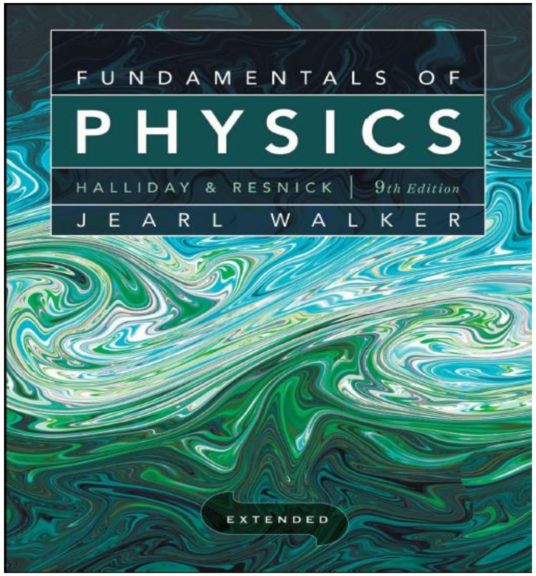
FİZ 137-25
CHAPTER 5

FORCE AND MOTION I



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2018 - 2019

The task of chapters 5 and 6 in which the part of mechanics known as ***“dynamics”*** will be developed.

In chapter 5 we will introduce ***Newton’s three laws of motion*** which is at the heart of classical mechanics.

We must note that Newton’s laws describe physical phenomena of a vast range.

Newton's laws explain the motion of the objects in our daily life; stars and planets. But Newton's laws fail in the following two circumstances:

1. When the speed of objects approaches (0,1 or more) the speed of light in vacuum ($c = 3 \times 10^8$ m/s). In this case we must use Einstein's ***special theory of relativity*** (1905).

2. When the objects under study become very small (e.g. electrons, atoms etc) In this case we must use ***quantum mechanics*** (1926).

Newton's First Law

Scientists before Newton thought that *a force was required in order to keep an object moving at constant velocity*.

An object was though to be in its "***natural state***" when it was at rest.

This mistake was made before ***friction*** was recognized to be a force.

For example, if we slide an object on a floor with an initial speed $\boldsymbol{v_o}$, very soon the object will come to rest.

If on the other hand we slide the same object on a very slippery surface such as ice, the object will travel a much larger distance before it stops.

Newton checked his ideas on the motion of the moon and the planets. In space there is no friction, therefore he was able to determine the correct form of what is since known as: ***"Newton's First Law".***

"Newton's First Law"

If no net force acts on a body, the body's velocity cannot change; that is the body cannot accelerate.

Note: If several forces act on a body (say $\vec{F}_A$, $\vec{F}_B$, and $\vec{F}_C$) the net force $\vec{F}_{net}$ is defined as: $\vec{F}_{net} = \vec{F}_A + \vec{F}_B + \vec{F}_C$ i.e. $\vec{F}_{net}$ is the vector sum of $\vec{F}_A, \vec{F}_B,$ and $\vec{F}_C$

Force

The concept of force was tentatively defined ***as a push or pull exerted on an object***.

We can define a force exerted on an object quantitatively by measuring the ***acceleration*** it causes using the following procedure.

We place an object of mass m = 1 kg on a frictionless surface and measure the acceleration ***a*** that results from the application of a force ***F***.

The force is adjusted so that a = 1 m/s^2.

We then say that F = 1 **newton** (symbol: **N**)

