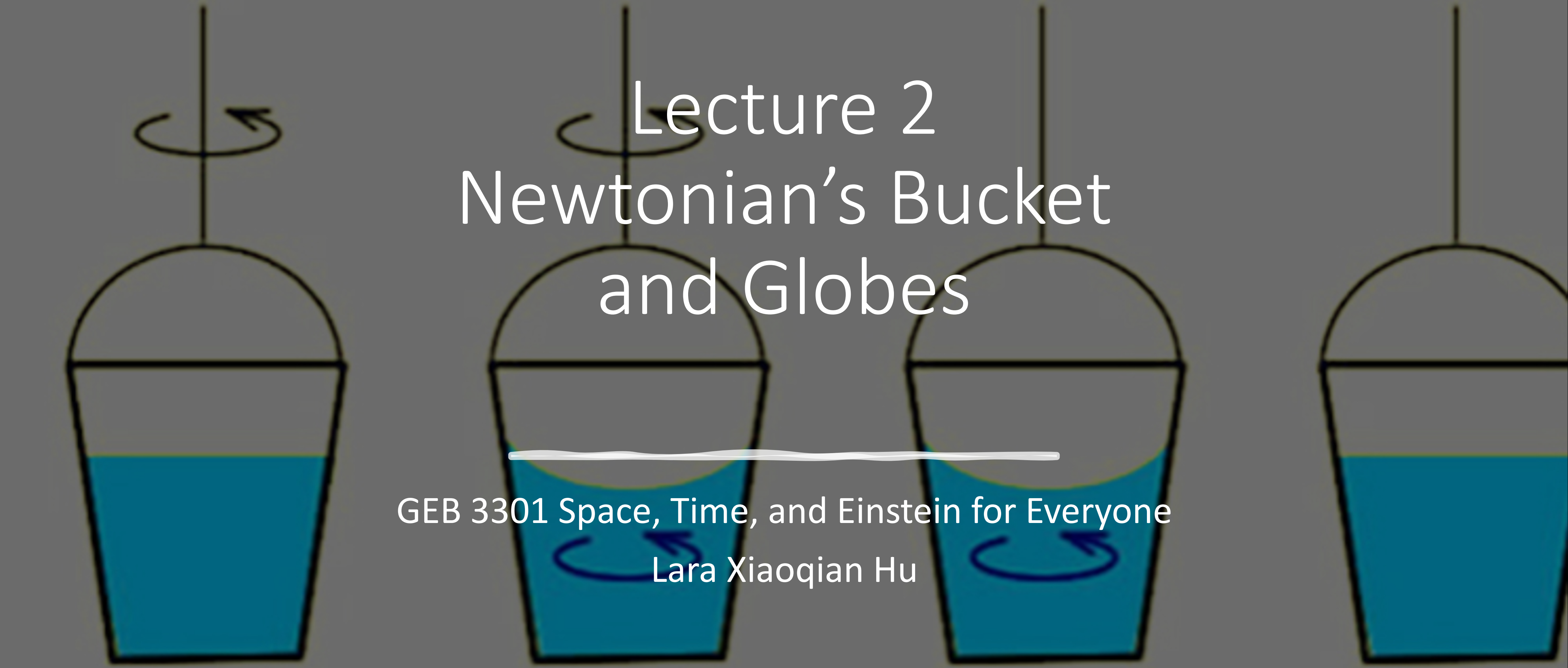

Lecture 2
Newtonian’s Bucket and Globes

GEB 3301 Space, Time, and Einstein for Everyone

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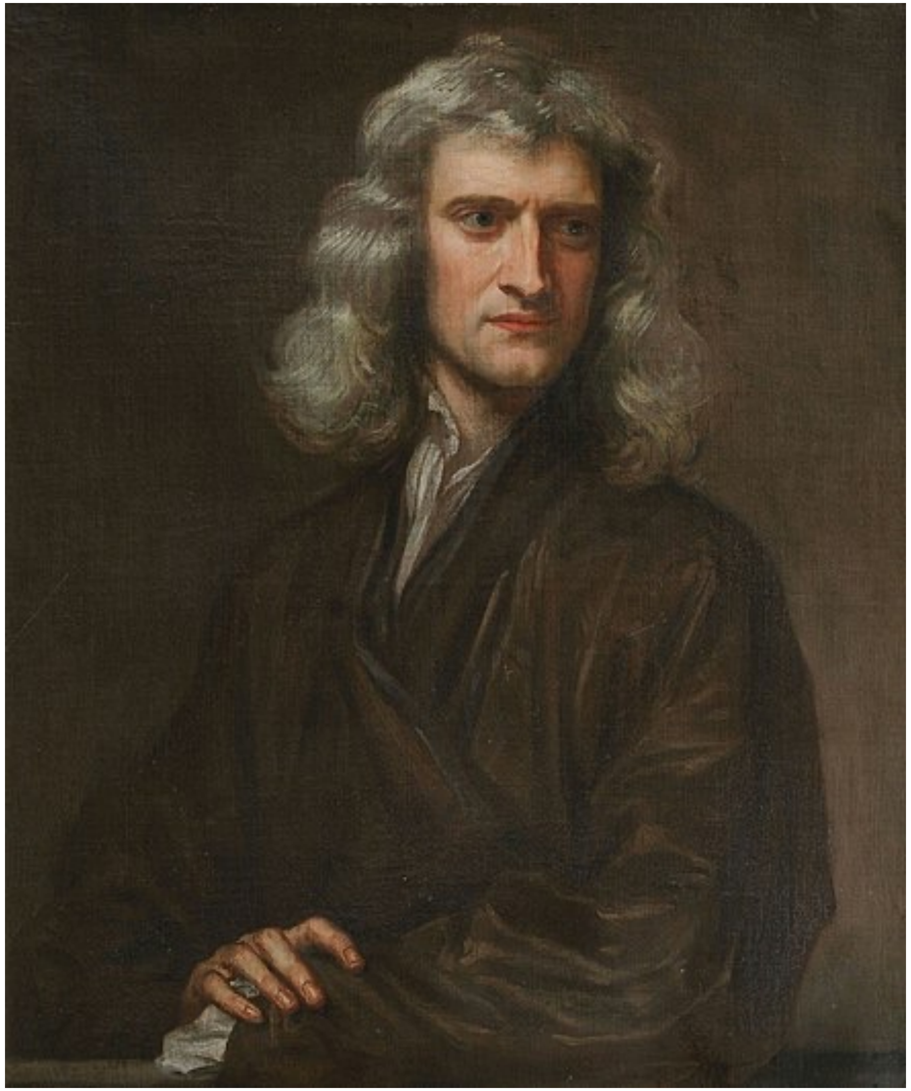
Review of last week

- Event: an idealized occurrence in the physical world having extension in neither space nor time.
- We denote by M the set of all possible events in our universe. A point of M represents an event. A region of M represents some collection of events.
- The single **world-line** of the particle completely describes everything one could want to know about the particle, for it tells us all the events experienced by the particle.
- Aristotelian View vs. Galilean View

Isaac Newton



Isaac Newton – His Life and Time

- Isaac Newton was born in 1642, the year Galileo died, and he died in 1727.
- Theory of Light
  - Developed theory of light as having a "mixed nature"
  - Proposed that white light could be decomposed by a prism (1672)
- Invention of Calculus
- Law of Universal Gravitation
  - Conjectured that gravity holds the moon in its orbit
  - Same force that pulls apples to the Earth also affects the moon (moon-earth interaction)

