

Lecture 2-1C:
The Three Laws of Motion

PHILOSOPHIÆ
N A T U R A L I S
P R I N C I P I A
M A T H E M A T I C A .

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IMPRIMATUR.
S. P E P Y S, *Reg. Soc.* P R Æ S E S.
Julii 5. 1686.

L O N D I N I,

Jussu Societatis Regiæ ac Typis *Josephi Streater.* Prostat apud
plures Bibliopolas. *Anno MDCLXXXVII.*

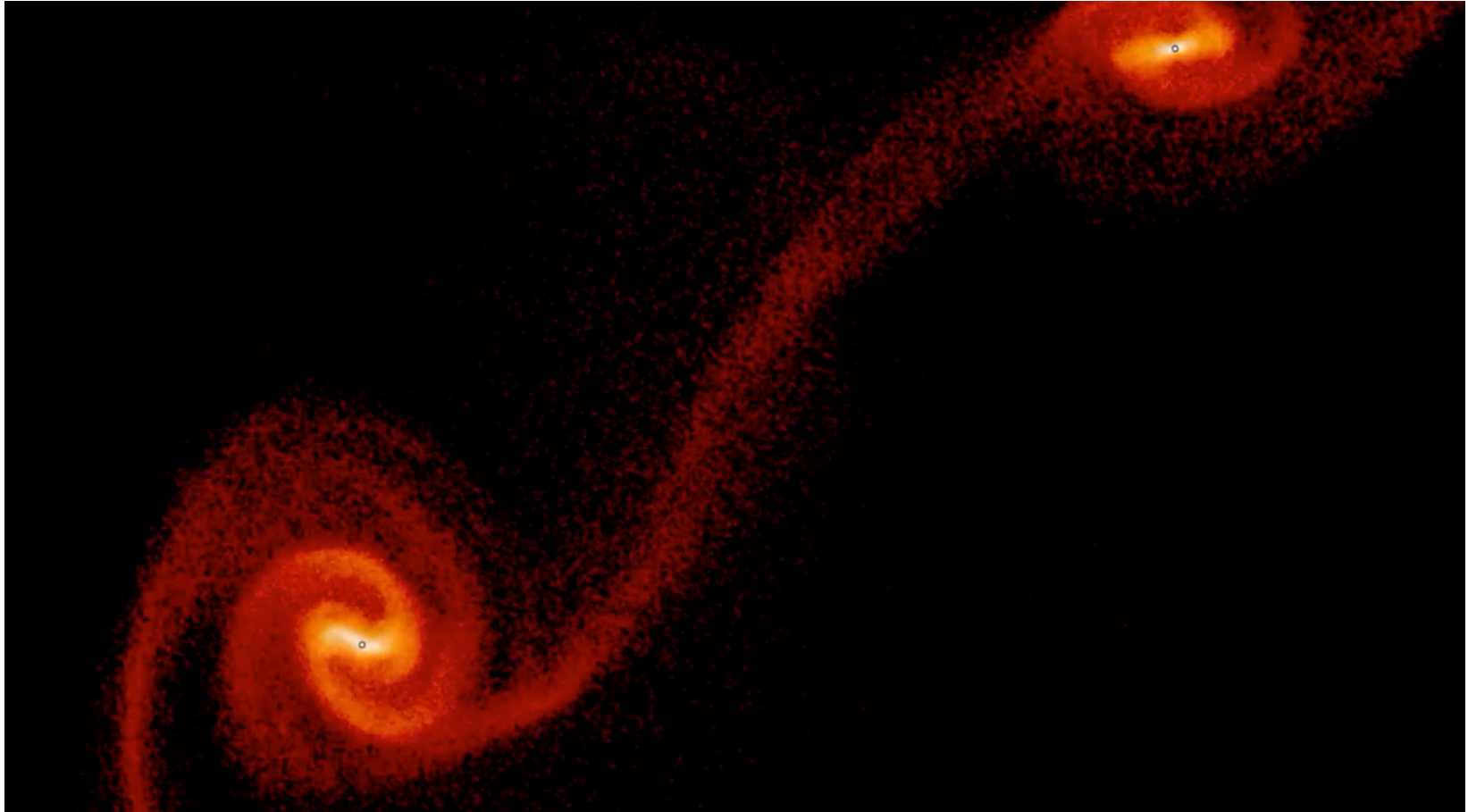
Title page of *Principia*, first edition (1687)

