Galileo Galilei
Galileo Galilei (Italian Astronomer, 1564-1642)

He was the first to use a telescope to look at the sky and discovered the following:

- Venus, like the Moon has phases, this supports the helio-centric (sun-centered) model
- Jupiter has 4 moons revolving around it – against the geo-centric model
- Saturn is oddly shaped (he could not resolve the Ring)
- The Moon has mountains and its face is not smooth
- There are spots on the Sun
- The Milky way is made of a mass of innumerable stars
Phases of the Planet Venus

\[ \alpha = 58^\circ \]

\[ \alpha = 42^\circ \]

\[ \alpha = 24^\circ \]

\[ \alpha = 15^\circ \]

\[ \alpha = 10^\circ \]
**Explanation**

*When Venus is on the opposite side of the Sun from the Earth, it appears full and has a small angular size.*

*When Venus is at the greatest angle to either side of the Sun (at greatest western or eastern elongation), it appears half illuminated and has an intermediate angular size.*

*When Venus is on the same side of the Sun as the Earth, we see it in a “new” phase and with a larger angular size.*
Galileo saw Jupiter’s 4 (largest) moons
He observed them regularly

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Sono Pericle.

Galileo Galilei, Filosofo della Sc. V. influenzato
da Aristotele, et io, pure, pensando di potere no solo riferire
sulle prime che nella scienza di Matematica nella Sc.
no di Padova,

volevo da parte determinata di presentare al Signor Pericle
l’archidea et fuposi di farmente impadronirsi di ogni
ragione et in intera maritana o terrestris non distinta pel
di nuovo artificio il maggiore rapito et adobe a disposizione
di vivere. L’archidea erane della più diite speculazioni di
profonda et grandissima rispetto L’edi et Vede dell’immas
di Vae horre et più di tempo prima Kraj gaymon poi et distinguendo
il numero et la quale dei Vesper si vendere le sue fisio
halliberista via nel camitiamento o alla fuga, o pure ross
nella epoca aperta diere et particolarmente distinguere ogni suo
modo di comportamento.

...
Galileo observed Saturn with its rings

These are sketches of three drawings Galileo made of Saturn through his primitive telescope. ("New Worlds," Couper & Henbest, p.86.)
Galileo's drawings of Saturn and the phases of Venus
Galileo Observed the Moon
The surface of our Moon is not smooth
Galileo observed the Sun
The Sun has dark spots
The Milky Way looks like a cloud
But it is made of billions of stars
Galileo Galilei found:

- Venus, like the Moon has phases, this supports the helio-centric (sun-centered) model

- Jupiter has 4 moons revolving around it – against the geo-centric model

- Saturn is oddly shaped (he could not resolve the Ring)

- The Moon has mountains and its face is not smooth

- There are spots on the Sun

- The Milky way is made of a mass of innumerable stars
The end of the earth-centered model

All these were proofs that the earth was not the center of the world

Galileo was tried by the Church for “heresy” and had to declared formally that he was wrong

In 1992 the Church “cleared” him of wrong-doing, basically apologized to him post mortem
Galileo was also a scientist/physicist

• He carried out experiments, such as dropping weights of different masses to study their free fall.

He stated that an object in motion will continue moving in a straight line at constant speed unless a force acts on it.
Sir Isaac Newton (1642-1727)
• He studied Mathematics in Cambridge (of course!)

• Because of the Plague the University closed and sent the students home

• He studied on his own and invented Calculus

• From experiments and observations and based on the work of others, he proposed 3 basic laws of motion
Newton’s First Law of Motion
(which is Galileo’s Law...)

- An object at rest will remain at rest until a force acts on it
- An object moving at a constant speed along a straight line will remain moving at a constant speed in a straight line until a force acts on it

(this is due to the inertia of mass)

An inertial frame of reference is either at rest or moving at a constant speed in a straight line

Example being inside of moving train, plane, etc..
Only the relative motion between objects has a meaning.

In everyday life there is friction to slow down moving objects; example of a skater.
Newton Second Law of Motion

- If a force acts on an object, its motion will change

[ when there is more than one force acting on an object, it is the net resulting force that will act on that object – if the resulting force is non-zero – if the forces are not cancelling each other]
Second Law: $F = ma$

- When a force $F$ acts on an object of mass $m$, the object of mass $m$ will have an acceleration $a$.
- Acceleration means a change in velocity.
- Velocity means not only speed but also direction.
- Speed = mile/hour.
- Speed + direction = velocity.
Example of a car

- Cruising a 60mph, the drink level is flat (no force, no acceleration)
- Pressing the gas ➔ feel a push backwards (inertia) Force and acceleration
- Pressing the brakes ➔ feel a push forwards (inertia) Force and acceleration

-Make a turn (at constant speed mph), you feel pushed to the side ➔ inertia again, Force and acceleration
In simpler terms

• When you push an object, it accelerates (picks up some speed) in the direction you are pushing
• The harder you push on the object, the more it accelerates
• The more massive an object (the larger its inertia), the harder it is to push/accelerate it

\[ F = ma, \text{ or also, } a = \frac{F}{m} \]
Newton’s Third Law of Motion

- To any “action” there is a “re-action”
- Whatever is being pushed, pushes back in the opposite direction with the same force
Examples