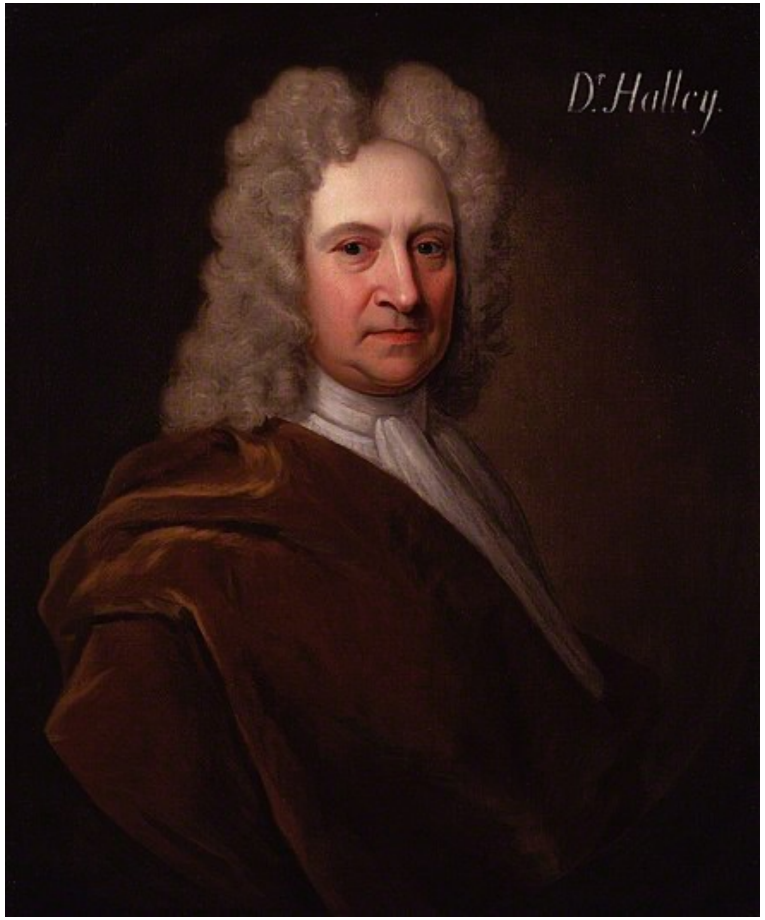
Isaac Newton – His Life and Time

- Newton's Theory of Mechanics
  - Formulated a theory of mechanics with universal laws
  - Initially hesitant to publish his results for 20 years
- Publication of Philosophiae Naturalis Principia Mathematica (1687)
  - Newton eventually published his views in 1687
  - Motivated by a question from astronomer Edmond Halley, clerk of the Royal Society of London

Isaac Newton – His Life and Time

- “The history of the Principia begins with a definite event: a trip from London to Cambridge to see Newton, made by Edmond Halley, one of the secretaries of the Royal Society, famous today primarily for his contributions to astronomy and for the comet named after him, but then also considered an able geometer. The date is 1684, presumably August. Newton, aged 41, is Lucasian Professor of Mathematics at Cambridge and a fellow of Trinity College, known at large for his published discoveries concerning light and color, but admired by the cognoscenti for his work in mathematics (not as yet published, but to some degree circulated in manuscript) and his grasp of the fundamentals of dynamics. During the visit, Halley asks Newton what path the planets would describe if they were continually attracted by the sun with a force varying inversely as the square of the distance.

Edmund Halley



Isaac Newton – His Life and Time

- Newton replies that the path would be an ellipse. This is not a mere guess on Newton's part, but a result he has obtained by mathematics, a proved statement. Newton--to continue with the story--cannot lay his hands on the calculation,' but promises to send it to Halley in London. He reworks the material and composes a short tract which Edward Paget takes to London to give Halley. On reading it. Halley gets so excited that he returns to Cambridge to see Newton once again. One effect of his visit is that Newton promises to make public his work. He accordingly sends a tract (presumably the one previously shown to Halley) to the Royal Society. Encouraged by Halley, and by the warm commendations of the Royal Society, Newton eventually completes a manuscript for publication. Such are the beginnings of the <u>Principia</u>" (Cohen, 197~, 47).

Newton – a Complicated Man

- Personal and Professional Life
  - Newton never married and had limited interactions with women
- Scientific Controversies
  - Involved in controversies over scientific priority
  - Engaged in a bitter dispute with Robert Hooke on the discovery of gravitational force as an inverse square law
- Newton's Humility and Acknowledgment
  - Described himself as a learner in the vast realm of knowledge
  - Expressed gratitude to the "Giants" who paved the way, possibly including Hooke

Newton – a Complicated Man

- Newton-Leibniz Disputes
  - Bitter disputes between Newton and Leibniz
  - Started over the priority of calculus invention
- Challenges to Newton's Conceptions
  - Leibniz challenged Newton's views on space, time, and gravity
  - Leibniz criticized Newton for reintroducing occult qualities into physics
- Leibniz-Clarke Correspondence
  - Correspondence between Leibniz and Samuel Clarke
  - Spanned from 1713 until Leibniz's death in 1717
  - Published as the Leibniz-Clarke correspondence, revealing their ongoing debates