https://en.wikipedia.org/wiki/Philosophi%C3%A6_Naturalis_Principia_Mathematica#/media/File:Principia-title.png



Chemotaxis of *Dictyostelium discoideum*
created by S. Lee, UCSD Firtel Lab

<http://people.biology.ucsd.edu/firtel/video/ax3single/video.htm>



Simulation of interacting galaxies

Credit: NASA <https://www.youtube.com/watch?v=BwhUI1qvG4k>

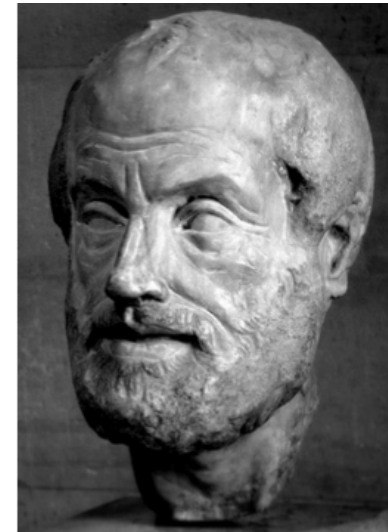


Babylonian observation of Halley's comet, 164 BC
British Museum, London

https://en.wikipedia.org/wiki/Babylonian_astronomy#/media/File: Babylonian_tablet_recording_Halley%27s_comet.jpg

Aristotelean Motion

Ancient Greeks, culminating in **Aristotle** (384-322 BC) proposed two fundamental types of motion:



Natural: all things tend to their "natural place", in stacked order of earth, water, air, fire, aether

