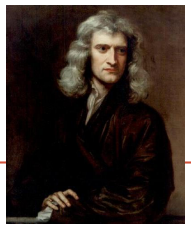
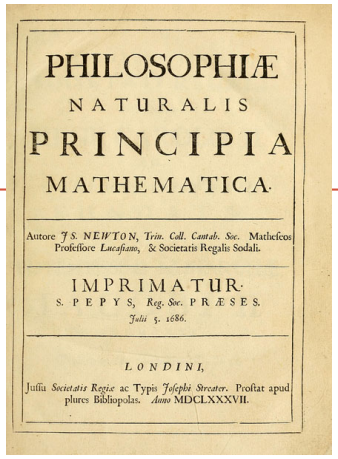
國立交通大學 電子物理系 NCTU Electrophysics

Chapter 4 The Laws of Motion




PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *Is. NEWTON, Trin. Coll. Cantab. Soc.* Matheseos Professore *Lucasiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Justu *Societatis Regiæ* ac Typis *Josephi Streater*. Prostat apud plures Bibliopolas. *Anno* MDCLXXXVII.

楊 本 立 副教授

Outline

1. The Concept of Force
2. Newton's First Law
3. Newton's Second Law
4. The Gravitational Force and Weight
5. Newton's Third Law

1. The Concept of Force
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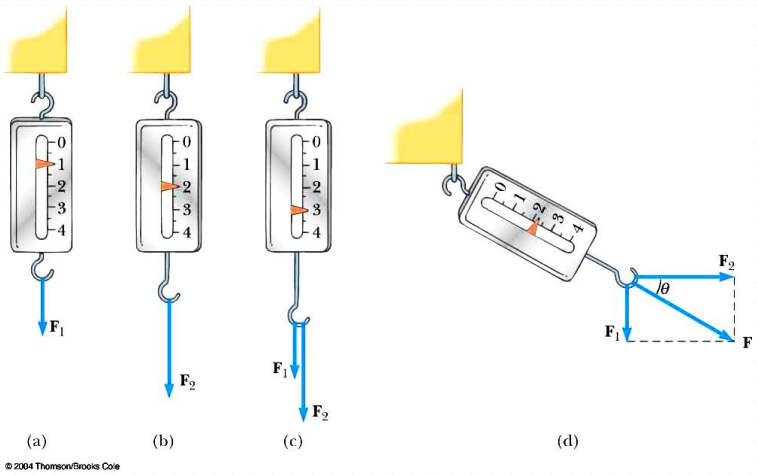
1. The concept of force

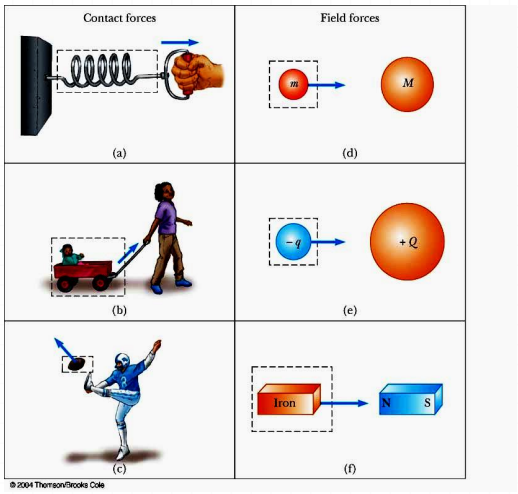
Force

- Force causes motion.
  - Net force = total force = resultant force.
  - Net Force $\neq 0$ → acceleration → change velocity.
  - Velocity is constant → net force = 0 → called "equilibrium".
- 🤓 Is uniform circular motion in equilibrium?
- How to measure force?
  - A spring can be used to measure force.

Force is a vector, experimentally verified as in the figure.

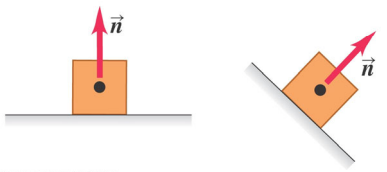


Contact force vs Field force

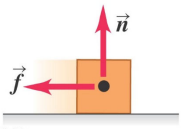


In atomic level, all contact forces are caused by electromagnetic force.

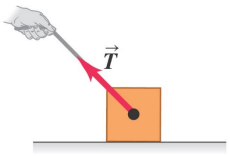
(a) **Normal force $\vec{n}$:** When an object rests or pushes on a surface, the surface exerts a push on it that is directed perpendicular to the surface.



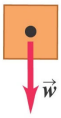
(b) **Friction force $\vec{f}$:** In addition to the normal force, a surface may exert a frictional force on an object, directed parallel to the surface.



(c) **Tension force $\vec{T}$:** A pulling force exerted on an object by a rope, cord, etc.



