Chapter 5 Force and Motion - I

- It's a **force** which *cause* an object to accelerate.

- The force is said to *act* on the object to change its velocity.

Newtonian Mechanics

- The relation between a force and the acceleration it causes was first understood by Isaac Newton, and the study of that relation is called *Newtonian mechanics*.

- Newtonian mechanics **does not** apply to all situations:
  (1) replaced with Einstein's special theory of relativity when the speeds of the interacting bodies are very large;
  (2) replaced with quantum mechanics when the interacting bodies are on the scale of atomic structure.

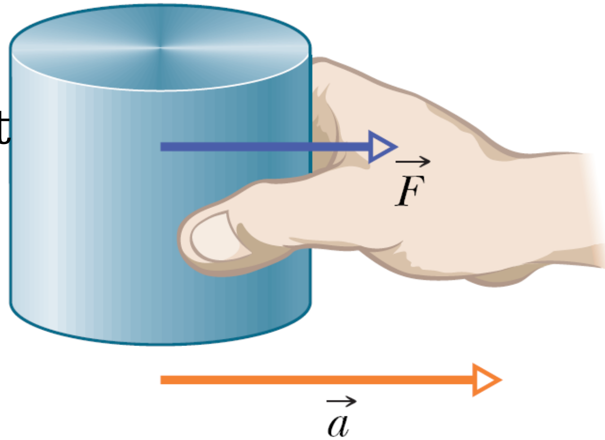
- Although Newtonian mechanics is now regarded as a special case of more general theories, it is still important because it applies to the motion of objects ranging in size from the very small to the astronomical.

Newton's 1st Law

Newton's 1st Law: If no force acts on a body, the body's velocity cannot change; that is, the body cannot accelerate.

- If the body is at rest, it stay at rest. If it is moving, it continues to move with the same velocity.

Force



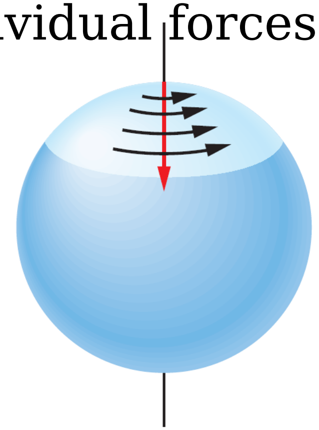
- define the unit of force in terms of the acceleration that a force gives to a standard reference body.

- a standard reference body: 1kg, an acceleration: 1m/s^2, give the unit of force: 1 **newton** (abbreviated **N**).

- Since a force is measured by the acceleration it produces, force is also a vector quantity.

- A **net force** (or **resultant force**) can be found, by adding the individual forces vectorially, when 2 or more forces act on a body.

- **principle of superposition for forces**: a single force that has the magnitude and direction of the net force has the same effect on the body as all the individual forces together.

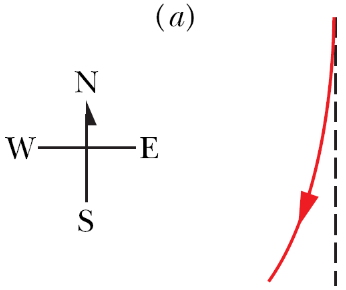


(a)

Newton's 1st Law: If no *net* force acts on a body ($\vec{F}_{net} = 0$), the body's velocity cannot change; that is, the body cannot accelerate.

Inertial Reference Frames

An inertial reference frame is one in which Newton's laws hold.



(b)

non-inertial frame

Mass

- The way of measuring mass in an inertial frame:

1) exert a force on a standard body with mass m_0 defined to be 1.0 kg, and this standard body accelerates at 1.0 m/s^2. Then the force on the body is 1.0 N.

2) the conjecture:
The ratio of the masses of 2 bodies is equal to the inverse of the ratio of their accelerations when the same force is applied to both.

3) apply that same force to a 2nd body, X, whose mass is not known. For body X and the standard body,

$$\frac{m_X}{m_0} = \frac{a_0}{a_X} \quad \text{gives} \quad m_X = m_0 \frac{a_0}{a_X}$$

For a_X=0.25 m/s^2,

$$m_X = (1.0 \text{ kg}) \frac{1.0 \text{ m/s}^2}{0.25 \text{ m/s}^2} = 4.0 \text{ kg}$$

4) it needs another experiment to check the correctness of the conjecture:
applying an 8.0 N force to the standard body gets an acceleration of 8.0 m/s^2
applying the 8.0 N force to body X get an acceleration of 2.0 m/s^2, then

$$m_X = (1.0 \text{ kg}) \frac{8.0 \text{ m/s}^2}{2.0 \text{ m/s}^2} = 4.0 \text{ kg} \qquad \text{check!}$$

- mass is an *intrinsic* characteristic of a body, ie, a characteristic that automatically comes with the existence of the body.

- mass is a scalar quantity.

- *the mass of a body is the characteristic that relates a force on the body to the resulting acceleration.*

- We can have a physical sensation of mass only when you attempt to accelerate a body.

