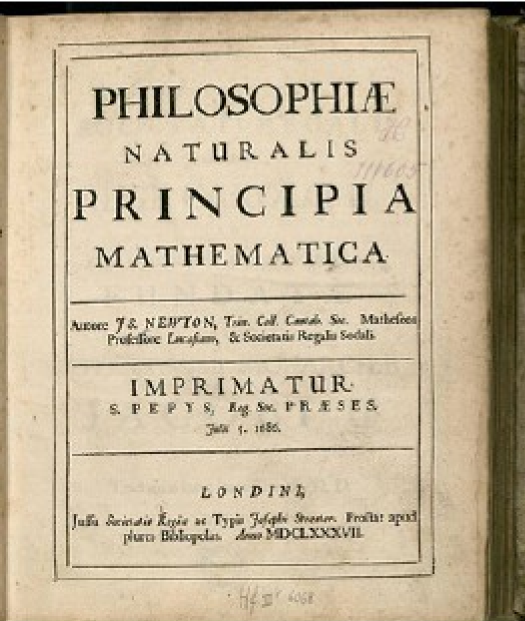
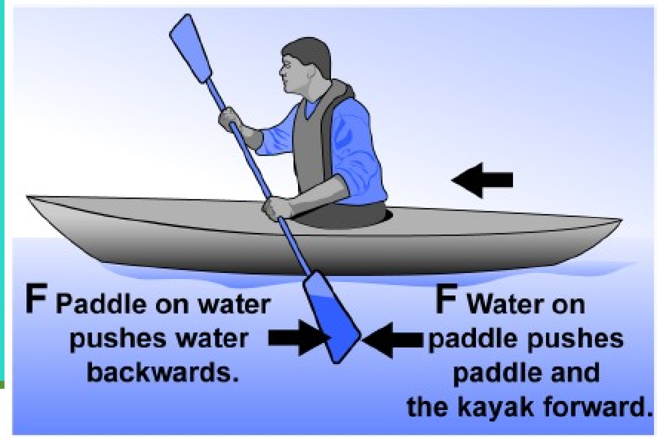
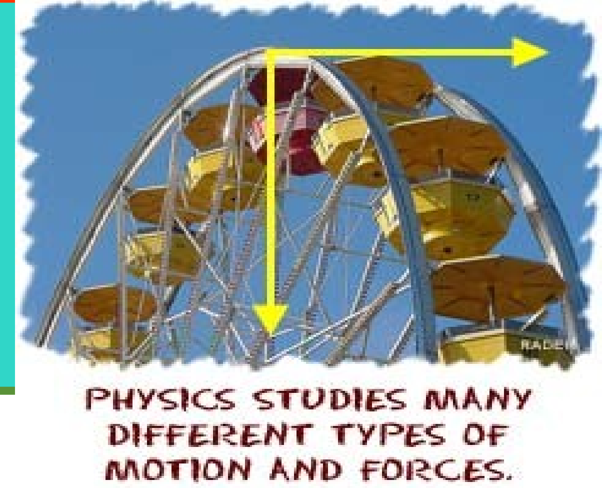
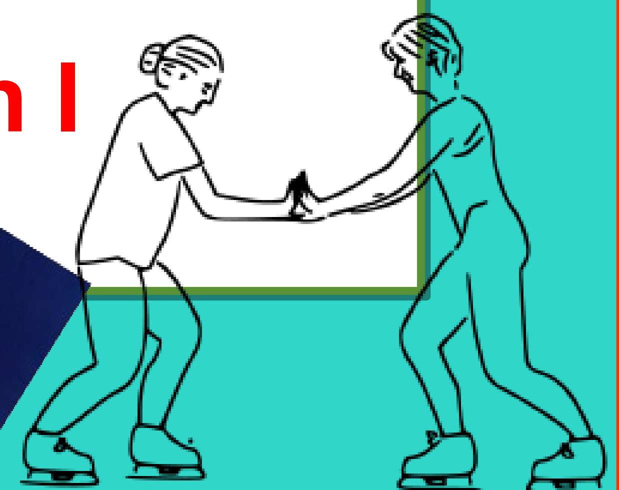


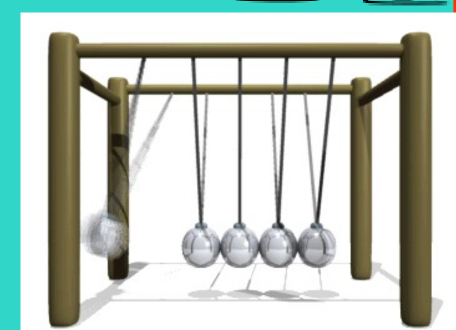




Chapter 5

Force and Motion I





5 FORCE AND MOTION—I 87

5-2 Newtonian Mechanics

- A force is a "push"or "pull" *acting on a object* and causes acceleration.

F ~ a

Mechanics of Particle Motion

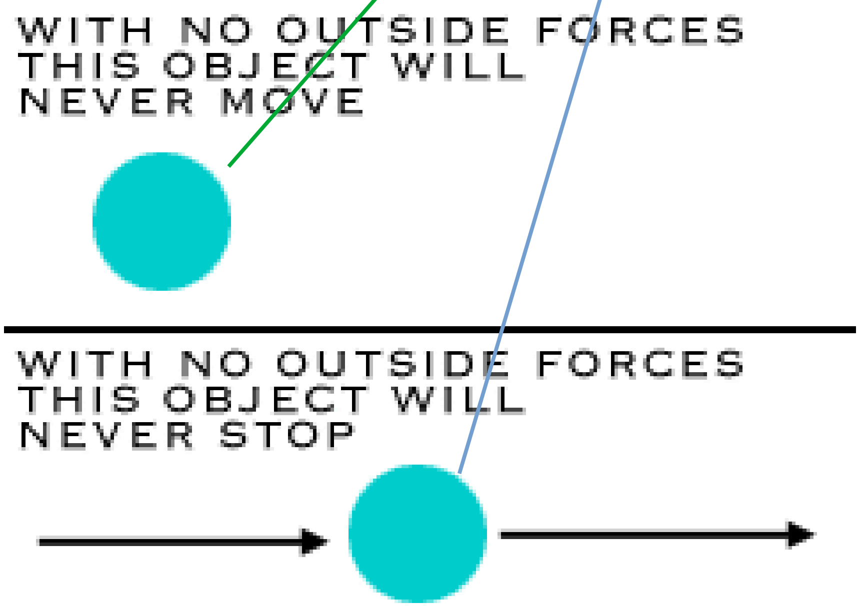
1. Newtonian Mechanics: Study of relation between force and acceleration of a body.
    - Sir Isaac Newton (1642-1727)
    - Three laws relating force and motion.
    - Valid for a wide range of **speed** and **scale** of *interacting bodies*. Valid for our daily life.
    - Newtonian Mechanics does not hold good for all situations!

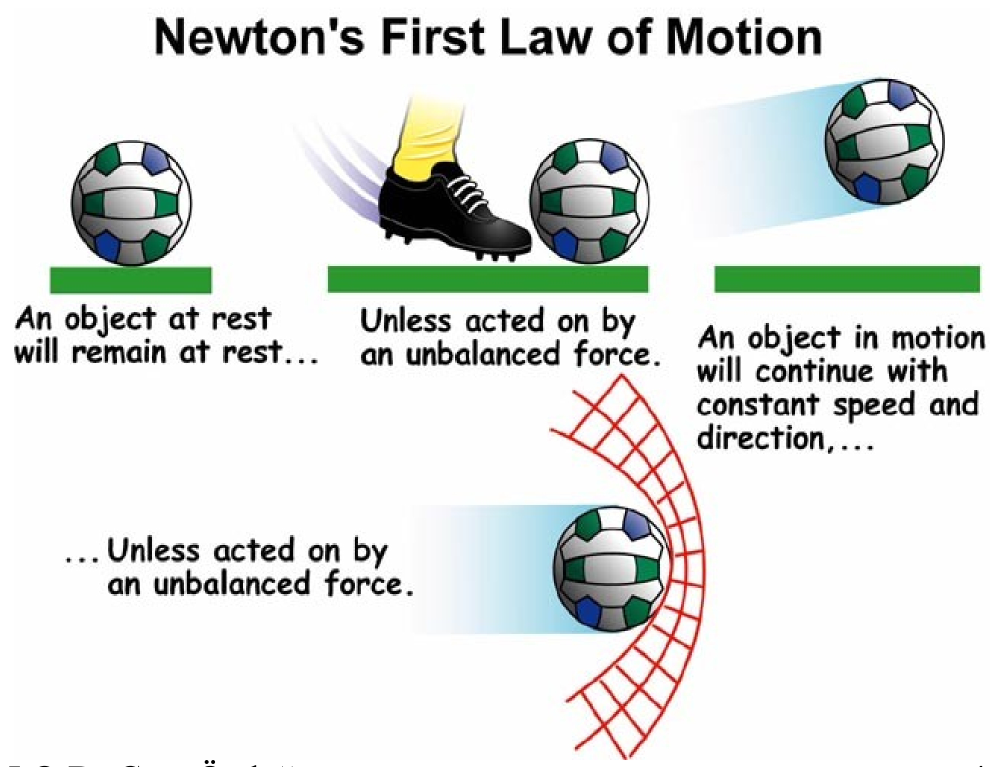
2. Special Theory of Relativity
    - Albert Einstein (1879-1955)
    - Holds for all speed including close to speed of light.
    - Replaces Newtonian Mechanics for *very large speed*.
3. Quantum Mechanics
    - Replaces Newtonian Mechanics for interacting bodies on the *scale of atomic structure (very small)*.

- Before Newtonian mechanics; Some influence (force) was thought necessary to keep a body moving. The "natural state" of objects was at rest.

- A body at rest tends to remain at rest & a body in motion at a constant velocity will tend to maintain the velocity.

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

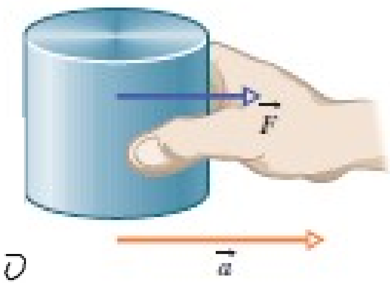




- A **force** is measured by the **acceleration** it produces.
  - – Forces have both *magnitudes* and *directions*.
- Principle of superposition of forces:
  - A net force has the same impact as a single force with identical magnitude and direction.

F_{net} : Sum of forces acting on a body (net force, resultant force)

1 Newton = 1 kg.m/s² (SI)



Newton's First 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.

