PHYSICS I

Assoc.Prof.Dr. Yeşim Moğulkoç

The Laws of Motion

The description of an object in motion included its position, velocity, and acceleration.

There was no consideration of what might influence that motion.

Two main factors need to be addressed to answer questions about why the motion of an object will change.

- Forces acting on the object
- The mass of the object

Dynamics studies the causes of motion.

Will start with three basic laws of motion

- Formulated by Sir Isaac Newton

Isaac Newton

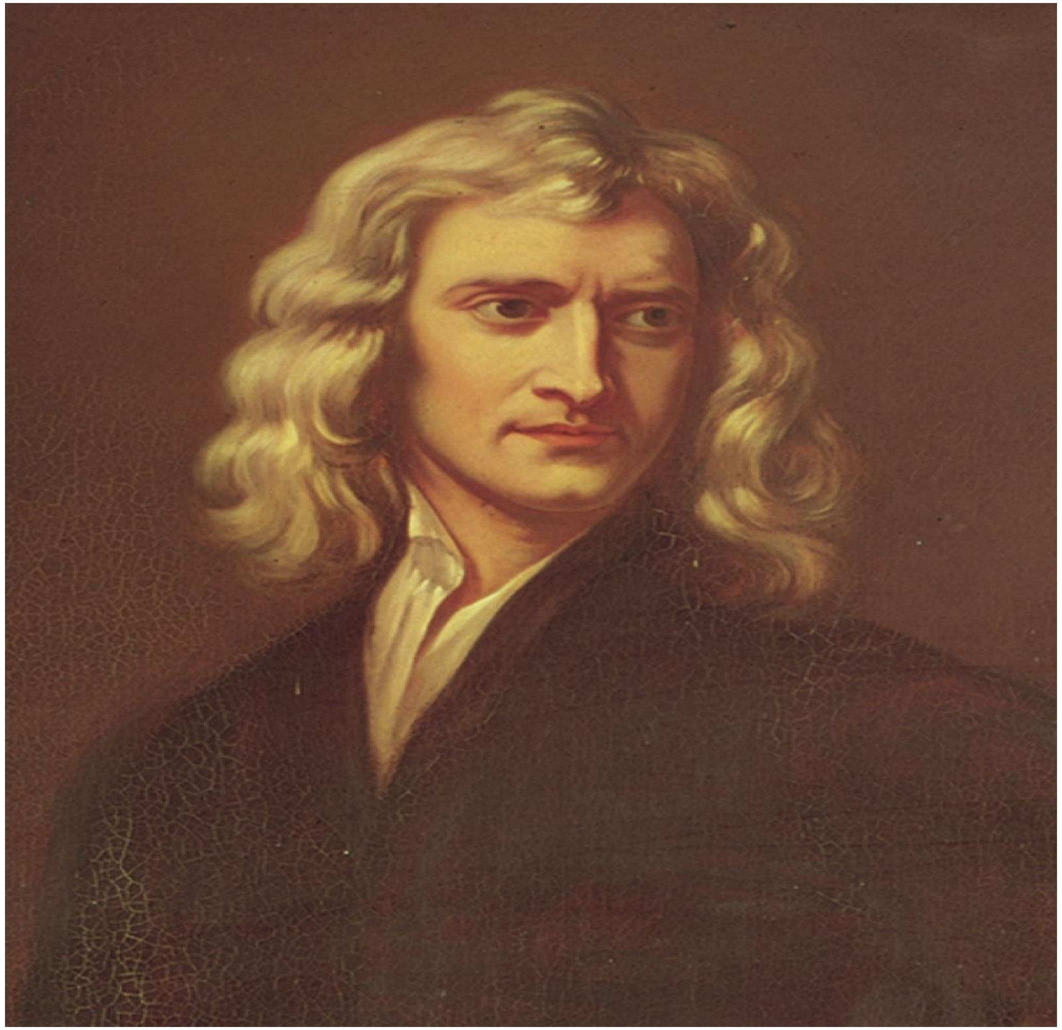
1642 – 1727

Formulated basic laws of mechanics

Discovered Law of Universal Gravitation

Invented form of calculus

Many observations dealing with light and optics



Force

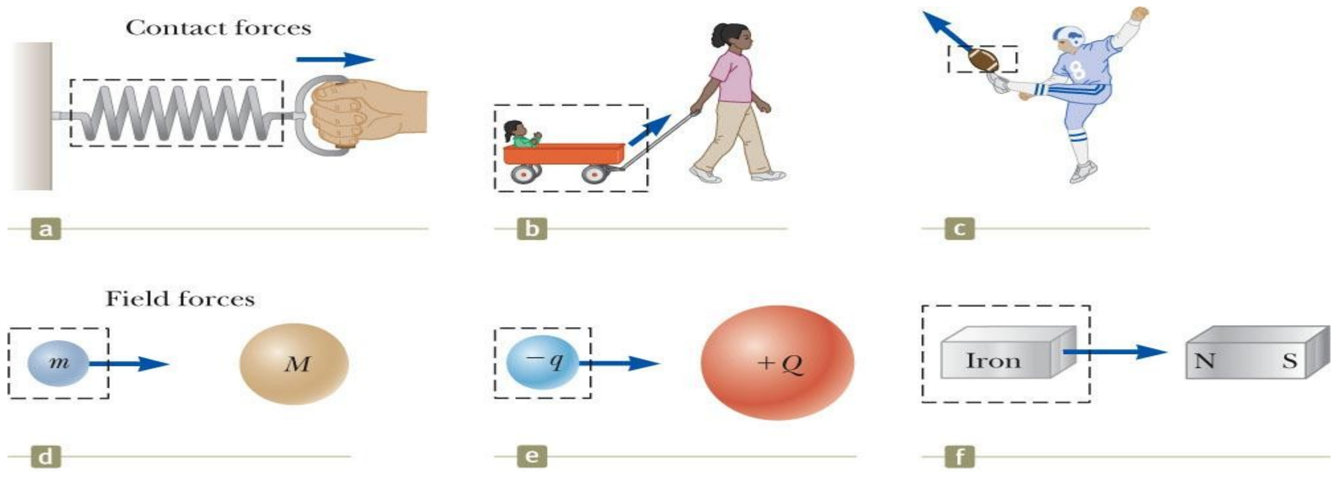
Forces in everyday experience

- Push on an object to move it