Violent: all other motions require applied force

Also deduced that heavy things fall faster

All based on *observation*, not *experimentation*



Scholars at an Abbasid library. Maqamat of al-Hariri

Illustration by Yahyá al-Wasiti, [Baghdad](#) 1237

https://en.wikipedia.org/wiki/House_of_Wisdom#/media/File:Maqamat_hariri.jpg

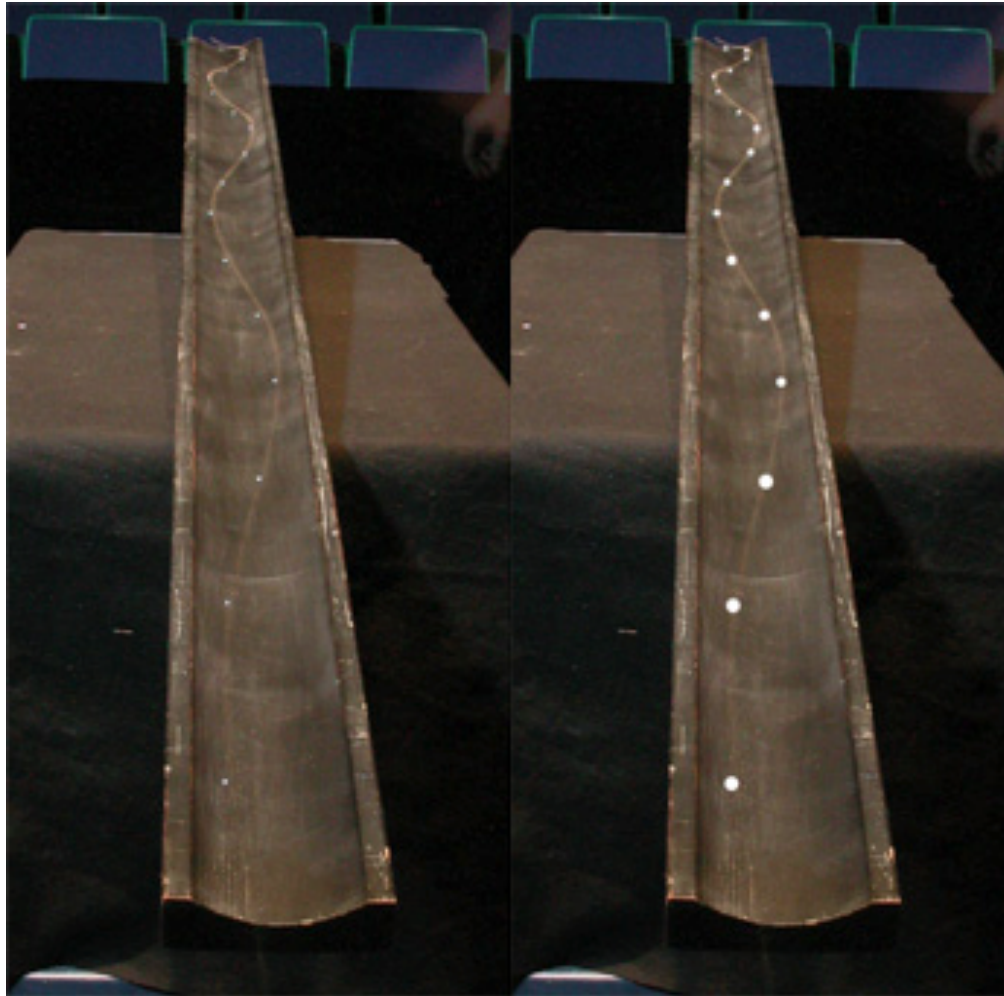
Islamic Golden Age

During 800-1300 CE, Islamic philosophers developed concepts of acceleration, inertia, momentum, angular momentum, circular motion, gravitational force, and universal laws of physics, as well as mathematical tools such as algebra



Scholars at an Abbasid library.
Maqamat of al-Hariri
Illustration by Yahyá al-Wasiti,
[Baghdad](#) 1237

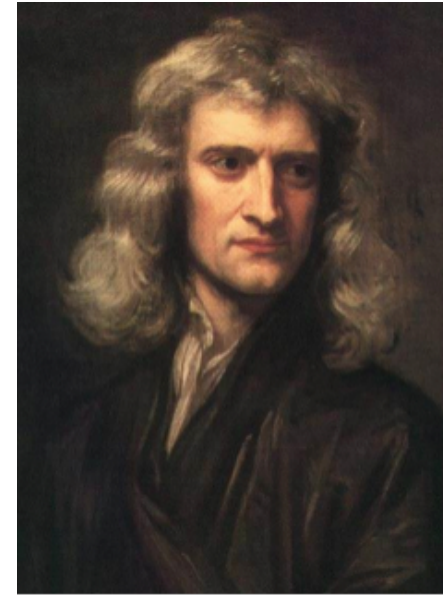
https://en.wikipedia.org/wiki/House_of_Wisdom#/media/File:Maqamat_hariri.jpg



Replica of Galileo's inclined plane experiment
<http://sciencedemonstrations.fas.harvard.edu/>

Newtonian Motion

Isaac Newton (1642-1727)
synthesized the work to date into
three laws of motion



1. Objects tend to remain at **constant velocity** unless acted on by a **force**
2. A **force** must be applied to change an object's velocity, the **acceleration** depending on the **mass** and **force** applied
3. Every force has an equal and opposite **counter force**

Law 1: Inertia

The *natural motion* of an object is constant (including zero) velocity; this is the concept of **inertia**

The physical quantity measuring inertia is:

momentum = mass x velocity

$$\vec{p} = m\vec{v}$$

True inertial motion is only realized in "no net force" environments; i.e., no friction, viscosity or gravity



Inertial motion made clear in weightless environment
of the International Space Station