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

5-5 Mass

- What is mass?
- Mass is the property of an object that measures how hard it is to change its motion. Body's **resistance** to a change in velocity.
  - It is an *intrinsic characteristic* of a body. It is *not* the same as weight, density, size etc.
  - The mass of a body is the characteristic that relates a force on the body to the resulting acceleration (F~a → F=ma).
- The *ratio of the masses* of two bodies is equal to the *inverse of the ratio of their accelerations* when the same force is applied to both.

$$\frac{m_X}{m_0} = \frac{a_0}{a_X}.$$

Example Apply an 8.0 N force to various bodies:

- Mass: 1kg → acceleration: 8 m/s^2
- Mass: 2kg → acceleration: 4 m/s^2
- Mass: 0.5kg → acceleration: 16 m/s^2
- Acceleration: 2 m/s^2 → mass: 4 kg

Newton's Second Law: The net force on a body is equal to the product of the body's mass and its acceleration.

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

- Identify the body in question, and *only* include forces that act *on* that body! Separate the problem axes (they are independent):

$$F_{net,x} = ma_x, \quad F_{net,y} = ma_y, \quad \text{and} \quad F_{net,z} = ma_z.$$

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.

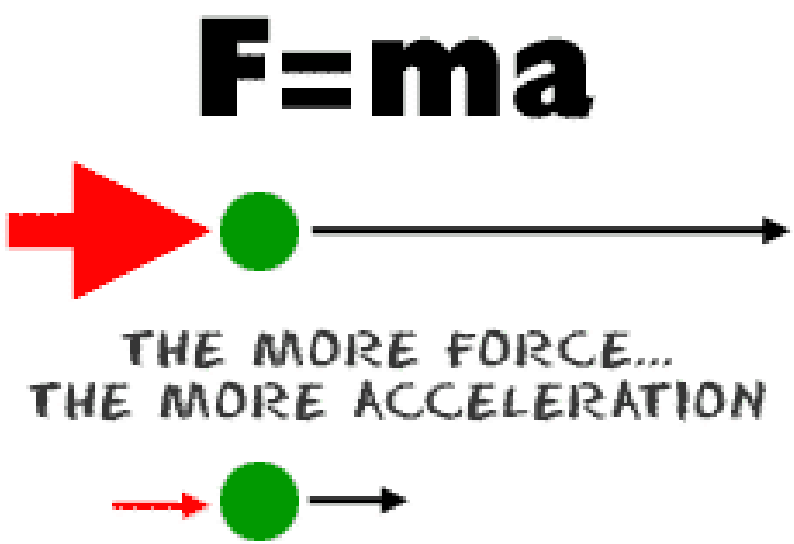


TABLE 5-1

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

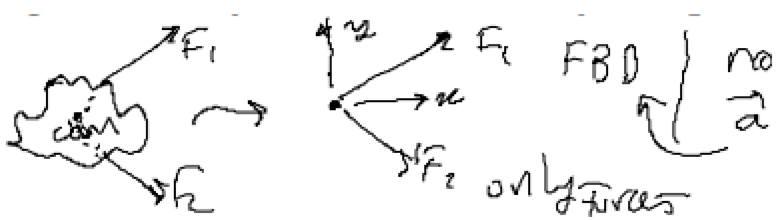
[a] $1\ \text{dyne} = 1\ g \cdot cm/s^2$.
[b] $1\ \text{lb} = 1\ \text{slug} \cdot ft/s^2$.

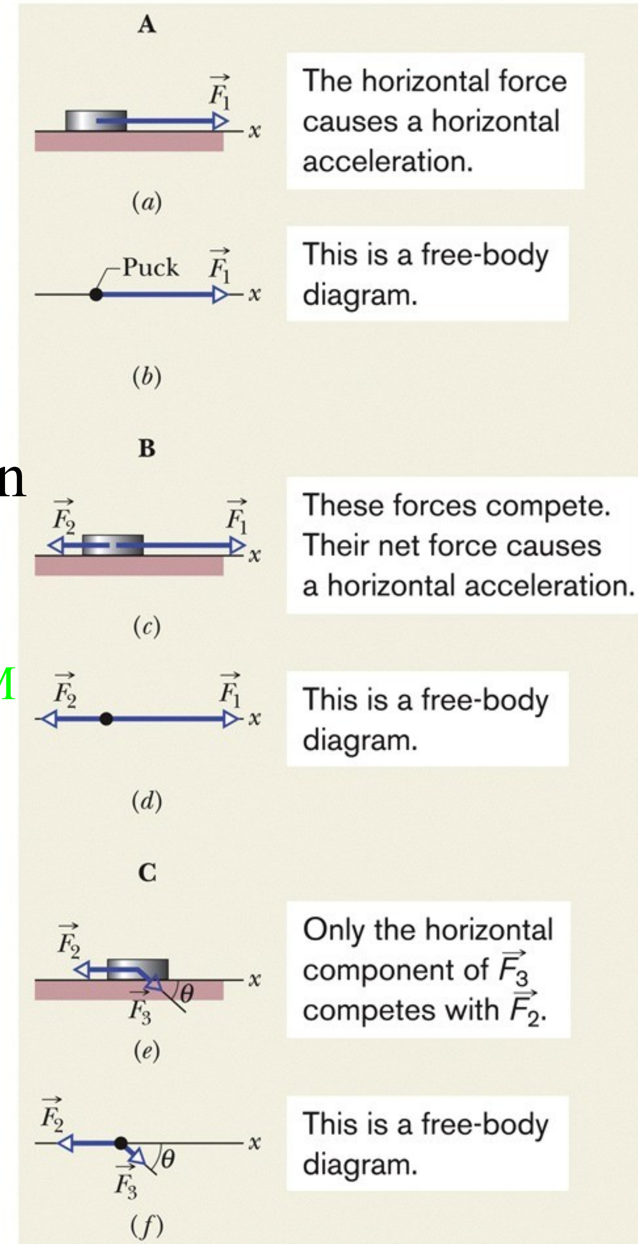
- If the net force on a body is zero:
  - Its acceleration is zero
  - The forces and the body are in *equilibrium*
  - *But* there may still be forces!

statics

- In a **free-body diagram**, the only body shown is the one for which we are summing forces.
  - Each force on the body is drawn as a vector arrow with its tail on the body.
  - A coordinate system is usually included.
  - Acceleration is NEVER part of a free body diagram - only forces on a body are present.

COM





Example:

Parts A, B, and C of Fig. 5-3 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 $\vec{F}_1$ and $\vec{F}_2$ are directed along the axis and have magnitudes $F_1 = 4.0$ N and $F_2 = 2.0$ N. Force $\vec{F}_3$ is directed at angle $\theta = 30°$ and has magnitude $F_3 = 1.0$ N. In each situation, what is the acceleration of the puck?

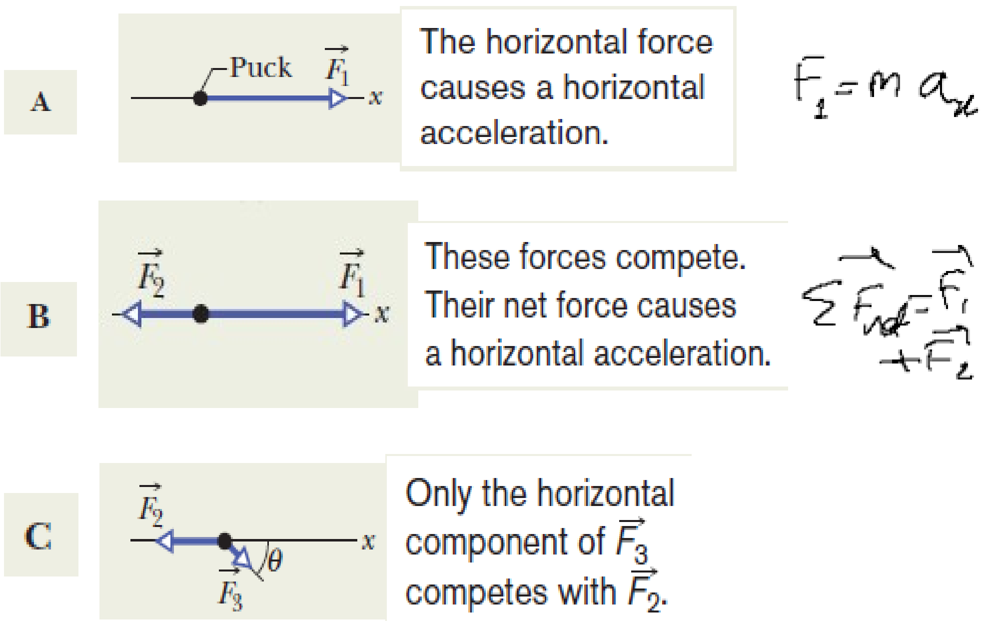


Fig. 5-3 In three situations, forces act on a puck that moves along an x axis.

Situation A: For Fig. 5-3*b*, where only one horizontal force acts, Eq. 5-4 gives us

$$F_1 = ma_x,$$

which, with given data, yields

$$a_x = \frac{F_1}{m} = \frac{4.0\text{ N}}{0.20\text{ kg}} = 20\text{ m/s}^2. \qquad \text{(Answer)}$$

The positive answer indicates that the acceleration is in the positive direction of the x axis.

Situation B: In Fig. 5-3*d*, two horizontal forces act on the puck, $\vec{F}_1$ in the positive direction of x and $\vec{F}_2$ in the negative direction. Now Eq. 5-4 gives us

$$F_1 - F_2 = ma_x,$$

which, with given data, yields

$$a_x = \frac{F_1 - F_2}{m} = \frac{4.0\text{ N} - 2.0\text{ N}}{0.20\text{ kg}} = 10\text{ m/s}^2. \qquad \text{(Answer)}$$

Thus, the net force accelerates the puck in the positive direction of the x axis.