Newton's 2^{nd} Law

Newton's 2^{nd} Law: The net force on a body is equal to the product of the body's mass and its acceleration.

In equation form

$$\vec{F}_{net} = m\,\vec{a} \quad \text{Newton's 2nd law}$$

and the 3 component equations

$$F_{net,x} = m\,a_x\,, \quad F_{net,y} = m\,a_y\,, \quad F_{net,z} = m\,a_z$$

- Be certain about which body we are applying it to.

- $\vec{F}_{net}$ must be the vector sum of *all* the forces that act on *that* body.

> The acceleration component along a given axis is caused *only by* the sum of the force components along that *same* axis, and not by force components along any other axis.

- if the net force on a body is 0, the body's acceleration is 0, too. (return to Newton's 1st law)

- In such a case, any forces on the body *balance* one another, and both the forces and the body are said to be in *equilibrium*.

- From Newton's 2nd law, $1\ \text{N} = (1\ \text{kg})(1\ \text{m/s}^2) = 1\ \text{kg}\cdot\text{m/s}^2$

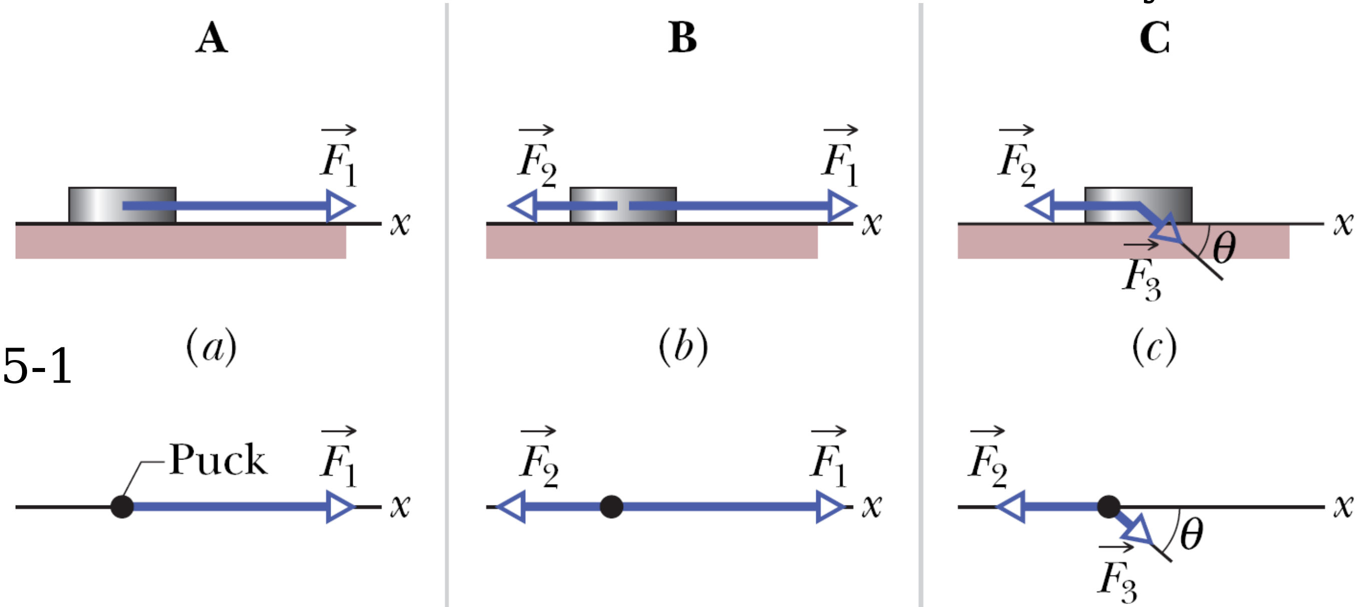
Unit in Newton's 2nd Law

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

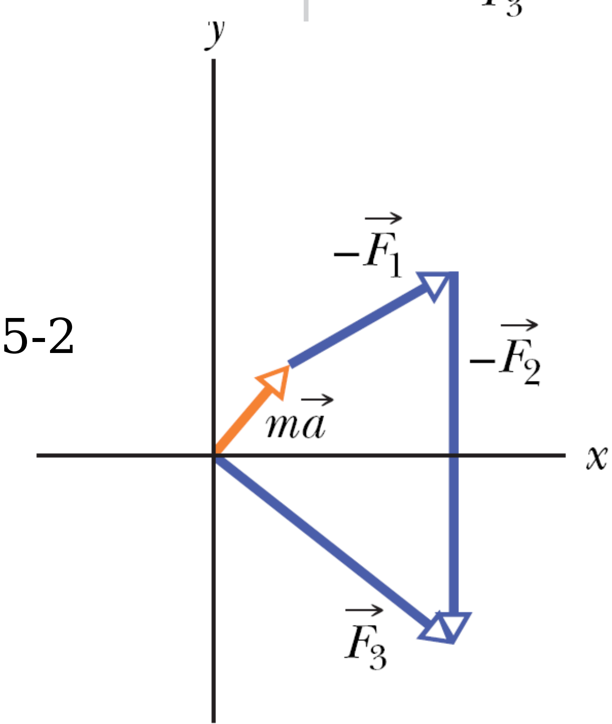
- A **system** consists of one or more bodies and any force on the bodies inside system from bodies outside the system is called an **external force**.

