First Law of Motion

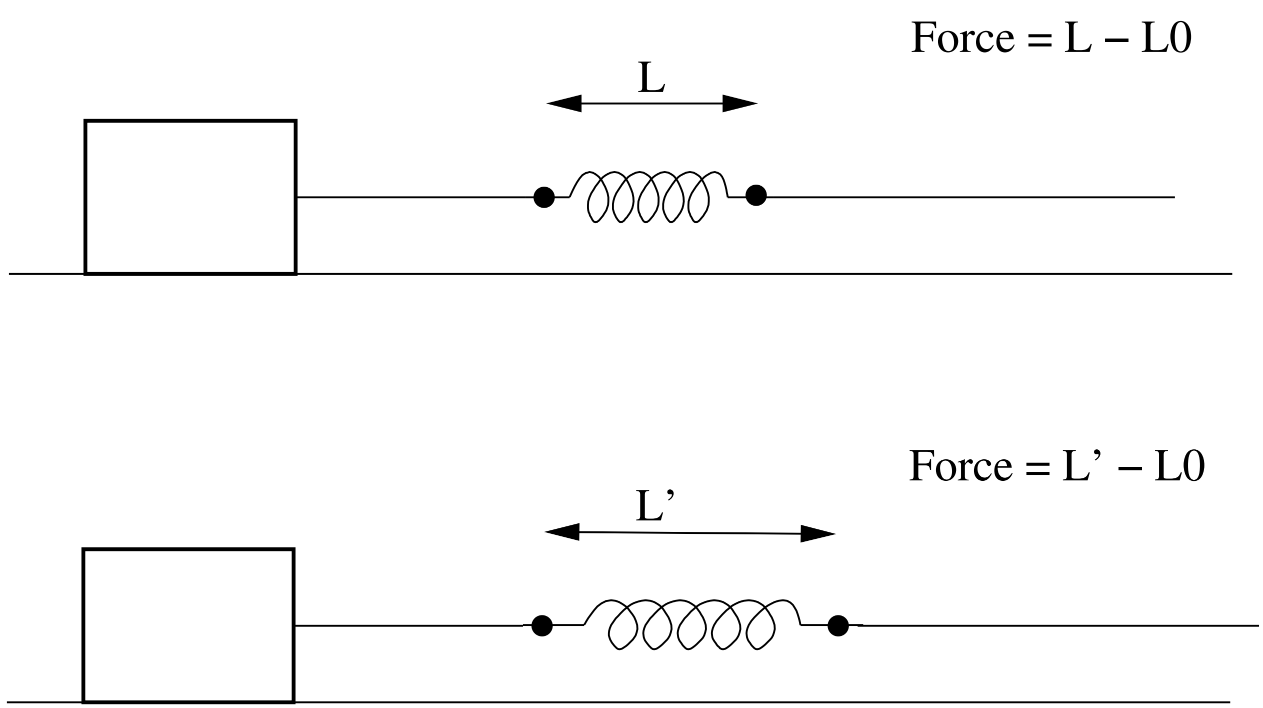
Isolated bodies move with uniform velocity.

- Common Notion: All moving bodies come to a halt.
- Friction is just another *force,* like pushing by a hand.
- Isolated Bodies
- Inertial Frames