Situation C: In Fig. 5-3*f*, force $\vec{F}_3$ is not directed along the direction of the puck's acceleration; only x component $F_{3,x}$ is. (Force $\vec{F}_3$ is two-dimensional but the motion is only one-dimensional.) Thus, we write Eq. 5-4 as

$$F_{3,x} - F_2 = ma_x. \qquad (5\text{-}5)$$

From the figure, we see that $F_{3,x} = F_3 \cos\theta$. Solving for the acceleration and substituting for $F_{3,x}$ yield

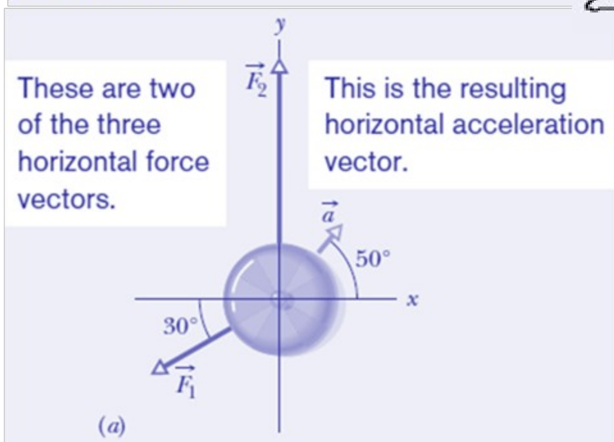
$$a_x = \frac{F_{3,x} - F_2}{m} = \frac{F_3\cos\theta - F_2}{m}$$

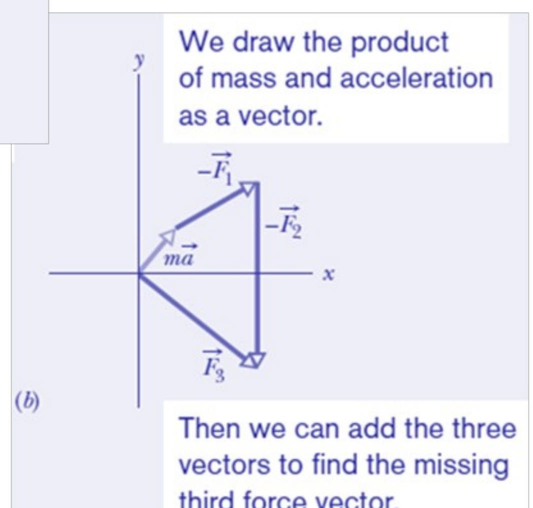
$$= \frac{(1.0\text{ N})(\cos 30°) - 2.0\text{ N}}{0.20\text{ kg}} = -5.7\text{ m/s}^2. \qquad \text{(Answer)}$$

Example:

In the overhead view of Fig. 5-4*a*, a 2.0 kg cookie tin is accelerated at 3.0 m/s^2 in the direction shown by $\vec{a}$, over a frictionless horizontal surface. The acceleration is caused by three horizontal forces, only two of which are shown: $\vec{F}_1$ of magnitude 10 N and $\vec{F}_2$ of magnitude 20 N. What is the third force $\vec{F}_3$ in unit-vector notation and in magnitude-angle notation?

$$\Sigma \vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 = m\vec{a}$$





KEY IDEA

The net force $\vec{F}_{net}$ on the tin is the sum of the three forces and is related to the acceleration $\vec{a}$ via Newton's second law ($\vec{F}_{net} = m\vec{a}$). Thus,

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 = m\vec{a},$$

which gives us

$$\vec{F}_3 = m\vec{a} - \vec{F}_1 - \vec{F}_2.$$

Calculations:

***x* components:** Along the *x* axis we have

$$F_{3,x} = ma_x - F_{1,x} - F_{2,x}$$
$$= m(a\cos 50°) - F_1\cos(-150°) - F_2\cos 90°.$$

Then, substituting known data, we find

$$F_{3,x} = (2.0\ \text{kg})(3.0\ \text{m/s}^2)\cos 50° - (10\ \text{N})\cos(-150°) - (20\ \text{N})\cos 90°$$
$$= 12.5\ \text{N}.$$

***y* components:** Similarly, along the *y* axis we find

$$F_{3,y} = ma_y - F_{1,y} - F_{2,y}$$
$$= m(a\sin 50°) - F_1\sin(-150°) - F_2\sin 90°$$
$$= (2.0\ \text{kg})(3.0\ \text{m/s}^2)\sin 50° - (10\ \text{N})\sin(-150°) - (20\ \text{N})\sin 90°$$
$$= -10.4\ \text{N}.$$

Vector: In unit-vector notation, we can write

$$\vec{F}_3 = F_{3,x}\hat{i} + F_{3,y}\hat{j} = (12.5\ \text{N})\hat{i} - (10.4\ \text{N})\hat{j}$$
$$\approx (13\ \text{N})\hat{i} - (10\ \text{N})\hat{j}. \qquad \text{(Answer)}$$

We can now use a vector-capable calculator to get the magnitude and the angle of $\vec{F}_3$. We can also use Eq. 3-6 to obtain the magnitude and the angle (from the positive direction of the *x* axis) as

$$F_3 = \sqrt{F_{3,x}^2 + F_{3,y}^2} = 16\ \text{N}$$

and

$$\theta = \tan^{-1}\frac{F_{3,y}}{F_{3,x}} = -40°. \qquad \text{(Answer)}$$

1) The Gravitational Force:

A gravitational force on a body is a certain type of pull that is directed toward a second body.

EARTH!

$$-F_g = m(-g) \quad \text{or } F_g = mg.$$

$$\vec{F}_g = -F_g\hat{j} = -mg\hat{j} = m\vec{g}.$$

2) Weight:

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

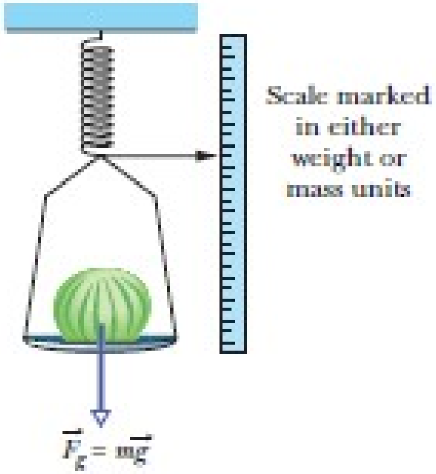
$$F_{net,y} = ma_y.$$

$$W - F_g = m(0)$$

or

$$W = F_g \quad \text{(weight, with ground as inertial frame).}$$

$$W = mg \text{ (weight)},$$



CAUTION: A body's weight is not its mass!

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

3) Normal Force: (Normal means perpendicular)

~ Normal vector

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

In the figure: <u>Newton's second law says for a positive-upward *y axis:*</u>

($F_{net,\,y} = ma_y$), as:

$$F_N - F_g = ma_y.$$

$$F_N - mg = ma_y.$$

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

For any vertical acceleration a_y of the table and block.

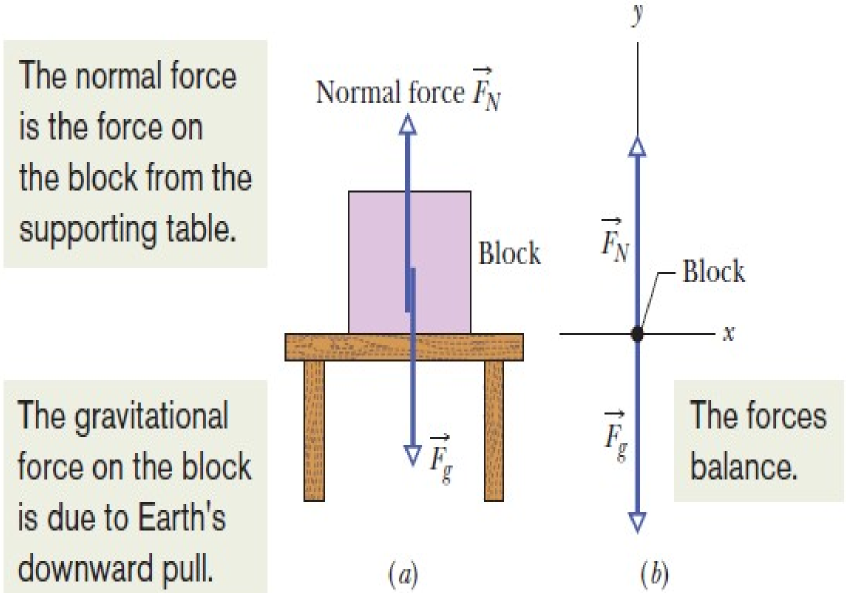


Fig. 5-7 (a) A block resting on a table experiences a normal force perpendicular to the tabletop. (b) The free-body diagram for the block.

$$\Sigma \vec{F}_{net,y} = \vec{F}_N + \vec{F}_g = ma_y$$

$$F_N - F_g = 0$$

$$F_N = F_g$$

4) Friction: motion no motion yet

- If we either slide or attempt to slide a body over a surface, the motion is resisted by a bonding between the body and the surface.
- The force **f** is either called frictional force or simply friction. Directed along the surface, opposite to the direction of intended motion.

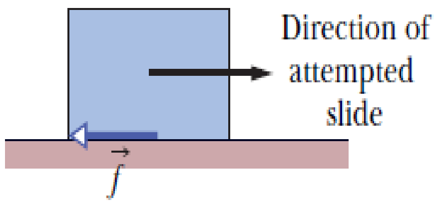


Fig. 5-8 A frictional force $\vec{f}$ opposes the attempted slide of a body over a surface.

- Sometimes, to simplify a stiuation, friction is assumed to be negligible. (So the surface is frictionless.)

5) Tension

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

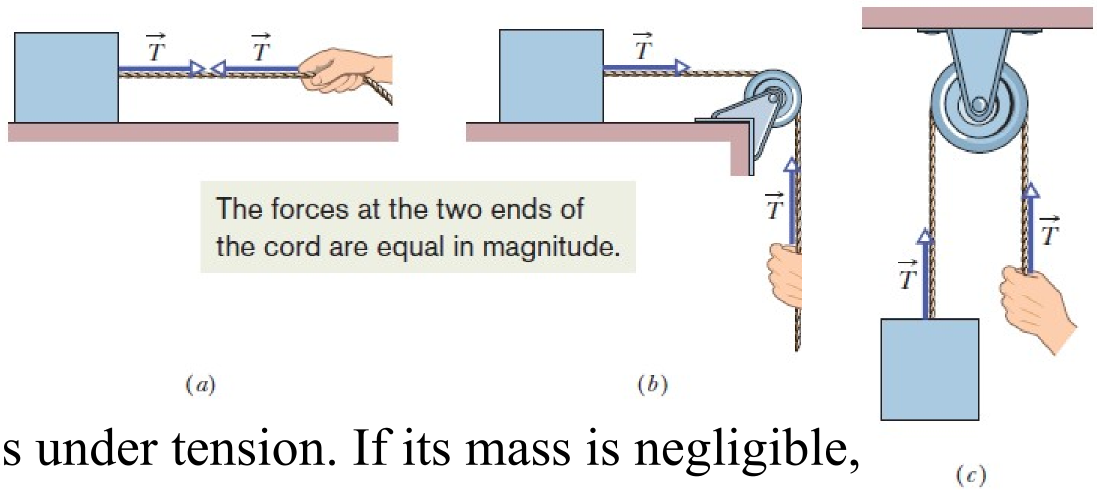


Fig. 5-9 (a) The cord, pulled taut, is under tension. If its mass is negligible, the cord pulls on the body and the hand with force **T**, even if the cord runs around a massless, frictionless pulley as in (b) and (c).