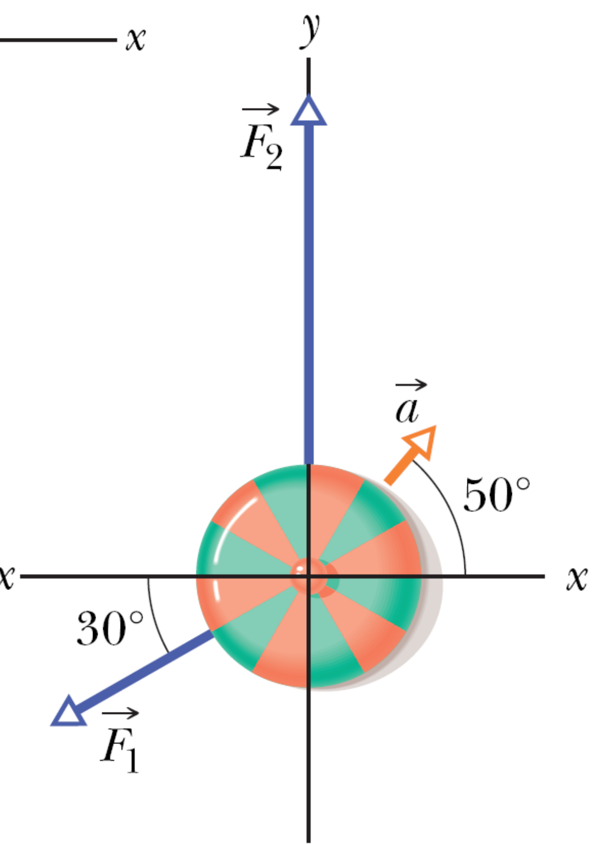
- **internal forces**: forces between 2 bodies inside the system

problem 5-1



problem 5-2





Some Particular Forces

The Gravitational Force

- A **gravitational force** on a body is a certain type of pull that is directed toward a 2nd body — Earth.

- in free fall with the free-fall acceleration, the only force acting on the body is the gravitational force.

$$\vec{F}_g = -F_g\,\hat{j} = -m\,g\,\hat{j} = m\,\vec{g}\,, \quad \text{and} \quad F_g = m\,g$$

the magnitude of the gravitational force is equal to the product mg.

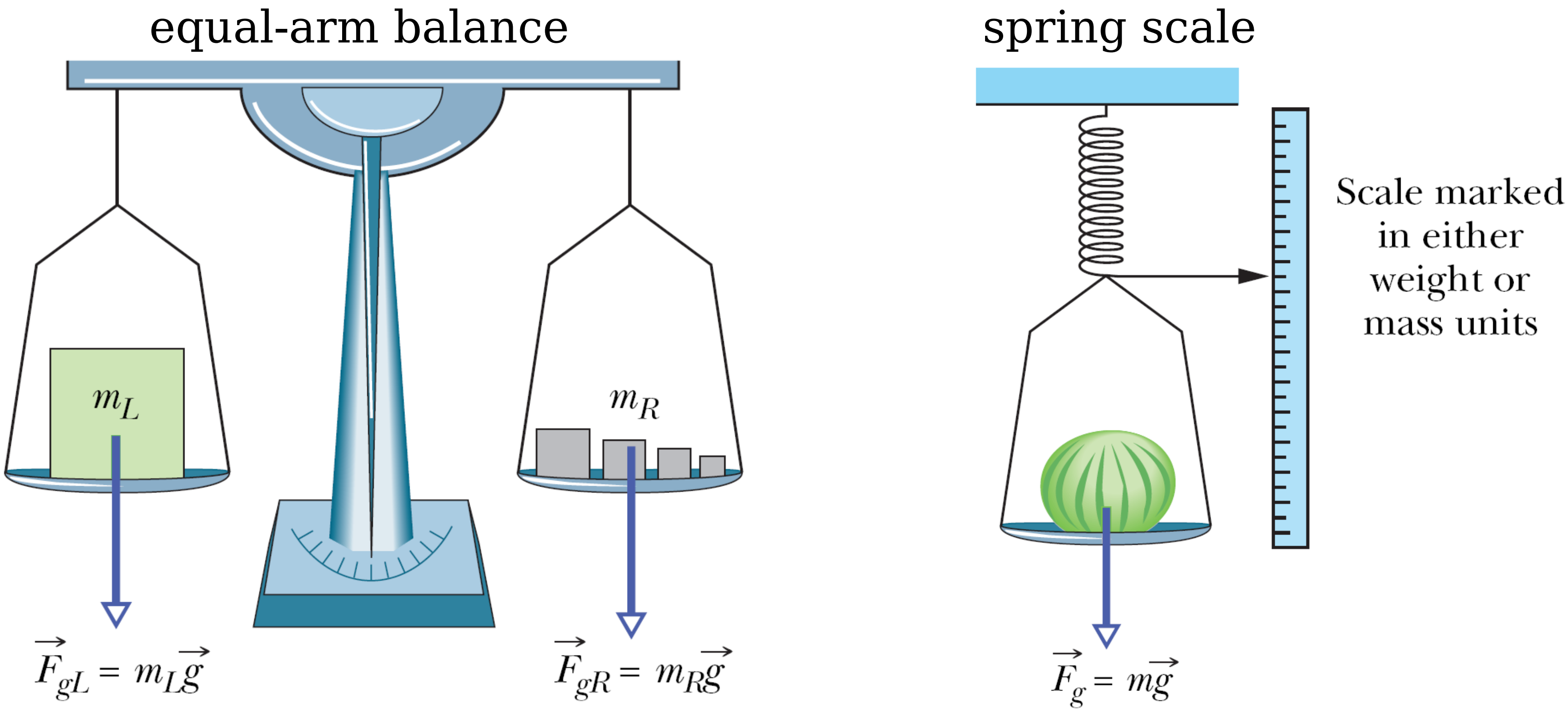
- This same gravitational force, with the same magnitude, still acts on the body even when the body is not in free fall.

