Lecture 10: Dynamics, Weight, and Normal Forces

Physics for Engineers & Scientists (Giancoli): Chapters 4 & 5
University Physics V1 (Openstax): Chapters 5 & 6

Example: When a 58g tennis ball is served, it accelerates from rest to a speed of 45m/s. The impact of the racket gives the ball a constant acceleration over a distance of 44cm. What is the magnitude of the net force acting on the ball?

The forces and accelerations in this problem are collinear. We may treat it 1-dimensionally.

The acceleration is needed to solve this problem (F=ma). We can find the acceleration from kinematics.

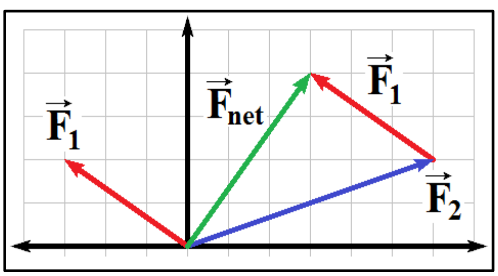
$x_0 = 0$ $x = 44\text{ cm} = 0.44\text{ m}$ $v_0 = 0$ $v = 45\text{ m/s}$ $a = ???$

$$v^2 = v_0^2 + 2a(x - x_0) = 2ax \qquad a = \frac{v^2}{2x} = \frac{\left(45\frac{m}{s}\right)^2}{2(0.44\text{ m})} = 2301.14\frac{m}{s^2}$$

$$F = ma = (0.058\text{ kg})\left(2301.14\frac{m}{s^2}\right) = 133.466\text{ N} \Rightarrow 130\text{ N}$$

Example: Two forces, $\vec{F}_1 = (-3\text{ N})\hat{\imath} + (2\text{ N})\hat{\jmath}$ and $\vec{F}_2 = (6\text{ N})\hat{\imath} + (2\text{ N})\hat{\jmath}$ are acting on an object with a mass of 1 kg. What is the magnitude of that object's acceleration?

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 = \underbrace{(-3\text{ N})\hat{\imath} + (2\text{ N})\hat{\jmath}}_{\vec{F}_1} + \underbrace{(6\text{ N})\hat{\imath} + (2\text{ N})\hat{\jmath}}_{\vec{F}_2} = (3\text{ N})\hat{\imath} + (4\text{ N})\hat{\jmath} = (5\text{ N})\angle 53.13°$$



$$|\vec{F}_{net}| = \sqrt{F_{net-x}^2 + F_{net-y}^2} = \sqrt{(3\text{ N})^2 + (4\text{ N})^2} = 5\text{ N}$$

$$\theta = \text{Tan}^{-1}\left(\frac{F_{net-y}}{F_{net-x}}\right) = \text{Tan}^{-1}\left(\frac{4\text{ N}}{3\text{ N}}\right) = 53.13°$$

$$\vec{a} = \frac{\vec{F}_{net}}{m} = \frac{(5\text{ N})\angle 53.13°}{1\text{ kg}} = \left(5\frac{m}{s^2}\right)\angle 53.13°$$

Example: A marksman fires a rifle. The 9.50 gram bullet accelerates from rest to 851 m/s in 1.31 ms at which point it leaves the barrel of the rifle. What is the average recoil force on the gun from the bullet?

Determine the force on the bullet from its acceleration.
The magnitude of the force on the rifle is the same.

$x_0 = 0$ $x =$ $v_0 = 0$ $v = 851\text{ m/s}$ $a = ???$ $t = 0.00131\text{ s}$

$$v = v_0 + at = at \qquad a = v/t = (851\text{ m/s})/(0.00131\text{ s}) = 649{,}618\text{ m/s}^2$$

$$F = ma = (0.00950\text{ kg})(649{,}618\text{ m/s}^2) = 6171.37\text{ N} \Rightarrow 6.17\text{ kN}$$

Weight

- Objects accelerate downward due to the gravitational force from the Earth.
- This force from gravity is called weight (W). $\vec{W} = m\vec{g}$

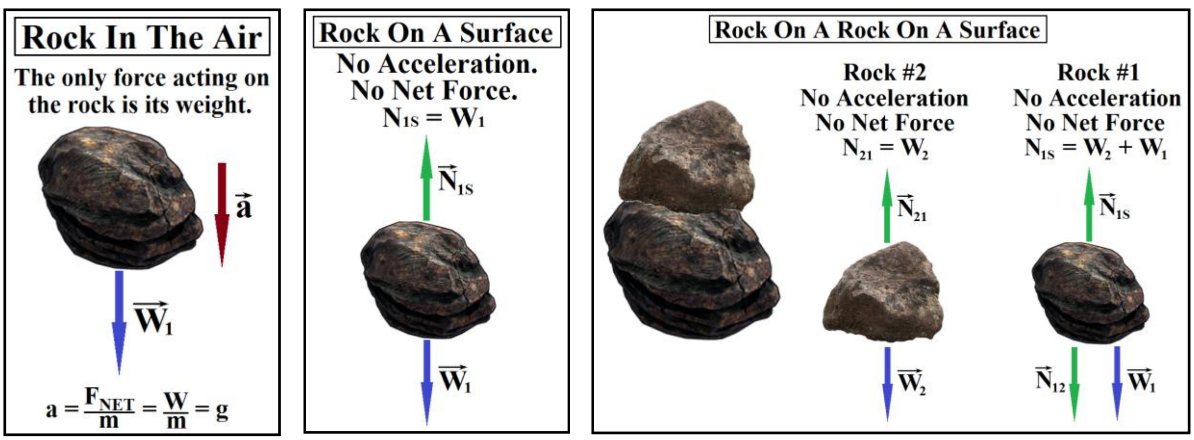
- Be careful not to confuse weight (a force) with mass (not a force).
    - The mass of objects in space doesn't change, but they have no weight.
    - On the moon, the gravitational acceleration is $g = 1.622\ m/s^2$. Masses are the same as they are on Earth, but weights are only a sixth of that on Earth.