- Throw or kick a ball
- May push on an object and not be able to move it

Forces are what cause any change in the velocity of an object.

- Newton’s definition
- A force is that which causes an acceleration

Classes of Forces



Contact forces involve physical contact between two objects

- Examples a, b, c

Field forces act through empty space

- No physical contact is required
- Examples d, e, f

Fundamental Forces

Gravitational force

- Between objects

Electromagnetic forces

- Between electric charges

Nuclear force

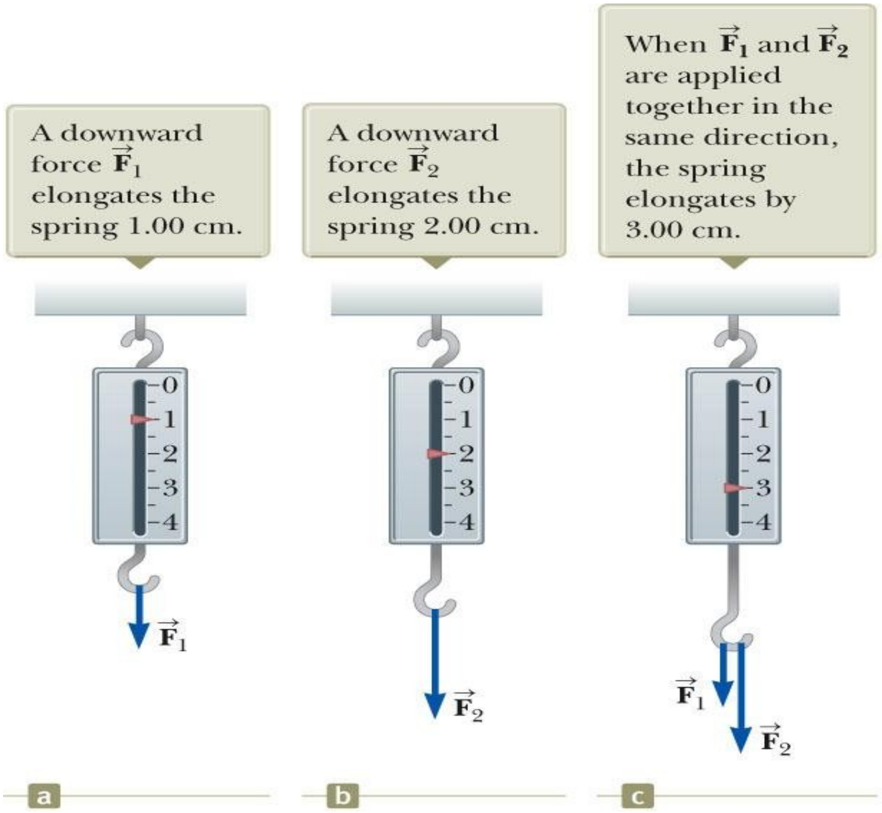
- Between subatomic particles

Weak forces

- Arise in certain radioactive decay processes

Note: These are all field forces.

More About Forces



A spring can be used to calibrate the magnitude of a force.

Doubling the force causes double the reading on the spring.