Weight

- The **weight** W of a body is the magnitude of the net force required to prevent the body from falling freely, as measured by someone on the ground.

The weight W of a body is equal to the magnitude F_g of the gravitational force on the body.

$$W = m\,g \qquad \text{weight}$$



- The weight of a body must be measured when the body is not accelerating vertically relative to the ground.

- The weighting in an vertically accelerating situation will get a different reading. Such a measurement is called an *apparent weight*.

- *Caution*: A body's weight is not its mass.

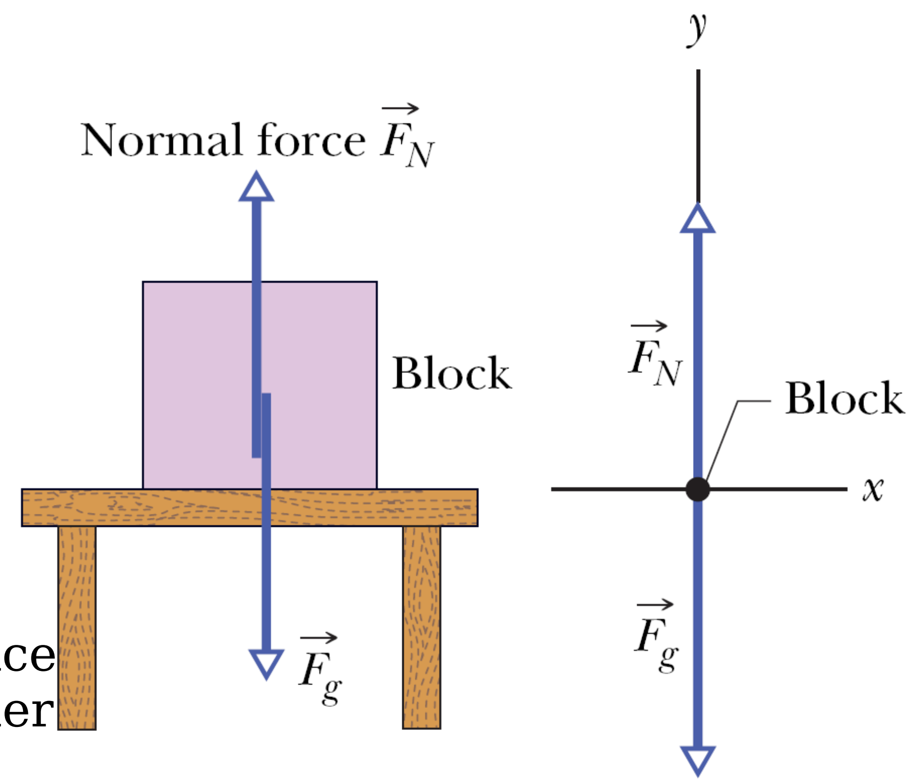
The Normal Force

When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a **normal force** $\vec{F}_N$ that is perpendicular to the surface.

$$F_N - F_g = F_N - mg = ma_y$$

$$\Rightarrow \quad F_N = m\left(g + a_y\right)$$

$$\Rightarrow \quad \text{For} \quad a_y = 0\,, \qquad F_N = mg$$

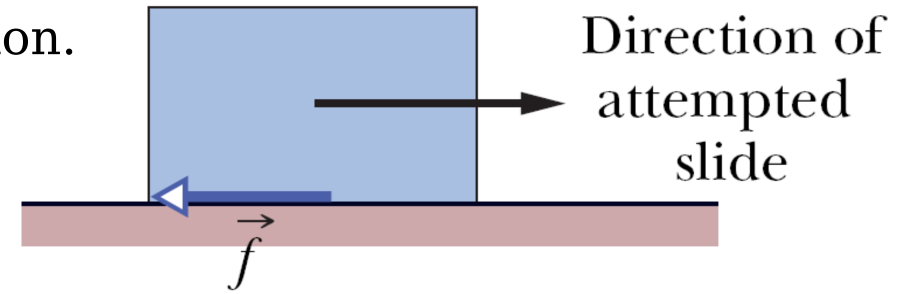


Friction

- The resistance between a body and a surface is considered to be a single force, called either the **frictional force** or **friction**.