5-8 Newton's Third Law: Symmetry in Forces

- When <u>two bodies interact</u>, the forces on the bodies from each other are always <u>equal in magnitude and opposite in direction</u> and collinear.

For the book and crate, we can write this law as the scalar relation

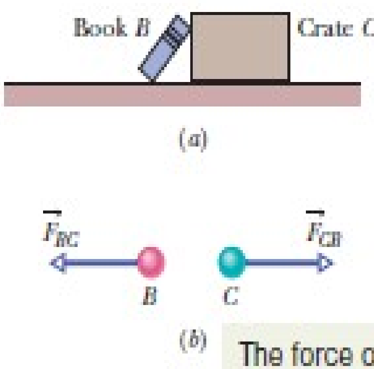
$$F_{BC} = F_{CB} \quad \text{(equal magnitudes)}$$

or as the vector relation

$$|F_{BC}| = |F_{CB}|$$

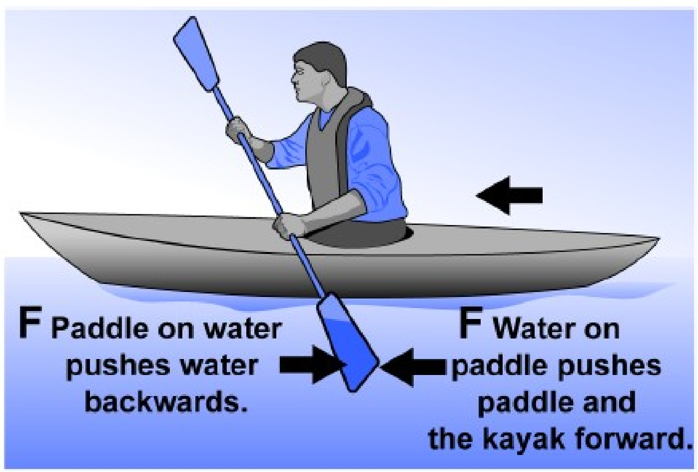
$$\vec{F}_{BC} = -\vec{F}_{CB} \quad \text{(equal magnitudes and opposite directions)},$$

same direction!?



The force on B due to C has the same magnitude as the force on C due to B.

- The forces between two interacting bodies are called a **third-law force pair.**



$$|F_{PW}| = |F_{WP}|$$

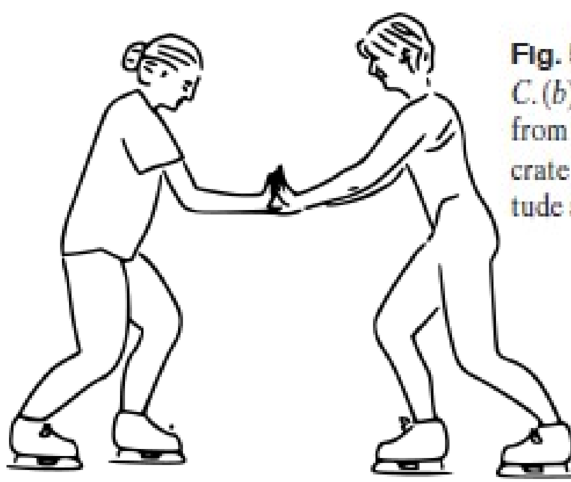


Fig. 5-10 (*a*) Book *B* leans against crate *C*. (*b*) Forces $\vec{F}_{BC}$ (the force on the book from the crate) and $\vec{F}_{CB}$ (the force on the crate from the book) have the same magnitude and are opposite in direction.

1) Suppose you are an astronaut in outer space giving a brief push to a spacecraft whose mass is bigger than your own. Compare the magnitude of the force you exert on the spacecraft, F_S, to the magnitude of the force exerted by the spacecraft on you, F_A, while you are pushing:

1. $F_A = F_S$ ← correct
2. $F_A > F_S$
3. $F_A < F_S$

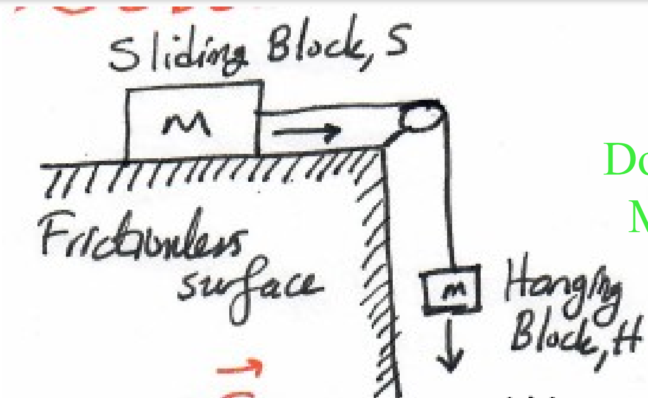
Third Law!

2) Compare the magnitudes of the acceleration you experience, a_A, to the magnitude of the acceleration of the spacecraft, a_S, while you are pushing:

1. $a_A = a_S$
2. $a_A > a_S$ ← correct
3. $a_A < a_S$

a=F/m

(F same ⇒ lower mass gives larger a)



$M = 3.3$ kg

$m = 2.1$ kg

Find

i) acceleration of block, S

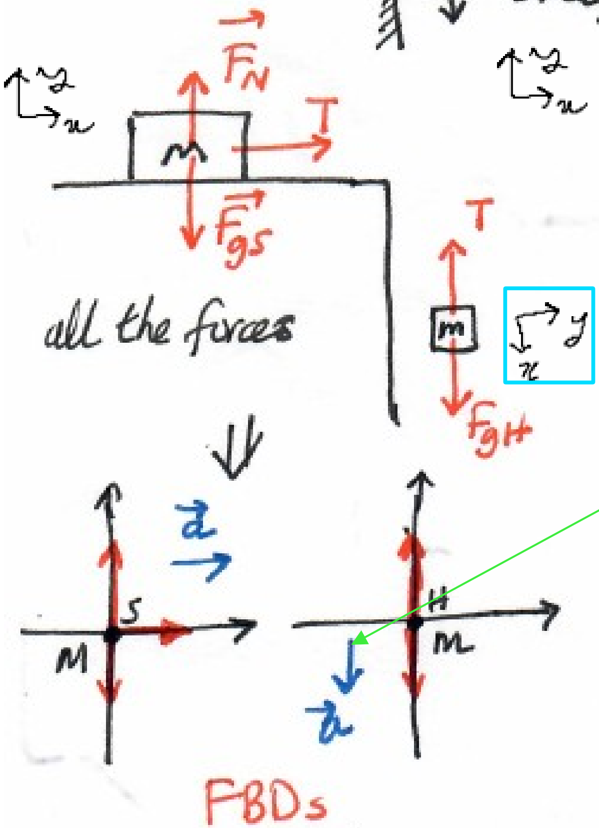
ii) " " " , H

iii) the tension in the cord

Do we have a MOTION?

First step → FBDs: draw for all masses & directions

Second step → decide coordinate systems



	M	m
y:	$F_N - F_{gS} = Ma_{yM}$	$T - F_{gH} = ma_{ym}$
x:	$T = Ma_{xM}$	

Simultaneous equations.

Good one: a_{xM}, a_{ym} are common for all the masses.

$a_{xM} = a_{ym} \equiv a$

① $F_N - Mg = 0$ ③ $T - mg = -ma$

② $T = Ma$

②&③ $Ma - mg = -ma$ $\left\{ \boxed{a = \frac{mg}{M+m} = 3.8\ \mathrm{m/s^2}} \right.$ i, ii

$\boxed{T = \frac{Mm}{M+m} g = 13\ \mathrm{N}}$ iii

check

$2.1\ \mathrm{kg} \times 9.8\ \mathrm{m/s^2} > 13\ \mathrm{N}$

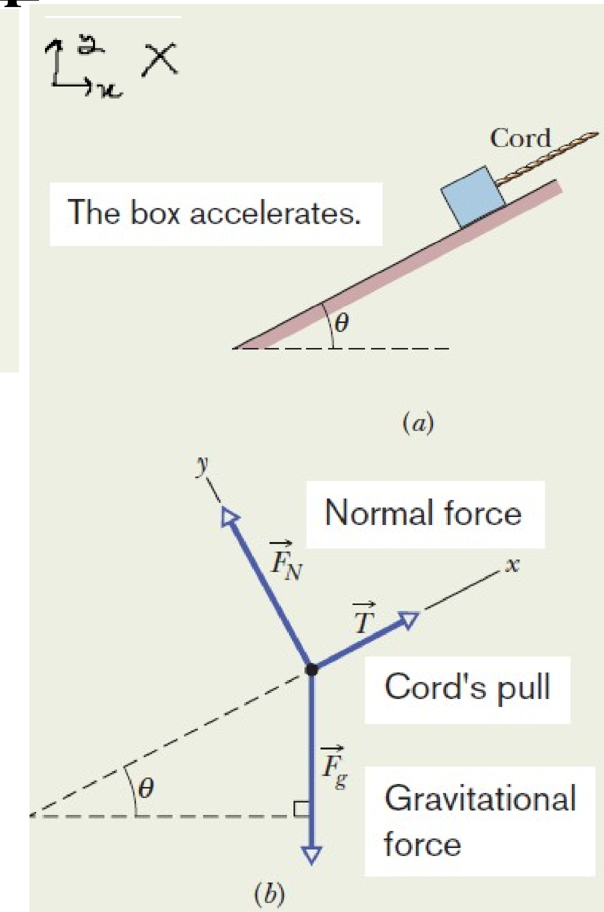
⇒ Downward motion

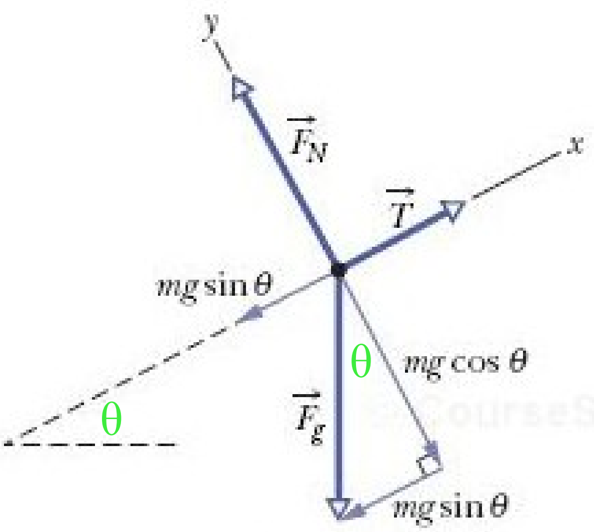
$F_{gH} - T = +ma_{xm}$

Same with previous one as multiplied by minus sign

Example : Cord accelerates block up a ramp

In Fig. 5-15*a*, a cord pulls on a box of sea biscuits up along a frictionless plane inclined at $\theta = 30°$. The box has mass $m = 5.00$ kg, and the force from the cord has magnitude $T = 25.0$ N. What is the box's acceleration component a along the inclined plane?





