Chap2 Laws of Motion

Force (interaction) vector

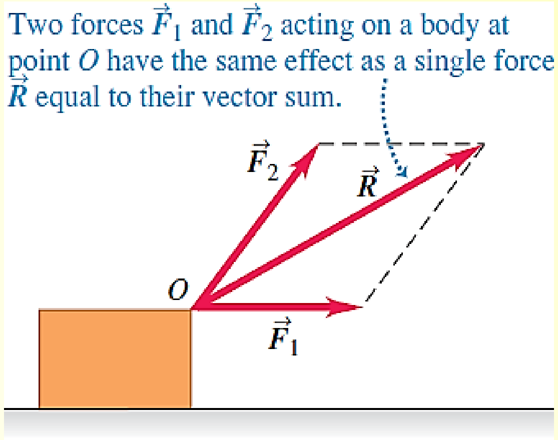
- **Fundamental interactions:**
  - * gravitational force ④
  - * electromagnetic force ②
  - * strong nuclear force ①
  - * weak nuclear force ③

electroweak (electromagnetic force + weak nuclear force)

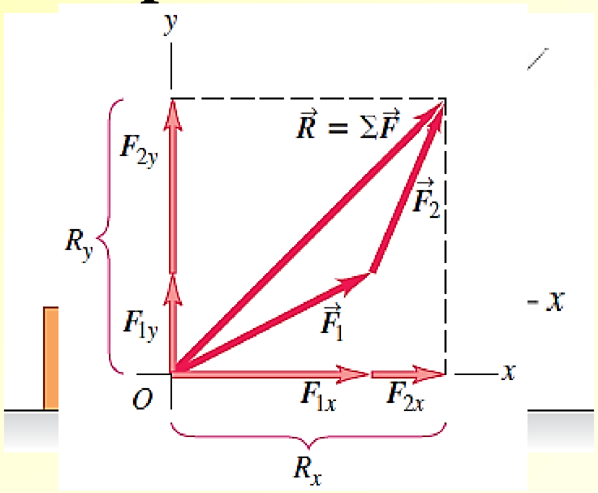
gravitational force, electromagnetic force: **Macroscopic scale**

strong nuclear force, weak nuclear force: **Subatomic scale**

- **Superposition of forces**



- **Components of a force**



Newton's Laws of Motion

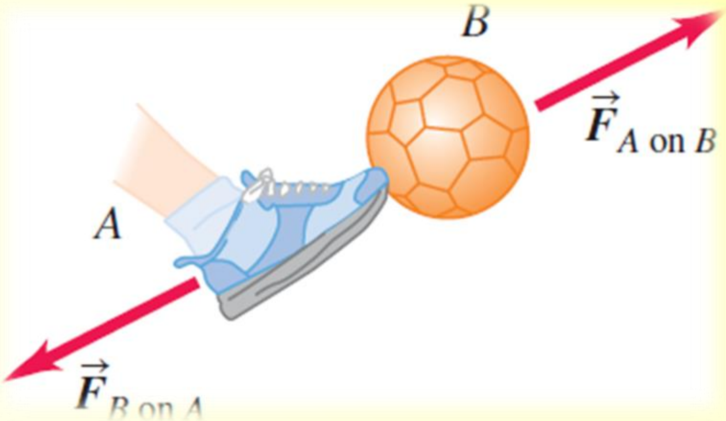
- **First law: (*or* Law of inertia)**

  inertia: *the ability of an object to resist a change in its state of motion*

- **Second law:**

  $\vec{F}_{net} = \sum \vec{F} = m\vec{a}$ [1 N = 1 kg·m/s^2]