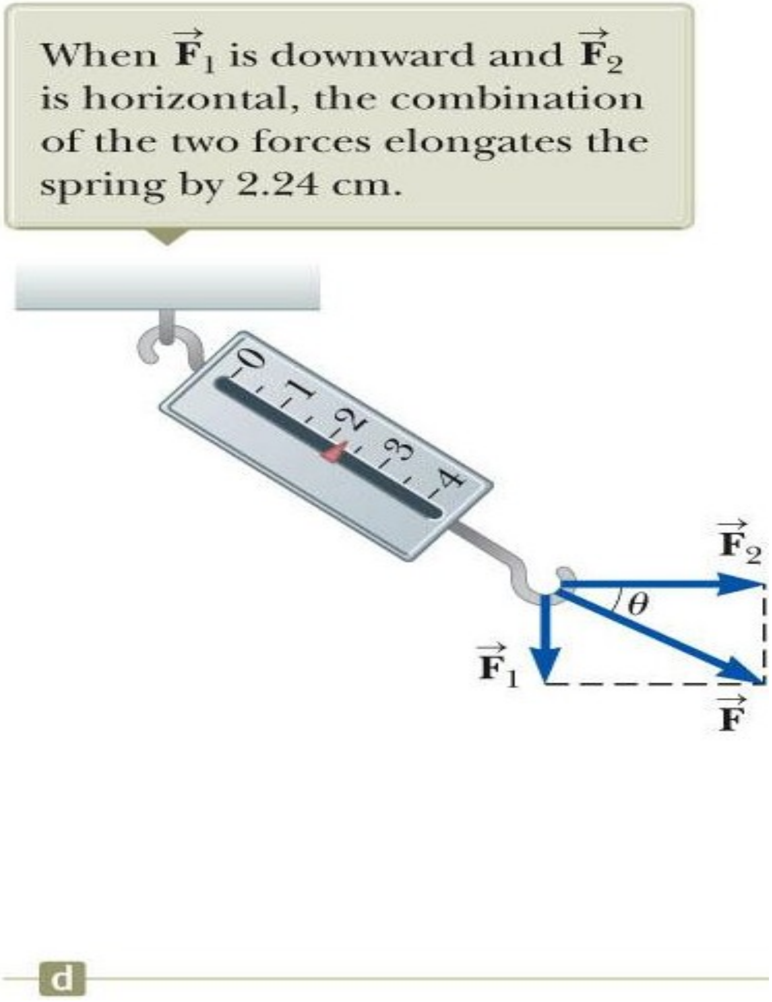
When both forces are applied, the reading is three times the initial reading.

Vector Nature of Forces

The forces are applied perpendicularly to each other.

The resultant (or net) force is the hypotenuse.

Forces are vectors, so you must use the rules for vector addition to find the net force acting on an object.



Newton’s First Law

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

- This is also called the *law of inertia.*
- It defines a special set of reference frames called *inertial frames.*
  - We call this an ***inertial frame of reference.***

Inertial Frames

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

If you accelerate relative to an object in an inertial frame, you are observing the object from a **non-inertial reference frame.**

A reference frame that moves with constant velocity relative to the distant stars is the best approximation of an inertial frame.

- We can consider the Earth to be such an inertial frame, although it has a small centripetal acceleration associated with its motion.

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.

- Force is the cause of *changes* in motion, as measured by the acceleration.
  - Remember, an object can have motion in the absence of forces.
  - Do not interpret force as the cause of motion.

Algebraically,

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

- With a proportionality constant of 1 and speeds much lower than the speed of light.

Gravitational Force

The gravitational force, $\vec{\mathbf{F}}_g$, is the force that the earth exerts on an object.

This force is directed toward the center of the earth.

From Newton's Second Law:

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

Its magnitude is called the weight of the object.

- Weight = $F_g = mg$

More About Weight

Because it is dependent on g, the weight varies with location.

- g, and therefore the weight, is less at higher altitudes.
- This can be extended to other planets, but the value of g varies from planet to planet, so the object's weight will vary from planet to planet.

Weight is not an inherent property of the object.

- The weight is a property of a *system* of items: the object and the Earth.

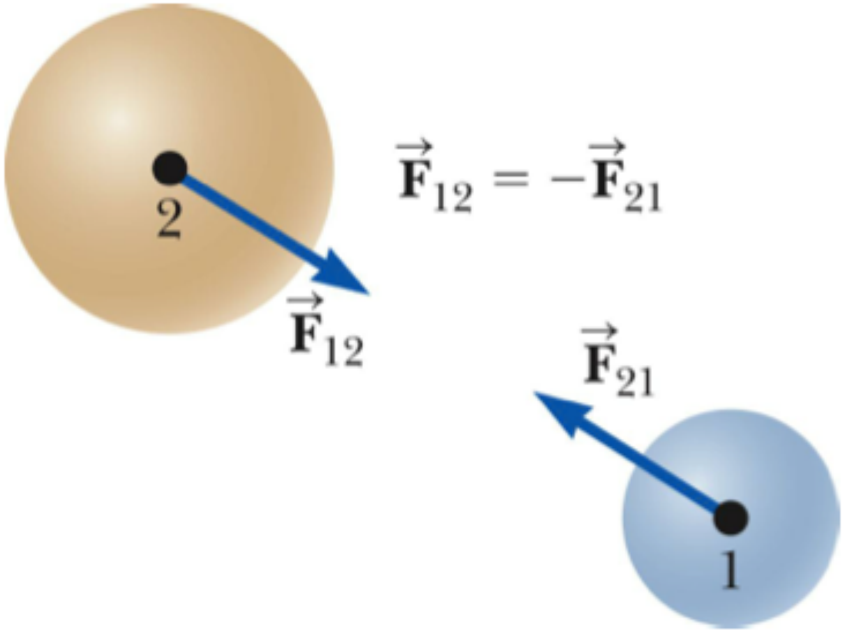
Note about units:

- Kilogram is **not** a unit of weight.
- 1 kg = 2.2 lb is an equivalence valid only on the Earth's surface.

