Foundation course - PHYSICS

Lecture 5-2: Force and motion

Dynamics of solid bodies

- Acceleration and force
- Newton's laws of motion
- Some particular forces (normal, weight, tension, friction)

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Dynamics

Essential questions:

- Why objects move
- What can cause an object to accelerate
- What acts on an object and changes its velocity

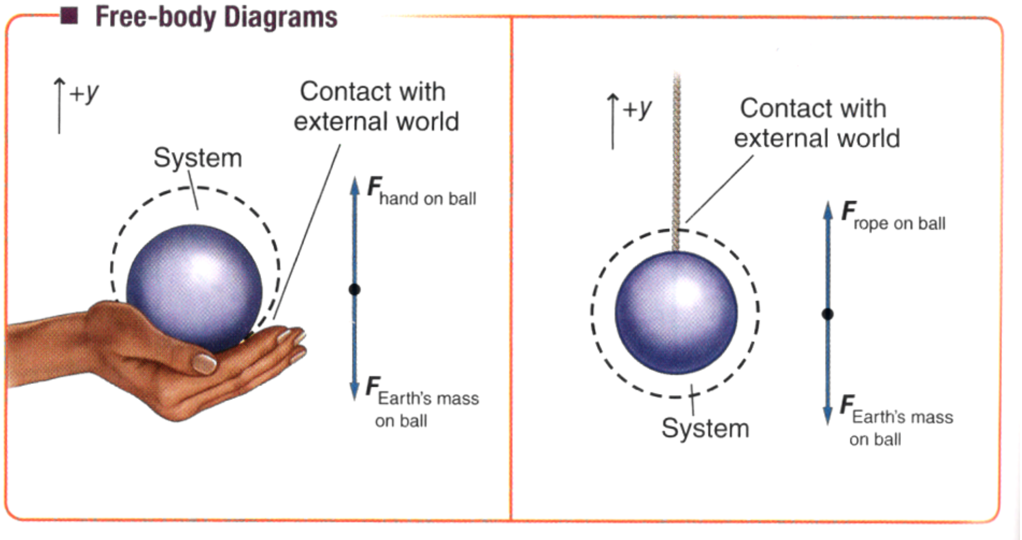
It is a FORCE

Force

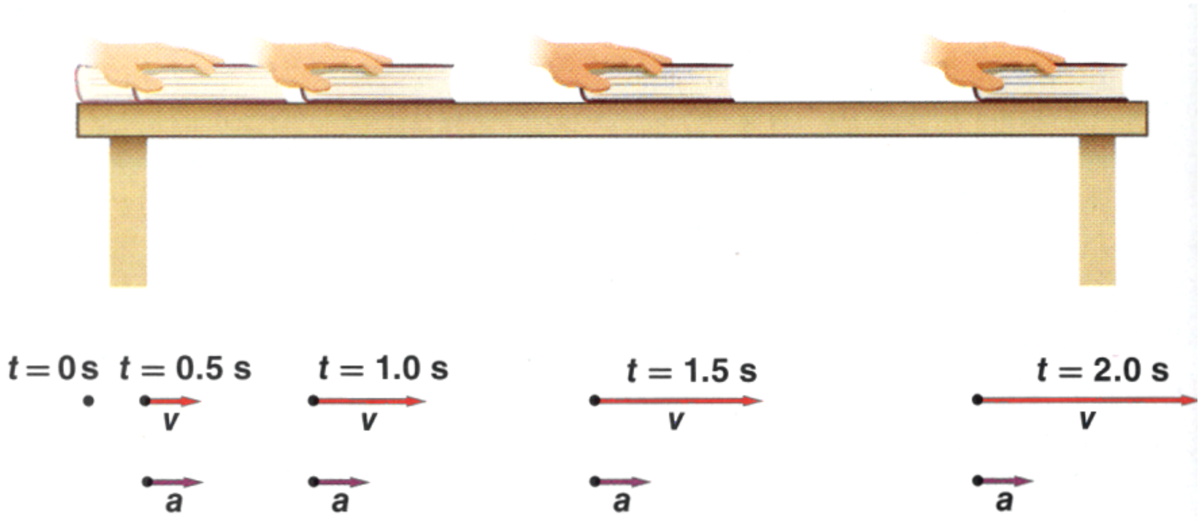
- is an interaction between objects
- is a vector (determined by its magnitude and its direction)
- magnitude is measured in units called newtons (N): 1 N = kg.m.s^{-2}

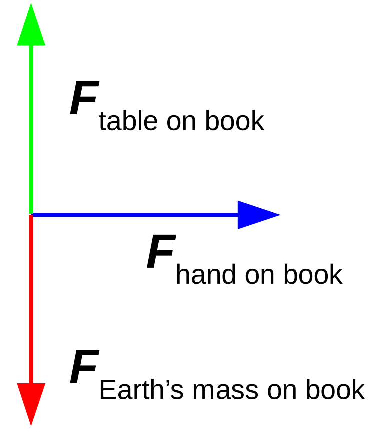
Free-body diagrams:

- a physical representation of forces acting on the system



Dynamics of solid bodies





Acceleration is the result of an unbalanced force acting on an object.