Second Law of Motion

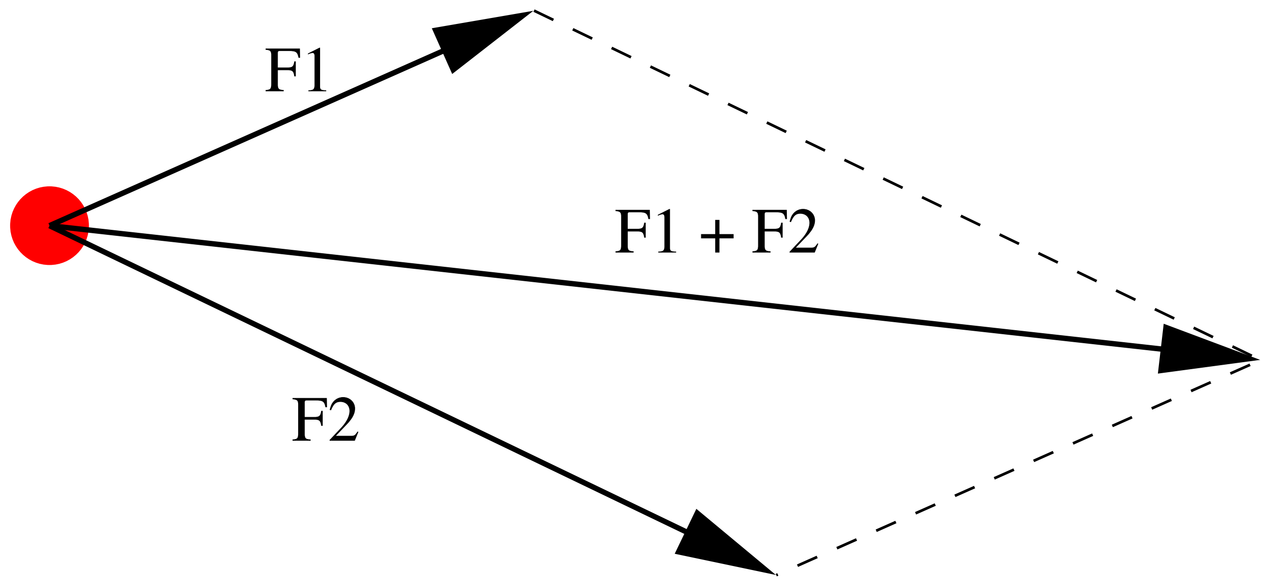
$$F = \frac{d}{dt}(mv) = ma$$

- It is a law, not a definition!
- Force: a spring force



Second Law of Motion

- Mass is a measure of inertia
- Force is a vector quantity.



Third Law of Motion

Every action has a reaction

- Describes the nature of forces
- Is it always true?
  There is some problem with electromagnetic forces.

Fundamental Forces

- Gravitational Forces
- Electromagnetic Forces
- Weak Nuclear Forces
- Strong Nuclear Forces

Gravitational Forces

- Tycho Brahe and Kepler
- Newton's Law of Gravitation

$$\mathbf{F} = G\frac{mm'}{r^2}\widehat{\mathbf{r}}$$

- Inertial or gravitational Mass?
- Explains planetary Motion (Large distances)
- Cavendish Experiment (On Earth)

Electrical and Magnetic Forces

- Coulomb's Law

$$\mathbf{F} = \frac{qq'}{r^2}\widehat{\mathbf{r}}$$

- Magnetic Force
- Fields $\mathbf{E}$ and $\mathbf{B}$
- Lorentz Force

$$\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$$

Nuclear Forces

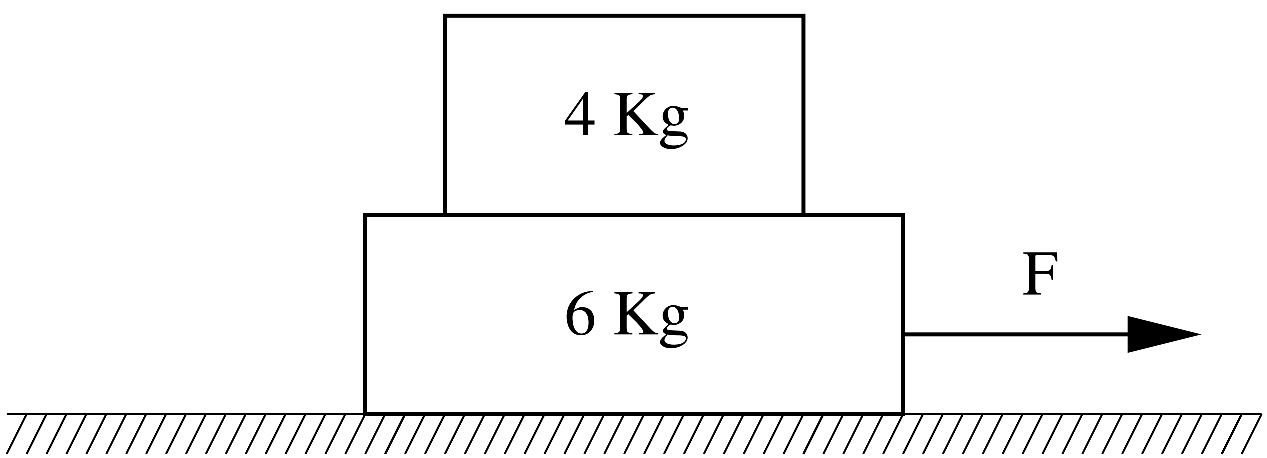
- Range of Nuclear Forces
- Scattering Experiments
- Newtonian or Quantum Mechanics?