• Sitting on a chair: the chair pushes back to support your weight, otherwise you are on the floor
• Stand on a chair with wheels and jump forward (don’t try to do it!): the chair will move backwards and you will likely fall not very far (and hurt yourself) – because the chair moved backward and couldn’t push you back as hard you wanted
• Stand on a concrete block and jump (don’t try that): the block won’t move but you will move forward … because the block pushed you back when you pushed it (it “supports” you when you jump)
Newton’s 3 Laws:

• An object will remain at rest or will continue moving in a straight line at a constant speed until a net force acts on it
• If a net force acts on an object, then the object motion changes $F = ma$
• If a force is applied to an object, that object pushes back with the same force but in the opposite direction (action-reaction)
The Law of Gravitation

- Drop an object and it accelerates toward Earth
- If there is acceleration (a) there must be a force (F) (Newton’s 2\textsuperscript{nd} Law: F=ma)
  \begin{itemize}
    \item The earth is applying a force (acting at a distance): The Force of Gravity
  \end{itemize}

The Force of Gravity is acting at a distance
It does not need contact to pull or push
• All objects fall under earth gravity with the same acceleration (except for friction with air)

Example: A small marble and a bowling ball dropped at the same time, reach the ground at the same time (same acceleration; already discovered by Galileo).

We denote this (Earth’s) acceleration “g”

\( f=mxg \) for a marble
\( F=Mxg \) for a balling ball

An object twice as massive has a force twice as strong

This force is nothing else than what we call the weight of the object
Next step - Apply Newton’s 3rd Law: if the earth pulls an object, that object pulls the earth

- the earth is pulling an object of mass $m$ with a force $F$ proportional to $m$, then
- The object of mass $m$ must be pulling the earth with an equal force (opposite direction) $F$ itself is proportional to the mass of the Earth

$\Rightarrow F$ is proportional to $M_e$ and to $m$

$\Rightarrow F = (\text{something}) \times M_e \times m$
This is true for any object of any mass

• This holds true for the Sun and planets
• This holds true for all objects on earth

\[ F_G = (\text{something}) \times m_1 \times m_2 \quad : \text{Gravitational force} \]

Newton found out using Calculus that this “something” is inversely proportional to the square of the distance between the objects

\[ F_G = G \times \left( m_1 \times m_2 \right) / (d \times d) \]

G is a constant of proportionality (the gravitational constant) and d is the distance between the two objects
The inverse square law for gravitation

- It can be explained using simple geometry
- The amount of Light falling on a surface decreases by an inverse square law of the distance to the source of Light
Gravity propagates through space all around like a source of light and so its intensity must decrease in the same manner.

Inverse square law

\[ F_g = \frac{GMm}{d^2} \]
• The same force that pulls objects toward the center of the earth is the one that is also responsible for the motion of the Moon.
an object in orbit is in free fall “around” the earth
Analogy
Most orbits are elliptical

- With the earth/sun occupying a focus
- If you give more velocity to a satellite its orbit becomes more elliptical and it goes further and further away from the earth
• Bound orbits: circular or elliptical
• Unbound orbits (escaping): hyperbolas and parabolas
• Escape Velocity: the velocity given to an object (satellite) such that it is unbound (never comes back toward Earth)

Newton Law of gravitation is used to determine the mass of celestial objects (e.g. planets, comets, galaxies...) from observations of their orbital motion.
Tidal Forces
Tidal Forces

• The tides on Earth (periodic rise and fall of the ocean level – every 6h) are due to the gravitational attraction of the Moon and Sun, called tidal forces.

• Tidal forces are better understood when considering force of gravity of one object (e.g. the Moon) on different parts of another object (e.g. The Earth).

• The closest part of the Earth feels a stronger pull than the parts further away.
Billiard balls at rest

(a)

A short distance
A longer distance
A still longer distance
A short time later

(b)

From the perspective of the center ball
The yellow arrows indicate the strength and direction of the Moon’s gravitational pull at selected points on the Earth.

From the perspective of the center of the Earth
As the Earth rotates underneath the oceans, a given location experiences alternating high tides and low tides.
The greatest deformation (spring tides) occurs when the Sun, Moon, and Earth are aligned and the tidal effects of the Sun and Moon reinforce each other.

The least deformation (neap tides) occurs when the Sun, Earth, and Moon form a right angle and the tidal effects of the Sun and Moon partially cancel each other.
Tidal forces and the spin of Earth

at \( t = 0 \)

Earth

- Earth’s rotation

Moon

Moon’s revolution around the Earth

at \( t = 1 \)

movement of water (torque produced)
Gravitational attraction of Earth’s tidal bulge “pulls” Moon ahead in its orbit.

Moon’s gravitational attraction pulls Earth’s tidal bulge “backward,” slowing Earth’s rotation.
With time the Moon is moving away
Tidal Locking of the Moon
Asymmetry of the Moon