Newton's Laws of Motion

Chapter 4

Why do things move?

Aristotle's view (developed over 2000 yrs ago):

- A **force** always has to act on an object to cause it to move.
- The **velocity** of the object is proportional to the strength of the applied force.
- **Concerning gravity** --- Heavier objects fall quicker to Earth than lighter ones because more force exerted on them (as manifested by their different weights).

… all intuitive ideas

Why do things move?

Problems with Aristotle's ideas …

- There are many examples in nature where after an initial force a **body keeps moving** with **no** continuing force.

Examples:

- Hockey puck after being struck,
- Satellite in space,
- Bullet after leaving a gun…

Nevertheless, Aristotle's ideas prevailed for over **1000 years**!!!

Why do things move?

Galileo's view (17th century):

- He experimentally determined that objects of **similar shape** but **differing weights** fell at the **same rate**.
- He also argued that the natural tendency of a **moving object** is to **continue to move** (ie. **no** force required to maintain its motion once it's started). (Developed equations of linear motion: $v = a.t$ and $d = \frac{1}{2} a.t^2$)

Both in contradiction to Aristotle's ideas...

Newtonian Concepts (1687):

He developed **"Mathematical principles of natural philosophy"** --- **Newton's Principia** ---

Four laws (three on motion and one on gravitation) **built on Galileo's ideas.**

- Laws could explain motion of **any object** eg. a ball or a planet! (**terrestrial & celestial**)
- Laws led to important **predictions**…
  e.g. discovery of Neptune!
- **Newton's laws** - a tremendous **step forward**.
- They continue to be used today to explain **ordinary motions** of everyday objects.

Newton's First Law of Motion

Describes what happens to an object in the absence of a force (similar to Galileo's ideas).

① An object remains **at rest** or in a **uniform motion in a straight line** unless acted upon by an external force.

ie. An object's **velocity** will **not** change unless it is acted upon by a **force**.

an object
- at rest, remains at rest
- in motion, continues at **constant velocity.**

Contrary to Aristotle's idea **no force** is needed to **keep an object moving** (in absence of friction etc.)

Newton's **Second** Law of Motion

Relates applied force to the resultant motion --- (involves the idea of acceleration).

② The **acceleration** of an object is **directly proportional** to the magnitude of the applied **force** and **inversely proportional** to its **mass.** (The acceleration is in **same direction** as the applied force.)

- We can express this law mathematically as:

$$\vec{a} = \frac{\vec{F}}{m}$$

where:

$\vec{a}$ = acceleration

$\vec{F}$ = force

m = mass

Newton's Second Laws of Motion

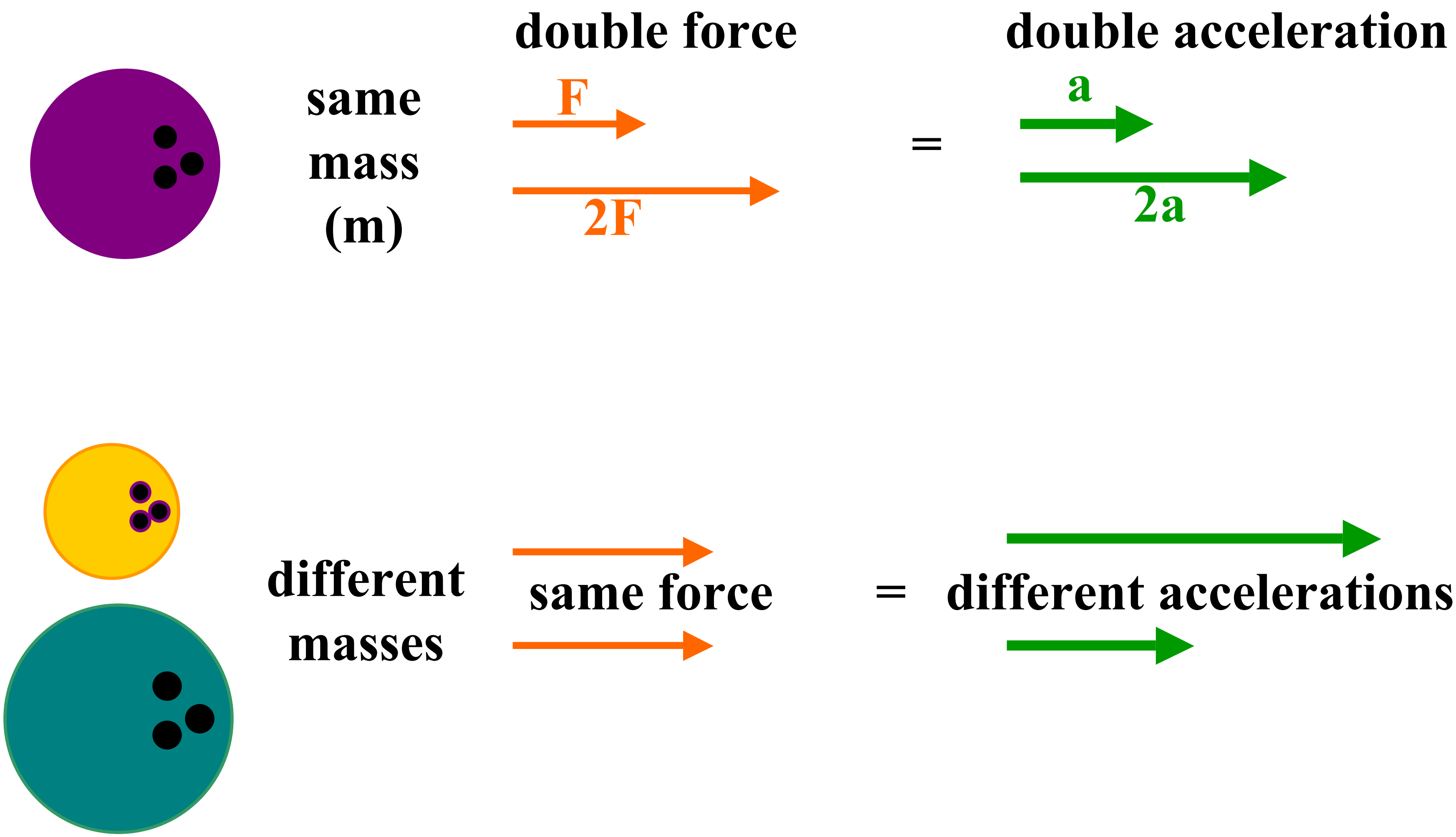
$$\vec{a} = \frac{\vec{F}}{m}$$

Note: The **acceleration** is directly related to the applied force, **not** to its **velocity** … again contrary to Aristotle's ideas.

- Newton's 2nd law is central to our understanding of everyday motion and relates two **key** quantities:
  - **total applied (net) force**
  - **mass of an object**
- The concept of **force** and **mass** are, in part, defined by Newton's second law.

Newton's Second Laws of Motion

Examples:



Units of Force: defined by 2nd Law

$$\vec{a} = \frac{\vec{F}}{m}$$

$a = m / s^2$
$m = kg$

or

$$\mathbf{F = m \cdot a} \qquad (kg \cdot m / s^2)$$

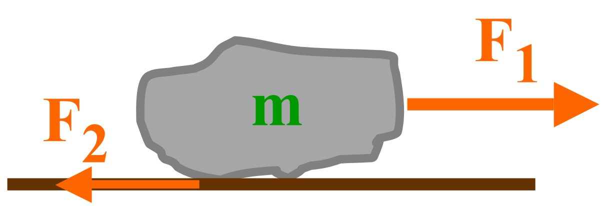
Metric unit of force is the "**Newton**".

1 Newton = 1 N = 1 kg.m /s^2

(force required to accelerate a mass of 1 kg at 1 m /s^2)

Net (Total) Force

- Newton's 2nd law refers to the **total** (or **net**) **force** acting on the object.
- **Force is a vector quantity (magnitude and direction are crucial).**
- **In nature there is often more than one force present (eg. friction) and it is necessary to add vector forces to determine net force.**



$$F_{net} = (F_1 - F_2) = m \cdot a$$

Summary of 1st and 2nd Laws

- First law is a special case of 2nd law, when velocity is zero or constant.