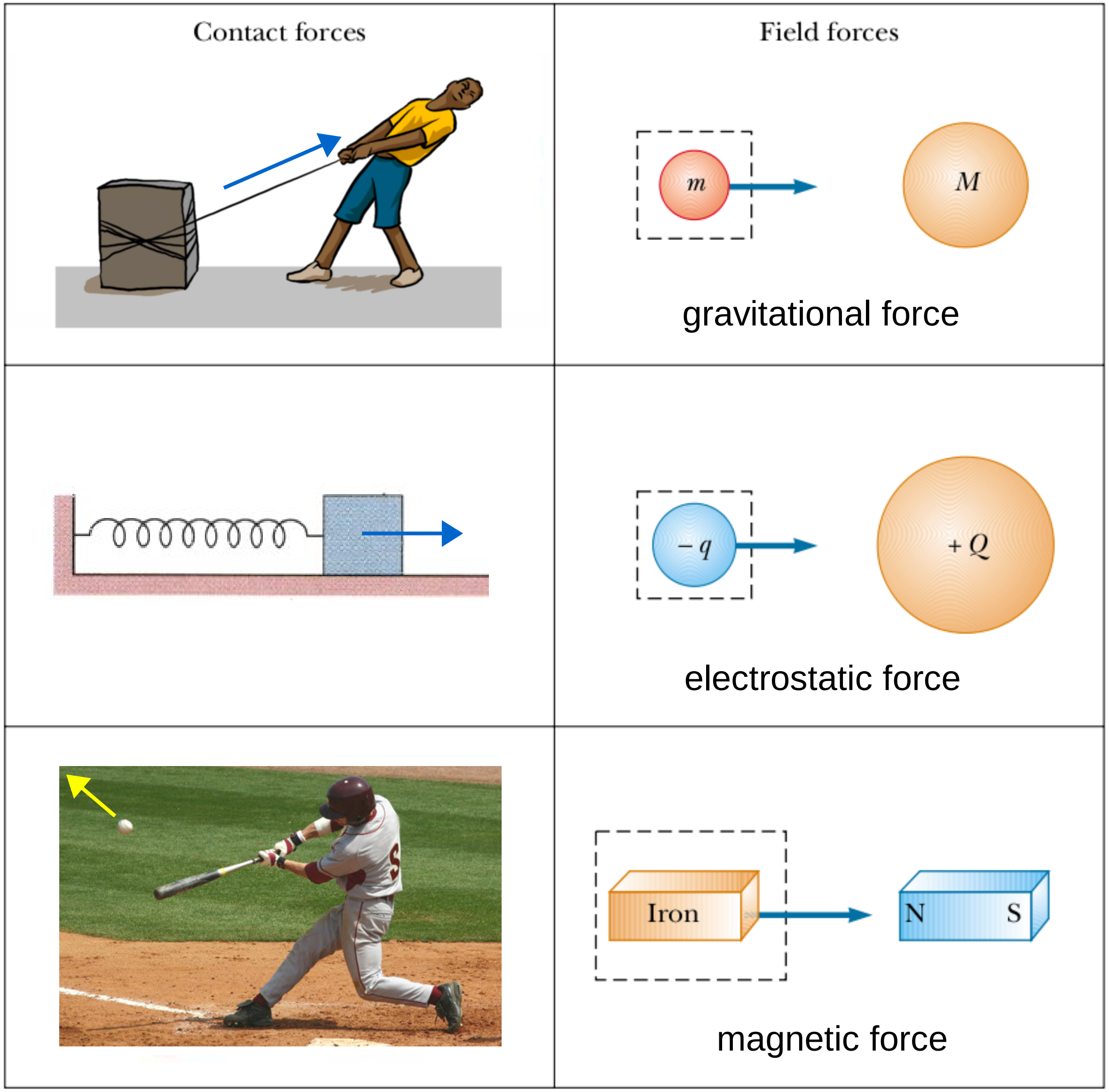
Contact and field forces

Contact force:

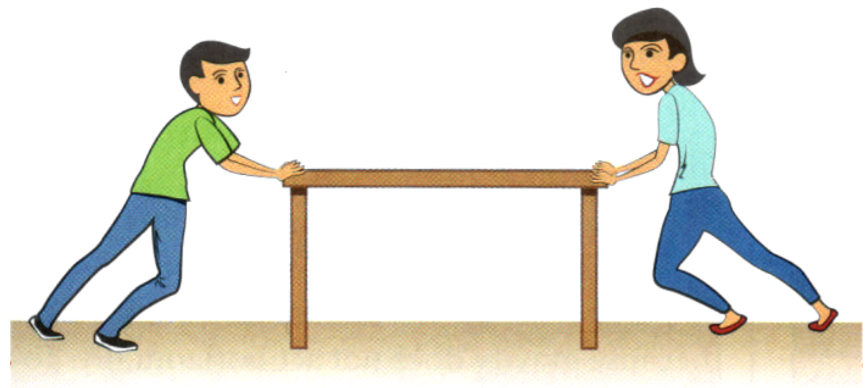
- an object from the external world touches the system and exerts a force on it

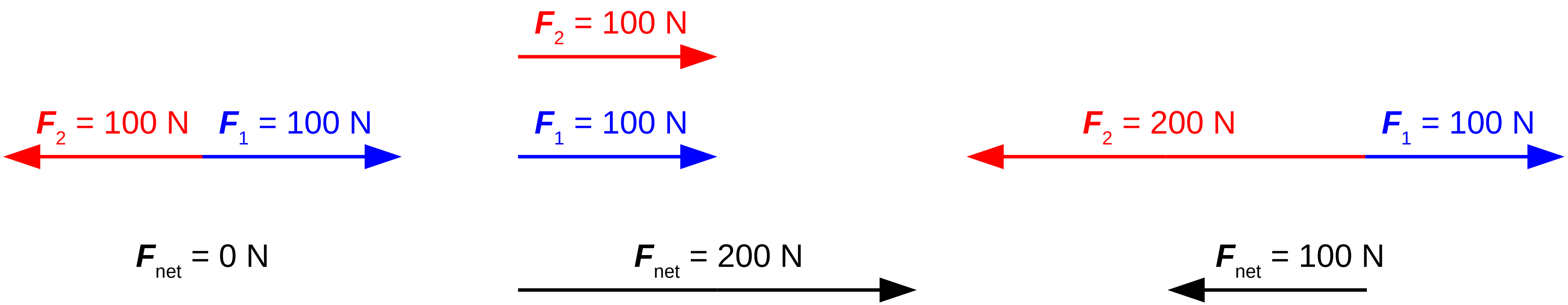
Field force:

- the force affects the system without touching
- examples: gravitational force, electromagnetic force



Combining forces





Equal forces
Opposite directions

Equal forces
Same direction

Unequal forces
Opposite directions

Net force: the vector sum of all forces acting on the object

Newton's first law

If the net **force** is **zero**, then **acceleration** equals **zero**.

If **acceleration** is **zero**, then **velocity** does not change – it means, the object is at **rest** or is moving with a **constant** velocity.

$$F_{net}=0 \Rightarrow a=0 \quad a=0 \Rightarrow v=constant$$

Newton's first law:

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

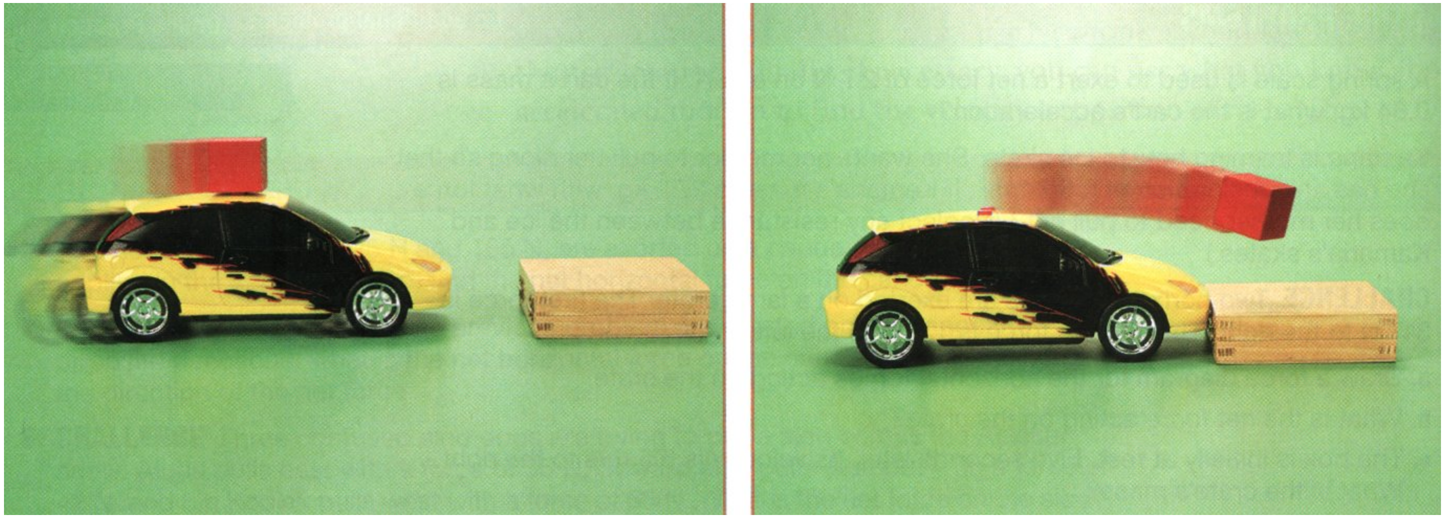
Newton's first law

Law of inertia

Inertia = the tendency of an object to resist changes in velocity

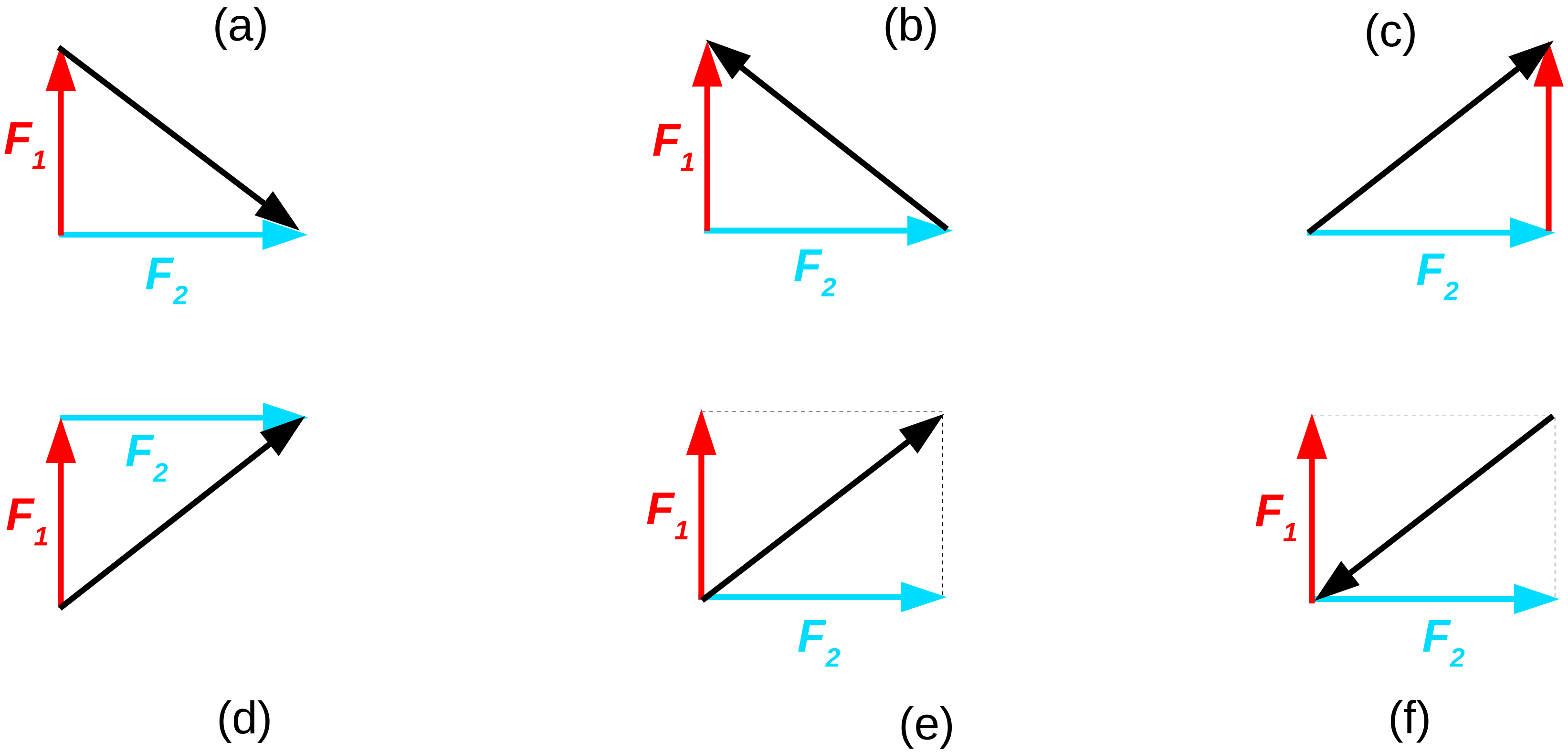
If the net force is zero, then an object is in **equilibrium**.

An object is in equilibrium if it is moving at a **constant velocity** ($\boldsymbol{v} = 0$ is a special case of the constant velocity).



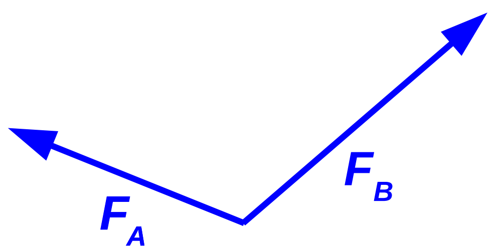
Checkpoint question:

Which of the six arrangements correctly show the vector addition of forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ to yield the third vector, which is meant to represent their net force $\boldsymbol{F_{net}}$?

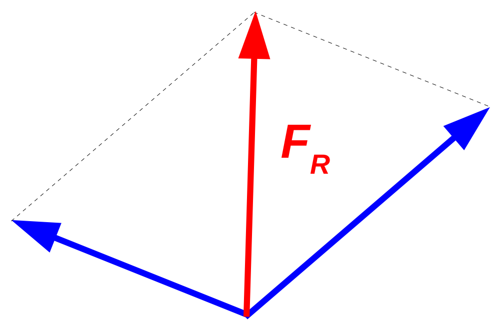


Equilibrium

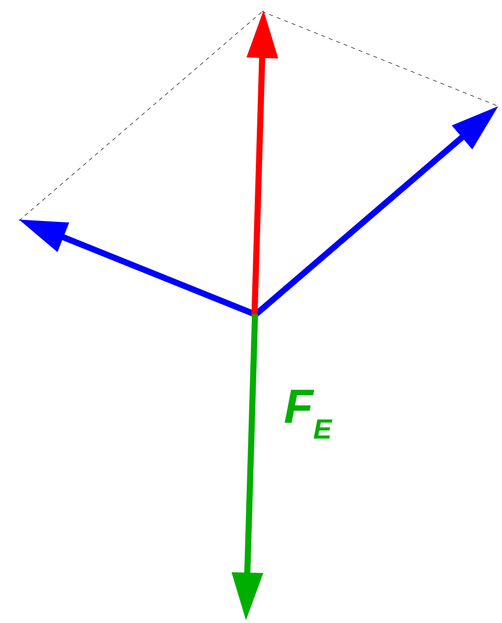
- the object is in **equilibrium**, when the **net force** on an object is **zero**
- the object in equilibrium moves with **constant velocity** (or is staying at rest)