Everyday Forces

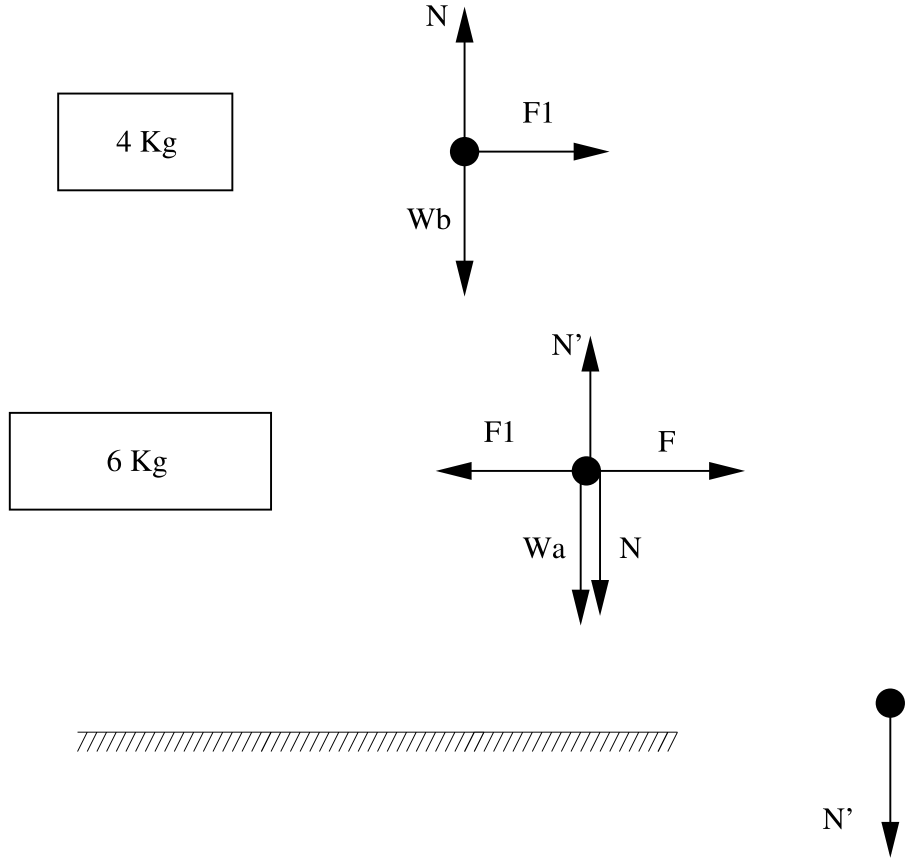
- Tension in the ropes
- Normal Forces
- Frictional Forces
- Viscous Forces
- Springs
- Atomic Forces

Examples

A 4 Kg block rests on top of a 6 Kg block, which rests on a frictionless table. Coefficient of friction between blocks is 0.25. A force $F = 10N$ is applied to the lower block.

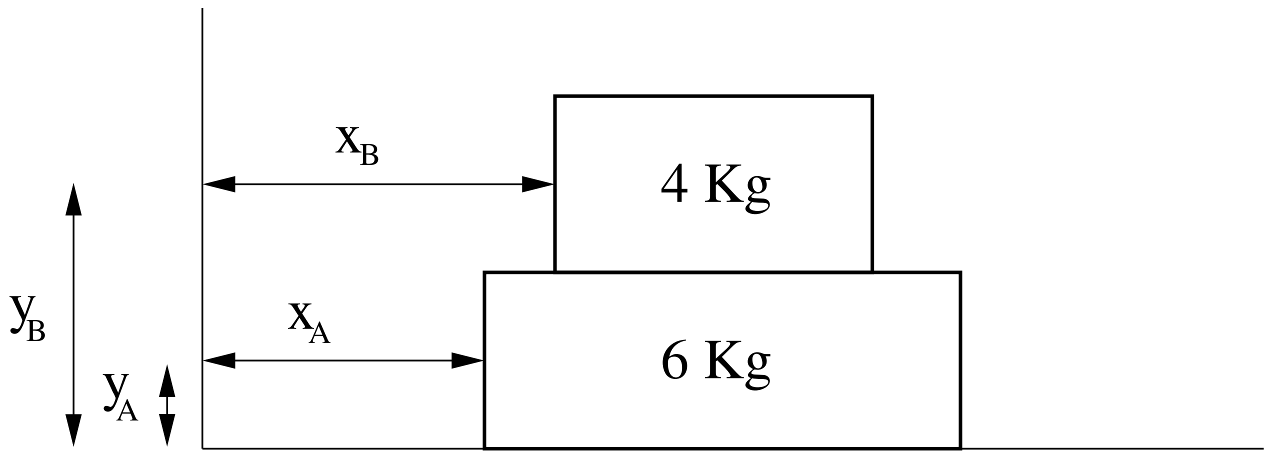


Force Diagrams



Coordinate System and Constraints

Fix the coordinate system to the table.



