Chapter 5

HWK 1, 8, 15, 24, 36, 47, 66

The Laws of Motion

Lec1

5.1 The Concept of Force

Force: pull or push on body causes it to move, or *causes an object to accelerate*

Object accelerates only: if the net force on it $\neq 0$
Net force = *total force*= *resultant force*, or the *unbalanced force* = vector sum of all forces acting on the object.

If net force =0 then the acceleration of the object is zero and its velocity remains constant.

Class of forces:

*Contact forces (*object and spring)

Field forces: act through empty space: The gravitational force, the electric force.

5.2 Newton's First Law and Inertial Frames

Newton's first law of motion or *law of inertia*, defines a special set of reference frames called *inertial frames*

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

When the puck is on the air hockey table located on the ground, you are observing it from an inertial reference frame — If you are also observing the puck from a train moving at constant velocity, the train is also an inertial reference frame.
When the train accelerates, however, you are observing the puck from a noninertial frame.
If the puck is in the accelerating train, the driver sees the puck as nonaccelerating (train is inertial relative to the driver). The puck appears

to be accelerating according to you on the ground. So we can identify a reference frame in which the puck has zero acceleration.

The Earth is assumed an inertial frame because of its orbital motion can often be neglected.

In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity (that is, with a constant speed in a straight line).

Any ***isolated object*** (one that does not interact with its environment) is either at rest or moving with constant velocity.

The tendency of an object to resist any attempt to change its velocity is called inertia.

5.3 Mass

Mass is that property of an object that measure the resistance an object to change its velocity.
SI unit of mass is the kilogram.

Mass and weight are two different quantities. The weight of an object is equal to the magnitude of the gravitational force exerted on the object and varies with location.

5.4 Newton's Second Law

When an nonzero resultant force acting on an object, it accelerates.
The acceleration of an object is directly proportional to the force acting on it.

Newton's second law: $\sum \mathbf{F} = m\,\mathbf{a}$

In inertial frames, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

The SI unit of force is the newton N = kg. m/s^2

Example 5.1 An Accelerating Hockey Puck

A hockey puck having a mass of 0.30 kg slides on the horizontal, frictionless surface of an ice rink. **Two hockey sticks strike** the puck simultaneously, exerting the forces on the puck shown in Figure. The force **F1** has a magnitude of **5.0 N**, and the force **F2** has a magnitude of **8.0 N**. determine both the magnitude and the direction of the puck's acceleration.

$$\sum F_x = F_{1x} + F_{2x} = F_1\cos(-20) + F_2\cos 60$$

$$= (5.0)(0.940) + (8.0)(0.500) = 8.7\text{N}$$

$$\sum F_y = F_{1y} + F_{2y} = F_1\sin(-20) + F_2\sin 60$$
$$= (5.0)(-0.342) + (8.0)(0.866) = 5.2\text{N}$$

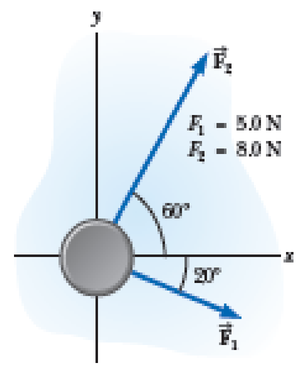


Figure 5.4 (Example 5.1) A hockey puck moving on a frictionless surface is subject to two forces $\vec{F}_1$ and $\vec{F}_2$.

$$a_x = \frac{\sum F_x}{m} = \frac{8.7}{0.3} = 29\text{m/s}^2, \quad a_y = \frac{\sum F_y}{m} = \frac{5.2}{0.3} = 17\text{m/s}^2$$

$$a = \sqrt{a_x^2 + a_y^2} = \sqrt{29^2 + 7.2^2} = 34\,\text{m/s}^2,$$

$$\theta = \tan^{-1}\frac{a_y}{a_x} = \tan^{-1}\frac{17}{29} = 30^0$$

5.5 The Gravitational Force and Weight The attractive force exerted by the Earth on an object is called the gravitational force $\mathbf{F}_g$. This force is directed toward the center of the Earth, and its magnitude is called the weight of the object. $\mathbf{F}_g = mg$. It depends on ***g***, weight varies with geographic location. Because ***g*** decreases with increasing distance from the center of the Earth, objects weigh less at higher altitudes than at sea level.

m = gravitational mass, different in behavior from inertial mass, measuring the resistance to changes in motion in response to an external force. Gravitational mass and inertial mass have the same value.