(NASA TV: <https://youtu.be/FdQA-pE2luQ?t=4m45s>)

Law 2: acceleration = force/mass

The velocity of an object is changed through an acceleration, which occurs when a **net force** acts on an object:

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

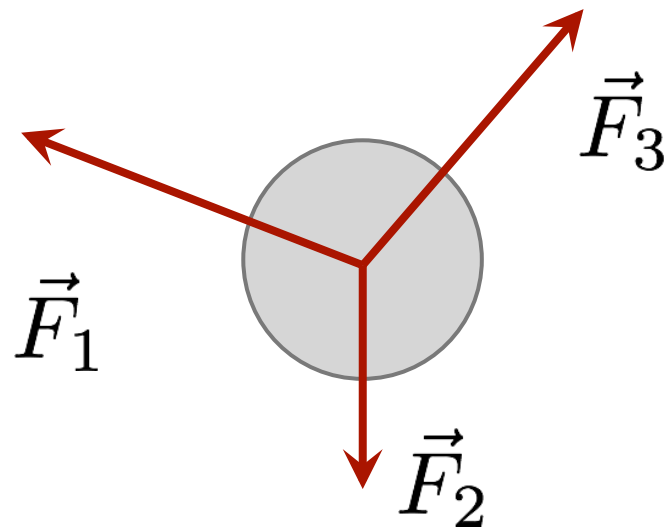
force = vector quantity
generator of motion
units of kg m/s² = Newtons

