4.5 Overview of Force Types

**Fundamental Forces**

1. Gravitational force
2. Weak Nuclear force
3. Electromagnetic
4. Strong nuclear force

**Non-Fundamental**

Electroweak

This lecture:

Gravitational force = Weight

Normal force (perpendicular to surface)

Friction force (parallel to surface)
4.6 Gravitational force

4.6.1 Newton's Law of Universal Gravitation:

Any 2 masses \( m_1, m_2 \) affect each other with an equal and opposite force of magnitude:

\[
F = G \frac{m_1 m_2}{r^2}, \quad \text{where } G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2
\]

This force is directed along a straight-line connection between \( m_1, m_2 \): gravitational constant.
Ex. 3  Two Persons

\[ m_1 = 80 \text{ kg}, \quad m_2 = 100 \text{ kg}, \quad r = 90 \text{ cm} \]

\[ F_{12} = 6.67 \times 10^{-11} \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2} \cdot \frac{80 \text{ kg} \cdot 100 \text{ kg}}{(0.9 \text{ m})^2} \]

\[ = 6.6 \times 10^{-7} \text{ N} \]

\[ = 0.00000066 \text{ N} \]

\[ \text{tiny!} \]

4.6.2  Weight \equiv \text{Gravitational Force due to attraction to Earth}
Ex. 4 Satellite \((m_s = 15\,\text{tons} = 15000\,\text{kg})\)

20000 km above the Earth's Surface

Solve for weight \(W_s\) and acceleration.

radius \(R_E = 6400\,\text{km} = 6.4 \times 10^6\,\text{m}\)

\[ r = 26.4 \times 10^6\,\text{m} \]

\[ F = \frac{G m_1 m_2}{r^2} \]

\[ W_s = F_{SE} = \frac{G m_s m_E}{r^2} = 6.67 \times 10^{-11} \frac{\text{Nm}^2}{\text{kg}^2} \left(1.5 \times 10^4 \frac{\text{kg}}{\text{kg}}\right) \left(6 \times 10^{24} \frac{\text{kg}}{\text{kg}}\right) \]

\[ \left(26.4 \times 10^6\,\text{m}\right)^2 \]
\[ W_s = 8.6 \times 10^3 \text{N} = 8600 \text{N} \]

\[ a_{SE} = \frac{F_{SE}}{m_s} = \frac{8600 \text{N}}{1.5 \times 10^4 \text{ kg}} = 0.57 \text{ m/s}^2 \]

\[ a_{ES} = \frac{F_{ES}}{m_E} = \frac{8600 \text{N}}{6 \times 10^{24} \text{ kg}} = 1.4 \times 10^{-21} \text{ m/s}^2 \]

\[ R_E = 6.4 \times 10^6 \text{ m} \]

6,400,000

6,401,000
Now suppose we move the satellite to the Earth’s surface:

\[ r = R_E \]

\[ W_s = F_{SE} = \frac{G m_s M_E}{R_E^2} \]

\[ = m_s \left( \frac{G M_E}{R_E^2} \right) \]

\[ = 1.47 \times 10^5 \text{N} \]

\[ a_{SE} = \frac{F_{SE}}{m_s} = \frac{1.47 \times 10^5 \text{N}}{1.5 \times 10^4 \text{kg}} = 9.8 \frac{\text{m}}{\text{s}^2} \]

acceleration of gravity on Earth
4.7 Normal Force

\[ \vec{F}_N = \vec{F}_{BG} = \text{force on the box by the ground} \]

\[
\text{box at rest: } m = 16 \text{ kg}
\]

[Diagram of a box on the ground with forces labeled]

\[ \vec{W} = mg \]

\[ \vec{a} = 0 \implies \Sigma \vec{F} = F_{\text{net}} = 0 \]

\[ \text{ground surface exerts a force } \vec{F}_{BG} \text{ on the box} \]

\[ \implies F_{\text{net}} = \vec{W} + \vec{F} \]
\[ \overrightarrow{F_N} \] normal force is the force exerted on an object in contact with a surface, directed perpendicularly ("normal") to the surface.