Two forces acting on the object



The **resultant force** is a sum of individual forces



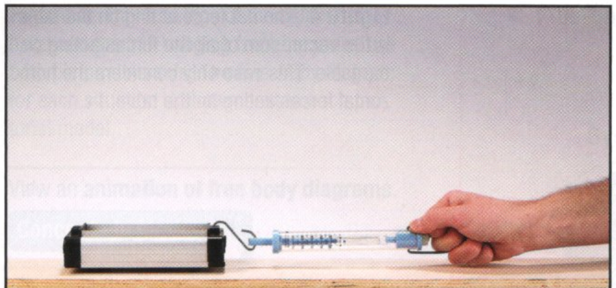
$$F_A + F_B = F_R$$

$$F_E = -F_R$$

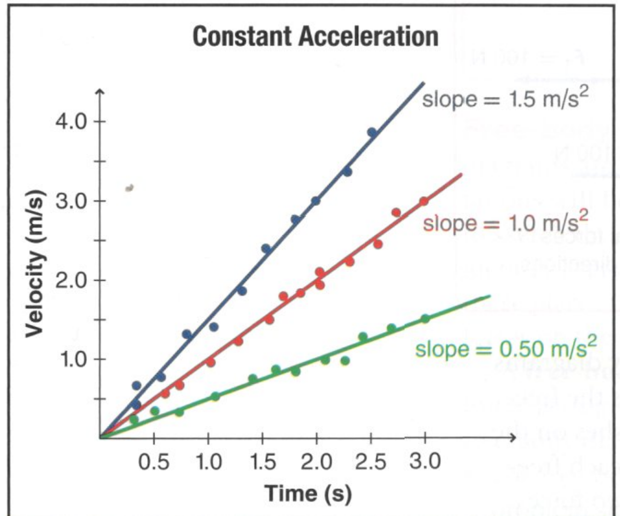
The **equilibrant force** has the same magnitude and opposite direction as the resultant force

To put the object in equilibrium, we must add the equilibrant force.

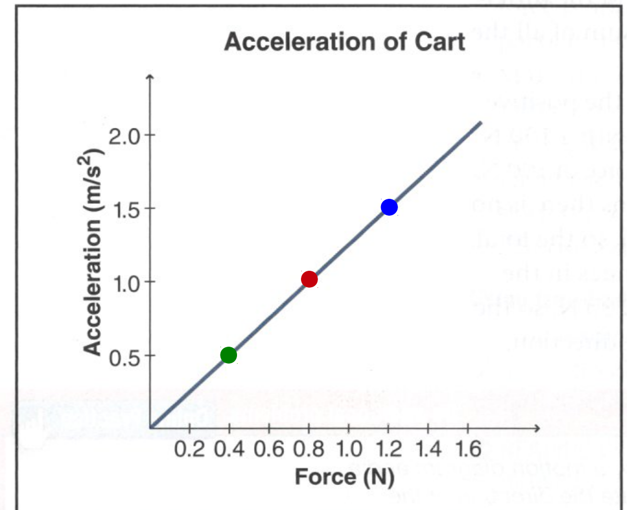
Acceleration and force



Applying a Constant Force



Velocity-Time Graphs for Constant Forces



Various Forces on Same Mass

Velocity increases linearly in time → acceleration is constant

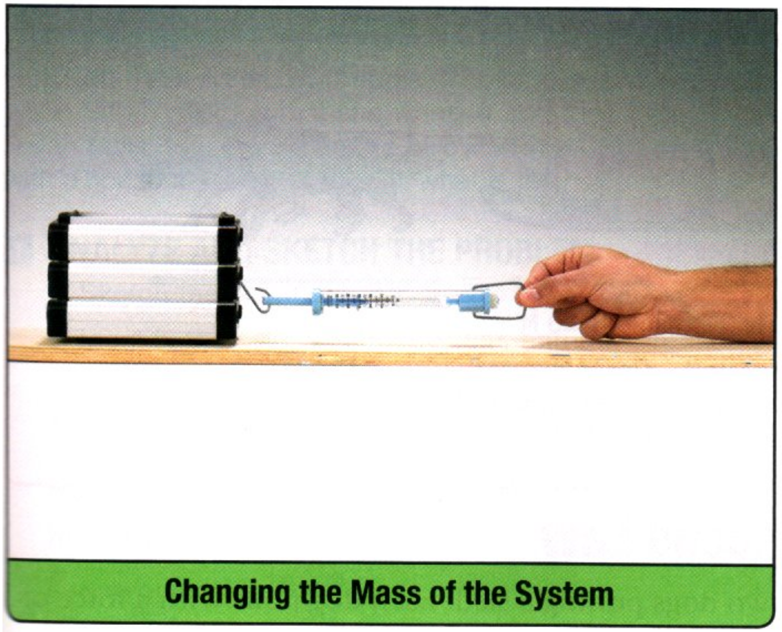
Applied force:

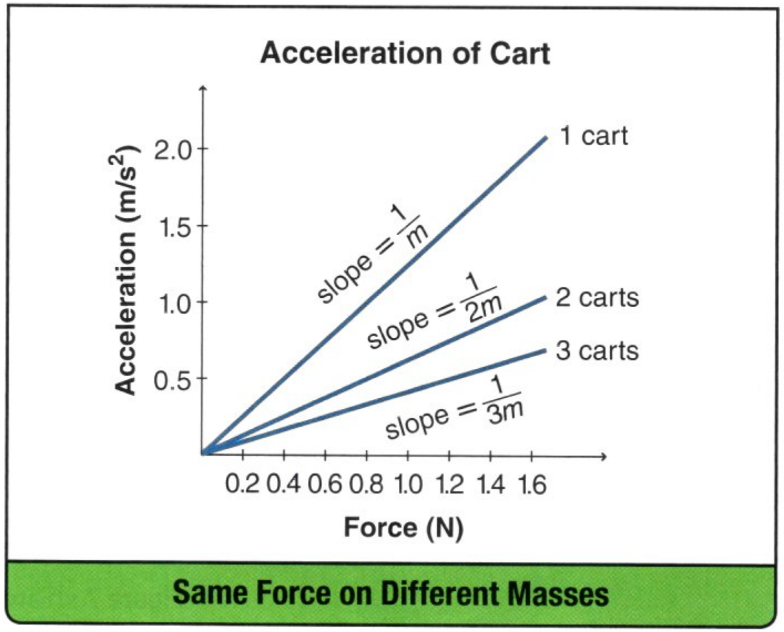
$F_{green} < F_{red} < F_{blue}$

The relationship between force and acceleration is linear → application of equation for a straight line:

$$y = kx + b$$

Acceleration and force


Changing the Mass of the System



Same Force on Different Masses

When the mass increases, a greater force is needed to produce the same acceleration.
The slope is reciprocal of the mass.

Using the equation for a straight line $y = kx$ we obtain $a = \frac{F_{net}}{m}$

Newton's second law

Newton's second law:

the acceleration of an object is proportional to the net force and inversely proportional to the mass of the object being accelerated.