- **Third law: action-reaction pair**

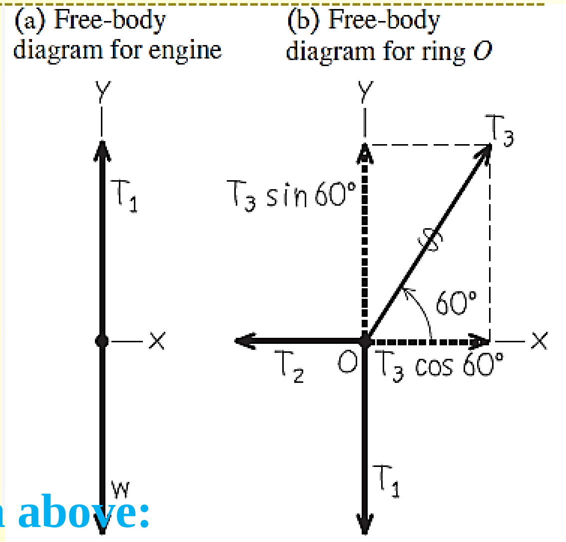


Application of Newton's Laws

✓ **Static application: (object in equilibrium)**

$$\sum \vec{F} = 0 \quad or \quad \sum F_x = 0, \ \sum F_y = 0$$

A car engine with weight *w* hangs from a chain that is linked at ring *O* to two other chains, one fastened to the ceiling and the other to the wall. Find expressions for the tension in each of the three chains in terms of *w*. The weights of the ring and chains are negligible compared with the weight of the engine.



The free-body diagrams & choice of coordinate axes are shown above:

For engine: $\sum F_y = T_1 + (-w) = 0 \Rightarrow T_1 = w$

For ring *O*: $\sum F_y = T_3 \sin 60^o + (-T_1) = 0$

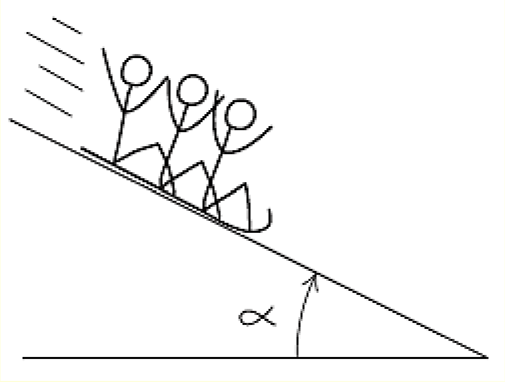
$\sum F_x = T_3 \cos 60^o + (-T_2) = 0$

$\Rightarrow T_3 = \dfrac{2\sqrt{3}}{3} w \Rightarrow T_2 = \dfrac{\sqrt{3}}{3} w$

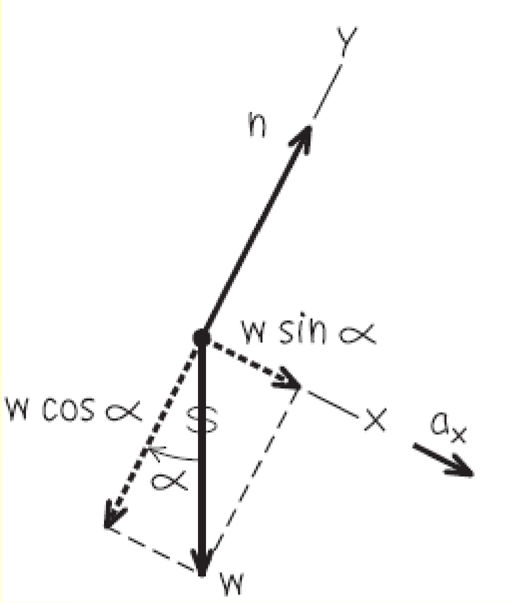
✓ Dynamic application: (object **not** in equilibrium)

$$\sum \vec{F} = m\vec{a} \quad or \quad \sum F_x = ma_x, \ \sum F_y = ma_y$$

A toboggan loaded with students (total weight *w*) slides down a snow-covered slope. The hill slopes at a constant angle *α*, and the toboggan is so well waxed that there is virtually no friction. What is its acceleration? What is the magnitude of the normal force exerted by the hill on the toboggan?