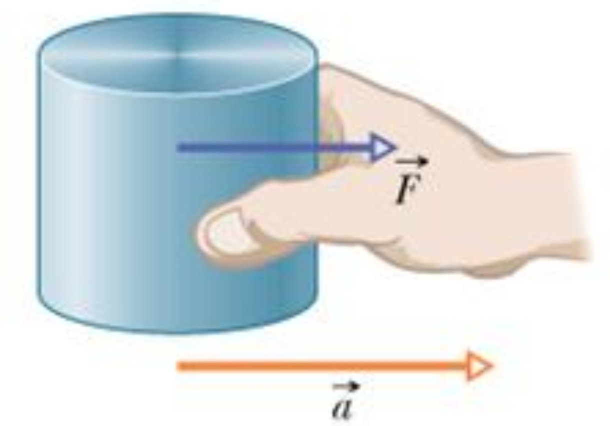


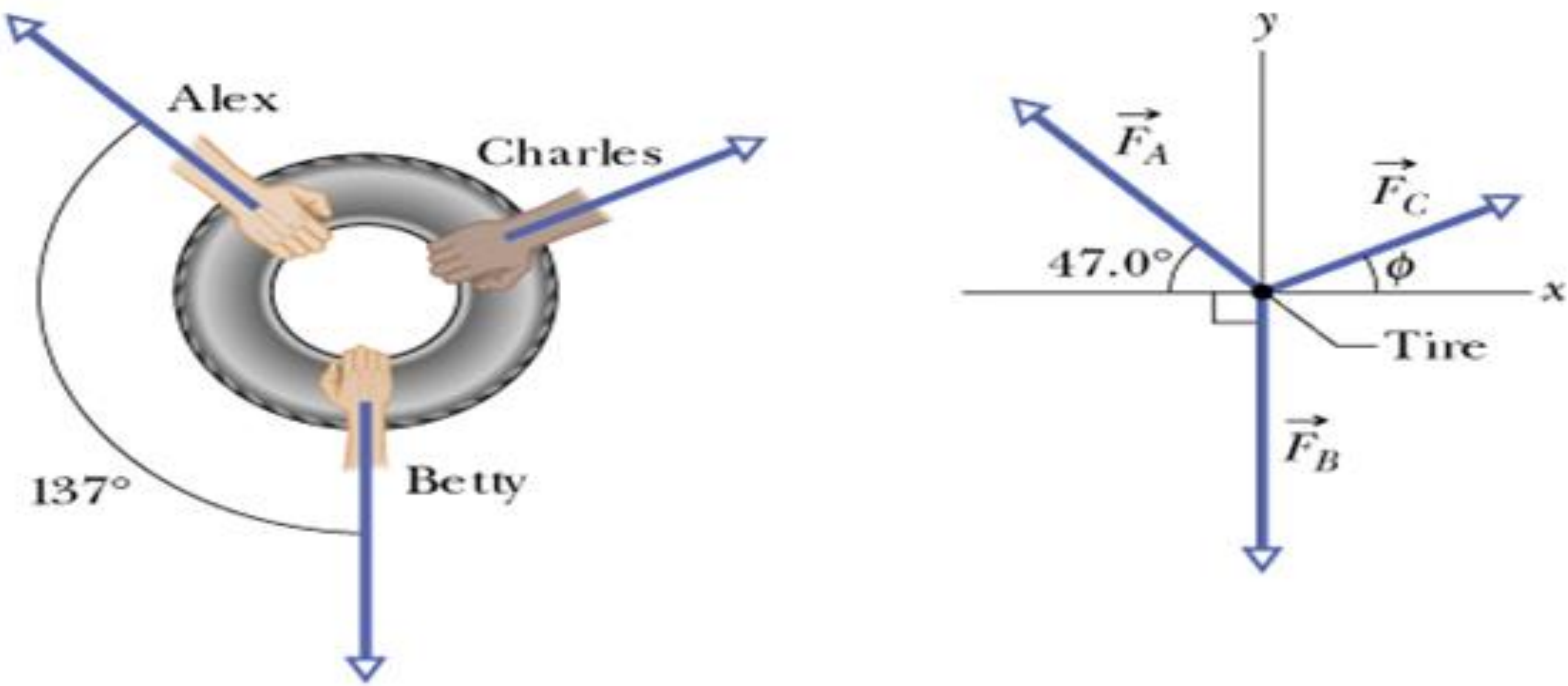
Table 5-1

Units in Newton's Second Law (Eqs. 5-1 and 5-2)

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

[a] $1 \text{ dyne} = 1 \text{ g} \cdot \text{cm/s}^2$.

[b] $1 \text{ lb} = 1 \text{ slug} \cdot \text{ft/s}^2$.



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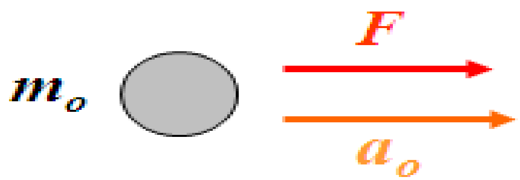
Mass

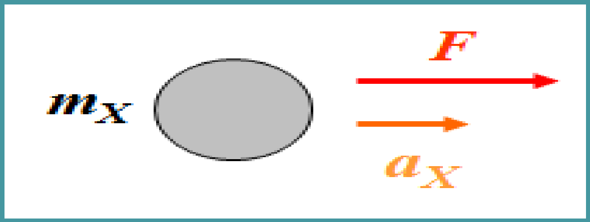
Mass is an ***intrinsic*** characteristic of a body that automatically comes with the existence of the body.

Mass of a body is the characteristic that relates a force ***F*** applied on the body and the resulting *acceleration* ***a***.

Consider that we have a body of mass m_o = 1 kg on which we apply a force F = 1 N. According to the definition of the newton, F causes an acceleration a_o = 1 m/s^2.



We now apply F on a second body of unknown mass m_X which results in an acceleration a_X. The ratio of the accelerations is inversely proportional to the ratio of the masses.



$$\frac{m_X}{m_o} = \frac{a_o}{a_X} \rightarrow m_X = m_o \frac{a_o}{a_X}$$

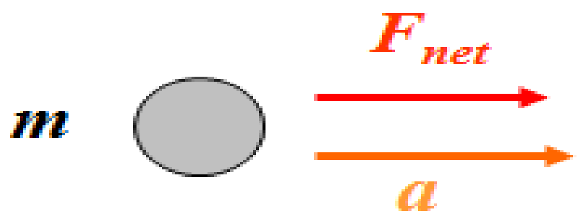
Thus by measuring a_X we are able to determine the mass m_X of any object.