(c)

Using Newton's Second Law, we have :

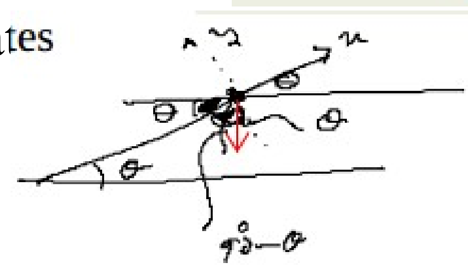
$$T - mg \sin\theta = ma.$$

which gives: $a = 0.100 \text{ m/s}^2,$

The positive result indicates that the box accelerates up the plane.

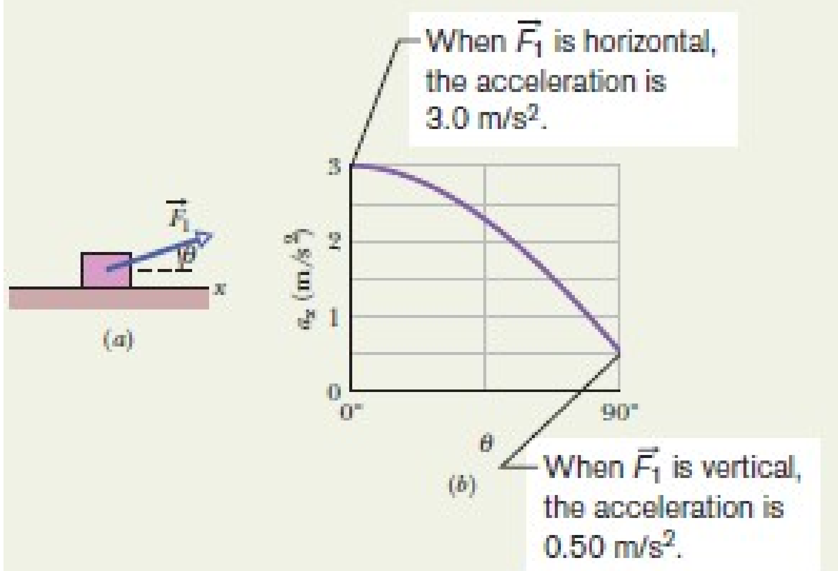
$$\sum F_x = T - mg\sin\theta = ma_x$$

$$\sum F_y = F_N - mg\cos\theta = ma_y = 0$$



Example : Reading a force graph

Figure 5-16*a* shows the general arrangement in which two forces are applied to a 4.00 kg block on a frictionless floor, but only force $\vec{F}_1$ is indicated. That force has a fixed magnitude but can be applied at an adjustable angle θ to the positive direction of the x axis. Force $\vec{F}_2$ is horizontal and fixed in both magnitude and angle. Figure 5-16*b* gives the horizontal acceleration a_x of the block for any given value of θ from 0° to 90°. What is the value of a_x for $\theta = 180°$?



Answer: a_x=-2 m/s^2

Example: Forces within an elevator cab

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.

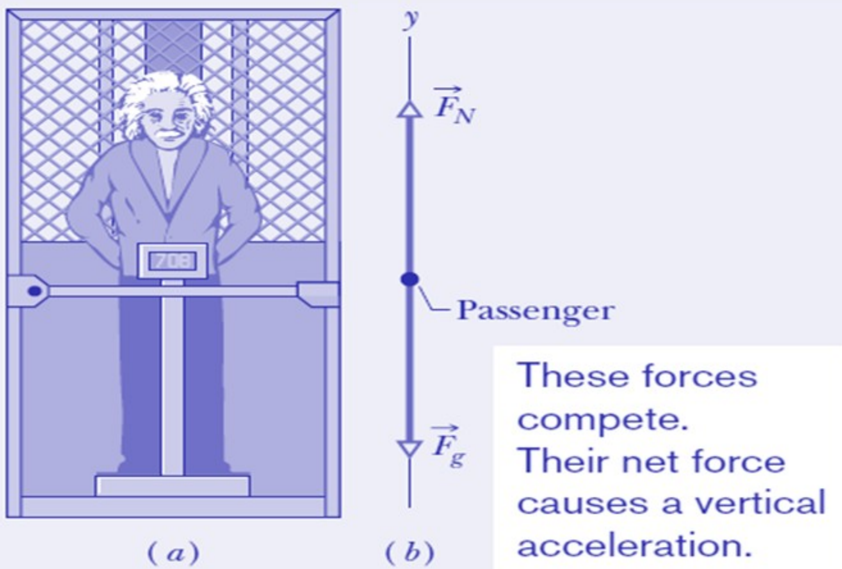


Fig. 5-17 (*a*) A passenger stands on a platform scale that indicates either his weight or his apparent weight. (*b*) The free-body diagram for the passenger, showing the normal force $\vec{F}_N$ on him from the scale and the gravitational force $\vec{F}_g$.

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

- The reading is equal to the magnitude of the normal force on the passenger from the scale.
- We can use Newton's Second Law only in an inertial frame. If the cab accelerates, then it is *not an inertial frame.* So we choose the ground to be our inertial frame and make any measure of the passenger's acceleration relative to it.

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

$$F_N - F_g = ma$$
$$F_N = F_g + ma.$$

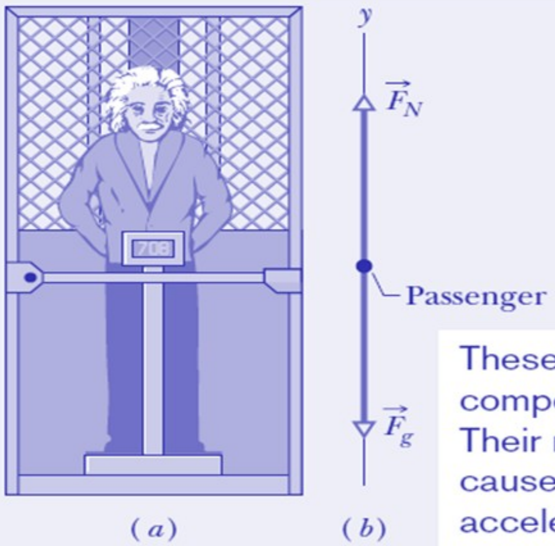
This tells us that the scale reading, which is equal to F_N, depends on the vertical acceleration. Substituting mg for F_g gives us

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

for any choice of acceleration *a*.

Example (Continued): Forces within an elevator cab

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.



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

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

For any constant velocity (zero or otherwise), the acceleration a of the passenger is zero.

Calculation: Substituting this and other known values into Eq. 5-28, we find

$$F_N = (72.2\text{ kg})(9.8\text{ m/s}^2 + 0) = 708\text{ N}. \quad \text{(Answer)}$$

This is the weight of the passenger and is equal to the magnitude F_g of the gravitational force on him.

(c) What does the scale read if the cab accelerates upward at 3.20 m/s² and downward at 3.20 m/s²?

Calculations: For $a = 3.20$ m/s², Eq. 5-28 gives

$$F_N = (72.2\text{ kg})(9.8\text{ m/s}^2 + 3.20\text{ m/s}^2) = 939\text{ N}, \quad \text{(Answer)}$$

and for $a = -3.20$ m/s², it gives

$$F_N = (72.2\text{ kg})(9.8\text{ m/s}^2 - 3.20\text{ m/s}^2) = 477\text{ N}. \quad \text{(Answer)}$$

(d) During the upward acceleration in part (c), what is the magnitude F_{net} of the net force on the passenger, and what is the magnitude $a_{p,cab}$ of his acceleration as measured in the frame of the cab? Does $\vec{F}_{net} = m\vec{a}_{p,cab}$?

Calculation: The magnitude F_g of the gravitational force on the passenger does not depend on the motion of the passenger or the cab; so, from part (b), F_g is 708 N. From part (c), the magnitude F_N of the normal force on the passenger during the upward acceleration is the 939 N reading on the scale. Thus, the net force on the passenger is

$$F_{net} = F_N - F_g = 939\text{ N} - 708\text{ N} = 231\text{ N}, \quad \text{(Answer)}$$

during the upward acceleration. However, his acceleration $a_{p,cab}$ relative to the frame of the cab is zero. Thus, in the noninertial frame of the accelerating cab, F_{net} is not equal to $ma_{p,cab}$, and Newton's second law does not hold.

Example: Acceleration of block pushing on block

In Fig. 5-18*a*, a constant horizontal force $\vec{F}_{app}$ of magnitude 20 N is applied to block *A* of mass m_A = 4.0 kg, which pushes against block *B* of mass m_B = 6.0 kg. The blocks slide over a frictionless surface, along an *x* axis.

(a) What is the acceleration of the blocks?

(b) What is the (horizontal) force $\vec{F}_{BA}$ on block *B* from block *A* (Fig. 5-18*c*)?