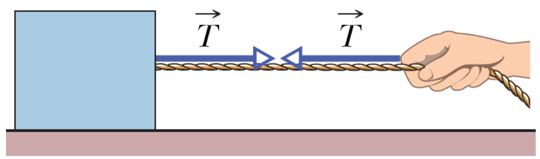
- This force is directed along the surface, opposite the direction of the intended motion.

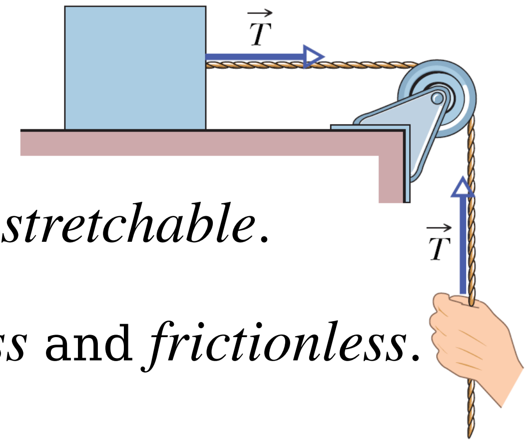
- friction sometimes is assumed to be negligible (*frictionless*).

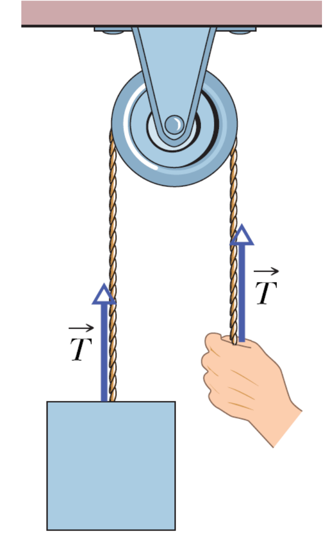


Tension

- When a cord is attached to a body and pulled taut, the cord pulls on the body with a force directed away from the body and along the cored. The force is called a *tension force*.







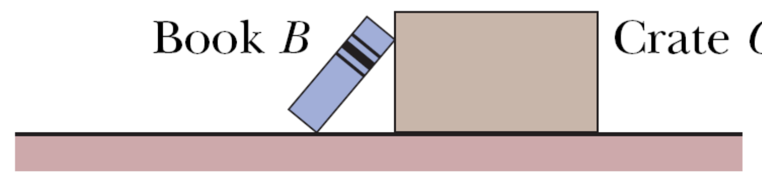
- A cord is often said to be *massless* and *unstretchable*.
- A pulley is often considered to be *massless* and *frictionless*.
- In Fig. c, the net force on the pulley from the cord has the magnitude $2T$.

Applying Newton's Laws

Newton's 3rd Law

- 2 bodies are said to *interact* when a force acts on each body due to the other body.

Newton's 3rd Law: When 2 bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.



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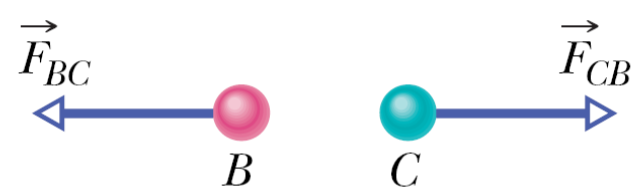
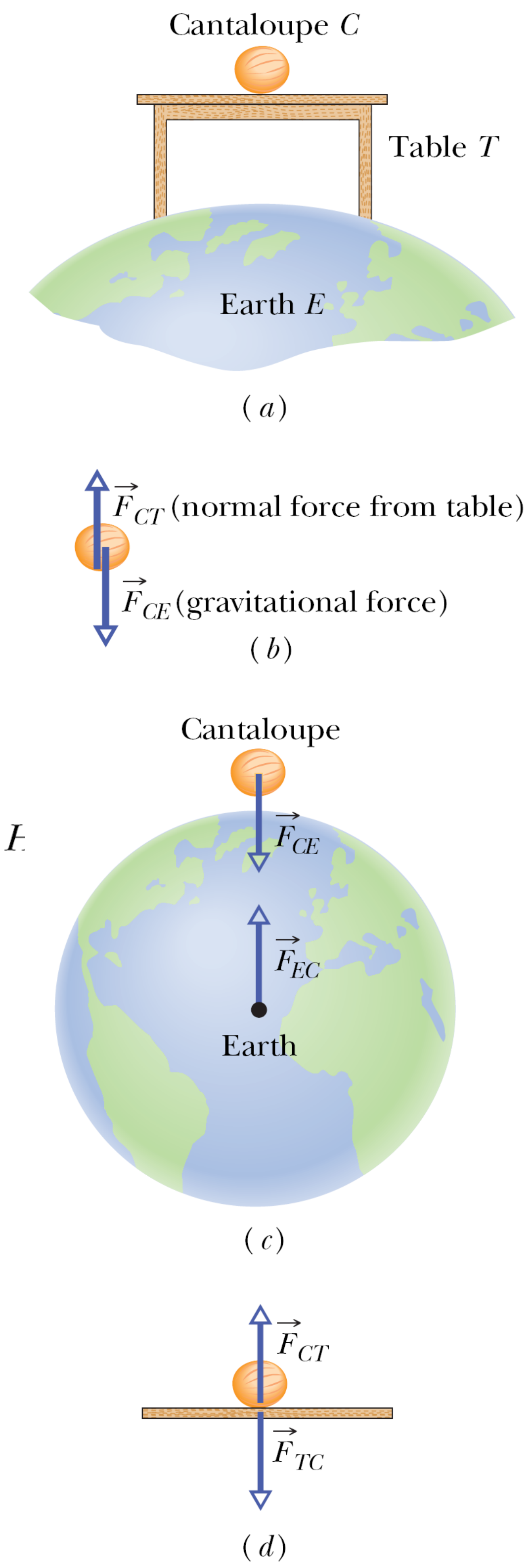