Normal Forces

- When two objects come in contact with each other, each surface repels the other.
- As these forces are directed perpendicular to the surface, they are called "Normal Forces."
- The strength of a given normal force is dependent upon the circumstances. Its value can change as the circumstances change.

Force Diagrams

- To account for the various forces acting objects, we typically make a force diagram showing the forces acting on each object individually.



Example: A large ceramic planter when filled with dirt has a mass of 86.0 kg. A second identical dirt-filled planter is placed on top of it. A third dirt-filled planter, which has a mass of 16.5 kg, is placed on top. Determine A) the normal force of the floor on the bottom planter, and B) the normal force the second planter exerts on the dirt at the top of the bottom planter.

- Start by making a diagram of the problem.
- Next make a force diagram for each object in the problem.
    - Force diagrams must include every force that acts upon that object.
    - All objects will have weight in a gravitational field
    - At every point of contact between objects, each object experiences a normal force repelling it from the other. These are equal and opposite.

An object in contact with more than one object will experience more than one normal force.

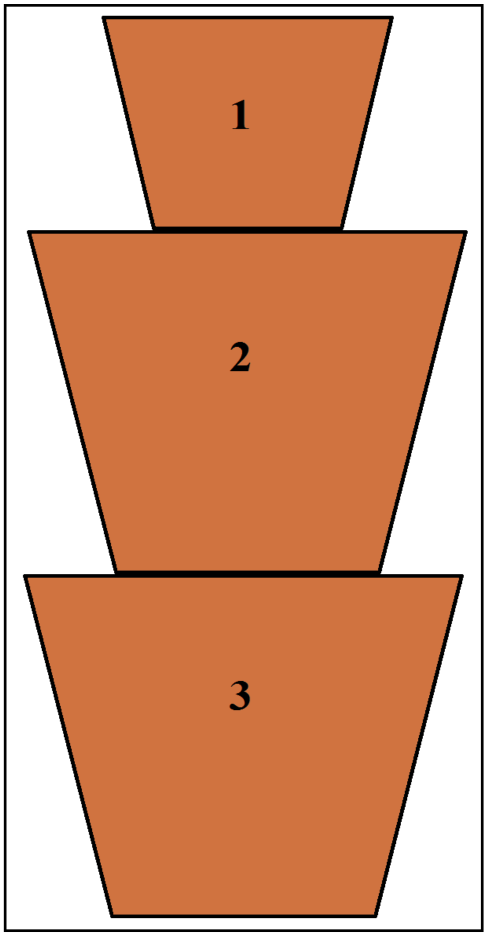
- At every point of contact between objects, each object experiences a friction force opposing its motion. These are also equal and opposite.

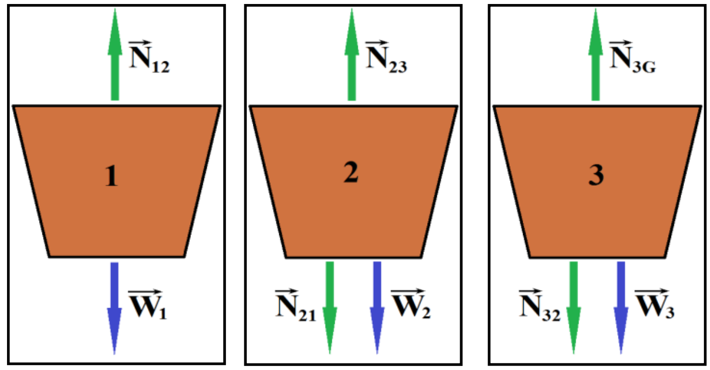
An object in contact with more than one object may experience more than one friction force.

- Any ropes, cords, chains, etc. will produce a force called tension (discussed later)

- Any other <u>applied forces</u> must also be included.

- In this problem, only vertical forces are relevant. The horizontal friction forces are zero as there are no other horizontal forces.





<u>Starting with the top planter</u>: Vertical forces must sum to zero.

$$N_{12} = W_1 = m_1 g = (16.5\text{ kg})(9.80\text{ m/s}^2) = 161.7\text{ N}$$

<u>Middle planter</u>: Vertical forces must sum to zero.