5.6 Newton's Third Law

If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force F_{21} exerted by object 2 on object 1.

F_{21} = - F_{12} (action force = - reaction force),

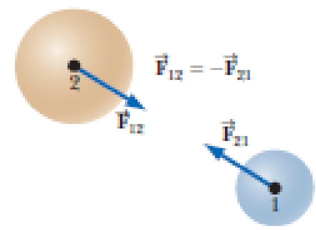


Figure 5.5 Newton's third law. The force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1.

The third law, is equivalent to stating that forces always occur in pairs, or that a single isolated force cannot exist.

The action force is equal in magnitude to the reaction force and opposite in direction and act on different objects.

A computer monitor at rest on a table: Action force is gravitational force $\mathbf{F_g}$ on the monitor, the reaction force to $\mathbf{F_g}$ = $\mathbf{F_{Em}}$ is the force exerted by the monitor on the Earth $\mathbf{F_{mE}}$ = - $\mathbf{F_{Em}}$.

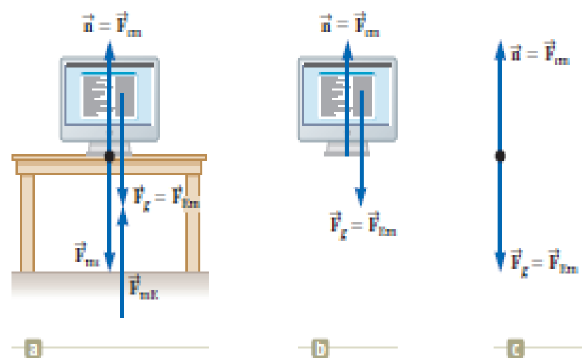


Table + monitor
upward normal force **n** = $\mathbf{F_{tm}}$, the reaction to **n** is the force exerted by the monitor downward on the table, $\mathbf{F_{mt}}$ = - $\mathbf{F_{tm}}$ = - **n.**

The normal force balances the gravitational force on the monitor, so that the net force on the monitor is zero.

Remember, the two forces in an action–reaction pair always act on two different objects.

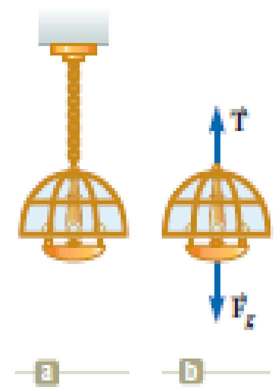
On one object, we are interested in the net force acting on it alone. **We draw the free-body diagram** which shows only the forces acting on *one object,* (the monitor only), which we will model as a particle and simplify the problem.

5.7 Analysis Models Using Newton's Second Law

When we apply Newton's laws to an object, we are interested only in external forces that act on the object.

We neglect the effects of friction; surfaces are *frictionless.*
We usually neglect the mass of any ropes, strings, or cables involved. the synonymous terms *light* and *of negligible mass.*
The rope exerts a force T; the magnitude T is called the tension in the rope which has the same value at all points of the rope.

Analysis Model: The Particle in Equilibrium

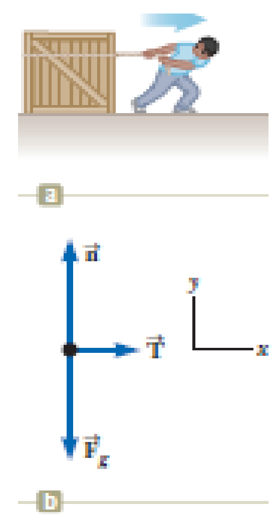


An object is in equilibrium, its acceleration =0
Or net force $\sum \mathbf{F} = 0$
Consider a lamp suspended from a light chain fastened to the ceiling. Downward gravitational force $\mathbf{F_g}$, upward force **T** exerted by the chain.