(b)

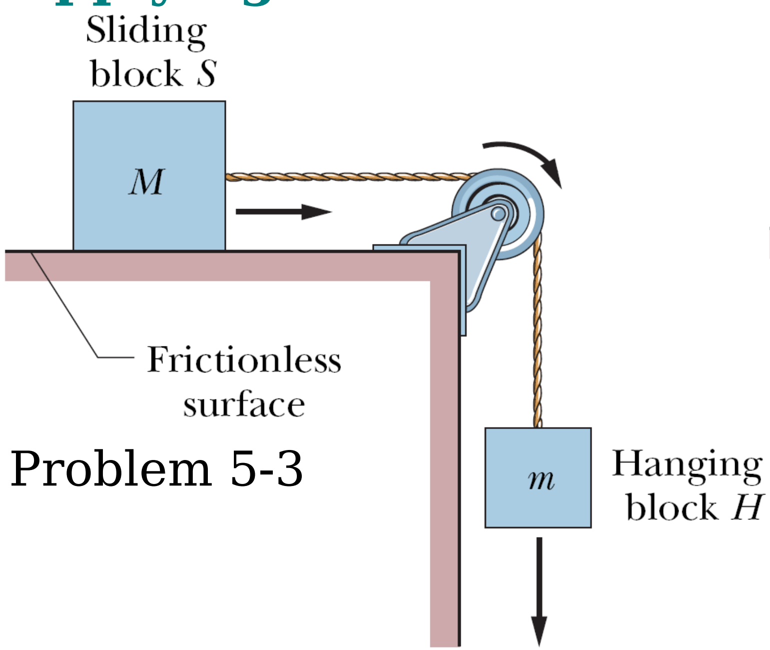
$$\vec{F}_{BC} = -\vec{F}_{CB} \quad \text{equal magnitudes and opposite directions}$$

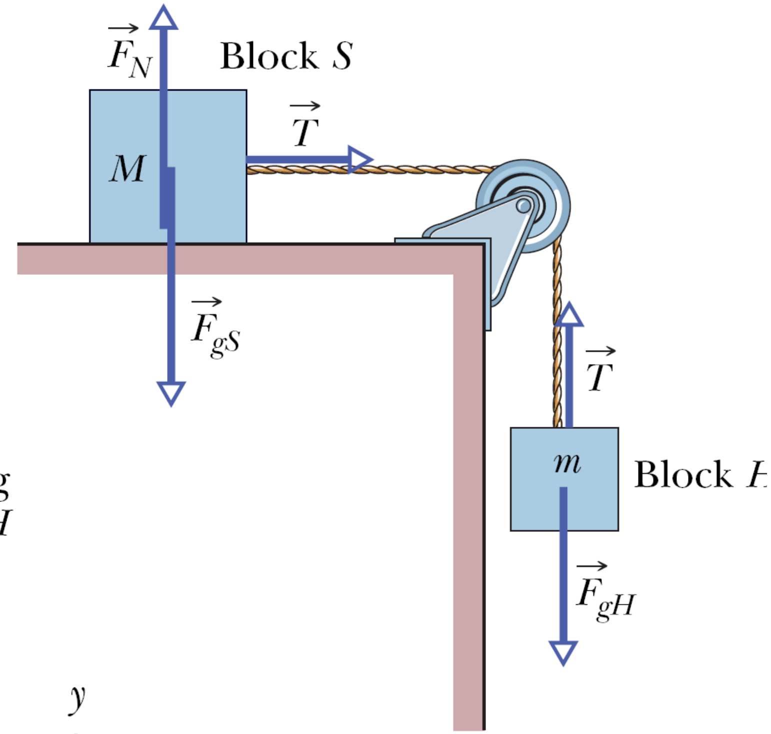
- The forces between 2 interacting bodies are called a **3rd-law force pair**.