Newton's Third Law

If two objects interact, the force $\vec{\mathbf{F}}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{\mathbf{F}}_{21}$ exerted by object 2 on object 1.

- $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$
- Note on notation: $\vec{\mathbf{F}}_{AB}$ is the force exerted *by* A *on* B.

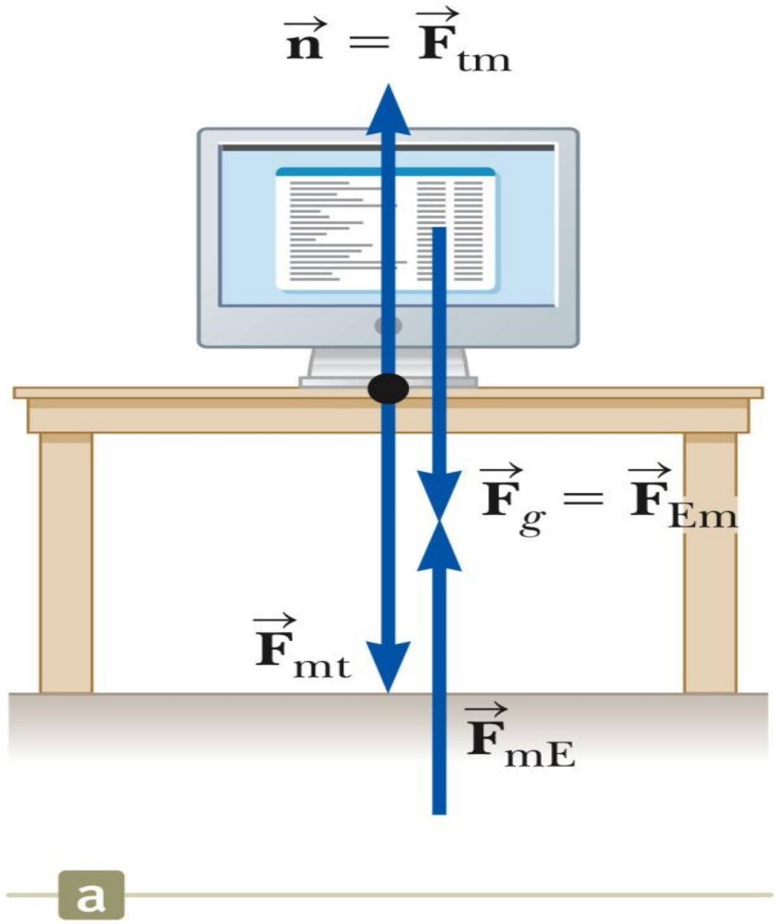


Action-Reaction Example

The normal force (table on monitor) is the reaction of the force the monitor exerts on the table.

- Normal means perpendicular, in this case

The action (Earth on monitor) force is equal in magnitude and opposite in direction to the reaction force, the force the monitor exerts on the Earth.