Newton's Second Law

The relations between the net force F_{net} applied on an object of mass m and the resulting acceleration a can be summarized in the following statement known as: ***"Newton's second law".***

The net force on a body is equal to the product of the body's mass and its acceleration

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



In equation form Newton's second law can be written as:

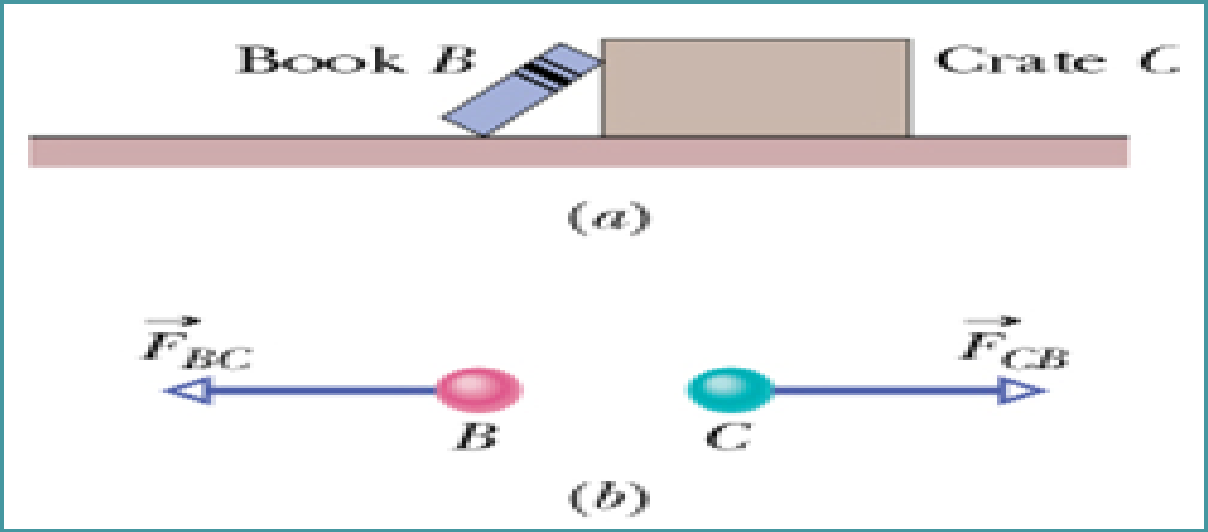
$$\boxed{\vec{F}_{net} = m\vec{a}}$$

The above equation is a compact way of summarizing three separate equations, for each coordinate axis:

$$\boxed{F_{net,x} = ma_x} \qquad \boxed{F_{net,y} = ma_y} \qquad \boxed{F_{net,z} = ma_z}$$

Newton's Third Law

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



For example consider a book leaning against a bookcase. We label $\vec{F}_{BC}$ the force exerted on the book by the case. Using the same convention we label $\vec{F}_{CB}$ the force exerted on the case by the book. Newton's third law can be written as:

$\vec{F}_{BC} = -\vec{F}_{CB}$ The book together with the bookcase are known as a "third-law force pair"

(c)

A second example is shown in the picture to the left.

The third-law pair consists of the earth and a cantaloupe.

Using the same convention as above we can express

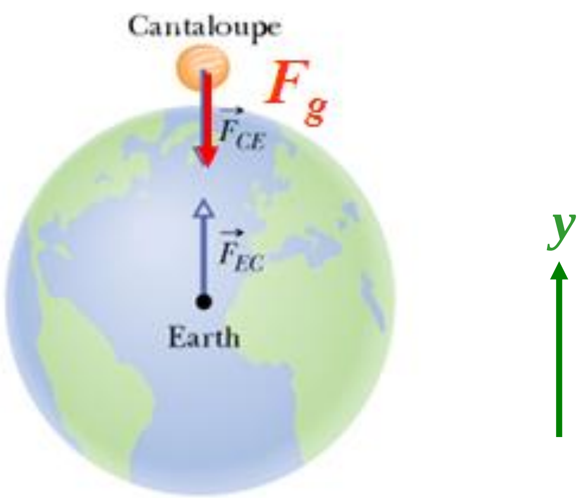
Newton's thir law as: $\vec{F}_{CE} = -\vec{F}_{EC}$

Some Characteristics of Forces Commonly Encounter in Mechanics

1. The Gravitational Force

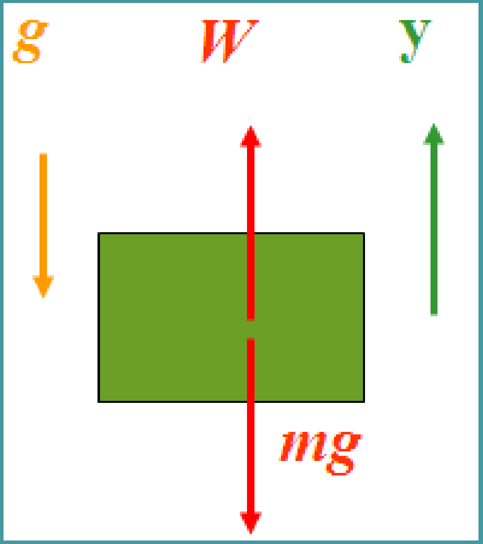
It is the force that the earth exerts on any object. It is directed towards the center of the earth. Its magnitude is given by Newton's second law.

$$\vec{F}_g = m\vec{a} = -mg\hat{j} \qquad \left|\vec{F}_g\right| = mg$$



2. Weight

The weight of a body is defined as the magnitude of the force required to prevent the body from falling freely.



$$F_{net,y} = ma_y = W - mg = 0 \rightarrow W = mg$$

The weight of an object is not its mass.

If the object is moved to a location where the acceleration of gravity is different (e.g. the moon where $g_{moon} = 1.7\ m/s^2$) ***the mass does not change but the weight does!***

3. Contact Forces

These forces act between two objects that are in contact.