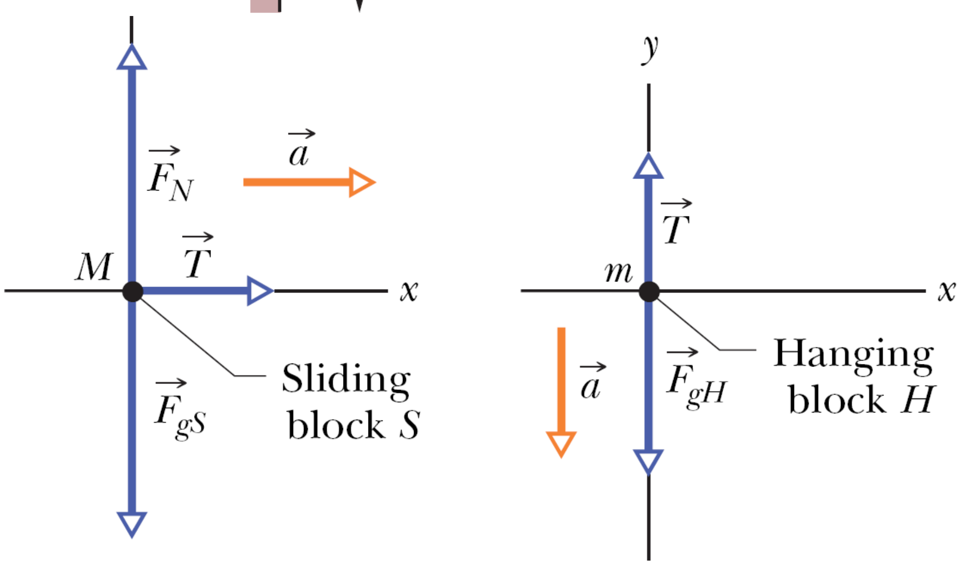


Applying Newton's Laws

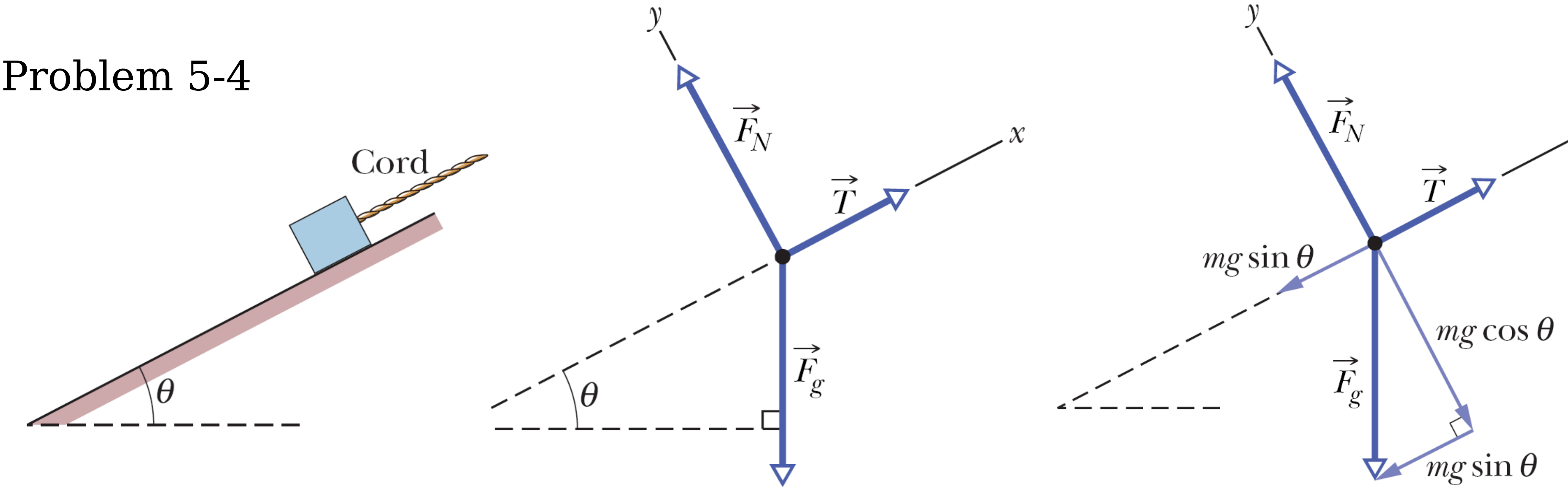
Problem 5-3



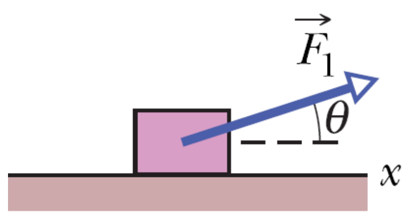




Problem 5-4



problem 5-5