The free-body diagram for toboggan & choice of coordinate axes are shown on the right:



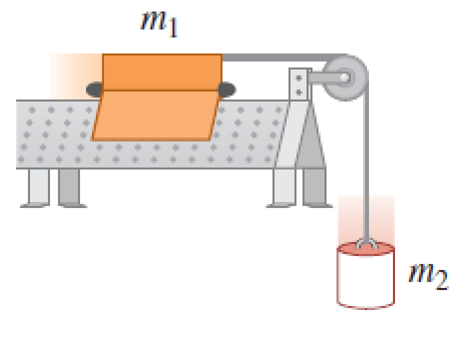
Newton's second law in component form tells us that:

***x*-direction:** $\sum F_x = w\sin\alpha = ma_x \Rightarrow a_x = g\sin\alpha$

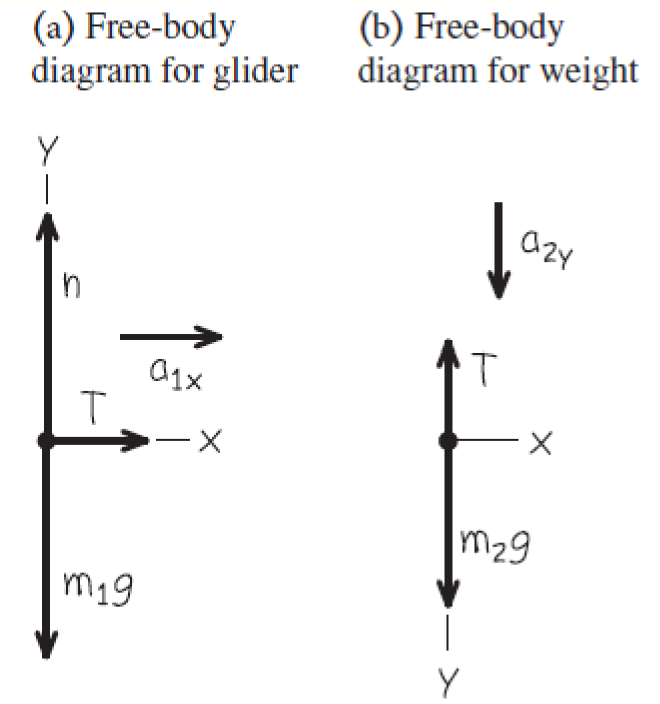
***y*-direction:** $\sum F_y = n - w\cos\alpha = ma_y = 0 \Rightarrow n = mg\cos\alpha$

Exercise:

An air-track glider with mass m_1 moving on a level, frictionless air track in the physics lab. The glider is connected to a lab weight with mass m_2 by a light, flexible, non-stretching string that pass over a stationary, frictionless pulley. Find the acceleration of each body and the tension in the string.



The free-body diagrams for glider & weight, and coordinate systems are shown on the right:



While the direction of the two bodies' accelerations are different, their magnitudes are the same. Thus it can be expressed as:

$$a_{1x} = a_{2y} = a$$

Newton's second law gives:

Glider: $\sum F_y = n - m_1 g = 0$

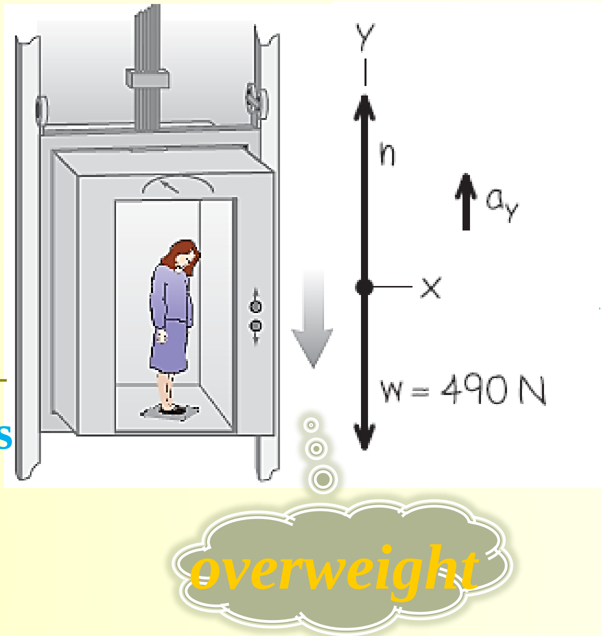
$$\sum F_x = T = m_1 a$$

Lab weight: $\sum F_y = m_2 g - T = m_2 a$

$$\Rightarrow a = \frac{m_2}{m_1 + m_2} g \Rightarrow T = \frac{m_1 m_2}{m_1 + m_2} g$$

Exercise:

A 50.0-kg woman stands on a bathroom scale while riding in an elevator. The elevator is initially moving downward at 10.0 m/s; it slows to a stop with constant acceleration in a distance of 25.0 m. What is the reading on the scale?



The free-body diagram for woman & choice of coordinate axes are shown on the upper right, the positive *y*-axis is chosen to be upward.

According to the constant-acceleration equation,

$$a_y = \frac{v_y^2 - v_{0y}^2}{2(y - y_0)} = \frac{0^2 - (-10.0)^2}{2(-25.0)} \ \mathrm{m/s^2} = +2.00 \ \mathrm{m/s^2}$$

Newton's second law gives in the *y*-direction,

$$\sum F_y = n - mg = ma_y \Rightarrow n = m(g + a_y) = 590 \ \mathrm{N}$$

apparent weight

By Newton's third law, the magnitude of the downward force exerted by the woman on the scale (i.e. the reading on the scale) equals the magnitude of normal force *n*.

So the scale reads 590 N.