The contact forces have two components

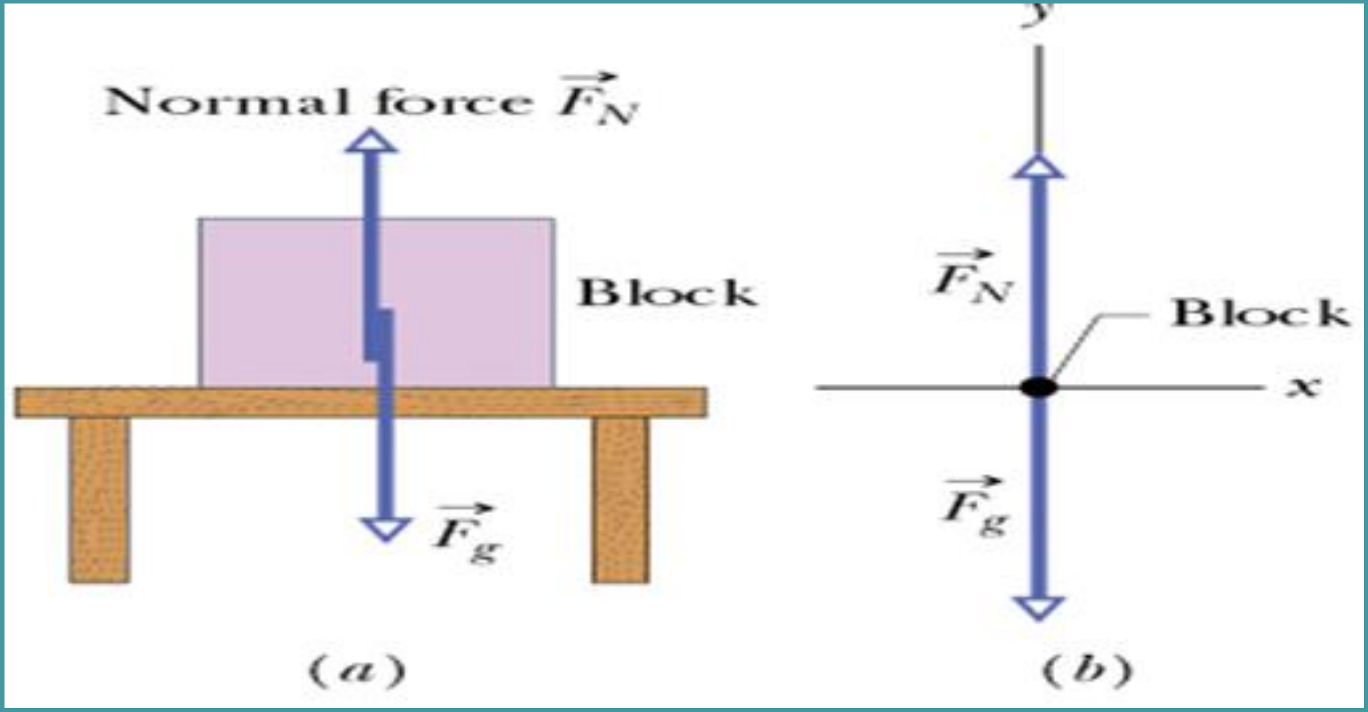
1. That is acting along the normal to the contact surface → **normal force**
2. That is acting parallel to the contact surface → **frictional force**

4. Normal Force

When a body presses against a surface, the surface deforms and pushes on the body with a normal force perpendicular to the contact surface.

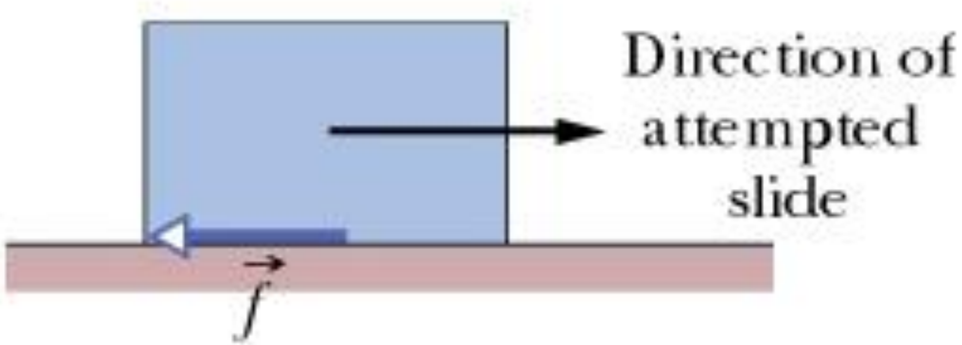
$$F_{net,y} = ma_y = F_N - mg = 0 \rightarrow F_N = mg$$

Note: In this case $F_N = mg$. This is not always the case.

