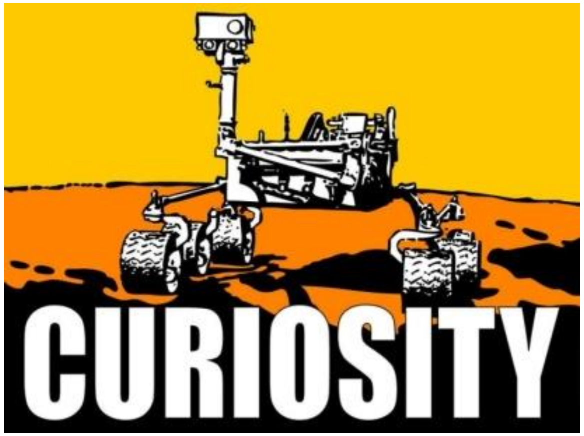
Review

Last August 6, 2012, NASA has successfully landed the rover Curiosity on Martian soil. Curiosity weighs about 8820 N here on Earth. What should it weigh on Mars, where the free-fall acceleration is 3.75 m/s^2?

a) 3375 N
b) 33075 N
c) 900 N
d) The weight would be the same.



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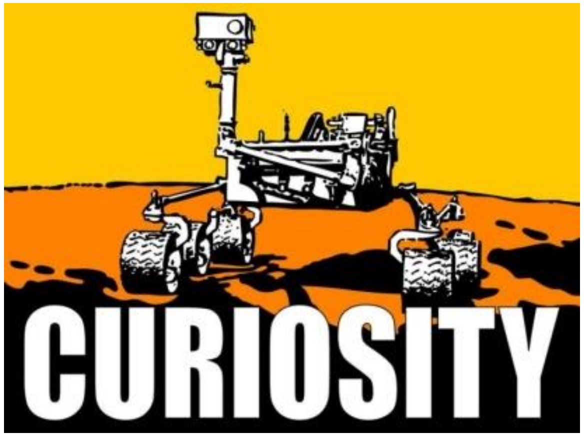

Review

A man is dragging a trunk up the loading ramp of a mover's truck. The ramp has a slope angle of 20.0°, and the man pulls upward with a force F whose direction makes an angle of 30.0° with the ramp. (a) How large a force F is necessary for the component F_x parallel to the ramp to be 60.0 N? (b) How large will the component F_y perpendicular to the ramp then be?

answer:

F = 69.3 N

F_y = 34.6 N