mass = scalar quantity
resistance to change in
motion

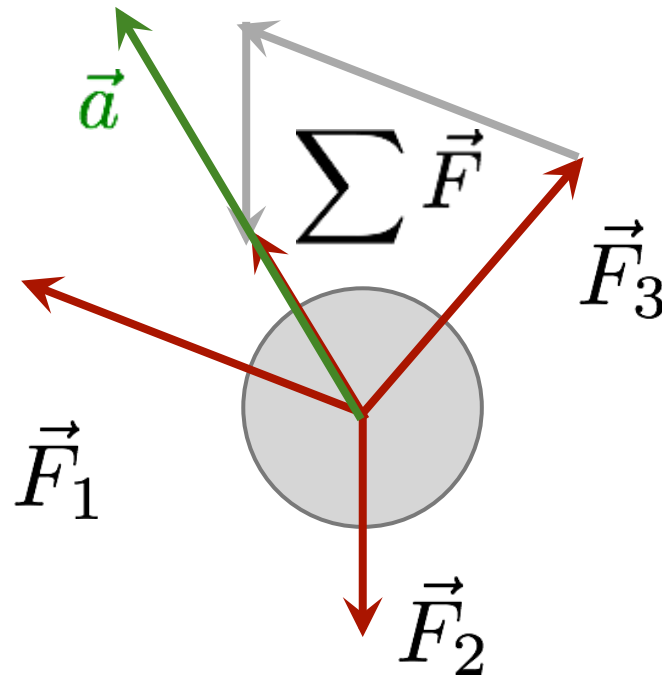


Force = Interaction

Acceleration arises from net force



Acceleration arises from net force



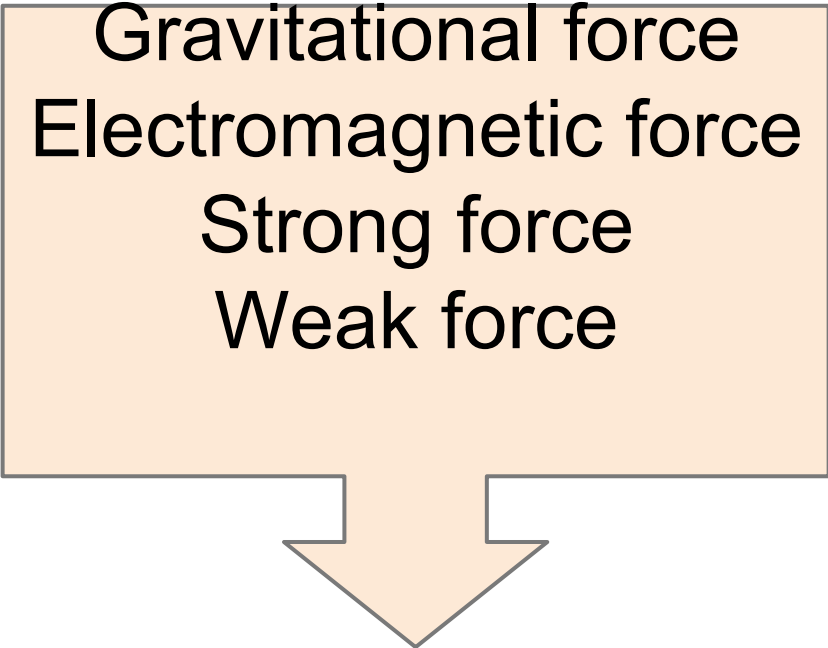
Types of forces

Act through contact

Striking force
Support (normal) force
Friction & Viscosity
Tension
Spring action
Bouyancy
Pressure