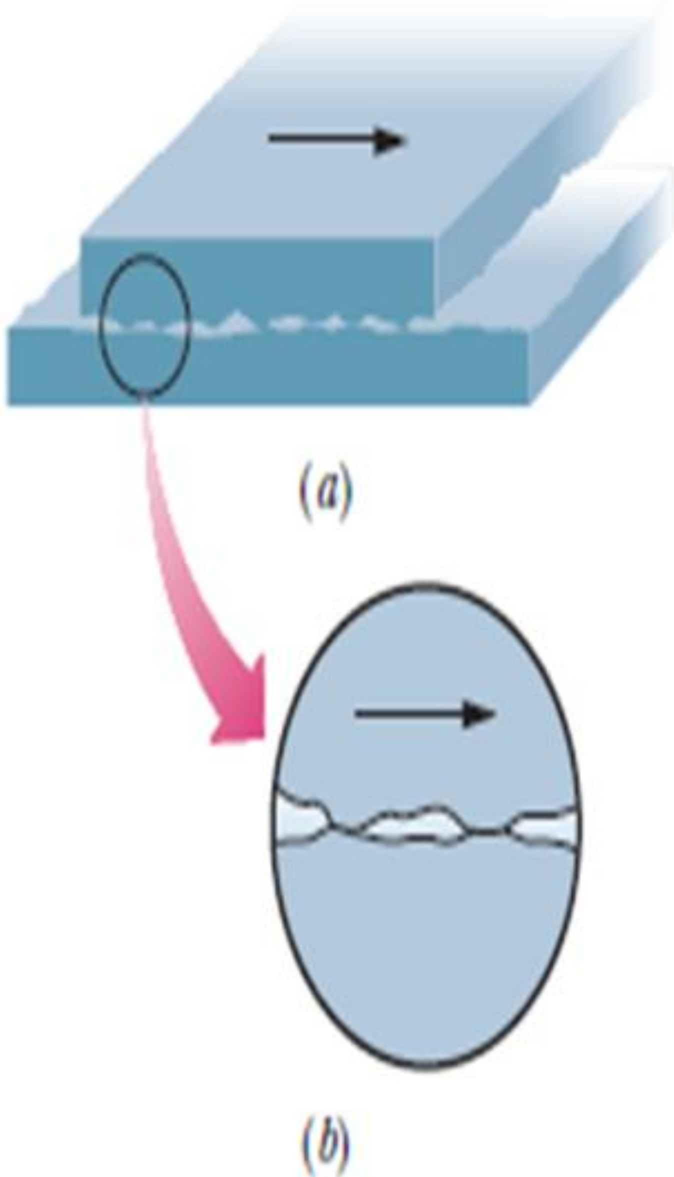


5. Friction

If we slide or attempt to slide an object over a surface, the motion is resisted by a bonding between the object and the surface. This force is known as "friction force".



Frictional Force

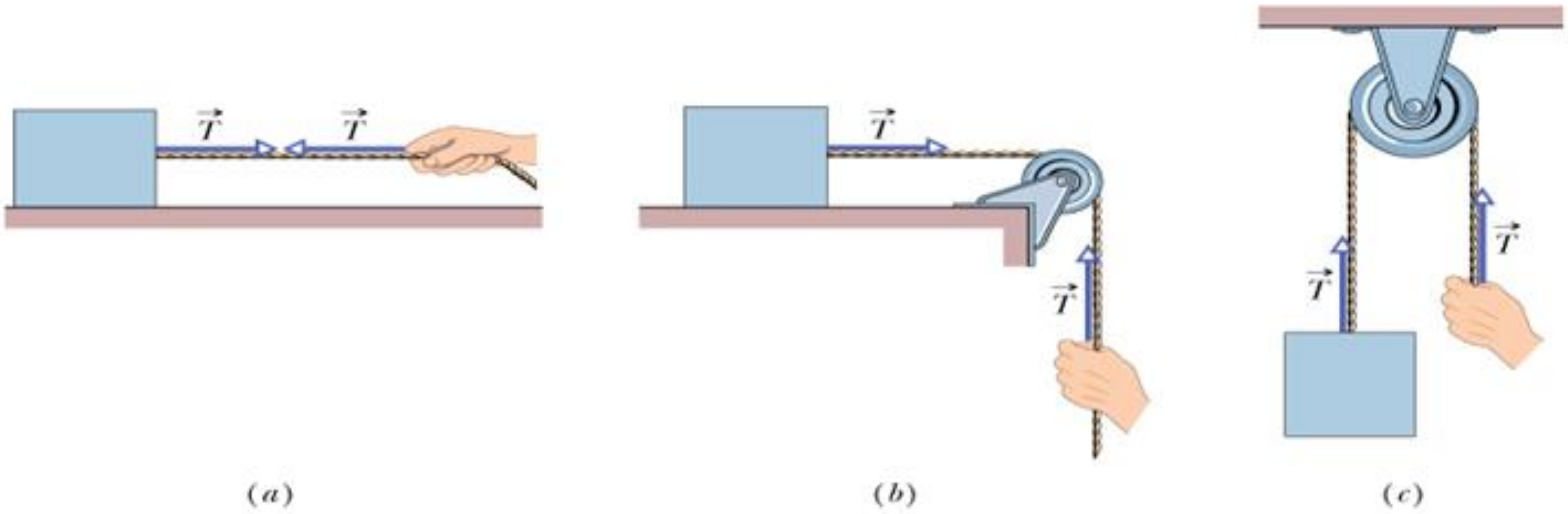


The mechanism of sliding friction. (*a*) The upper surface is sliding to the right over the lower surface in this enlarged view. (*b*) A detail, showing two spots where cold-welding has occurred. Force is required to break the welds and maintain the motion.

6. Tension

This is the force exerted by a rope or a cable attached to an object. Tension has the following characteristics:

1. It is always directed along the rope
2. It is always pulling the object
3. It has the same value along the rope



The following assumptions are made in the definition of tension:

a. The rope has negligible mass compared to the mass of the object it pulls

b. The rope does not stretch.

c. If a pulley is used, we assume that the pulley is massless and frictionless.