$$
\begin{aligned}
y_A &= const \\
y_B &= const \\
x_A &= x_B + const
\end{aligned}
$$

Equations

Equations of Motion in Y direction.

$$\begin{aligned} m_A \ddot{y_A} &= N' - W_A - N \\ m_B \ddot{y_B} &= N - W_B \end{aligned}$$

Constraints

$$\begin{aligned} \ddot{y_A} &= 0 \\ \ddot{y_B} &= 0 \end{aligned}$$

Solution

$$\begin{aligned} N' &= W_A + W_B \\ N &= W_B \end{aligned}$$

Equations

Equations of Motion in X direction.

$$
\begin{aligned}
m_A \ddot{x_A} &= F - F_1 \\
m_B \ddot{x_B} &= F_1
\end{aligned}
$$

Constraints

$$
\ddot{x_A} = \ddot{x_B}
$$

Solution

$$
\begin{aligned}
\ddot{x_A} = \ddot{x_B} &= \frac{F}{m_A + M_B} = 1\mathrm{m/s} \\
F_1 &= m_B \ddot{x_B} = 4N
\end{aligned}
$$

Example Continued...

- The force $F_1 < \mu N = 10$ N, the maximum frictional force between the blocks. Hence the solution is consistent with assumption.
- What would be the motion if $F = 40$ N?
  If the blocks move together then $x_B = 4$ m/s and $F_1 = 16$ N! More than the maximum frictional force!

Equations

Equations of Motion in X direction.

$$
\begin{aligned}
m_A \ddot{x_A} &= F - F_1 \\
m_B \ddot{x_B} &= F_1
\end{aligned}
$$

But,

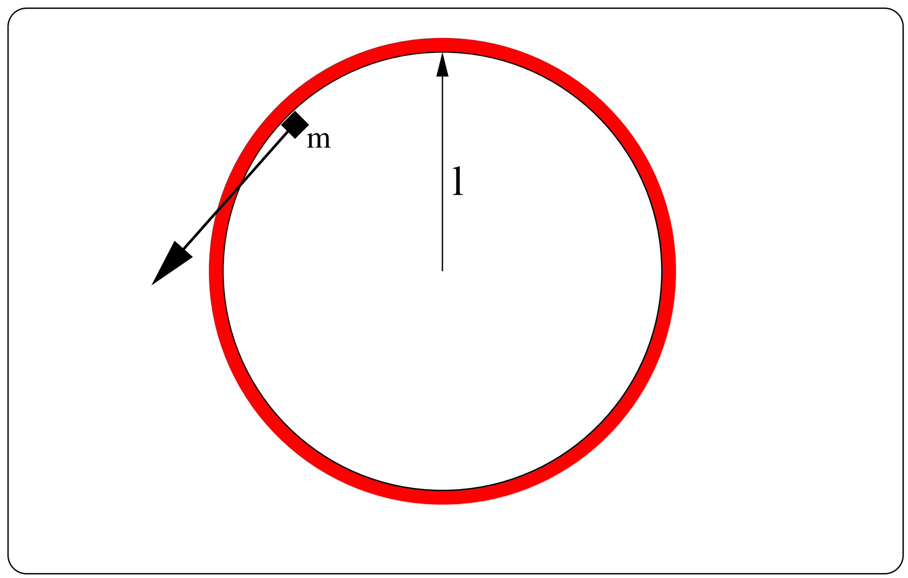
$$
F_1 = \mu N
$$

Solution

$$
\begin{aligned}
\ddot{x_A} &= \frac{F - \mu N}{m_A} = 5\mathrm{m/s} \\
\ddot{x_B} &= \frac{\mu N}{m_B} = 2.5\mathrm{m/s}
\end{aligned}
$$

Another Example

A block of mass m slides on a frictionless table. It is constrained to move move inside a ring of radius l fixed to the table. At $t = 0$ the block is touching the ring and has a velocity v_0 in tangential direction.



Equations

- Constraint Equation is $r = l$, that is $\dot{r} = \ddot{r} = 0$.
- Equations of Motion

$$\begin{aligned} m\left(\ddot{r} - r\dot{\theta}^2\right) = -ml\dot{\theta}^2 &= -N \\ m\left(r\ddot{\theta} - 2\dot{r}\dot{\theta}\right) = mr\ddot{\theta} &= -f \end{aligned}$$

- Eliminating N, we get

$$\begin{aligned} \ddot{\theta} &= -\mu\dot{\theta}^2 \\ v(t) &= l\dot{\theta} \\ &= \frac{v_0}{1 + \mu v_0 t/l} \end{aligned}$$