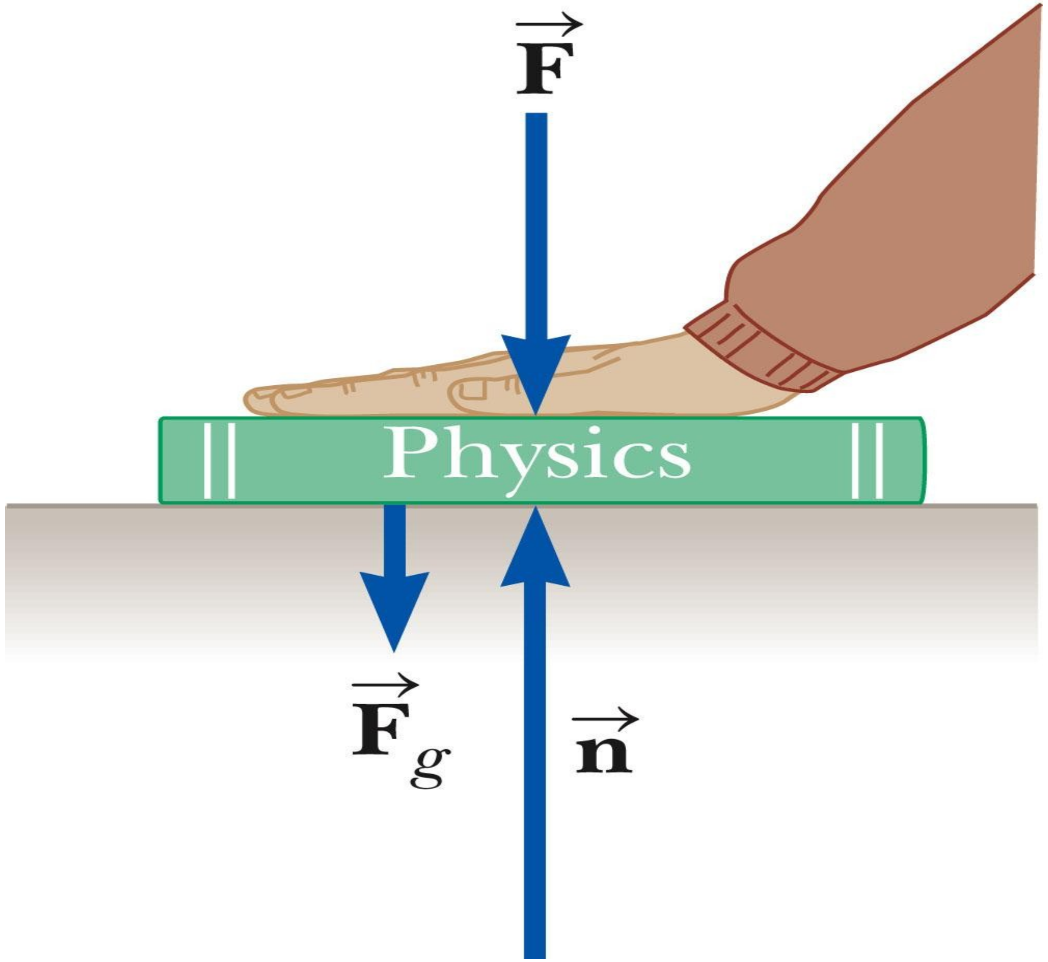
The Normal Force

The normal force is **not** always equal to the gravitational force of the object.

For example, in this case

$$\sum F_y = n - F_g - F = 0 \text{ and } n = mg + F$$

$\vec{\mathbf{n}}$ may also be less than $\vec{\mathbf{F}}_g$



Inclined Planes

Categorize as a particle under a net force since it accelerates.

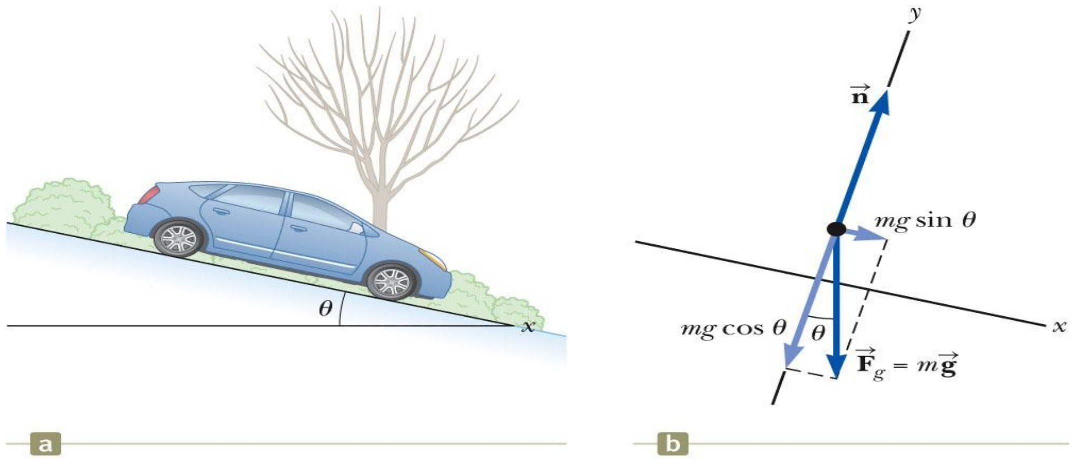
Forces acting on the object:

- The normal force acts perpendicular to the plane.
- The gravitational force acts straight down.

Choose the coordinate system with *x* along the incline and *y* perpendicular to the incline.

Replace the force of gravity with its components.

Apply the model of a particle under a net force to the x-direction and a particle in equilibrium to the y-direction.



Example – Atwood's Machine

Forces acting on the objects:

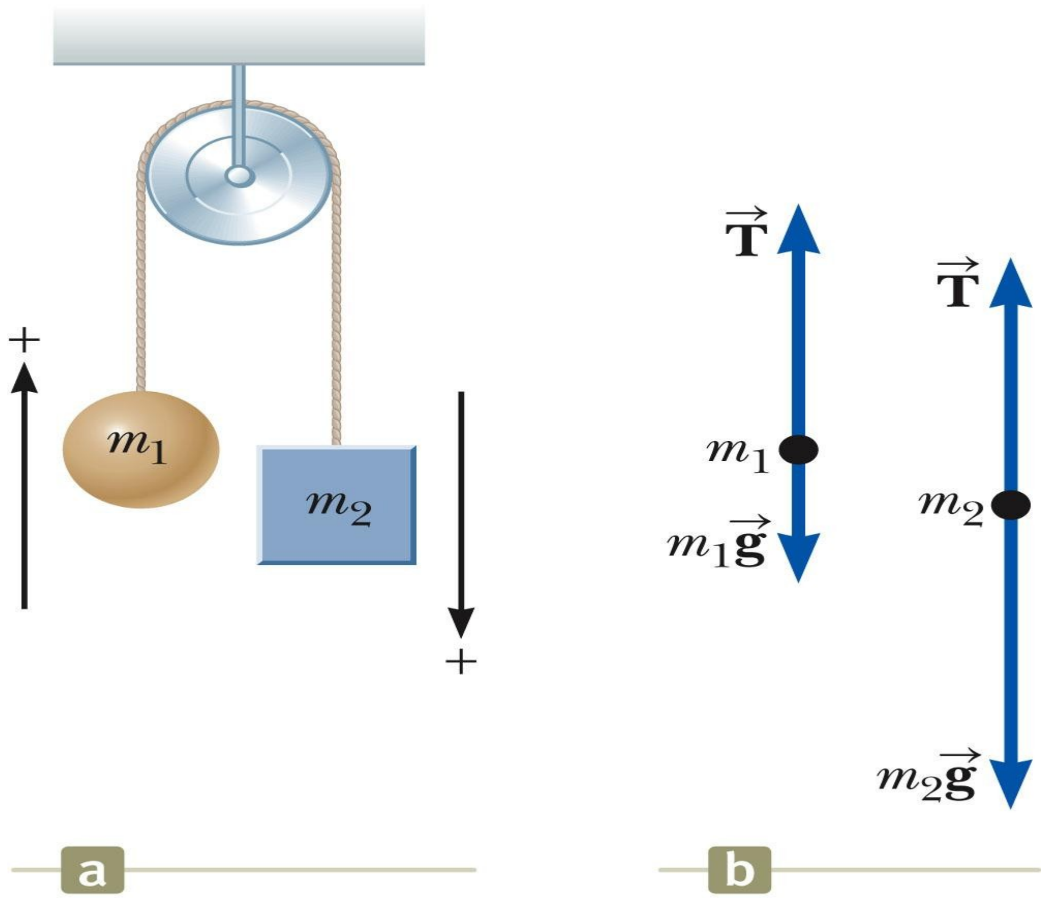
- Tension (same for both objects, one string)
- Gravitational force

Each object has the same acceleration since they are connected.

Draw the free-body diagrams Apply

Newton's Laws

Solve for the unknown(s)



Exploring the Atwood’s Machine

Vary the masses and observe the values of the tension and acceleration.

- Note the acceleration is the same for both objects
- The tension is the same on both sides of the pulley as long as you assume a massless, frictionless pulley.

What if?

- The mass of both objects is the same?
- One of the masses is much larger than the other?

Example:

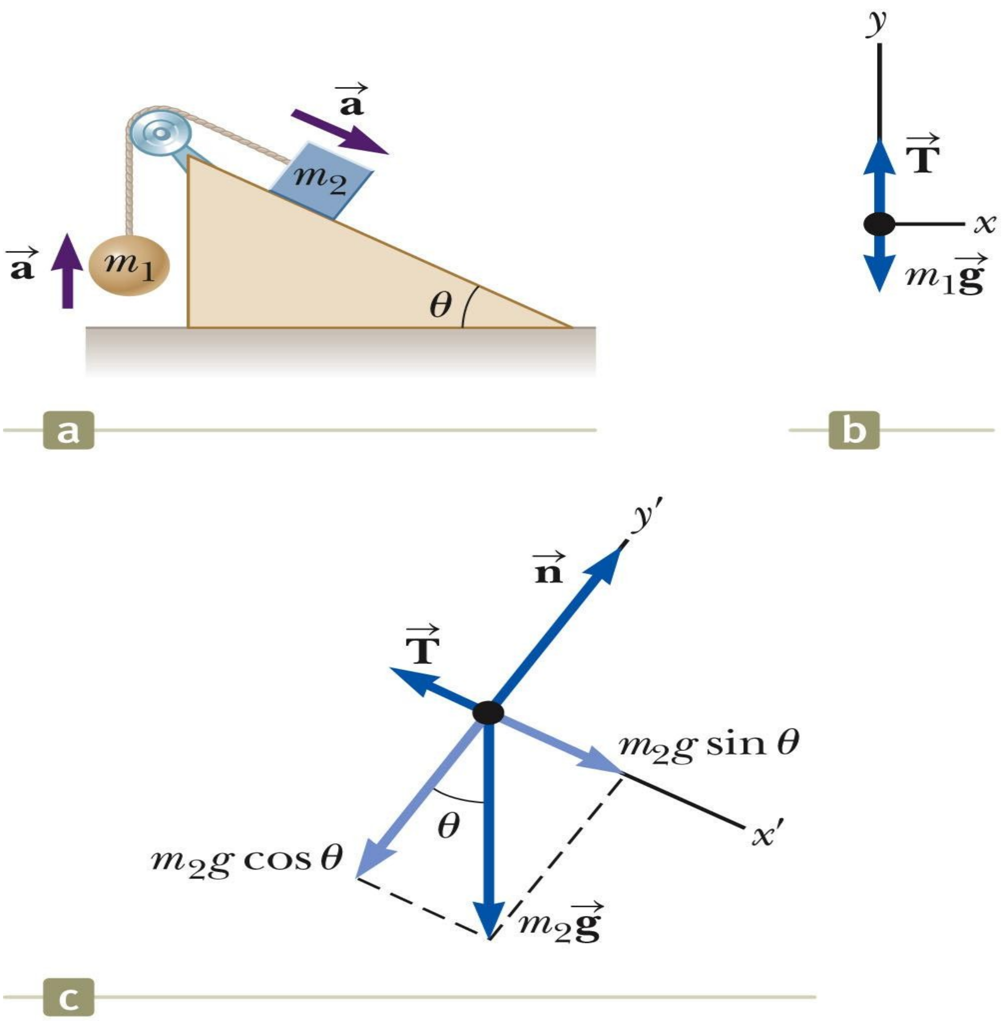
Draw the free-body diagram for each object