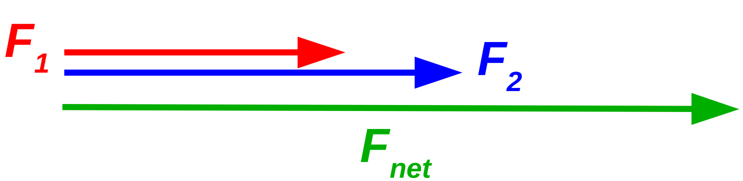
$$a = \frac{F_{net}}{m} \Rightarrow F_{net} = m \cdot a$$

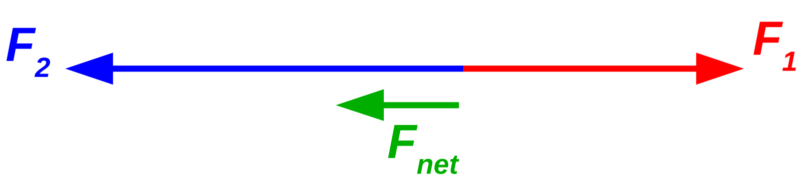
Forces are measured in **newtons** (N):

1 N = 1 kg.m.s^{-2}

Force is a **vector** *(size, direction)*

If more than one force is acting on an object, it is necessary to determine the net force (as a sum of individual forces).



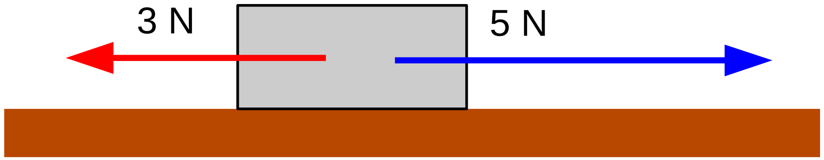


Example: forces

There are two horizontal forces acting on a block on a frictionless floor. If a third horizontal force $\boldsymbol{F_3}$ also acts on the block, what are the magnitude and direction of $\boldsymbol{F_3}$ when the block is

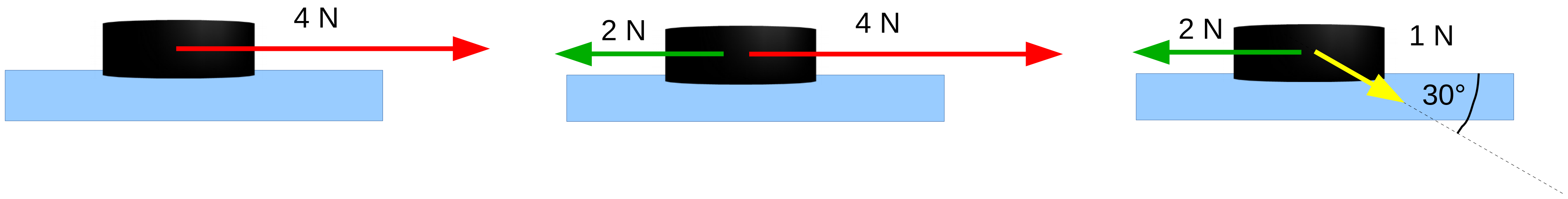
(a) stationary

(b) moving to the left with a constant speed of 5 m/s?



Example: forces and acceleration

Figure show three situations in which one or two forces act on a puck that moves over frictionless ice along an *x* axis, in one-dimensional motion. The puck's mass is m = 0.20 kg. Forces $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are directed along the axis. In each situation, what is the acceleration of the puck?



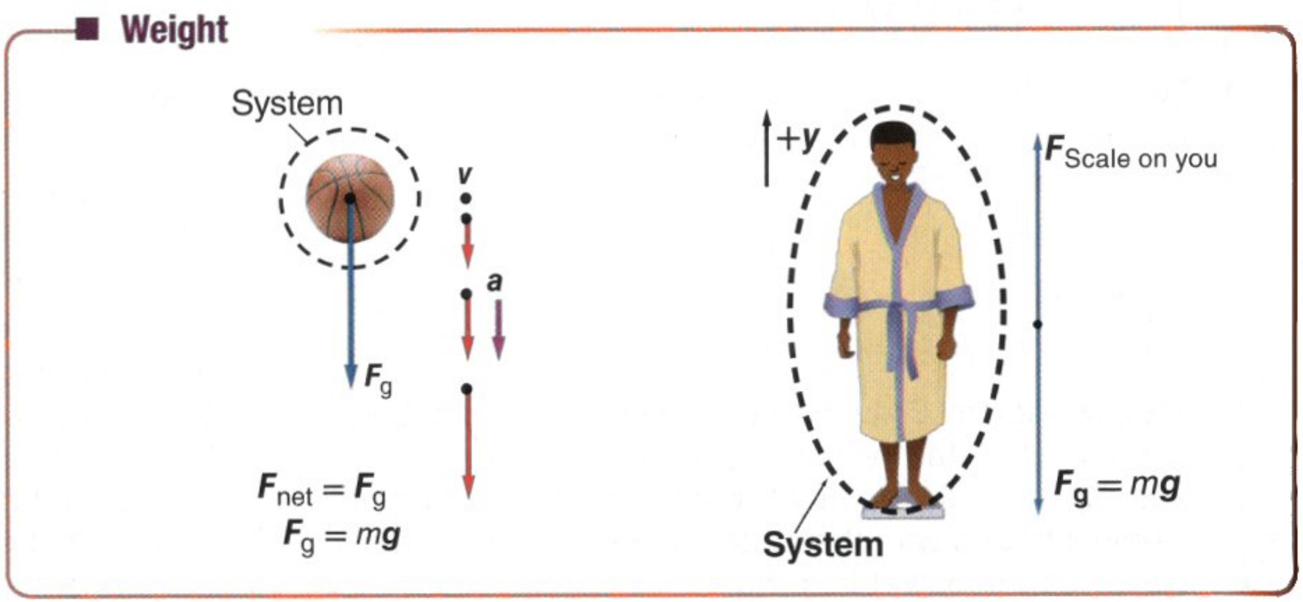
Weight

An object's **weight** is the gravitational force (due to Earth's mass) experienced by that object:

$$\boldsymbol{F}_g = m\,\boldsymbol{g} = \boldsymbol{W}$$

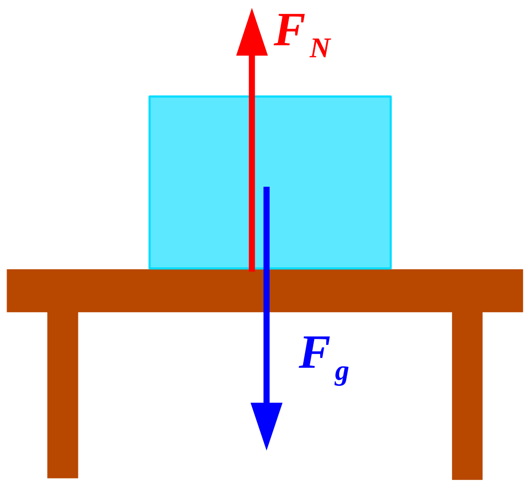
m … mass of the object
g … gravitational acceleration

The gravitational acceleration near Earth's surface is 9.8 $m.s^{-2}$
Weight is a force, the proper units are newtons (N).