(d) **Weight $\vec{w}$:** The pull of gravity on an object is a long-range force (a force that acts over a distance).



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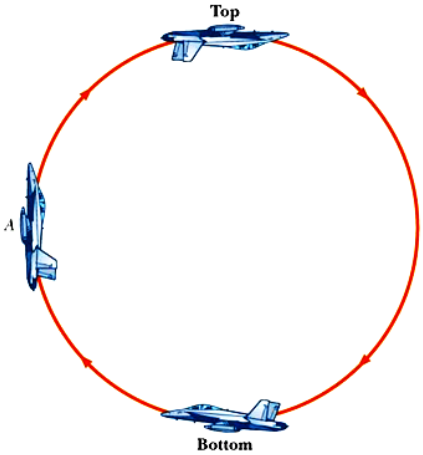
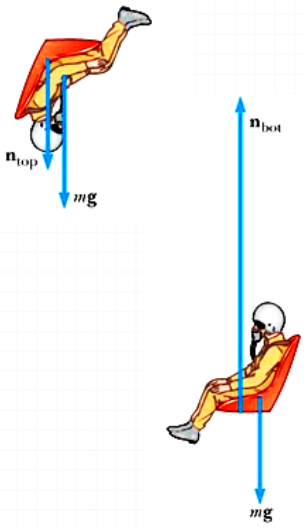
Which direction is for the normal force?





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1. The Concept of Force
2. Newton's First Law
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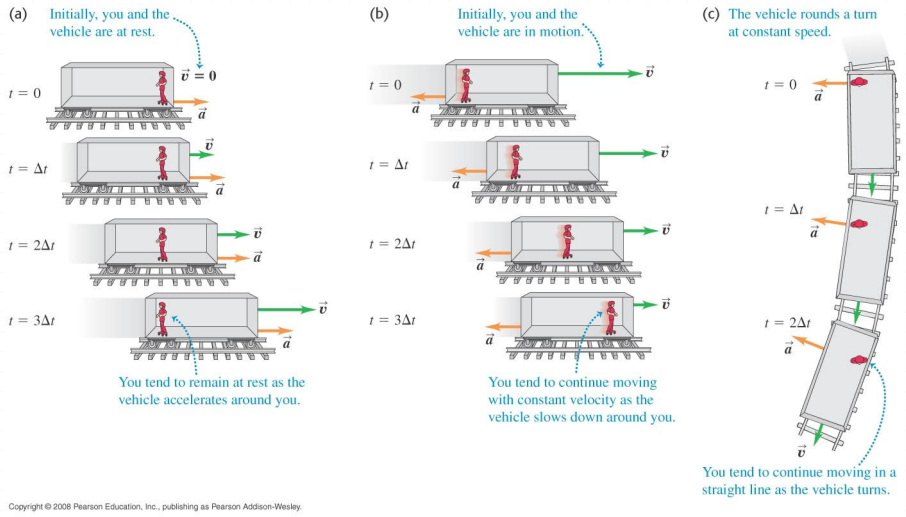
2. Newton's first law

Newton's First Law

- If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.
  - It defines ***inertial frames***, where Newton's laws can only be applied.
  - External force = 0, an object at rest remains at rest, and an object in motion continues in motion with a constant velocity.
  - Also called the ***law of inertia***.

😎 In a non-inertial frame, fictious force will arise from nowhere and violates Newton's laws.



How to find an inertial Frames?

- Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame.
  - A reference frame that moves with constant velocity relative to the distant stars is the best approximation of an inertial frame.
  - We can consider the Earth to be such an inertial frame although it has a small centripetal acceleration ($<< g$) associated with its rotation and orbital motion.
  - No absolute reference frame. (Mach's principle)

https://en.wikipedia.org/wiki/Bucket_argument
https://en.wikipedia.org/wiki/Mach%27s_principle

In Mach's idea this concept of absolute motion should be substituted with a total relativism in which every motion, uniform or accelerated, has sense only in reference to other bodies.

https://en.wikipedia.org/wiki/Mach%27s_principle

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called *inertia*. (c.p. Lenz's law in electromagnetics)
- *Mass* is that property of an object that specifies how much resistance an object exhibits to changes in its velocity.
  - If same force is applied to two masses:

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

  - SI unit: kg

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3. Newton's second law

Newton's Second Law

- When viewed from an inertial frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.
  - Algebraically, $\Sigma F = m\,a$ (valid only for $v << c$)
  - Unit of Force: Newton (N) = kg m/s^2
  - Force is the cause of change in motion, as measured by the acceleration.
  - "*Ma*" is not a force!
  - Internal force has no contribution to the acceleration.