$$\sum F_y = ma_y = 0 = mg - T \qquad or \qquad T = mg$$

Note that **T** and $\mathbf{F_g}$ are *not* an action–reaction pair because they act on the same object—the lamp

Analysis Model: The Particle Under a Net Force



Acceleration ≠ 0, means a nonzero net force acting on the object. A crate being pulled to the right on a frictionless, horizontal surface, as in Figure

For the horizontal motion:

$$\sum F_x = T = m a_x \qquad a_x = \frac{T}{m}$$

$$\sum F_y = ma_y = 0 = n - mg = 0, \qquad n = m\,g$$

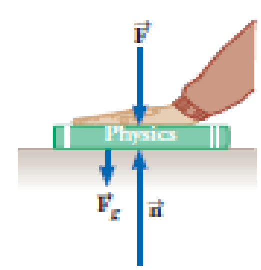


Figure 5.9 When a force $\vec{F}$ pushes vertically downward on another object, the normal force $\vec{n}$ on the object is greater than the gravitational force: $n = F_g + F$.

If you push down with a force F on a book on a table the normal force is *greater* than the force of gravity, since

$$\sum F_y = ma_y = 0 = n - (mg + F) = 0,$$

$$n = mg + F$$

Example 5.4 A Traffic Light at Rest

A traffic light weighing 122 N hangs from a cable tied to two other cables fastened to a support, as in Figure 5.10a. 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**. Will the traffic light remain hanging in this situation, or will one of the cables break?
we construct two free-body diagrams—one for the traffic light, shown in Figure 5.10b, and one for the knot that holds the three cables together, as in Figure 5.10c.

Solution **For the traffic light:**

$$\sum F_y = 0 = T_3 - F_g = 0,$$

$$T_3 = F_g = 122\,N$$

For the knot [عند العقدة] :

$$\sum F_x = 0 = -T_1 cos37 + T_2 cos53 = 0,$$

$$\Rightarrow T_2 = \frac{cos37}{cos53}\ T_1 \ = \ 1.33\ T_1$$

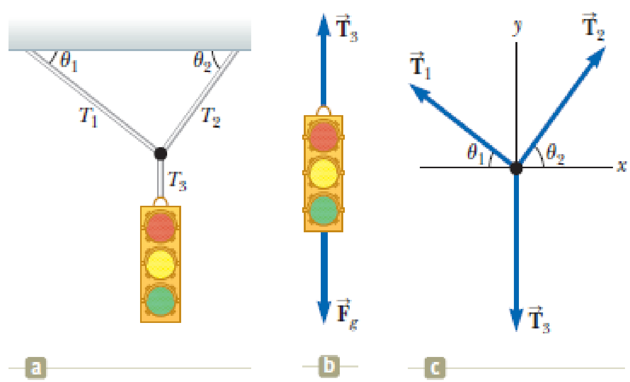


Figure 5.10 (Example 5.4) (a) A traffic light suspended by cables. (b) The forces acting on the traffic light. (c) The free-body diagram for the knot where the three cables are joined.

$$\sum F_y = 0 = T_1 sin37 + T_2 sin53 - T_3 = 0$$

$$T_1\,(0.6) + (1.33\ T_1)(0.8) - 122 = 0$$

$$\Rightarrow T_1 \ = 73.4 \quad N$$

$$and \quad T_2 = 1.33\ \times T_1 \qquad\qquad T_2 = 97.4N$$

Example 5.6 The Runaway Car

A car of mass *m* is on an icy driveway inclined at an angle θ as in Figure 5.11a.

(A) Find the acceleration of the car, assuming the driveway is frictionless.