Answer: a_x=2 m/s^2,

F_{BA}=12 N

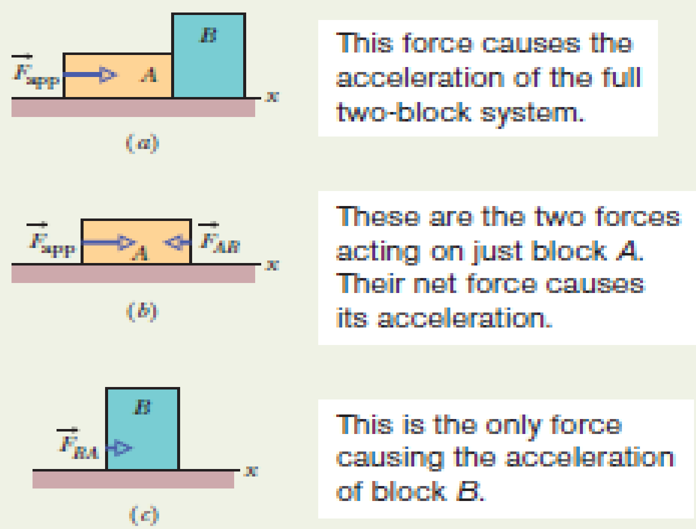
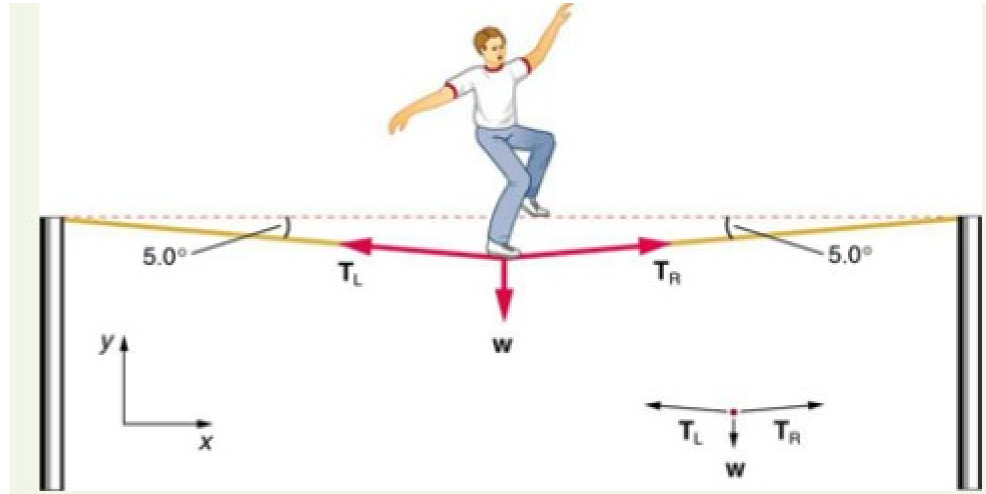


Fig. 5-18 (*a*) A constant horizontal force $\vec{F}_{app}$ is applied to block *A*, which pushes against block *B*. (*b*) Two horizontal forces act on block *A*. (*c*) Only one horizontal force acts on block *B*.

Example:

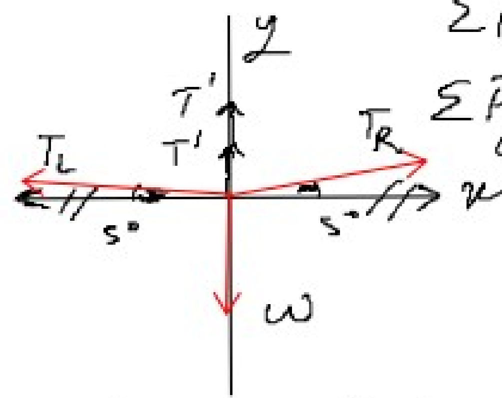
(OpenStax 4.6) Calculate the tension in the wire supporting the 70.0-kg tightrope walker shown in Figure.



$$T = \frac{w}{2\sin(5.0°)} = \frac{mg}{2\sin(5.0°)},$$

$$T = \frac{(70.0\ \text{kg})(9.80\ \text{m/s}^2)}{2(0.0872)},$$

$$T = 3900\ \text{N}.$$



$\Sigma F_x = T_{Rx} - T_{Lx} = m a_x$

$\Sigma F_y = 2T' - mg = m a_y \sim 0$

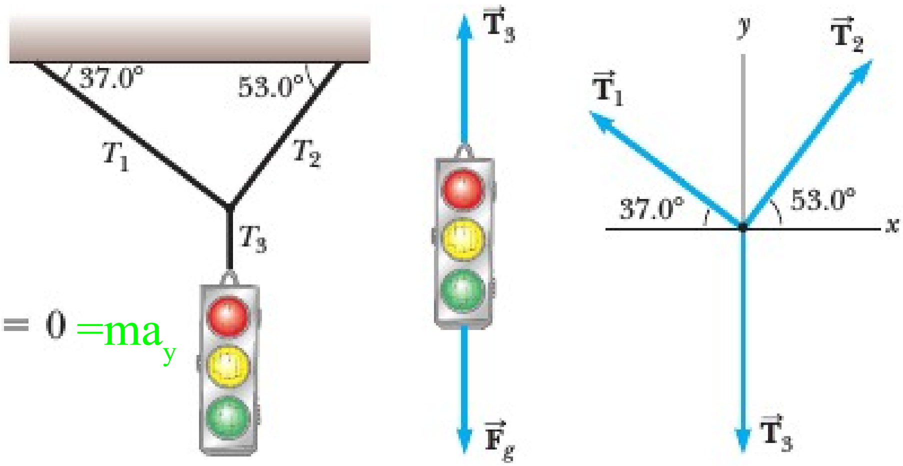
$T = \frac{mg}{2 \sin 5°}$

$|T'| = |T_{Ry}| = T_{Ly}$

$\sim T \sin 5°$

(Serway 5.4) A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support as in Figure. The upper cables make angles of 37.0° and 53.0° with the horizontal. These upper cables are not as strong as the vertical cable and will break if the tension in them exceeds 100 N. Does the traffic light remain hanging in this situation, or will one of the cables break?

2 unknowns (T_1, T_2) & 2 equations



$$(1)\quad \sum F_x = -T_1 \cos 37.0° + T_2 \cos 53.0° = 0 = ma_x$$

$$(2)\quad \sum F_y = T_1 \sin 37.0° + T_2 \sin 53.0° + (-122\text{ N}) = 0 = ma_y$$

$$(3)\quad T_2 = T_1\left(\frac{\cos 37.0°}{\cos 53.0°}\right) = 1.33T_1$$

$$T_1 \sin 37.0° + (1.33T_1)(\sin 53.0°) - 122\text{ N} = 0$$

$$T_1 = 73.4\text{ N}$$

$$T_2 = 1.33T_1 = 97.4\text{ N}$$

Both < 100 N √

Both values are less than 100 N (just barely for T_2), so the cables will not break.

Example:

(Serway 5.9) When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in Figure, the arrangement is called an Atwood machine. The device is sometimes used in the laboratory to calculate the value of g. Determine the magnitude of the acceleration of the two objects and the tension in the lightweight cord.

ignore the weight of the cord

(1) $\sum F_y = T - m_1 g = m_1 a_y$

(2) $\sum F_y = m_2 g - T = m_2 a_y$

System acceleration $a_{ym1} = a_{ym2} = a$

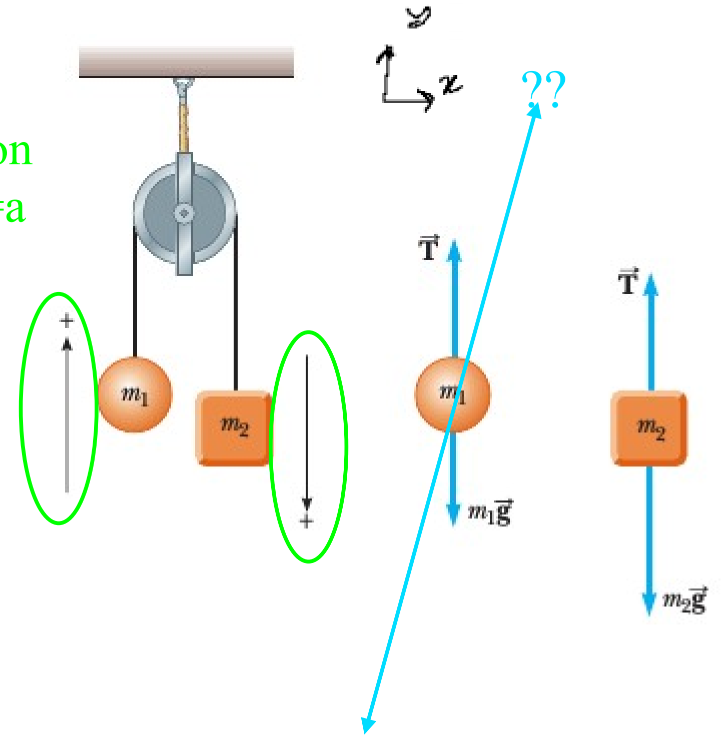
eliminate T

$$-m_1 g + m_2 g = m_1 a_y + m_2 a_y$$

(3) $a_y = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) g$

check if $m_2 > m_1$ or $m_2 < m_1$

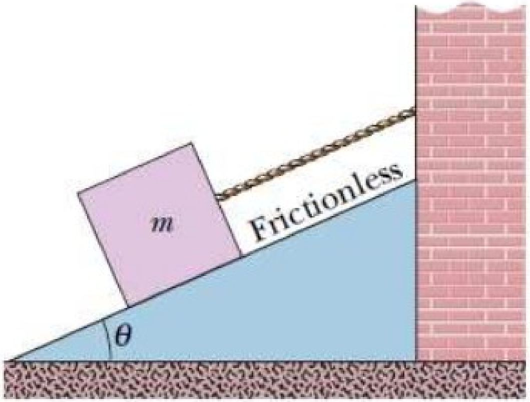
(4) $T = m_1(g + a_y) = \left(\frac{2 m_1 m_2}{m_1 + m_2}\right) g$



$-1*(T - m_2 g) = -m_2 a_y$

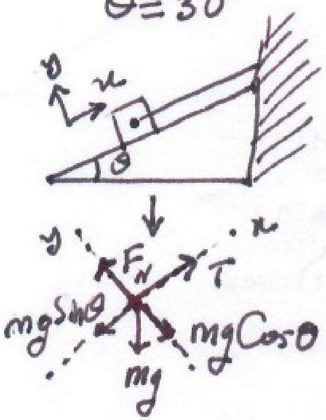
Same!

1. In Figure, let the mass of the block be 8.5 kg and the angle be 30°. Find (a) the tension in the cord and (b) the normal force acting on the block. (c) If the cord is cut, find the magnitude of the resulting acceleration of the block.



