Chapter 4

Force and Newton's Laws of Motion

Ch 4 Force and Motion

- Summery of Motion
- Force
- Newton's 1st Law
- Reference Frames
- Newton's 2nd Law
- Mass
- Free Body Diagram

What did we learn so far?

- How do objects move?
  - Position, velocity and acceleration as a function of time.

$$\vec{r}(t),\ \vec{\upsilon}(t),\ \vec{a}(t)$$

  - Example: 1D-motion with a constant acceleration.

$$x(t) = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

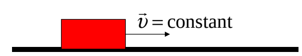
$$\upsilon(t) = \upsilon_0 + at$$

$$a = \text{costant}$$

  - 2-d motion with constant acceleration

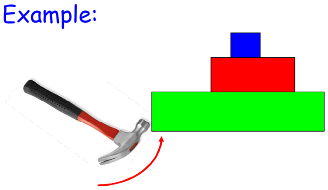
Why do objects move?

- Historical prospective:
  - Aristotle:
    - The natural state of an object is to be at rest.
    - For an object to move with a constant velocity a force needs to be applied.
  - Galileo Galilei:
    - He recognizes that if a moving object is not disturbed by external forces it will keep moving at a constant rate.



Newton's First Law

- Formulation:
  - If no force acts on a body, the body's velocity cannot change.
  - If no force acts on an object it remains at rest or it continues its linear uniform motion.
- Example:

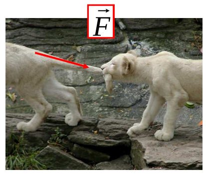


A few pointers

- A linear and uniform motion is as "natural" for a body as for it to be at rest.
- The presence of an acting force is not a reason by itself for an object to be moving.
- If a body is not moving uniformly, $a \neq 0$ there is a force acting on it!
- If a body is moving on a curved trajectory there is definitely a force acting on it.

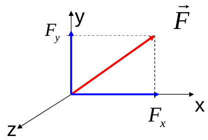
Force

- The force is a vector:
  - Magnitude
  - Direction
  - Application point



- The force has components:

$$\vec{F} = F_x \hat{x} + F_y \hat{y}$$



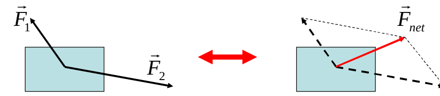
- Unit: N (Newton)
  - 1N is the force that results in acceleration of 1 m/s^2 when applied to a standard body with mass 1 kg.

Net Force: $\vec{F}_{net}$

- Forces add and subtract as vectors.
- The sum of all forces acting on a single body is called net force (resulting force).

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$$

- Principle of superposition:
  - The effect of all forces acting on a single, point mass is equivalent to the effect of a single force (the net force) acting on this body.



Newton's First Law - revisited

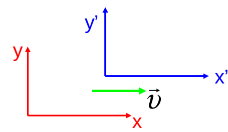
- Newton's First Law: an object will
  - stay at rest, or
  - maintain its motion at a constant velocity and in a straight line

  as long as
  - no force is exerted on the object, or
  - all forces cancel each other (F_{net}=0)
- Says who? An observer at rest, or moving at a constant speed.

$$\vec{F}_{net} = \vec{F}_{drag} + \vec{G} = 0$$

Inertial and Noninertial Reference Frames

- Inertial reference frame:
  - It is at rest or it moves at a constant velocity.
  - Use Newton's 1st law



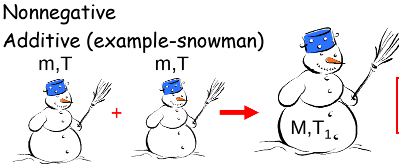
- Noninertial reference frame:
  - Accelerating reference system
  - Newton's 1st law does not apply

What about the Earth?

- The Earth is rotating and it is not an inertial reference frame.
- The effect is noticeable only for long range motions (air travel, missile trajectories, winds in the atmosphere)
- For the purpose of this class we will consider the Earth as an inertial reference frame, unless stated otherwise.