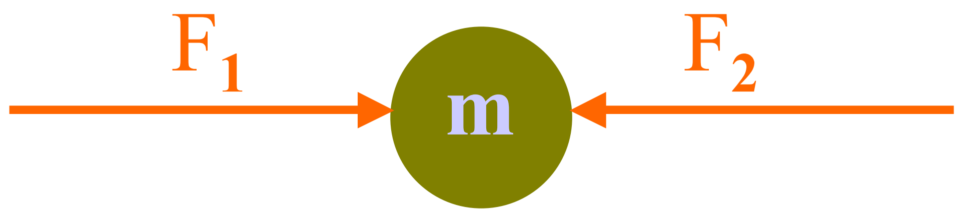
  (ie. when there is **no net force** present, $F_{net} = 0$)

$$a = \frac{F_{net}}{m} = 0$$

(as $a = 0$, the velocity of object will **not** change.)

However, this does **not** mean that there are **no forces** present.

Consider:



- If $F_2 = - F_1$, then the **net force = 0** and **no acceleration occurs.**
- Thus, forces can be present but only the **net force** causes a **change** in motion.
- Newton's 2nd law allows us to **quantify** the effect of **forces** on an object's **motion**.

Mass

- Definition: Mass is a measure of the amount of matter in a body.

But: Newton's 2^{nd} law tells us that the mass is a measure of **resistance to changes** in **motion**!!

i.e. It is more **difficult** to change the motion (accelerate) **more massive** objects.

- This resistance is called "**Inertia**".
- Alternate definition: Mass is a measure of an **object's inertia**, which is the property that causes it to **resist changes** in its **motion** (direction or speed).

Mass

- **Mass** is measured **in Kg** (not a vector).
- We can use Newton's second law to **compare** masses.

  Eg. Measure an **unknown mass** against a "**standard mass**" by determining the **acceleration** produced for a **given net force**.

$$F = m_1 \,.\, a_1 \quad = m_2 \,.\, a_2$$

or $$m_2 = \frac{m_1 . a_1}{a_2}$$

- However, it is often easier to **compare weights** (as accelerations are difficult to measure).

Weight

- Qus: What is weight? Is it the same as mass?
- Weight is due to the force of gravity acting on an object…
- As weight is a **force**, by Newton's 2^{nd} law:

$$\mathbf{W = m \cdot g}$$

W = weight of body of mass m
g = acceleration due to gravity.

- **Weight is a vector and is always directed downwards towards the center of the Earth.**
- **Weight** is measured in **Newtons**, whereas **mass** is measured in **kilograms**.

Weight

Example: A body of mass 100 kg near Earth's surface has a weight:

$$W = m \cdot g = 100 \times 9.8 = 980\,\mathbf{N}$$

Weight is therefore proportional but **not equal** to mass.

Weight is dependent on the **gravitational field** we are in and varies slightly over the surface of Earth…eg. as 'g' varies.

On the Moon the gravitational acceleration is about 1/6th of 'g', thus your **weight** will be **6 times less** than on Earth but your **mass** will be the **same**.

Weight

Example: A body of mass 100 kg on the moon weighs:

$$W = m \cdot g = 100 \times 9.8 / 6 = 163 \text{ N}$$

(Compared with 980 N on Earth)

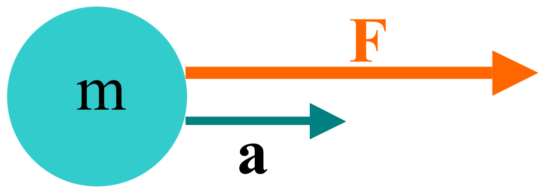
Note: In English (imperial) system, weight (W) is measured in **lbs** (pounds) – which is also a **force**.

1 lbs = 4.45 N so, W = 163 N = 36.6 lbs only!

A mass of 1 kg therefore weighs 2.2 lbs near Earth's surface (or 9.8 N).

Summary

- Newton's 1st and 2nd laws relate the **net force** to the **resultant acceleration** of an object.



$$\vec{a} = \frac{\vec{F}}{m}$$

- Weight and mass are **not** the same!
- Weight is a gravitational force exerted on a body of mass 'm' :

$$W = m \, . \, g$$

- Mass is an inherent property of a body related to its quantity of matter. Mass is also a measure of its resistance "inertia" to change in motion.
- The **weight** of an object **may vary**, depending on 'g' varying, but its **mass is constant.**