17) $m = 8.5\ kg$ $\theta = 30°$

i) $T = ?$ acceleration is zero
Newton 2nd law



FBD

x: ① $T - mg\sin\theta = ma_x = 0$ y: $F_N - mg\cos\theta = ma_y = 0$ ②

① $T = (8.5\ kg)(9.8\ m/s^2)\sin 30° = 41.65\ N \rightarrow 42\ N$

ii) $F_N = ?$ ② $F_N = mg\cos\theta = (8.5\ kg)(9.8\ m/s^2)\cos 30° =$
$= 72.14\ N \sim 72\ N$

iii) cord is cut $\rightarrow a = ?$ a_x: not zero any more

① ~~T~~ $- mg\sin\theta = ma_x \rightarrow a_x = a = -g\sin\theta$
$= -(9.8\ m/s^2)\frac{1}{2} = -4.9\ m/s^2$

(−) ⇒ acceleration is downward. Also check $\theta = 90°$
no further contact with surface ⇐ $a = g$

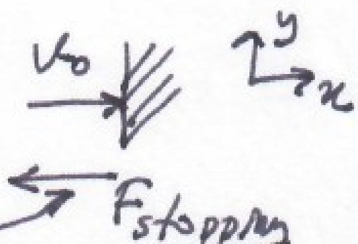
18) $W = 700\ kN$

2. A car traveling at 53 km/h hits a bridge abutment. A passenger in the car moves forward a distance of 65 cm (with respect to the road) while being brought to rest by an inflated air bag. What magnitude of force (assumed constant) acts on the passenger's upper torso, which has a mass of 41 kg? constant acceleration

$v = 0.22\ m/s$

20) $v_0 = 53\ km/h = 53\ km/h \cdot \frac{1000\ m}{1\ km} \cdot \frac{1\ h}{3600\ s} = 17.5\ m/s$

$\Delta x = 0.65\ m$



acting force to stop by air bag? $m = 41\ kg$

$v^2 = v_0^2 + 2a\Delta x \rightarrow 0 = (17.5\ m/s)^2 + 2a\,0.65\ m \rightarrow a = -236\ m/s^2$ deceleration

$\vec{F}_{stopping} = m\vec{a} = |F_{stopping}|(-\hat{i})$

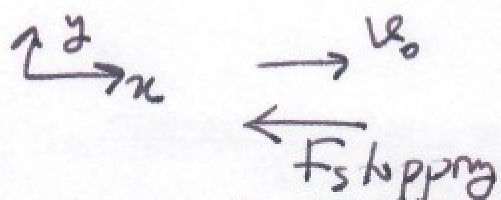
$\Rightarrow 41\ kg(-236\ m/s^2)\hat{i} = |F|(-\hat{i})$ $\quad \vec{a} = (-236\ m/s^2)\hat{i}$

$\rightarrow |\vec{F}| = 9.7 \times 10^3\ N$

3.A car that weighs 1.30×10^4 N is initially moving at 40 km/h when the brakes are applied and the car is brought to a stop in 15 m. Assuming the force that stops the car is constant, find (a) the magnitude of that force and (b) the time required for the change in speed. If the initial speed is doubled, and the car experiences the same force during the braking, by what factors are (c) the stopping distance and (d) the stopping time multiplied?

28) $w = 1.30\times10^4 N$

$v_0 = 40\, km/h \cdot \frac{1000m}{1km} \cdot \frac{1h}{3600s} = 11.11\, m/s$



$\Delta x = 15m$ Force that stops the car is constant → constant acceleration

i) $F = ?$

$v^2 = v_0^2 + 2a\Delta x \rightarrow 0 = (11.11 m/s)^2 + 2a\, 15m \rightarrow a = -4.12 m/s^2$

$\rightarrow F(-\hat{i}) = ma(-\hat{i}) \rightarrow F = \frac{1.30\times10^4 N}{9.8\, m/s^2} \cdot 4.12\, m/s^2 = 5.5\times10^3 N$ ($N \sim kg\, m/s^2$)

ii) $v = v_0 + at \rightarrow 0 = 11.11 m/s - 4.12 m/s^2\, t \rightarrow t = 2.7s$ stopping time

iii) $v_0 \rightarrow 2v_0$ & same force during braking

3. (Continued) A car that weighs 1.30×10^4 N is initially moving at 40 km/h when the brakes are applied and the car is brought to a stop in 15 m. Assuming the force that stops the car is constant, find (a) the magnitude of that force and (b) the time required for the change in speed. If the initial speed is doubled, and the car experiences the same force during the braking, by what factors are (c) the stopping distance and (d) the stopping time multiplied?.

$\ldots\, m/s - 4.12\, m/s^2\, t \rightarrow \underline{t = 2.7\, s}$

iii) $v_0 \rightarrow 2v_0$ & same force during braking

$\Delta x = ?$

$$0 = (2v_0)^2 + 2a\Delta x' \qquad 0 = (v_0)^2 + 2a\Delta x \qquad \left\{ \frac{\Delta x'}{\Delta x} = \frac{4v_0^2/2a}{v_0^2/2a} = 4 \right.$$

factor of

Doubling v_0 → quadrupling Δx

iv) $t = ?$ stopping time

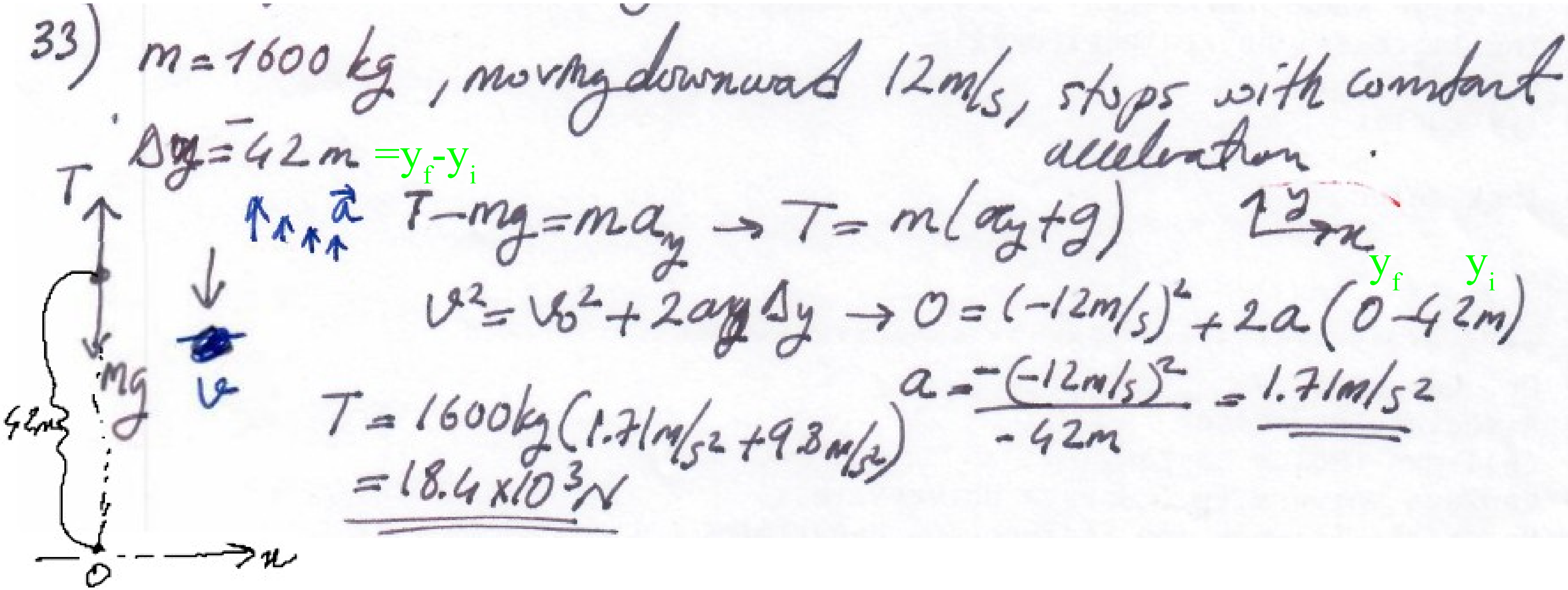
$$0 = 2v_0 + at' \qquad 0 = v_0 + at \qquad \left\{ \frac{t'}{t} = \frac{2v_0/a}{v_0/a} = 2 \right.$$

factor of

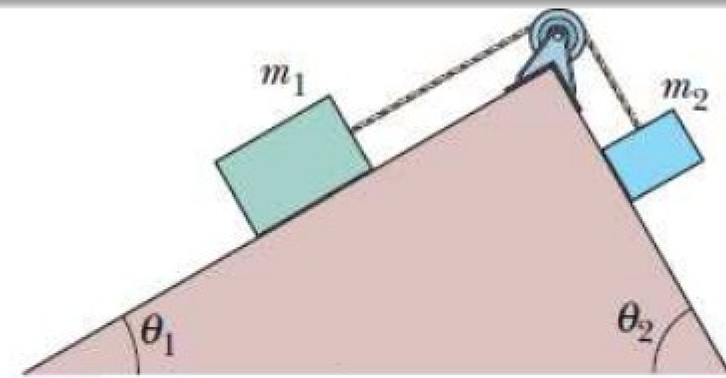
Doubling v_0 → doubling t

4. An elevator cab and its load have a combined mass of 1600 kg. Find the tension in the supporting cable when the cab, originally moving downward at 12 m/s, is brought to rest with constant acceleration in a distance of 42 m.

v_0 $v_f=0$ Δx

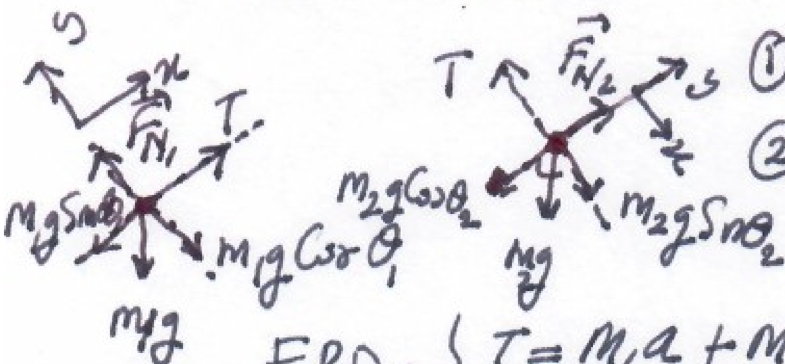


5. Figure shows a box (mass m_1=3.0 kg) on a frictionless plane inclined at angle θ_1 =30° . The box is connected via a cord of negligible mass to a box (mass m_2=2.0 kg) on a frictionless plane inclined at angle θ_2 =60°. The pulley is frictionless and has negligible mass. What is the tension in the cord?