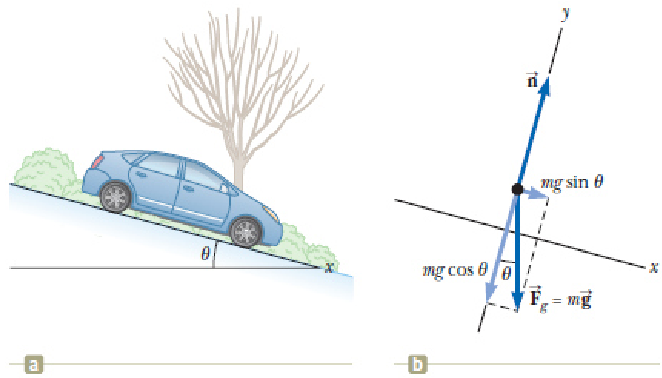


Figure 5.11 (Example 5.6) (a) A car on a frictionless incline. (b) The free-body diagram for the car. The black dot represents the position of the center of mass of the car. We will learn about center of mass in Chapter 9.

Conceptualize

Solution: $a_y = 0$:

$$\sum F_x = mg\, sin\theta = ma_x, \qquad a_x = g\, sin\theta,$$

$$\sum F_y = n - mg\, cos\theta = 0, \qquad \Rightarrow n = mg\, cos\,\theta$$

(B) Suppose the car is released **from rest** at the top of the incline, and the distance from the car's front bumper to the bottom of the incline is ***d***. How long does it take the front bumper to reach the bottom, and what is the **car's speed** as it arrives there?

$$x_f = x_i + v_i t + \frac{1}{2} a_x t^2,$$

$$x_f = d,\ x_i = 0,\ and\ \ v_i = 0.$$

$$d = \frac{1}{2} a_x t^2 \quad \Rightarrow \quad t = \sqrt{\frac{2d}{g\, sin\theta}}, \qquad \text{and}$$

$$v_f^2 = v_i^2 + 2a_x \cdot d, \qquad v_f = \sqrt{2g\, d\, sin\theta}$$

What If? (A) What previously solved problem does this become if θ = 90°? (B) What problem does this become if θ= 0?

(A) $\theta = 90°$, $a_x = g\, sin\, 90 = g$ *(free-fall situation)* and

$$n = mgcos\, 90 = 0$$

(B) $\theta = 0$, $a_x = g\, sin\, 0 = 0$, and $n = mg\, cos\, 0 = mg$,

car at rest as the incline becomes horizontal.

Example 5.7 One Block Pushes Another

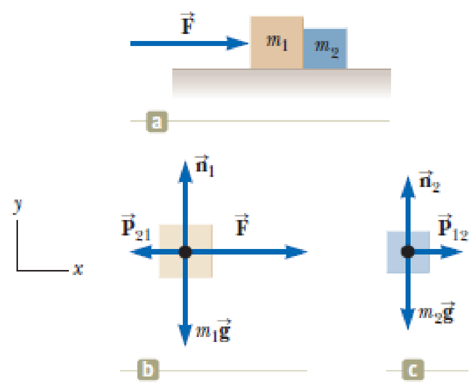


Figure 5.12 (Example 5.7) (a) A force is applied to a block of mass m_1, which pushes on a second block of mass m_2. (b) The forces acting on m_1. (c) The forces acting on m_2.

Two blocks of masses m_1 and m_2, with $m_1 > m_2$, are placed in contact with each other on a frictionless, horizontal surface, as in Figure 5.12a. A constant horizontal force F is applied to m_1 as shown.

(A) Find the magnitude of the acceleration of the system.

Solution treat (m_1+m_2) as one object

$$\sum F_x(system) = F = (m_1 + m_2)a_x$$

$$a_x = \frac{F}{m_1 + m_2}$$

(B) Determine the magnitude of the contact force between the two blocks.

Solution

Free-body diagram. The contact force is denoted by $P = P_{12}$ (the force exerted by m_1 on m_2) = P_{21} (force by 2 on 1) which is directed to the right.

Applying Newton's second law to m_2 gives

$$\sum F_x = P_{12} = m_2\, a_x \quad = \left(\frac{m_2}{m_1 + m_2}\right) \cdot F$$

P_{21} is the reaction to P_{12}, so $\mathbf{P_{21} = P_{12}}$.

Applying Newton's second law to m_1 gives

$$\sum F_x = F - P_{21} = F - P_{12} = m_1\, a_x,$$

$$P_{12} = F - m_1 a_x = F - m_1\left(\frac{F}{m_1 + m_2}\right) = \left(\frac{m_2}{m_1 + m_2}\right) \cdot F$$