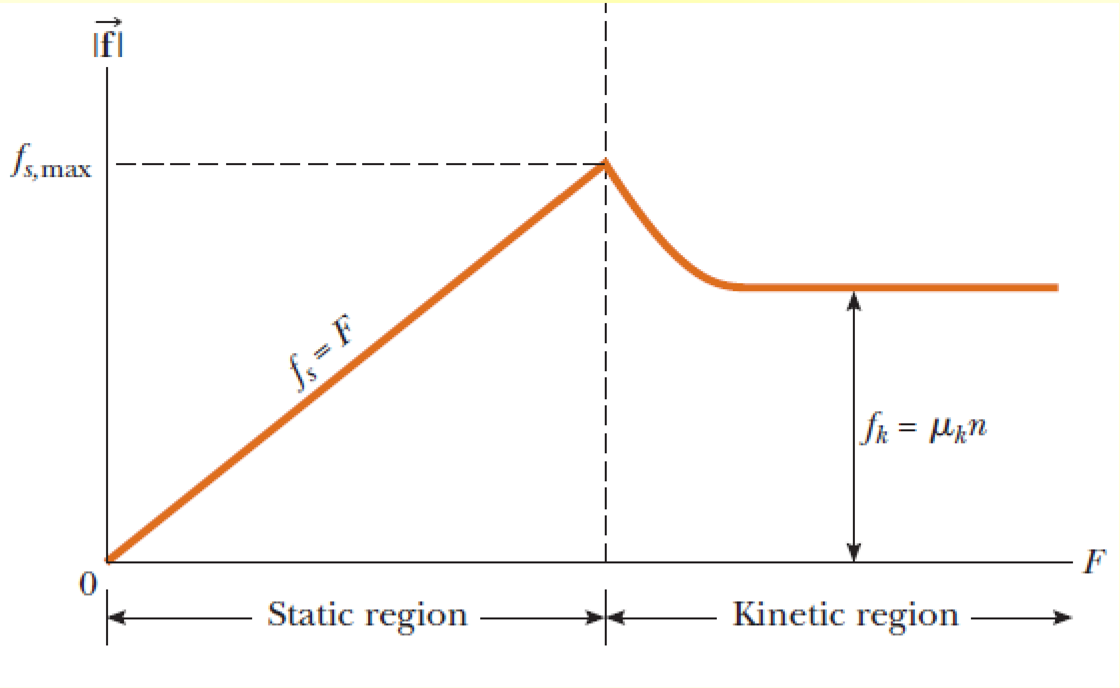
Frictional Forces

- **Static friction:** $\vec{f}_s = -\vec{F}$

  $f_s \le f_{s,\max}$; $f_{s,\max} = \mu_s n$ (μ_s: *coefficient of static friction*)

- **Kinetic friction:** $f_k = \mu_k n$ (μ_k: *coefficient of kinetic friction*)

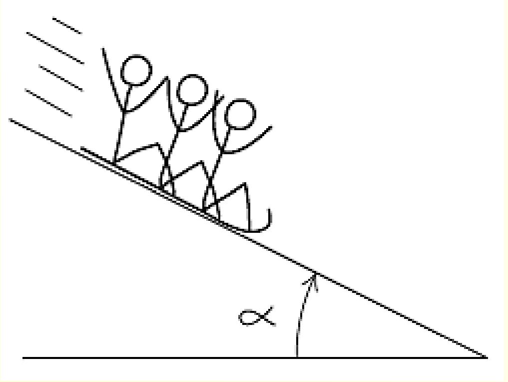
  $f_k < f_{s,\max}$



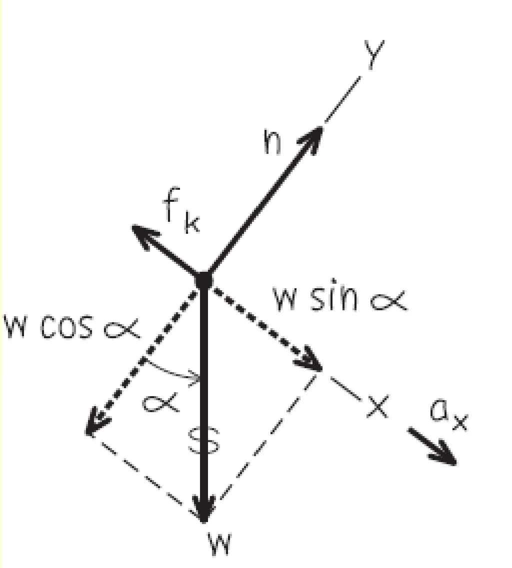
- **Rolling friction**

Exercise:

A toboggan loaded with students (total weight *w*) slides down a snow-covered slope. The wax of the toboggan has worn off, so there is now a nonzero coefficient of kinetic friction μ_k. The toboggan accelerates down the hill, and the hill slopes at a constant angle α. Derive an expression for the acceleration in terms of g, α, μ_k, and *w*.



The free-body diagram for toboggan & choice of coordinate axes are shown on the right:



Newton's second law in component form tells us that:

***y*-direction:** $\sum F_y = n + (-mg\cos\alpha) = 0 \;\Rightarrow\; n = mg\cos\alpha$

***x*-direction:** $\sum F_x = mg\sin\alpha + (-f_k) = ma_x$

$f_k = \mu_k n$

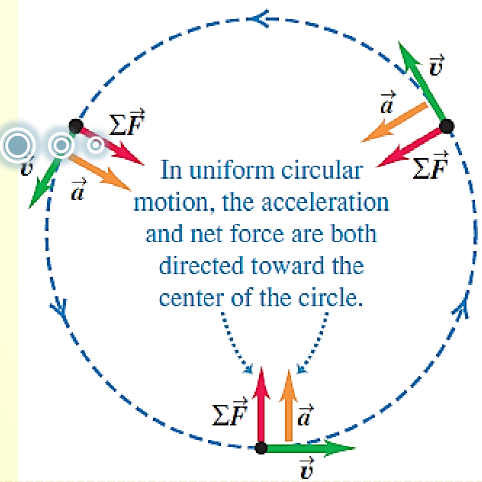
$n = mg\cos\alpha$

$\Rightarrow f_k = \mu_k mg\cos\alpha$

$$a_x = g(\sin\alpha - \mu_k\cos\alpha)$$

Dynamics of Circular Motion

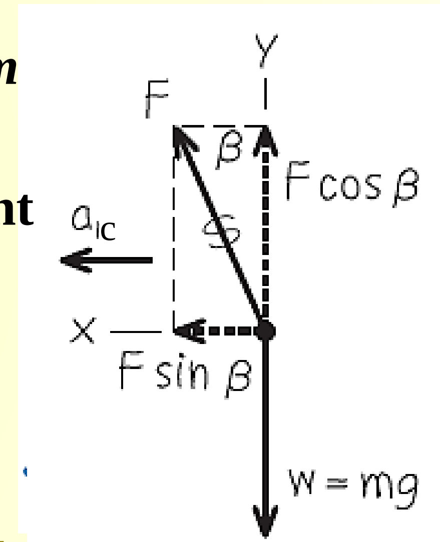
Centripetal force (F_c)



$$F_{net} = \sum F = ma_c = m\frac{v^2}{R} \quad \text{(uniform circular motion)}$$

$$= \frac{4\pi^2 mR}{T^2} = mR\omega^2$$

An inventor designs a pendulum clock using a bob with mass *m* at the end of a thin wire of length *L*. Instead of swinging back and forth, the bob is to move in a horizontal circle with constant speed *v*, with the wire making a fixed angle *β* with the vertical direction. This is called a conical pendulum because the suspending wire traces out a cone. Find the tension *F* in the wire and the period *T* (the time for one revolution of the bob).



Newton's second law in component form says,

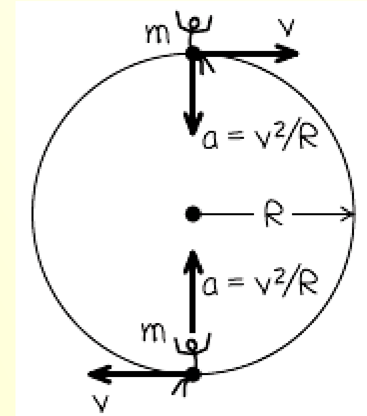
***y*-direction:** $\sum F_y = F\cos\beta + (-mg) = 0 \Rightarrow F = mg/\cos\alpha$

***x*-direction:** $\sum F_x = F\sin\beta = ma_c$

$\Rightarrow$ $R = L\sin\beta$, $a_c = g\tan\beta$, $a_c = \dfrac{4\pi^2 R}{T^2}$ $\Rightarrow$ $T = 2\pi\sqrt{\dfrac{L\cos\beta}{g}}$

Exercise:

A passenger on a carnival Ferris wheel moves in a vertical circle of radius *R* with constant speed *v*. The seat remains upright during the motion. Find expressions for the force the seat exerts on the passenger at the top of the circle and at the bottom.



The free-body diagrams for the two positions are shown on the right:

The positive *y*-direction is taken as upward in both cases.

At the top, the acceleration is downward, so $a_y = -v^2/R$,

and Newton's second law says

***Top*:** $\sum F_y = n_T + (-mg) = ma_y = -m\frac{v^2}{R} \Rightarrow n_T = mg(1 - \frac{v^2}{gR})$

At the bottom, the acceleration is upward, so $a_y = +v^2/R$,

and Newton's second law says

***Bottom*:** $\sum F_y = n_T + (-mg) = ma_y = +m\frac{v^2}{R} \Rightarrow n_T = mg(1 + \frac{v^2}{gR})$