- One cord, so tension is the same for both objects
- Connected, so acceleration is the same for both objects

Categorize as particles under a net force

Apply Newton’s Laws Solve for the

unknown(s)



Forces of Friction

Friction is proportional to the normal force.

- $f_s \leq \mu_s n$ and $f_k = \mu_k n$
  - μ is the **coefficient of friction**
- These equations relate the magnitudes of the forces; they are not vector equations.
- For static friction, the equals sign is valid only at *impeding* motion, the surfaces are on the verge of slipping.
- Use the inequality for static friction if the surfaces are not on the verge of slipping.

Some Coefficients of Friction

TABLE 5.1 *Coefficients of Friction*

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

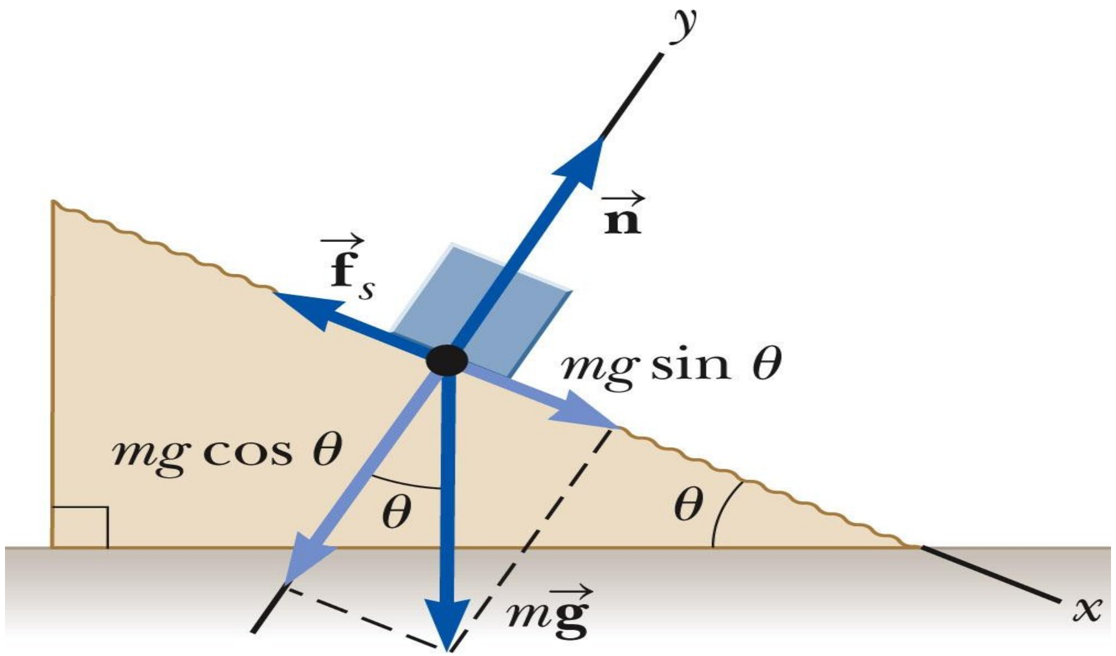
Friction Example, 1

The block is sliding down the plane, so friction acts up the plane.

This setup can be used to experimentally determine the coefficient of friction.

$\mu = \tan \theta$

- For μ_s, use the angle where the block just slips.
- For μ_k, use the angle where the block slides down at a constant speed.