Inertial Reference Frames

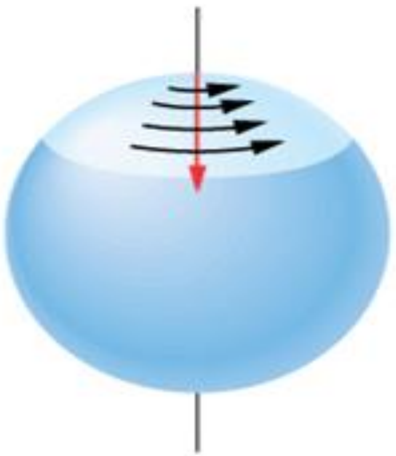
We define a reference frame as "**inertial**" if Newton's three laws of motion hold.

In contrast, reference frames in which Newton's law are not obeyed are labeled "**non-inertial**".

Newton believed that such at least one inertial reference frame ***R*** exists.

Any other inertial frame ***R'*** that moves with **constant velocity** with respect to ***R*** is also an inertial reference frame.

In contrast, a reference frame ***R"*** which **accelerates** with respect to R is a <u>non-inertial reference frame</u>.



The earth rotates about its axis once every 24 hours and thus it is accelerating with respect to an inertial reference frame. Thus we are making an approximation when we consider the earth to be an inertial reference frame. This approximation is excellent for most small scale phenomena. *Nevertheless for large scale phenomena such as global wind systems, this is not the case and corrections to Newton's laws must be used.*

Applying Newton's Laws

Part of the procedure of solving a mechanics problem using Newton's laws is drawing a ***free body diagram.***

This means that among the many parts of a given problem we choose one which we call the ***"system".***

Then we choose axes and enter ***all the forces*** that are acting on the system (omitting those acting on objects that were not included in the system).

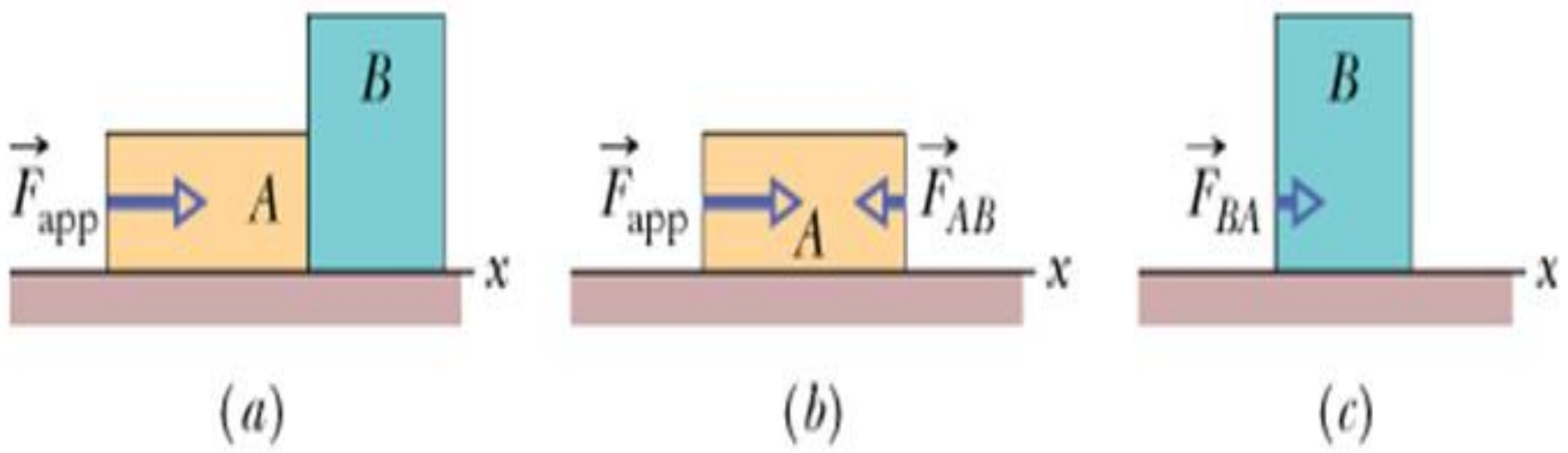
An example is given in the figure below. This is a problem that involves two blocks labeled "A" and "B" on which an external force $\vec{F}_{app}$ is exerted.

