Chapter 4  Laws of motion

Force — simply put, pushing, pulling, and kicking (etc.) on object.

* while forces can cause motion, they do not have to...

\[ mg \]

\[ \text{book} \]

\[ N \leftrightarrow \text{table} \]

\[ \text{Normal force} \]

\[ \text{(force of table on book)} \]

gravitational force  balances  Normal force  so no motion.

Classification of forces

* Contact forces — physically contact object such as throwing a ball

* Field forces — "action" at a distance e.g. gravity, electric, magnetic forces

Fundamental forces of nature

* Death + Taxes  **not** true!

\[ \text{Gravitational} \]

\[ \text{Electromagnetic} — \text{(Electric and magnetic)} \]

\[ \text{Strong Nuclear forces} — \text{hold protons/neutrons together.} \]

\[ \text{Weak Force} — \text{certain radioactive decay.} \]

GUTS — Grand Unified Theory — try to explain all forces as manifestations of one global force.
Force is a vector.

If more than one force is present, how do I calculate the total net force:

\[ \vec{F}_{\text{net}} = \sum \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 \leq \text{vector sum,} \]

or "superposition" of force vectors.
Newton's First law of motion - law of inertia

- In absence of external forces, and when viewed in an inertial reference frame, an object at rest stays at rest and an object in motion with constant velocity (and zero acceleration)

\[ \Rightarrow \text{if } F = 0, \ a = 0 \]

\[ \Rightarrow \text{what is an external force?} \]

For example, if we consider a book, the forces which hold the atoms/molecules of book together are internal. They give book its chemical composition, mass density, and shape. Forces which try to move the book as a whole are external.

\[ \Rightarrow \text{what in an inertial reference frame?} \]

- a frame of reference in which an object has no acceleration when it is not interacting with other objects

Example consider an air hockey puck

(Use one cart as dense)

\[ \Rightarrow \text{Consider horizontal motion.} \]

\[ \Rightarrow \text{when puck not moving, } a = 0, \text{ puck not interacting (horizontally) with objects.} \]

\[ \Rightarrow \text{what if puck moving at constant velocity?} \]

\[ a = 0, \text{ no other objects interacting horizontally.} \]

\[ \Rightarrow \text{what if force push a horizontal push?} \]
Demo—one cart on another.

- For observer who is fixed & relative to tracks in PPT slide, rail car and passenger are accelerating.
  \[ \Rightarrow \text{Newton's Law of motion apply} \]

- For observer who is moving at constant velocity relative to tracks, we have a reference frame (B) which is moving relative to fixed track position (A):
  \[ \vec{\gamma_A} = \vec{\gamma_{B}} + \vec{\gamma_{BA}} \]
  \[ \Rightarrow \text{Newton's laws of motion still apply} \]

Inertial frame

- Non-Inertial Frame: moving with rail car
  \[ \Rightarrow \text{there appears to be a "fictitious" force which makes the passenger move from one end of car to another.} \]
Mass - property of object which defines resistance to change in velocity (motion)

Newton's 2nd Law:
\[ \sum F = ma \]
- net force \( \vec{F} \)\) \( \uparrow \)
- \( \vec{a} \)\) acceleration \( \uparrow \)
- \( m \) mass (resistance to change in velocity)

Note if \( \sum F = 0 \) (1st Law), \( \vec{a} = 0 \) so \( \vec{V} \) is constant.

Since \( \vec{F}, \vec{a} \) are vectors:
\[ \sum F_x = ma_x \quad \sum F_y = ma_y \quad \sum F_z = ma_z \]

Unit of Force \( \Rightarrow \) Newton = \( \text{kgm/s}^2 \)

I-Clicker Question

Gravitational Force and Weight:
\[ \vec{F}_g = mg \]
- \( m \) mass
- \( \vec{F}_g \) gravitational force or weight

Note: \( m \neq \text{weight} \)

and gravitational mass and inertial mass are the same
Newton's 3rd Law

If two objects interact, $F$ of object 1 on 2 is equal in magnitude, but opposite in direction to force of 2 on 1

\[ F_{12} = -F_{21} \]

"Every action has equal and opposite reaction."

Example of "Bad" Physics - Roadrunner vs. Each Other

\[ \text{EIT Slide } \times 2 \]

Now lots of examples:

- Elevator at rest

Draw free body diagram of all forces acting on object of interest

- Force of floor of elevator on person

\[ mg \]
1. Draw free body diagram ⇒ all forces acting on body of interest.
2. Define coordinate system.
3. Apply Newton's Laws

\[ T - mg = ma \]

If \( a = 0 \) (mass not moving) then

\[ T = mg = 0 \quad ⇒ \quad T = mg \]

Inclined Plane

Choose rotated coordinate system to convert 2-D problem to 1-D motion.
\[ N - mg \cos \theta = ma_y = 0 \]
\[ -mg \sin \theta = ma_x = ma \]

\[ ma = -mg \sin \theta \]

\[ a = -g \sin \theta \]

What does it mean that mass cancels?

\[ N = mg \cos \theta \quad \text{Normal force changes depending on } \theta, g, m. \]

Normal force "adjusts" to whatever it needs to be to make \( a_y = 0 \).

One block pulling another (similar to Example 5.47)

\[ \text{Prob 4.43} \]

What is acceleration of blocks?

* Draw free body diagram for each separately.
By Newton's 3rd law, $|T_1| = |T_2| = T$

Y motion: $N_1 - m_1g = 0$  \hspace{1cm} $N_2 - m_2g = 0$

\[
\begin{align*}
N_1 &= m_1g \\
N_2 &= m_2g
\end{align*}
\]

X motion:

\[
T = m_1a_1
\]

$F - T = m_2a_2$

how are $a_1$ and $a_2$ related?

$a = a_1 = a_2$, if distance between $m_1$ and $m_2$ is fixed, (string doesn't go slack or stretch).

\[
\begin{align*}
T &= m_1a_1 \\
F - T &= m_2a_2 \\
\text{combine} &\Rightarrow F - m_1a_1 = m_2a_1
\end{align*}
\]

\[
a = \frac{F}{m_1 + m_2}
\]

Example — Atwood's Machine Prob 4.28

$\Rightarrow$ Show active Fig 5.14

I Clicker Question x 3

Pulleys — for now, consider pulleys to be massless — they only change direction of force
1. Draw Free body diagrams for each mass.
2. Choose coordinate system for each mass.
3. Solve coupled equations.

\[ T - m_1 g = m_1 a \]
\[ N - m_2 g \cos \theta = 0 \]
\[ m_2 g \sin \theta - T = m_2 a \]

Combine:

\[ m_2 g \sin \theta - m_1 g = (m_1 + m_2) a \]

\[ a = g \frac{m_2 \sin \theta - m_1}{m_1 + m_2} \]
If $m_2 \sin \theta > m_1$, then $a > 0 \Rightarrow$ moves in 
positive $x$ direction as defined in coordinate system 
or down the incline.

If $m_2 \sin \theta < m_1$, then $a < 0 \Rightarrow$ moves in 
negative direction or up incline.

If $m_2 \sin \theta = m_1$, \quad a = 0 \Rightarrow \text{no movement}.

(if mass is at rest).