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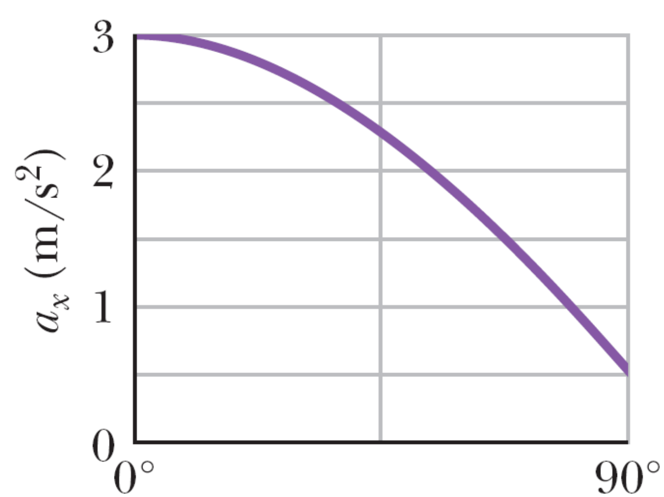
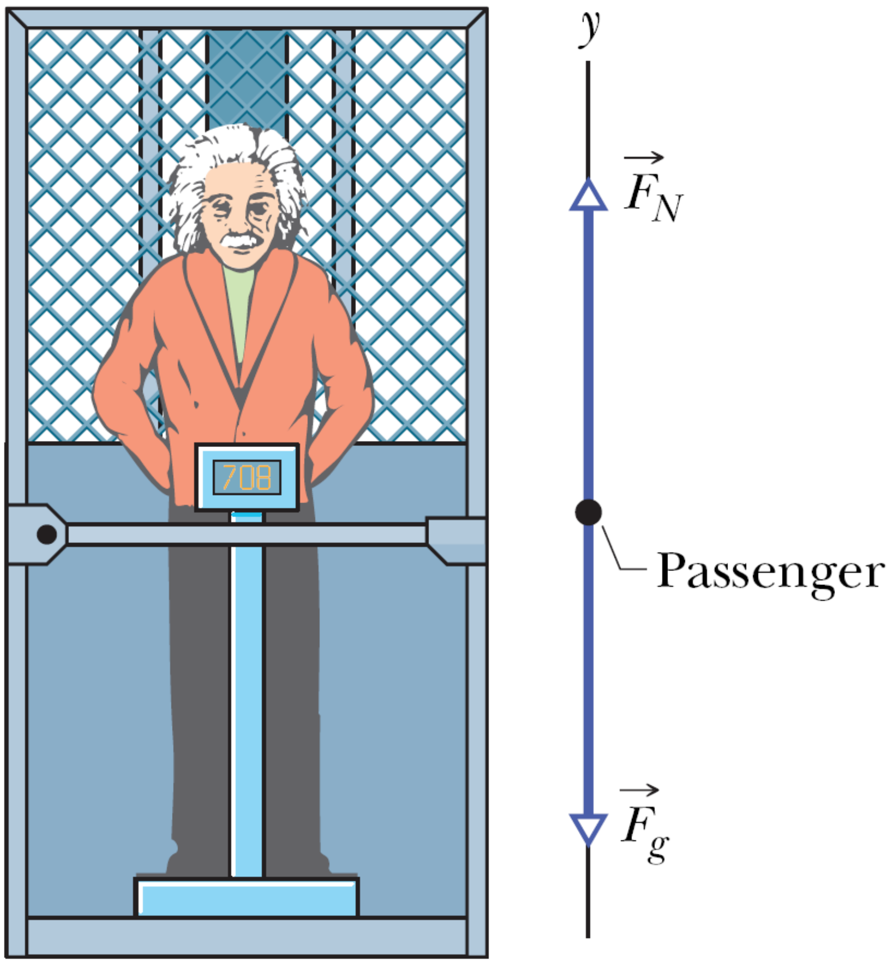
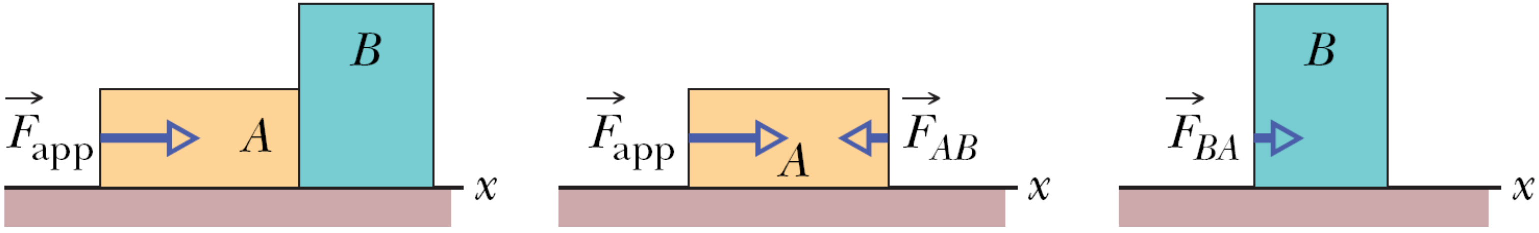


problem 5-6



Problem 5-7



The chosen problems: 16, 50, 64.