5) $m_1 = 3.0$ kg & $m_2 = 2$ kg } frictionless planes $T = ?$

$\theta_1 = 30°$ $\theta_2 = 60$



x:

① $T - m_1 g \sin\theta_1 = m_1 a^x$

② $m_2 g \sin\theta_2 - T = m_2 a$

y:

③ $F_{N_1} - m_1 g \cos\theta_1 = m_1 a_{y_1} = 0$

④ $F_{N_2} - m_2 g \sin\theta_2 = m_2 a_{y_2}$

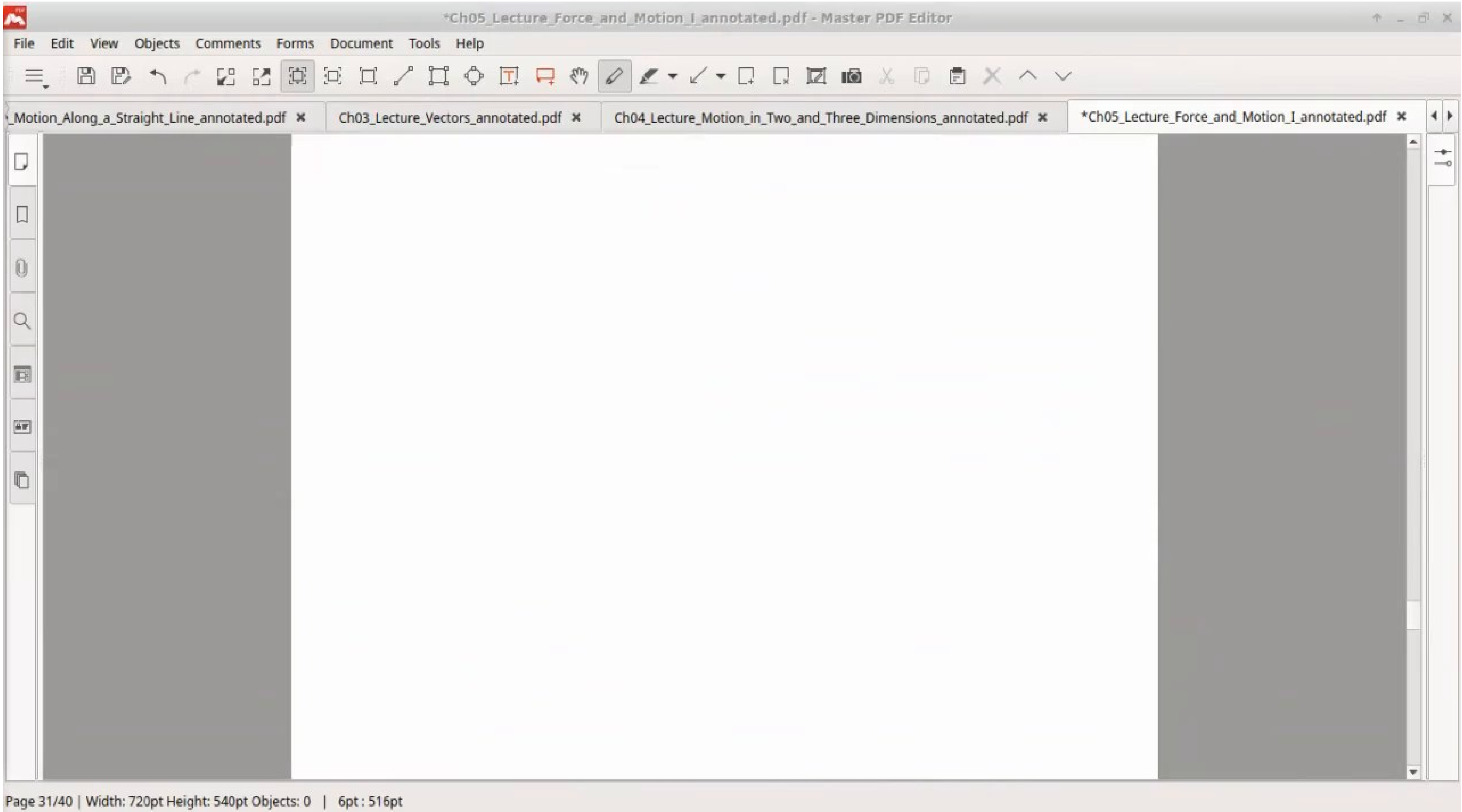
Two unknowns → eliminate T ① & ②

FBDs

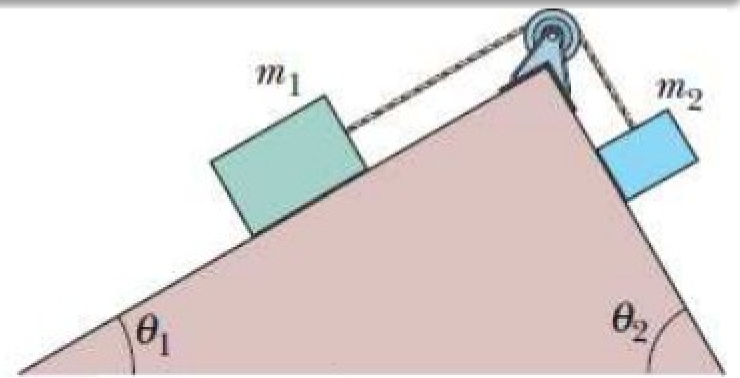
$T = m_1 a + m_1 g \sin\theta_1 \rightarrow m_2 g \sin\theta_2 - (m_1 a + m_1 g \sin\theta_1) = m_2 a$

$\Rightarrow a = \dfrac{g(m_2 \sin\theta_2 - m_1 \sin\theta_1)}{m_1 + m_2} = 0.45\ m/s^2$ put into either ① or ②

Solved Problem 5



5. (Continued) Figure shows a box (mass m_1=3.0 kg) on a frictionless plane inclined at angle θ_1 =30^o . The box is connected via a cord of negligible mass to a box (mass m_2=2.0 kg) on a frictionless plane inclined at angle θ_2 =60^o. The pulley is frictionless and has negligible mass. What is the tension in the cord?



before pulling, study the cases

$m_2 \sin\theta_2 > m_1 \sin\theta_1 \Rightarrow a>0$ — m_2 slides down, m_1 slides up { $m_2\downarrow$ $m_1\uparrow$

$m_2 \sin\theta_2 < m_1 \sin\theta_1 \Rightarrow a<0$ — m_2 slides up, m_1 slides down { $m_2\uparrow$ $m_1\downarrow$

$m_2 \sin\theta_2 = m_1 \sin\theta \Rightarrow a=0$ — balanced

$$T = m_1\left(\frac{m_2\sin\theta_2 - m_1\sin\theta_1}{m_1+m_2}\right)g + m_1 g\sin\theta_1 = \frac{m_1 m_2 g(\sin\theta_2 + \sin\theta_1)}{m_1+m_2}$$

$= 16.06\,N$

Newtonian Mechanics

- Forces are pushes or pulls
- Forces cause acceleration

Force

- Vector quantities
- 1 N = 1 kg m/s^2
- Net force is the sum of all forces on a body

Newton's First Law

- If there is no net force on a body, the body remains at rest if it is initially at rest, or moves in a straight line at constant speed if it is in motion.

Inertial Reference Frames

- Frames in which Newtonian mechanics holds

Mass

- The characteristic that relates the body's acceleration to the net force
- Scalar quantity

Newton's Second Law

$$\vec{F}_{\text{net}} = m\vec{a} \quad \textbf{Eq. (5-1)}$$

- Free-body diagram represents the forces on one object

Some Particular Forces

- Weight:

$$W = mg \quad \textbf{Eq. (5-12)}$$

- Normal force from a surface
- Friction along a surface
- Tension in a cord

Newton's Third Law

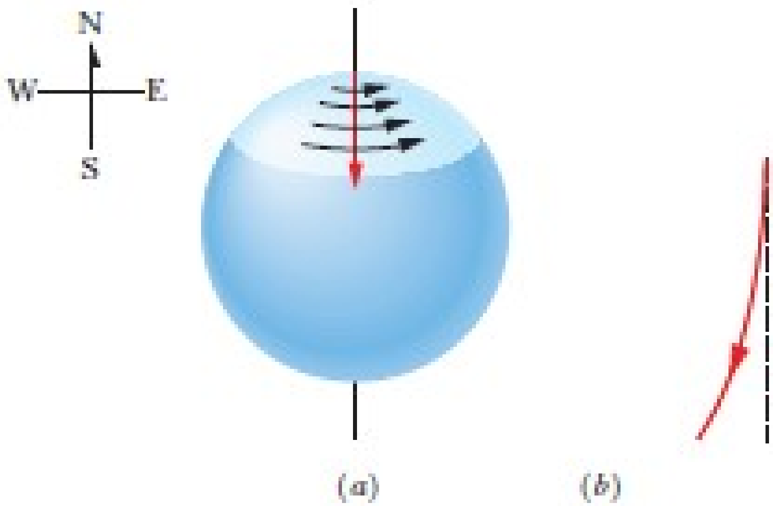
- Law of force-pairs
- If there is a force **by** *B* **on** *C*, then there is a force **by** *C* **on** *B*:

$$\vec{F}_{BC} = -\vec{F}_{CB} \quad \textbf{Eq. (5-15)}$$

Additional Materials

5-4 Force; Inertial Reference Frames

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



(a) The path of a puck sliding from the north pole as seen from a stationary point in space. Earth rotates to the east. (b) The path of the puck as seen from the ground.

Earth's rotation causes an apparent deflection.

- If a puck is sent sliding along a *short strip of* frictionless ice—the puck's motion obeys Newton's laws as observed from the Earth's surface.
- If the puck is sent sliding along a *long ice strip extending from* the north pole, and if it is viewed from a point on the Earth's surface, the puck's path is not a simple straight line.
- The apparent deflection is not caused by a force, but by the fact that we see the puck from a rotating frame. In this situation, the ground is a **noninertial frame.**

Force; The Four Basics Forces

Concept Connections: The Four Basic Forces

The four basic forces will be encountered in more detail as you progress through the text. The gravitational force is defined in **Uniform Circular Motion and Gravitation**, electric force in **Electric Charge and Electric Field**, magnetic force in **Magnetism**, and nuclear forces in **Radioactivity and Nuclear Physics**. On a macroscopic scale, electromagnetism and gravity are the basis for all forces. The nuclear forces are vital to the substructure of matter, but they are not directly experienced on the macroscopic scale.

Table 4.1 Properties of the Four Basic Forces[1]

Force	Approximate Relative Strengths	Range	Attraction/Repulsion	Carrier Particle
Gravitational	10^{-38}	∞	attractive only	Graviton
Electromagnetic	10^{-2}	∞	attractive and repulsive	Photon
Weak nuclear	10^{-13}	$< 10^{-18}$ m	attractive and repulsive	W^+, W^-, Z^0
Strong nuclear	1	$< 10^{-15}$ m	attractive and repulsive	gluons