The normal force

- term normal means **perpendicular** direction of the force
- when a body presses against a surface, the surface deforms and pushes on the body with as normal force $\boldsymbol{F_N}$ that is perpendicular to the surface



$$F_N - F_g = m a_y$$

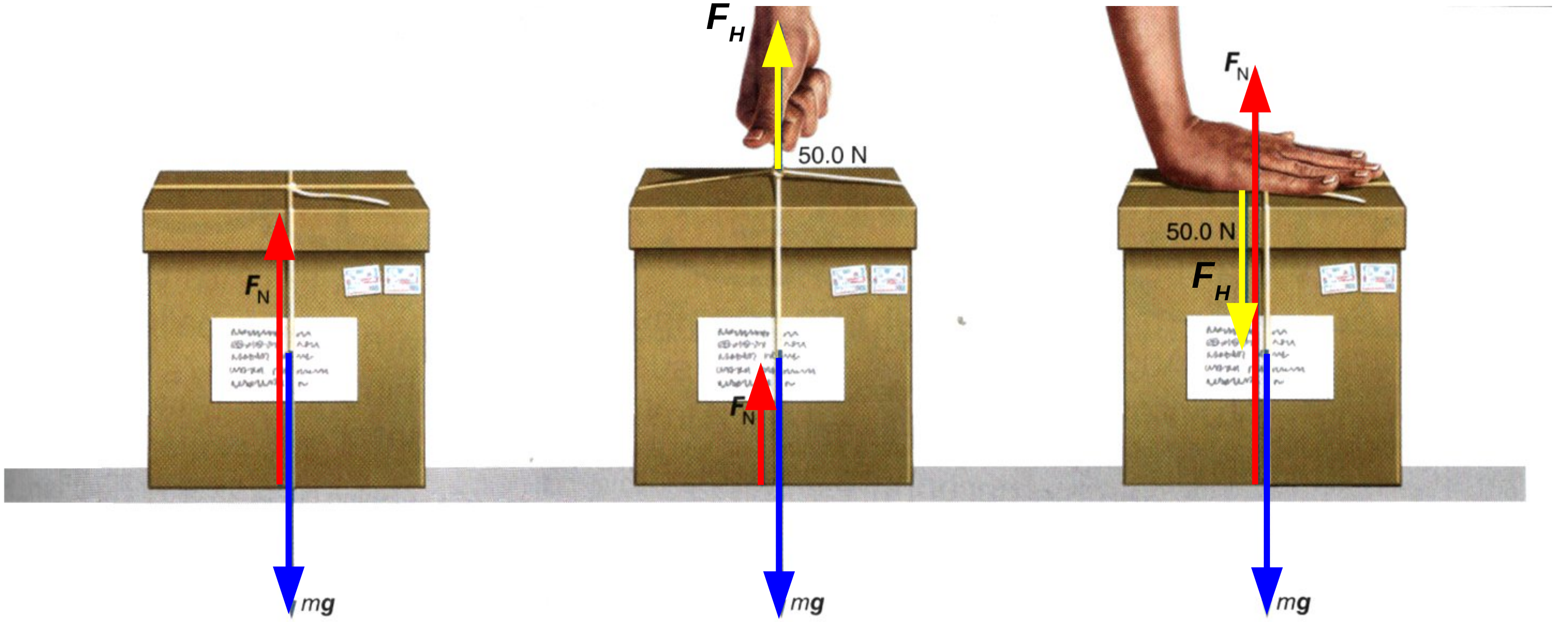
$$F_N = m g + m a_y$$

$$F_N = m(g + a_y)$$

If objects are not accelerating, then $a_y = 0$

$$F_N = m g$$

The normal force



$F_N = m\mathbf{g}$, $\mathbf{F}_{net} = 0$

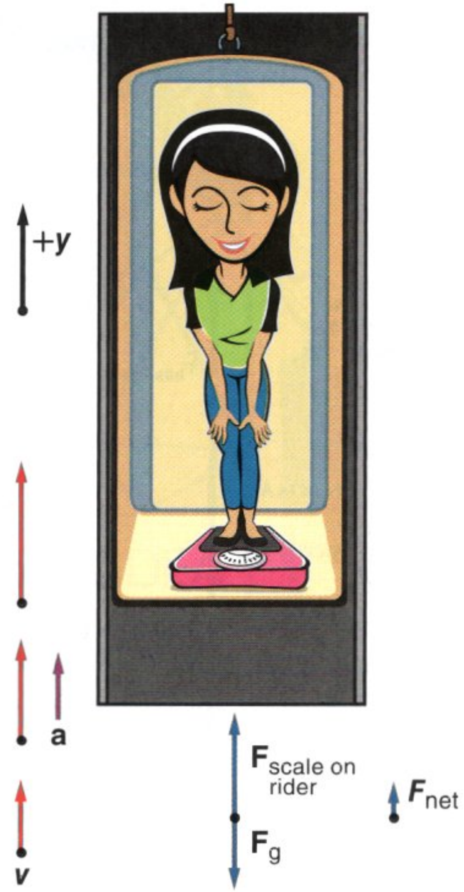
$F_N < m\mathbf{g}$, $\mathbf{F}_{net} = 0$

$F_N > m\mathbf{g}$, $\mathbf{F}_{net} = 0$

Weight

Apparent weight

- acceleration of the system is upward, the net force must be upward
- the upward force of the scale must be greater than the downward force of your weight
- the scale reading is greater than your weight



Weightlessness – object's apparent weight is zero

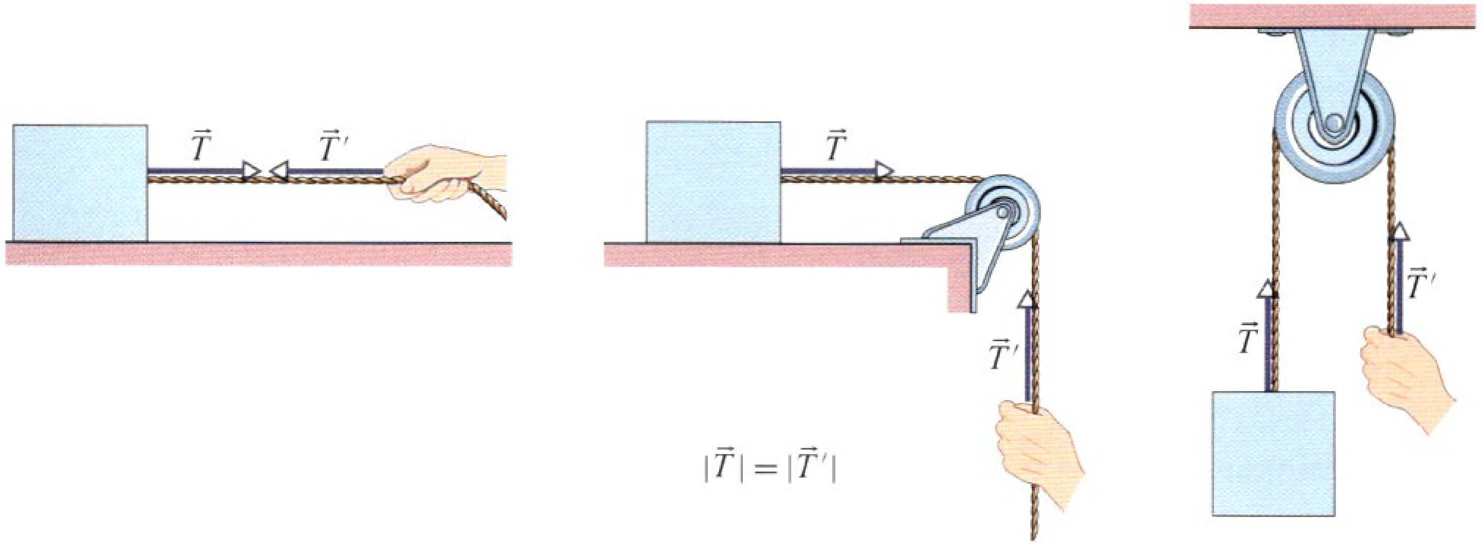
Example: force and acceleration

An elevator cab that weights 27.8 kN moves upward. What is the tension in the cable if the cab's speed is:

(a) increasing at a rate of 1.22 m/s^2

(b) decreasing at a rate of 1.22 m/s^2?