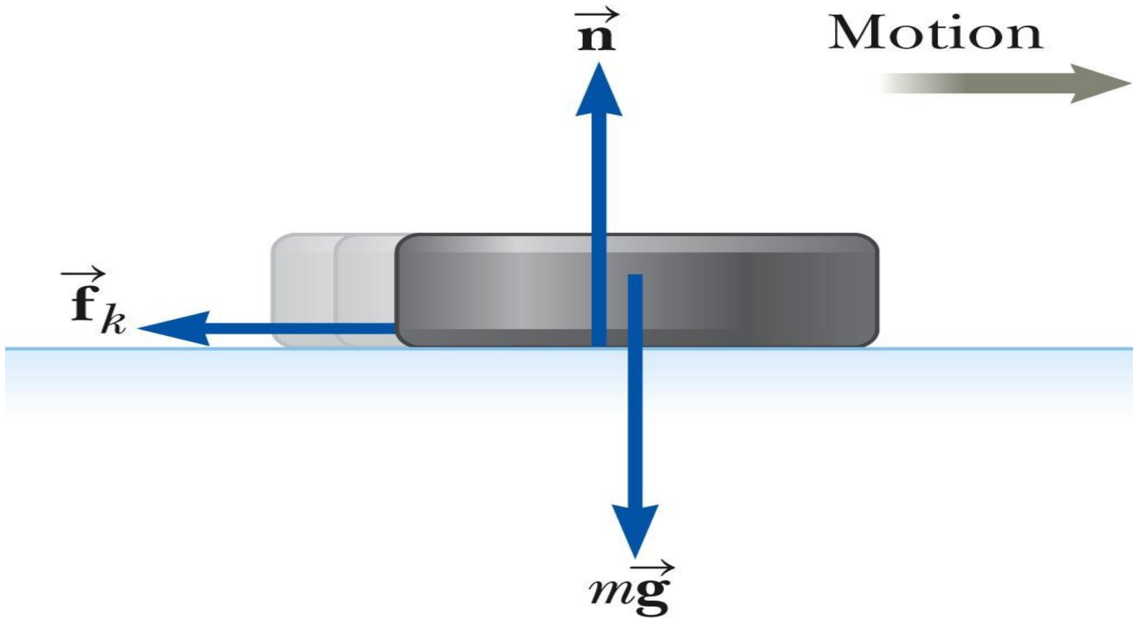
Friction, Example 2

Draw the free-body diagram, including the force of kinetic friction.

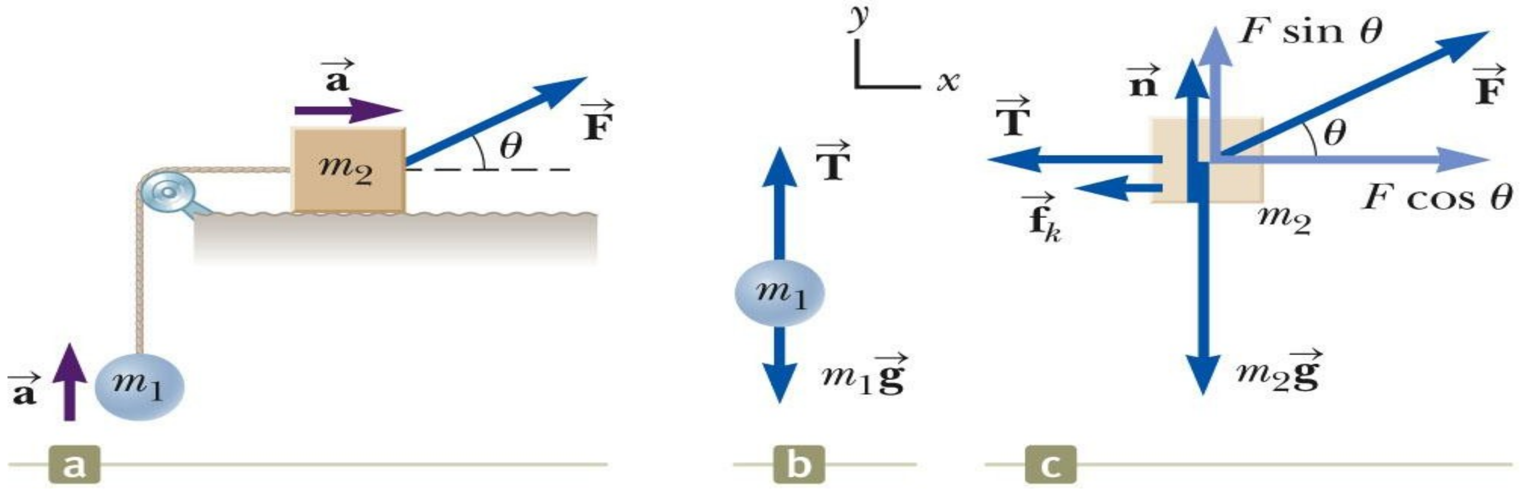
- Opposes the motion
- Is parallel to the surfaces in contact

Continue with the solution as with any Newton's Law problem.

This example gives information about the motion which can be used to find the acceleration to use in Newton's Laws.



Friction, Example 3



Friction acts only on the object in contact with another surface. Draw the free-body diagrams.

Apply Newton's Laws as in any other multiple object system problem.