Act over distance

Gravitational force
Electromagnetic force
Strong force
Weak force



four fundamental
forces of nature

Force Laws & Dependencies

Constant force

$$\vec{F} = m\vec{g}$$

Force depending
on displacement

$$\vec{F} = -k\Delta\vec{r}$$

Force depending
on velocity

$$\vec{F} = -bv^2\hat{v}$$

Force depending
on other forces

$$\vec{F} = \mu_k\vec{F}_N$$

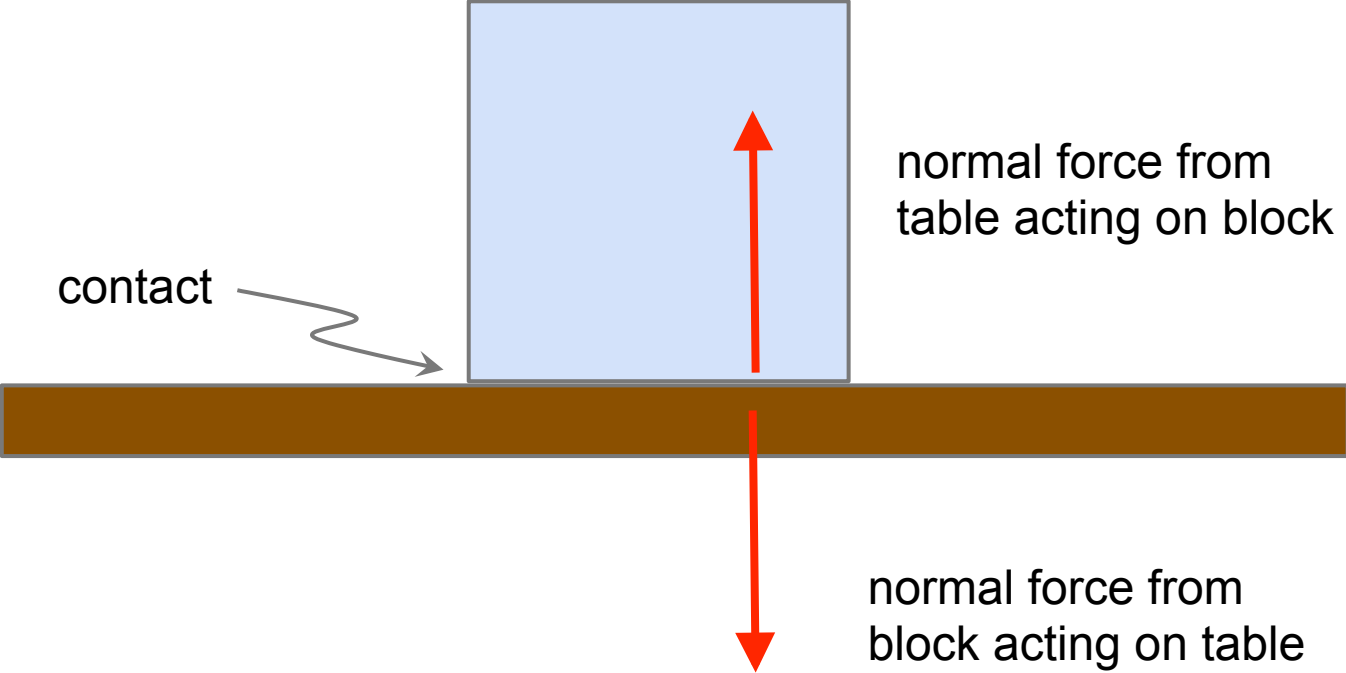
Law 3: Action/Reaction Pairs

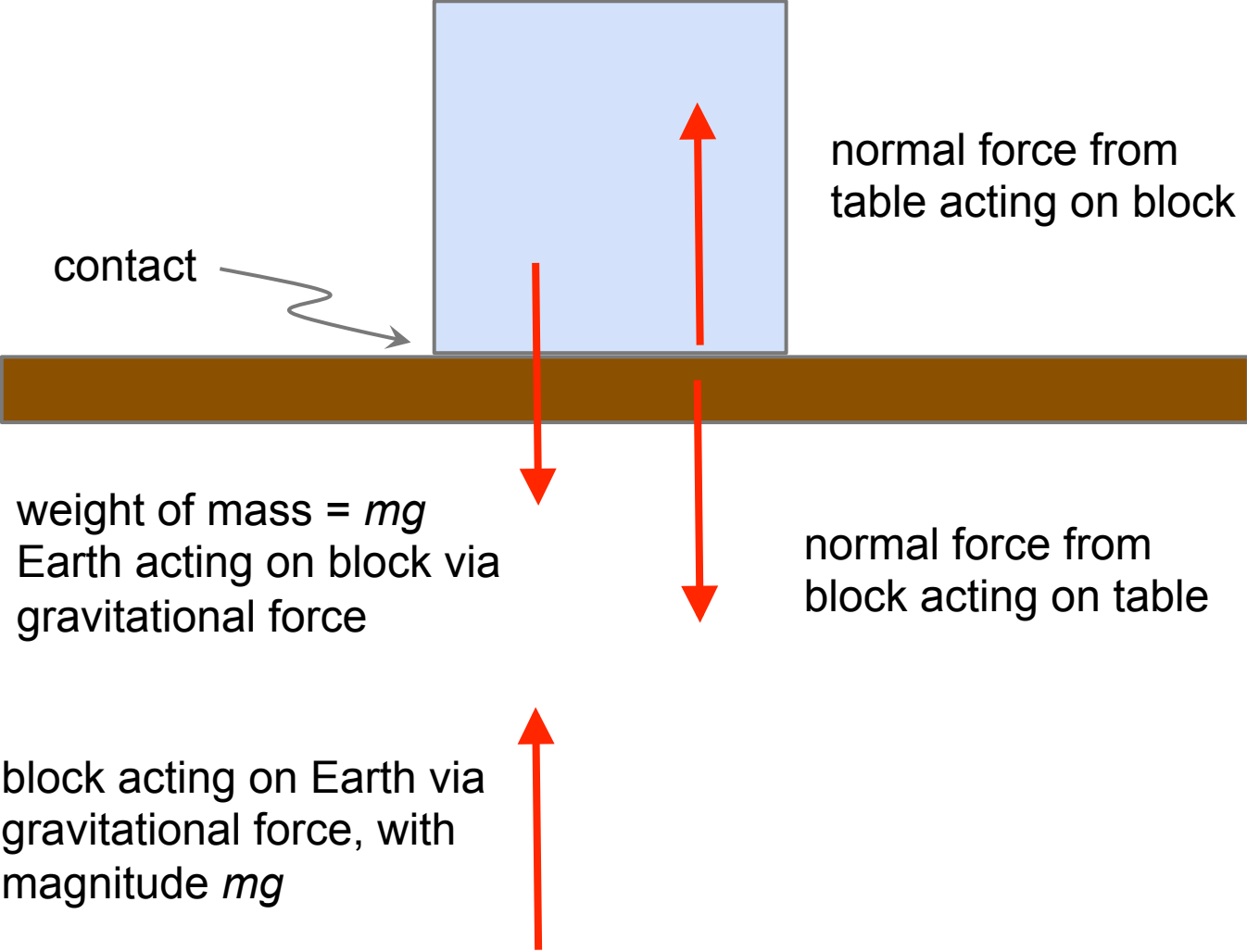
The interaction aspect of forces means they come in equal and opposite pairs