The tension force

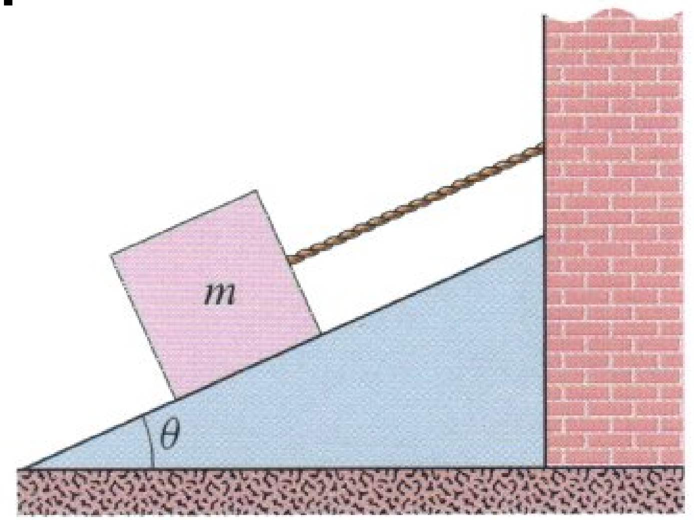


Body attached to a cord

- the cord pulls on the body with force ***T*** directed away from the body and along the cord
- the cord is massless and unstretchable and it exists only as a connection between two objects
- the cord pulls on both bodies with the same force magnitude *T*

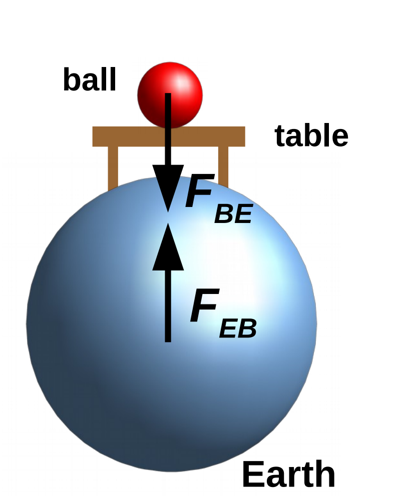
Example: inclined planes

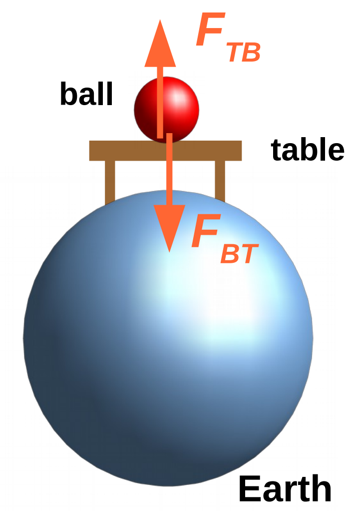
The mass of the block is 8.5 kg and the angle θ is 30°.
Find:
(a) the tension in the cord
(b) the normal force acting on the block
(c) If the cord is cut, find the magnitude of the resulting acceleration of the block. (Assume no friction)



Newton's third law

All forces occur in interaction pairs





Interaction pair

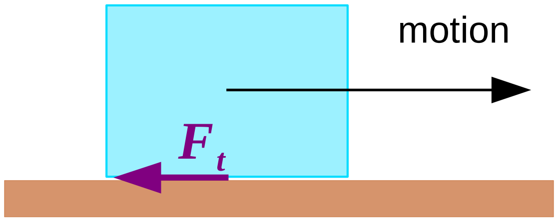
- a set of two forces that are in opposite directions, have equal magnitudes, and act on different objects
- sometimes called action-reaction pair
- both forces either exist together or not at all

$$F_{A\,on\,B} = -F_{B\,on\,A}$$

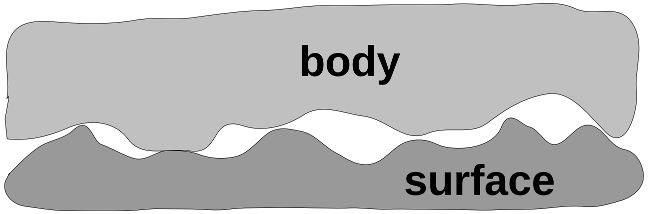
Newton's third law:

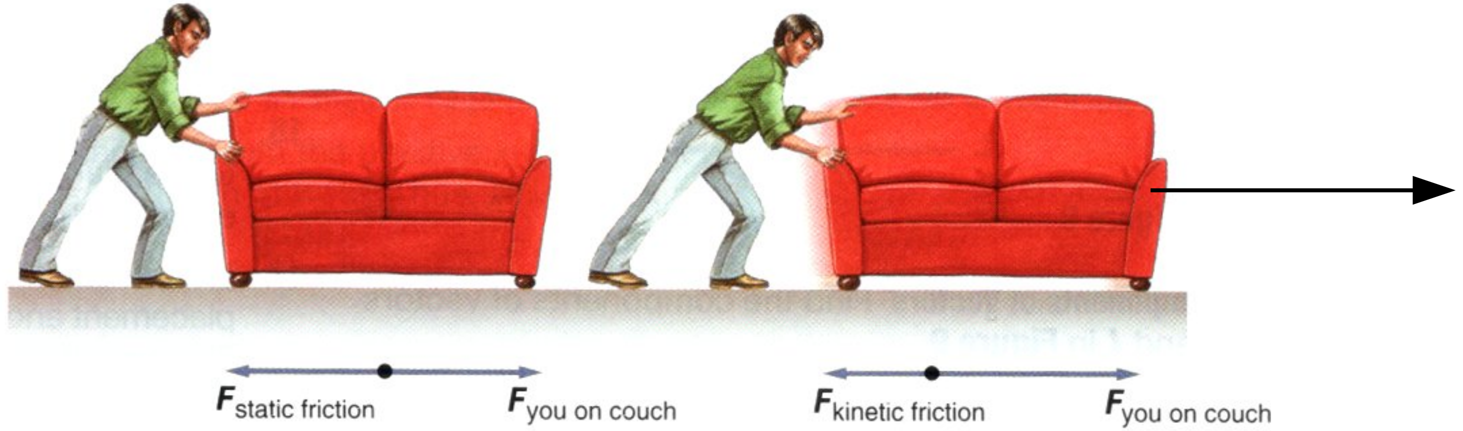
When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

The friction force



The **frictional force** is **parallel to the surface** and directed so as to oppose the sliding.
Friction is due to bonding between the body and the surface.