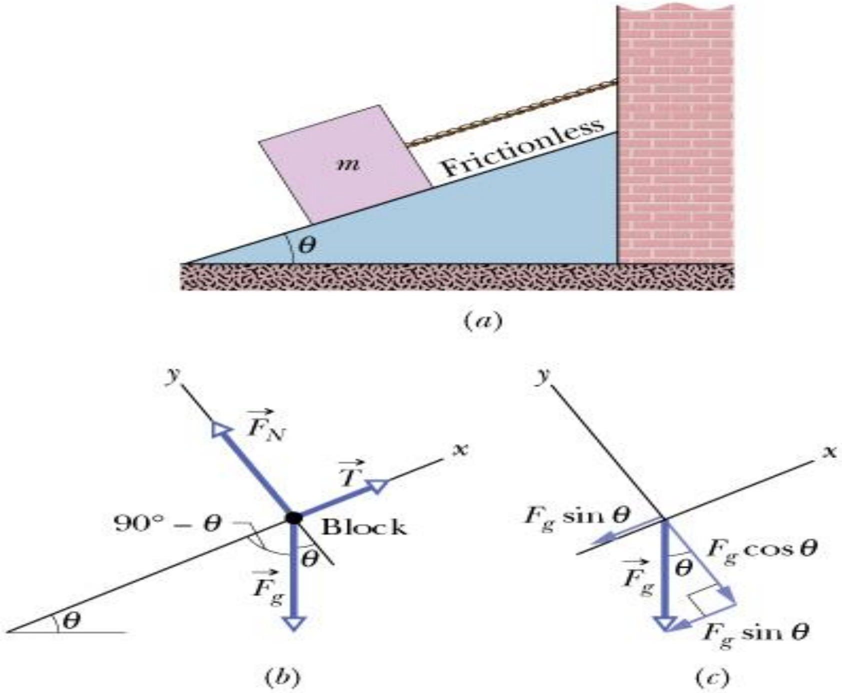
We have the following "system" choices:

a. System = block A + block B. The only horizontal force is $\vec{F}_{app}$

b. System = block A. There are now two horizontal forces: $\vec{F}_{app}$ and $\vec{F}_{AB}$

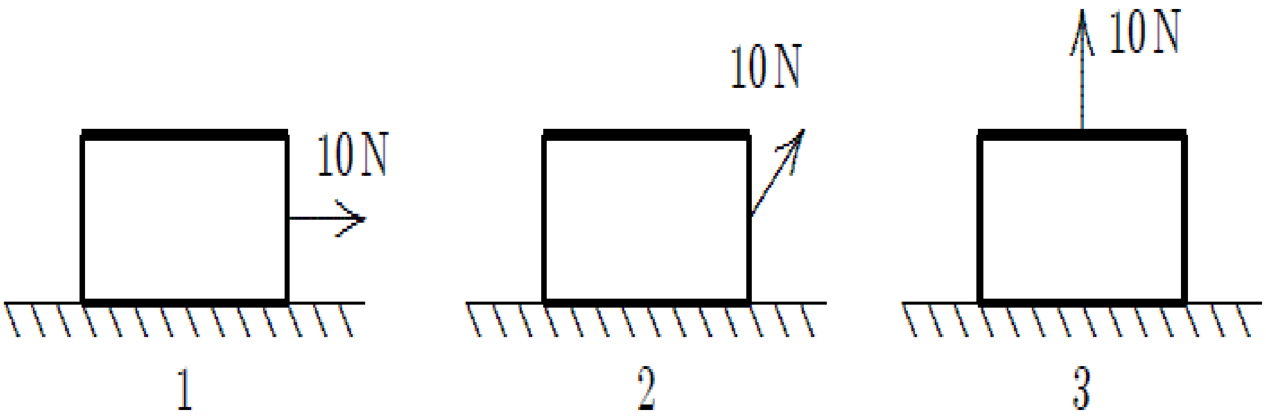
c. System = block B. The only horizontal force is $\vec{F}_{BA}$





1. Choose the system to be studied
2. Make a simple sketch of the system
3. Choose a convenient coordinate system
4. Identify all the forces that act on the system.
5. Apply Newton’s laws of motion to the system

22. A crate rests on a horizontal surface and a woman pulls on it with a 10-N force. Rank the situations shown below according to the magnitude of the normal force exerted by the surface on the crate, least to greatest.



A. 1, 2, 3
B. 2, 1, 3
C. 2, 3, 1
D. 1, 3, 2
E. 3, 2, 1

ans: E

In Fig. 5-17*a*, a passenger of mass $m = 72.2$ kg stands on a platform scale in an elevator cab. We are concerned with the scale readings when the cab is stationary and when it is moving up or down.

(a) Find a general solution for the scale reading, whatever the vertical motion of the cab.

Calculations: Because the two forces on the passenger and his acceleration are all directed vertically, along the y axis in Fig. 5-17*b*, we can use Newton's second law written for y components ($F_{net,y} = ma_y$) to get

$$\boxed{F_N - F_g = ma}$$

or

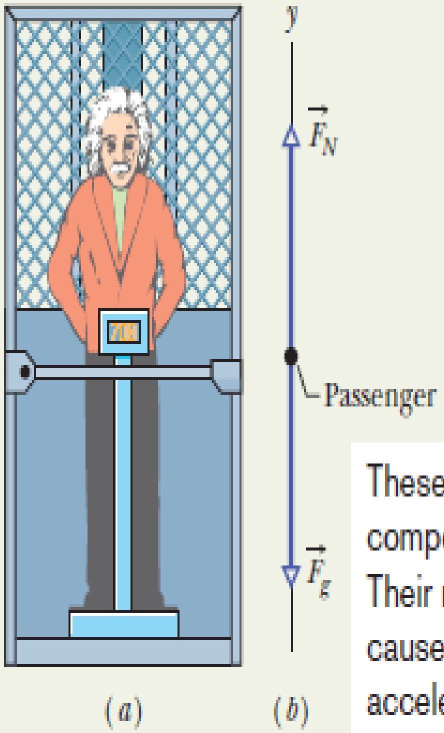
$$F_N = F_g + ma. \qquad (5\text{-}27)$$

This tells us that the scale reading, which is equal to F_N, depends on the vertical acceleration. Substituting mg for F_g gives us

$$\boxed{F_N = m(g + a)} \quad \text{(Answer)} \qquad (5\text{-}28)$$

for any choice of acceleration a.