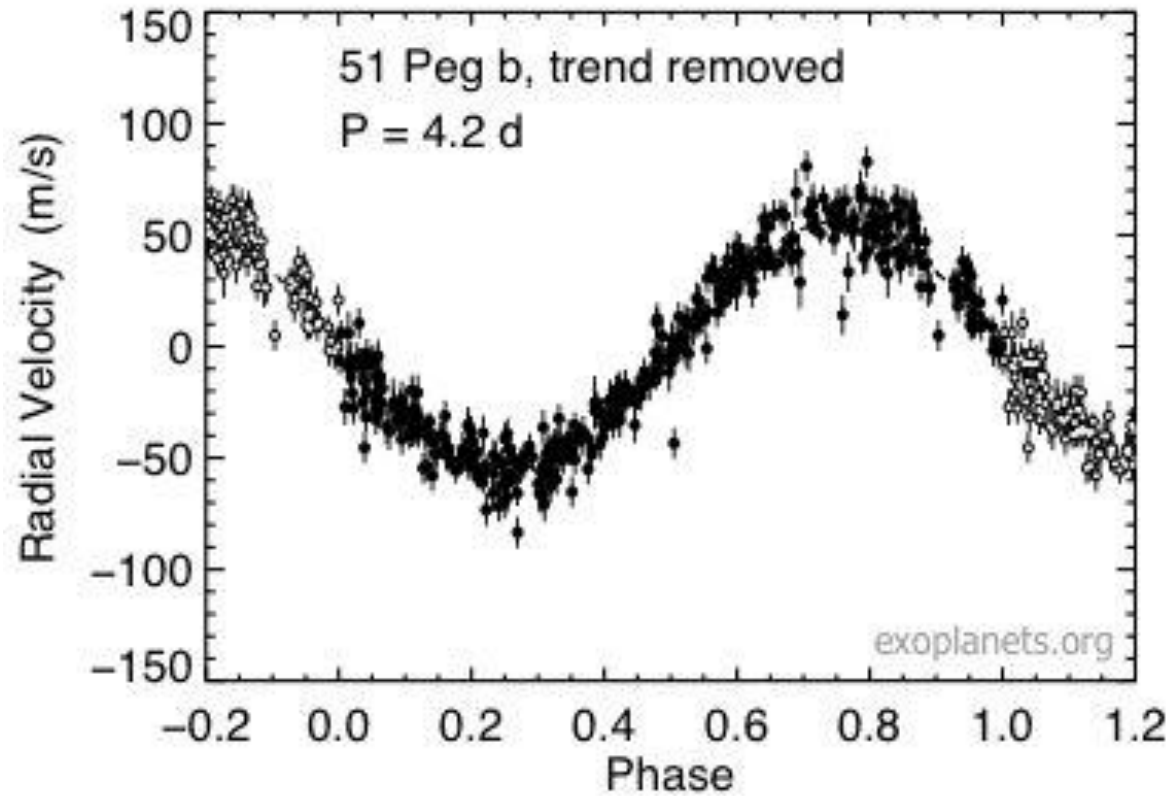
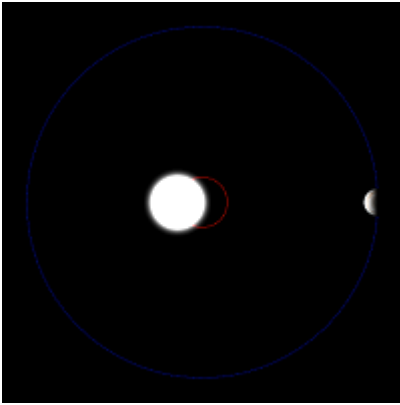
$$\vec{F}_{12} = -\vec{F}_{21}$$