The top planter creates a normal force pushing down.

$$N_{23} = N_{21} + W_2 = N_{12} + m_2 g = 161.7\text{ N} + (86.0\text{ kg})(9.80\text{ m/s}^2) =$$
$$161.7\text{ N} + 842.8\text{ N} = 1004.5\text{ N}$$

<u>Bottom Planter</u>: Vertical forces must sum to zero.

The middle planter creates a normal force pushing down.

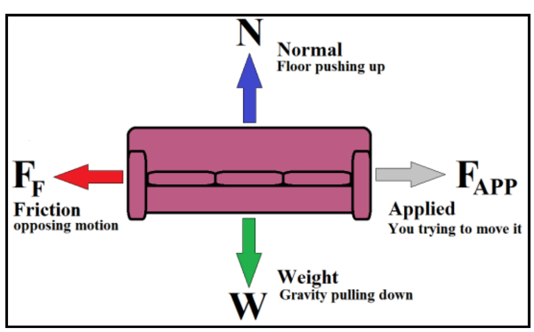
$$N_{3G} = N_{32} + W_3 = N_{23} + m_3 g = 1004.5\text{ N} + (86.0\text{ kg})(9.80\text{ m/s}^2)$$
$$= 1004.5\text{ N} + 842.8\text{ N} = 1847.3\text{ N}$$

A) $N_{3G} = 1847.3$ N B) $N_{32} = N_{23} = 1004.5$ N

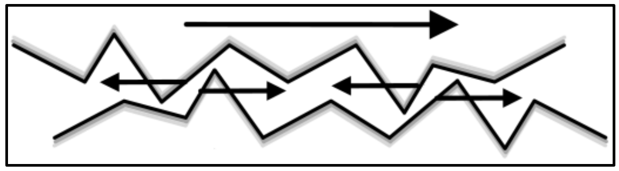
<u>Friction</u>

- When we push on an object (such as a couch) it won't move until a sufficient magnitude of force is applied.
- It doesn't move because the force of friction (static friction) matches the applied force and points in the opposite direction.

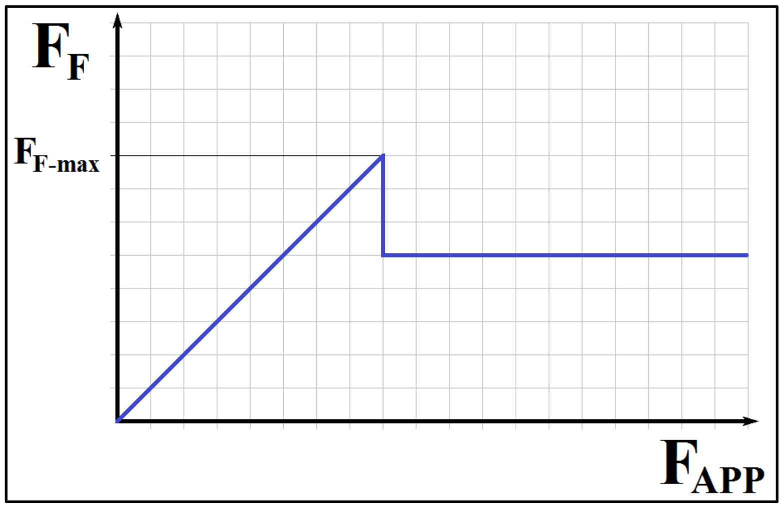
If the acceleration is zero ($a = 0$), then the net force must be zero ($F_{NET} = 0$). For the net force to be equal to zero, the force of friction must be equal in magnitude to the applied force ($F_F = F_{APP}$) and opposite in direction.



- Friction occurs because on the small scale surfaces are rough and numerous tiny normal forces appear when you try to slide the surfaces across each other.



- Once sufficient force is applied to overcome static friction ($F_{F\text{-}Max}$), the force of friction takes on a constant value related to the normal force.



- Friction is <u>parallel to the surface</u> and always <u>opposes motion</u>.
- Solving problems with friction
  - If the object is known to be stationary, use $F_{NET} = 0$ to find F_F.
  - If the object is known to be moving, use $F_F = \mu_k N$
    - N is the normal force related to that point of contact.
    - μ_k is the "coefficient of kinetic friction"
  - If it is not known if the object is stationary or moving, find out.
    - Assume the object is stationary, and use $F_{NET} = 0$ to find F_F
    - Calculate $F_{F\text{-}Max} = \mu_s N$
      - N is the normal force related to that point of contact.
      - μ_s is the "coefficient of static friction"
    - If the calculated value of F_F exceeds $F_{F\text{-}Max}$ ($F_F > F_{F\text{-}Max}$), then the object is moving. The value of F_F previously calculated is not applicable. Set $F_F = \mu_k N$.
    - If the calculated value of F_F does not exceed $F_{F\text{-}Max}$ ($F_F \leq F_{F\text{-}Max}$), then the object is stationary. Keep the value of F_F previously calculated (it is applicable).