(b) What does the scale read if the cab is stationary or moving upward at a constant 0.50 m/s?



These forces compete. Their net force causes a vertical acceleration.

Fig. 5-17 (*a*) A passenger stands on a platform scale that indicates either his weight or his apparent weight. (*b*) The free-body diagram for the passenger, showing the normal force $\vec{F}_N$ on him from the scale and the gravitational force $\vec{F}_g$.

41. A man weighing 700 Nb is in an elevator that is accelerating upward at $4\,\mathrm{m/s^2}$. The force exerted on him by the elevator floor is:

A. 71 N

B. 290 N

C. 410 N

D. 700 N

E. 990 N

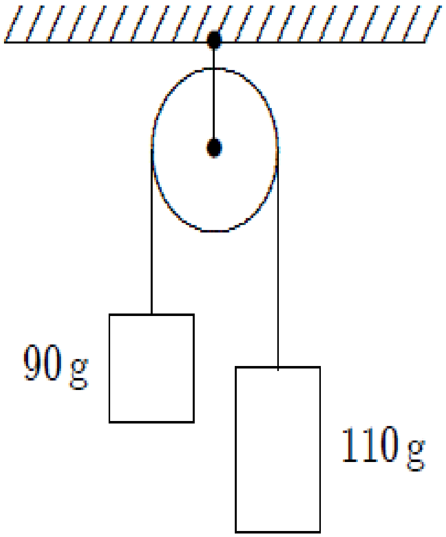
ans: E

49. A 32-N force, parallel to the incline, is required to push a certain crate at constant velocity up a frictionless incline that is 30° above the horizontal. The mass of the crate is:

A. 3.3 kg
B. 3.8 kg
C. 5.7 kg
D. 6.5 kg
E. 160 kg

ans: D

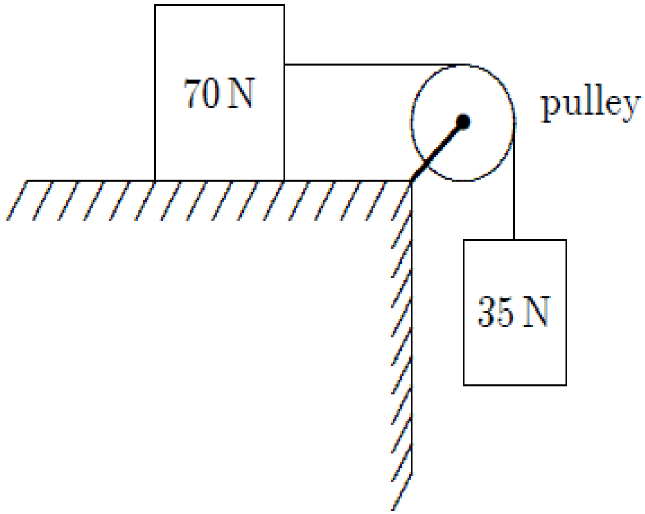
59. Two blocks are connected by a string and pulley as shown. Assuming that the string and pulley are massless, the magnitude of the acceleration of each block is:



A. $0.049\,\mathrm{m/s^2}$
B. $0.020\,\mathrm{m/s^2}$
C. $0.0098\,\mathrm{m/s^2}$
D. $0.54\,\mathrm{m/s^2}$
E. $0.98\,\mathrm{m/s^2}$

ans: E

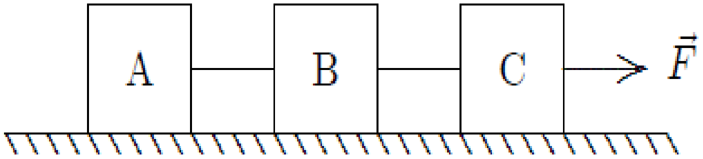
60. A 70-N block and a 35-N block are connected by a string as shown. If the pulley is massless and the surface is frictionless, the magnitude of the acceleration of the 35-N block is:



A. $1.6\,\mathrm{m/s^2}$
B. $3.3\,\mathrm{m/s^2}$
C. $4.9\,\mathrm{m/s^2}$
D. $6.7\,\mathrm{m/s^2}$
E. $9.8\,\mathrm{m/s^2}$

ans: B

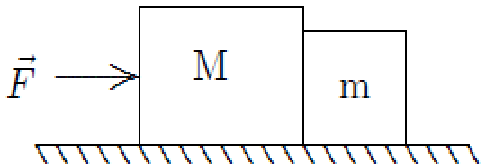
66. Three blocks (A,B,C), each having mass M, are connected by strings as shown. Block C is pulled to the right by a force $\vec{F}$ that causes the entire system to accelerate. Neglecting friction, the net force acting on block B is:



A. zero
B. $\vec{F}/3$
C. $\vec{F}/2$
D. $2\vec{F}/3$
E. $\vec{F}$

ans: B

67. Two blocks with masses m and M are pushed along a horizontal frictionless surface by a horizontal applied force $\vec{F}$ as shown. The magnitude of the force of either of these blocks on the other is:



A. $mF/(m+M)$
B. mF/M
C. $mF/(M-m)$
D. $MF/(M+m)$
E. MF/m

ans: A