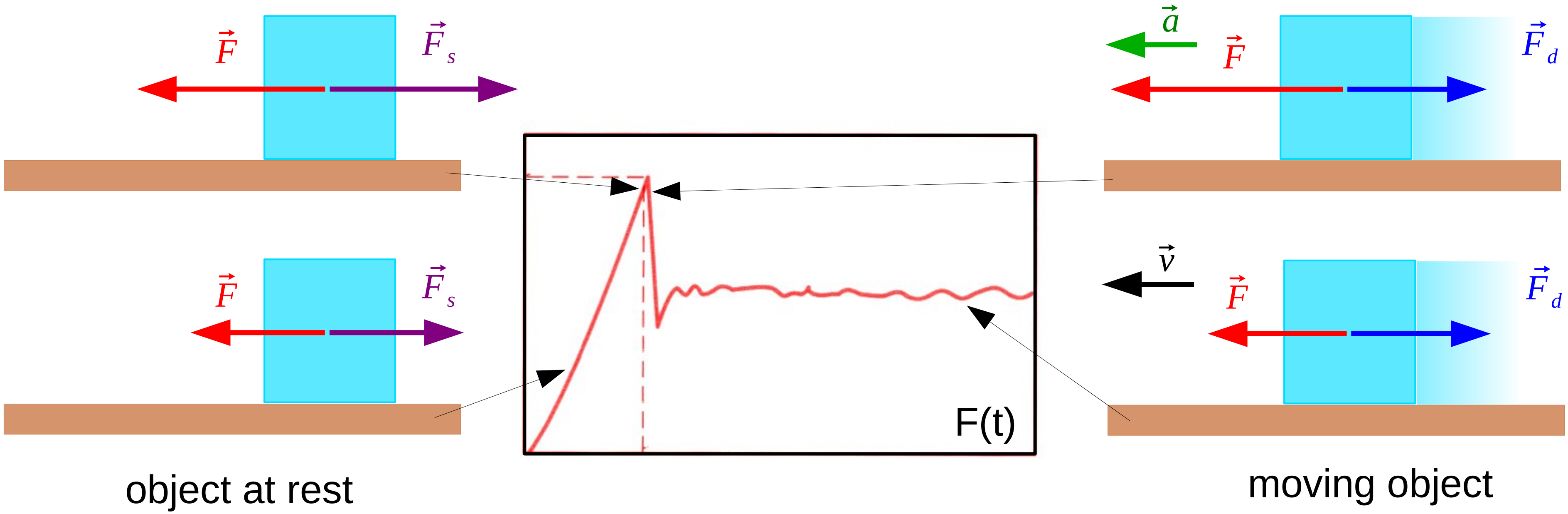




Static friction increases up to a maximum to balance the applied force.

The couch accelerates when the applied force exceeds the maximum static friction force.

Friction



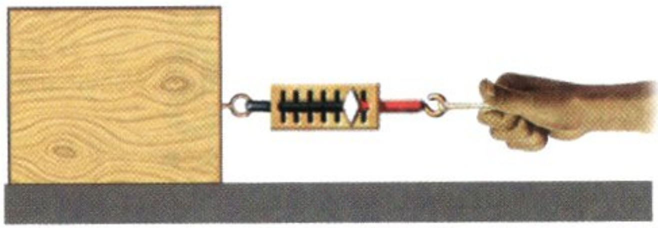
Kinetic friction

- acts on moving objects
- is exerted on one surface by another when the two surfaces rub against each other because one or both surfaces are moving

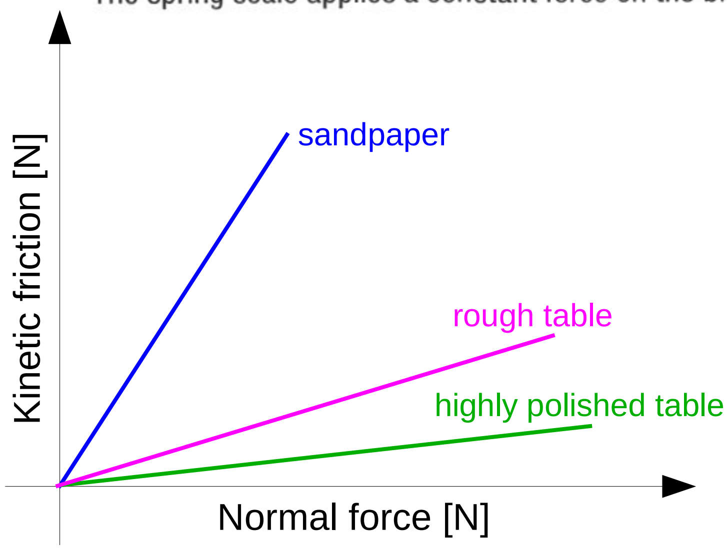
Static friction

- is the force exerted on one surface by another when there is no motion between the two surfaces

Kinetic and static friction



The spring scale applies a constant force on the block.



$$F_{f,kinetic} = \mu_k F_N$$

The slope of the line on a kinetic friction force v. normal force graph is called the **coefficient of kinetic friction, μ_k.**

$$F_{f,static} \leq \mu_s F_N$$

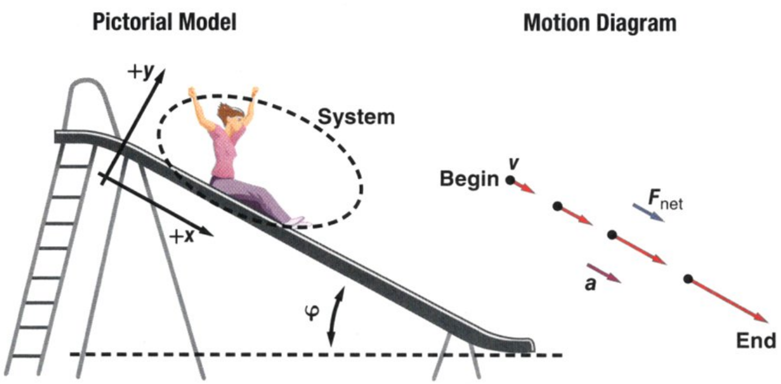
μ_s is the **coefficient of static friction** between the two surfaces

The friction forces F_t are always perpendicular to the normal force.

Table Typical Coefficients of Friction*

Surfaces	Coefficient of static friction (μ_s)	Coefficient of kinetic friction (μ_k)
Cast iron on cast iron	1.1	0.15
Glass on glass	0.94	0.4
Leather on oak	0.61	0.52
Nonstick coating on steel	0.04	0.04
Oak on oak	0.62	0.48
Steel on steel	0.78	0.42
Steel on steel (with castor oil)	0.15	0.08

Example: inclined planes



A girl, who has a mass of 45 kg, is going down a slide sloped at 27°. The coefficient of kinetic friction is 0.23. How fast does she slide 1.0 s after starting from rest?

Example: inclined planes