Mass m, M

- Experiment: same force acting on different bodies results in different accelerations.
- Definition: an intrinsic characteristic of a body that relates the magnitude of a force acting on the body to the resulting acceleration.
- Properties:
  - Scalar
  - Nonnegative
  - Additive (example-snowman)



M=m+m
$T_1 \neq T+T$

Newton's Second Law

- The net force (F) on a body is equal to the product of its mass (m) and its acceleration (a).

$$\vec{F}_{net} = m\vec{a}$$

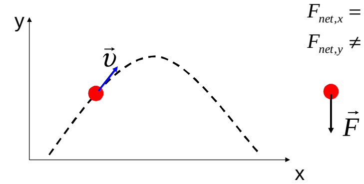
$$\updownarrow$$

$$F_{net,x} = ma_x, F_{net,y} = ma_y$$

Some pointers

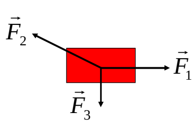
- The net force and the acceleration are in the same direction.
- Motion is uniform in directions perpendicular to the force ($v_\perp$=const).
- Example: projectile motion

$$F_{net,x} = 0 \Rightarrow \quad v_x = \text{constant}$$
$$F_{net,y} \neq 0 \Rightarrow \quad v_y \neq \text{constant}$$



More pointers

- If the net force is zero does not mean than there are no forces acting on the body!
- If a body is at rest or it is moving with a constant velocity the net force acting on this body is ZERO.



More interpretations

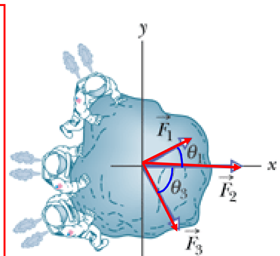
- If the net force is zero it means that:
  - the forces are in balance
  - The sum of the corresponding components of the acting forces is ZERO

$$\sum F_{n,x} = 0, \sum F_{n,y} = 0$$

  - The acceleration is zero, a=0
  - If the body is at rest it will stay at rest
  - If the body is moving it will continue to move with the same velocity on a straight line.

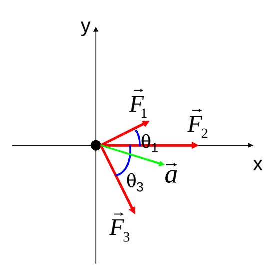
Example Problem

- Three astronauts, propelled by jet backpacks, push and guide a 120 kg asteroid exerting the forces F_1=32 N, F_2=55 N and F_3=41 N at angles θ_1=30° and θ_3=60°.
- What is the acceleration of the asteroid?



Free-body Diagram

- The body is substituted with a point mass.
- All forces are shown as vectors with a tail at the point mass and a head pointing in the direction of the force.
- The acceleration is shown as a vector.
- A coordinate system is indicated.



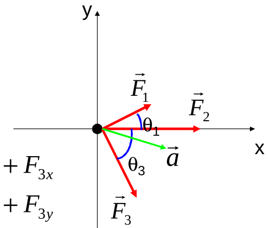
Solution

$m = 120\ kg$
$F_1 = 32\ N$
$F_2 = 55\ N$
$F_3 = 41\ N$
$\theta_1 = 30^\circ$
$\theta_3 = -60^\circ$

$\vec{a} = ?$

$$\vec{F}_{net} = m\vec{a}$$

$$F_{net,x} = ma_x$$
$$F_{net,y} = ma_y$$



$$F_{net,x} = F_{1x} + F_{2x} + F_{3x}$$
$$F_{net,y} = F_{1y} + F_{2y} + F_{3y}$$

$$a_x = \frac{1}{m}(F_1 \cos\theta_1 + F_2 + F_3 \cos\theta_3) = 0.86 m/s^2$$

$$a_y = \frac{1}{m}(F_1 \sin\theta_1 + 0 + F_3 \sin\theta_3) = -0.16 m/s^2$$

$$\vec{a} = 0.86\hat{x} - 0.16\hat{y} m/s^2$$