force from object 1
acting on object 2

force from object 2
acting on object 1





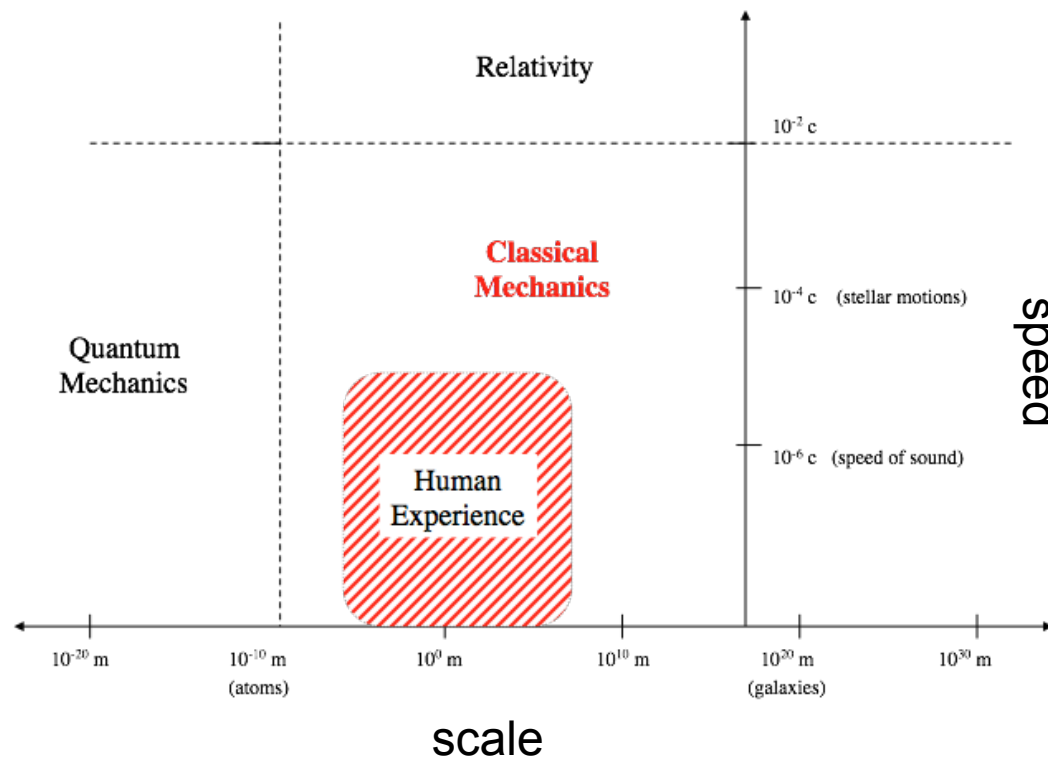


Existence of an unseen planetary companion inferred from the reaction motion of the star.

https://upload.wikimedia.org/wikipedia/commons/e/ee/51_Peg_b_rv.jpg

Newton's Laws only apply to classical, macroscopic systems

Scientific laws are persistent patterns observed in nature in a certain set of conditions



Summary

Newton's three laws of motion describe the patterns of motion of physical objects:

1. objects have constant velocities unless acted on by a force
2. acceleration = force/mass
3. all forces come in action/reaction pairs

Forces generally emerge at contact, but four fundamental forces - gravity, electromagnetism, strong, weak - can act at a distance