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4. The Gravitational Force and Weight

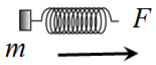
Gravitational Force

- The gravitational force, F_g, is the force that the earth exerts on an object.
  - This force is directed toward the center of the earth.
  - Its magnitude is called the weight of the object.
  - Weight = $|F_g| = mg$
  - Weight will vary with location.
  - Weight and mass are different quantities.

Gravitational Mass vs. Inertial Mass

- In Newton's Laws, the mass is the inertial mass and measures the resistance to a change in the object's motion.
- In the gravitational force, the mass is determining the gravitational attraction between the object and the Earth.
- Experiments show that gravitational mass m_g = inertial mass m_a, which inspires **Einstein's General Relativity**.

Inertial mass



$$m_a = \frac{F}{a}$$

Gravitational mass

$$m_g = \frac{F_g}{g}$$

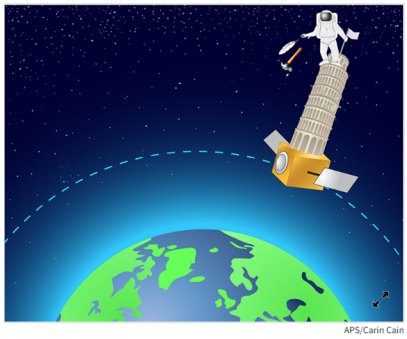
😎 If $m_a \neq m_g$, the acceleration due to gravity might be different for different bodies!

The current experiment verified that two masses of titanium and platinum aboard a satellite orbiting Earth fall exactly in the same way to a precision of 1 part per 10^{15}. [Phys. Rev. Lett. 129, 121102 (2022)]

Satellite Confirms the Principle of Falling

Philippe Brax
Institute of Theoretical Physics, University of Paris-Saclay, France
September 14, 2022 • *Physics* 15, 94

The *MICROSCOPE* satellite experiment has tested the equivalence principle with an unprecedented level of precision.



APS/Carin Cain

MICROSCOPE Mission: Final Results of the Test of the Equivalence Principle
Pierre Touboul *et al.*
Phys. Rev. Lett. 129, 121102 (2022)
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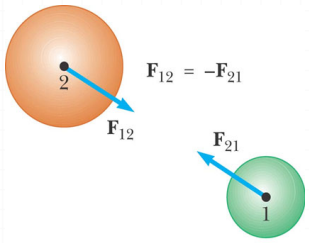
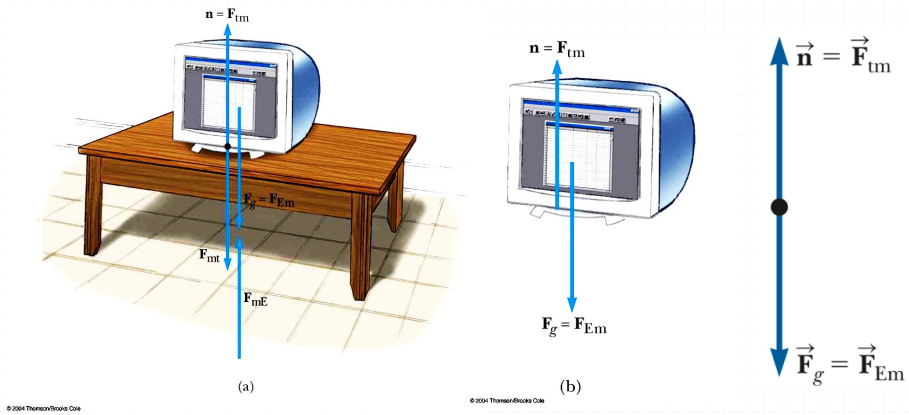
5. Newton's third law

Newton's Third Law

- If two objects interact, the force F_{12} exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force F_{21} exerted by object 2 on object 1.
  - $F_{12} = -F_{21}$
  - F_{AB} is the force exerted by A on B
  - **Force always occurs in pair.**
  - The action-reaction force pair always acts on different objects.

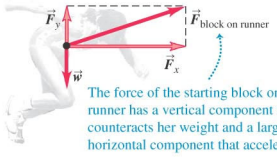


Free-body diagram



n: Normal force

(a)



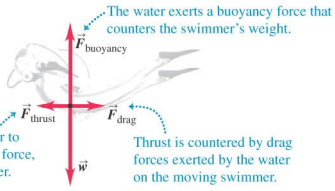
The force of the starting block on the runner has a vertical component that counteracts her weight and a large horizontal component that accelerates her.

(b)

To jump up, this player will push down against the floor, increasing the upward reaction force $\vec{n}$ of the floor on him.

This player is a freely falling object.

(c)



The water exerts a buoyancy force that counters the swimmer's weight.

Kicking causes the water to exert a forward reaction force, or thrust, on the swimmer.

Thrust is countered by drag forces exerted by the water on the moving swimmer.