\( F_N \) not always equal \& opposite to \( W \).
Ex. 5  Normal Forces and Apparent Weight: 
The Elevator Problem

- $m = 16 \text{ kg}$

a.) if $\ddot{V} = \text{const}$
   $$\ddot{a}_{\text{net}} = 0$$
   $$\Sigma F = F_{\text{net}} = 0$$
   $$F_N - W = 0$$
   $$F_N = W = mg = 157 \text{ N}$$

b.) acc. upward
   $$\ddot{a}_{\text{net}} = +1.5 \frac{m}{s^2}$$
   $$\Sigma F = F_{\text{net}} = m \ddot{a}_{\text{net}}$$
   $$F_N - W = m \ddot{a}_{\text{net}}$$
   $$F_N = W + m \ddot{a}_{\text{net}}$$
   $$mg + ma_{\text{net}} = 167 + 24 \text{ N}$$
   $$mg + ma_{\text{net}} = 181 \text{ N}$$
c.) acc. downward
\[ \ddot{a}_{\text{net}} < 0 \]
\[ \ddot{a}_{\text{net}} = -1.5 \, \frac{m}{s^2} \]

\[ \sum F = m \ddot{a}_{\text{net}} \]
\[ F_N - W = m \ddot{a}_{\text{net}} \]
\[ F_N = W + m \ddot{a}_{\text{net}} \]
\[ = mg + m \ddot{a}_{\text{net}} \]
\[ = 157 \, N - 24 \, N \, \text{apparent weight} \]
\[ = 133 \, N \, \text{Smaller than true weight} \]
4.8 Friction forces act between surfaces in contact, directed parallel to the surface.

4.8.1 Static frictional force

\[ f_s \leq \mu_s F_N \]

\[ \vec{V}_{\text{Box}} = 0 \]

\[ \text{if } F_{\text{pull}} < f_s \text{, then } f_s \text{ exactly counteracts } F_{\text{pull}} \text{ such that } \vec{F}_{\text{net}} = 0 \]

"Static friction coefficient", depends on block and ground surfaces.
if $\vec{F}_{\text{pull}} > f_s^\text{max}$, block starts moving

\[ f_s^\text{max} = \mu_s F_N \]

$\vec{f}_s$ directed along surface, opposite to $\vec{F}_{\text{pull}}$

Ex. 6 metal block (10 kg) on wooden surface: $\mu_s = 0.6$

Minimally required horizontal force to set the block in motion:

\[ f_{\text{hor}} = \mu_s F_N = (0.6)(98\text{N}) = 59\text{N} \]

\[ = f_s^\text{max} \]

$F_N = W = 98\text{N}$
\[ \sum F_y = F_N + F_{pwy} - W = 0 \]
\[ F_N = W - F_{pwy} \]
4.8.2 Kinetic Friction force
acts on "sliding" object, opposite to the direction of motion

\[ f_k = \mu_k F_N \]

Kinetic friction coefficient

\[ \mu_k < \mu_s \]

for the same 2 surface

Snow Surface
4.9 Tension Force

- forces transmitted by ropes, wires, cables, etc.
  always directed along the object

["ideal" ropes: massless, unstretchable]

→ no loss
Ex. Freight Train

Train accelerates from 20 mph to 50 mph in 2 minutes. What minimal tension do the connecting wires have to support?

\[ \sum F_y = m_2 a = T_2 \]

\[ a = \frac{\Delta V}{\Delta t} = \frac{13.3 \text{ m/s}^2}{120 \text{ s}} = 0.111 \text{ m/s}^2 \]

\[ T_2 = (25000 \text{ kg}) \times (0.111 \text{ m/s}^2) = 2780 \text{ N} \]

\[ \sum F_y = T_1 - T_2 = m_1 a \]

\[ T_1 = m_1 a + T_2 = 4780 \text{ N} = T_{\text{max}} \]