Principia

- Newton's *Principia*
  - Axiomatic treatment of mechanics principles
  - Newton establishes definitions and postulates "three laws of motion"
- Theorems and Deductions
  - Newton deduces theorems about body motions and acting forces
  - Demonstrates the relationship between laws and observed phenomena
- Non-use of Calculus
  - Despite inventing calculus, Newton didn't employ it in the *Principia*
  - Preferred the geometric style familiar to his contemporaries

Principia

- Newton's View on Space
  - Accepted the Euclidean hypothesis
  - Believed space had a three-dimensional Euclidean structure
  - Contrary to relationist view, considered space a distinct container for material objects
- *De Gravitatione* ("On the Gravity and Equilibrium of Fluids")
  - Unpublished during Newton's time, discovered in the 1940s
- *Scholium* (following definition eight of the Principia)
  - Provides additional insights into Newton's account
- Note: The essays in this anthology were written without knowledge of the unpublished *De Gravitatione*.

Principia – Let's hear your view

- Question: Why Newton felt it necessary to discuss apparently philosophical questions in a physics text?
- Well, this issue, like many others, is neither strictly philosophical nor strictly scientific. Indeed, before the twentieth century, the distinction was made far less rigidly than it is now.

The Newtonian System

- Newtonian System and Principia
  - Newton started writing the Principia in 1684
  - Galileo's call for mathematical representation of natural phenomena (61 years prior)
- Describing vs. Explaining Natural Phenomena
  - Describing: Representing natural phenomena mathematically
  - Explaining: Using mathematical principles to explain phenomena
- Importance of Mathematical Principles
  - Newton aimed to explain natural phenomena through mathematical principles
  - Principia sought to establish a comprehensive system based on these principles

The Newtonian System - Galileo

- Galileo had himself produced several mathematical laws or principles, among them, the law of falling bodies: $s = \frac{1}{2}gt^2$ which related the distance (s) that an object falls in a time (t), where (g) is the acceleration due to gravity.
- The problem with Galileo's approach is that it is too particular.

The Newtonian System - Galileo

- The law of falling bodies which Galilei formulated is restricted in several ways:
- (1) it deals only with freely falling bodies;
- (2) it deals with the motion under the influence of one special force, gravity;
- (3) it assumes that the force of gravity is a constant.
- PS, none of this is meant to take anything away from the magnitude of Galileo’s achievement which was great indeed, but only to illustrate Galileo's approach, which was to formulate particular principles for particular phenomena.

The Newtonian System - Descartes

- Descartes and Cartesian Physics
  - Descartes sought general mathematical principles for all motions
  - Inspired by the deductive ideal of Euclidean geometry
- Goal: Deductive System
  - Produce a small set of principles (like Euclid's axioms) for natural phenomena
  - Deduce descriptions of all natural phenomena (like Euclid's theorems)
- Cartesian Physics
  - In 1644, Descartes formulated 3 laws of nature and 7 rules of impact
  - These laws and rules formed the basis of Cartesian physics

The Newtonian System - Descartes

- Three Laws of Nature:

1. Law of Inertia: Objects at rest remain at rest, and objects in motion continue in motion with the same speed and direction unless acted upon by an external force.
2. Law of Conservation of Motion: The total quantity of motion in the universe remains constant unless acted upon by external forces.
3. Law of Action and Reaction: For every action, there is an equal and opposite reaction.

The Newtonian System - Descartes

- FIRST LAW: Each thing, in so far as in it lies, always perseveres in the same state, and when once moved, always continues to move.
- SECOND LAW: Every motion in itself is rectilinear, and therefore things which are moved circularly always tend to recede from the center of the circle which they describe.
- THIRD LAW: If a moved body collides with another, then if it has less force to continue in a straight line than the other body has to resist it, it will be deflected in the opposite direction and, retaining its own motion, will lose only the direction of its motion. If it has a greater force, then it will move the other body along with itself and will give as much of its motion to that other bodies as it loses.

The Newtonian System - Descartes

- Seven Rules of Impact:

1. Rule of Persistence: An object in motion will continue moving unless affected by another object.
2. Rule of Direction: The direction of motion will change when an object encounters another object.
3. Rule of Refraction: The path of motion will bend when an object passes through a medium of different density.
4. Rule of Resistance: The amount of resistance encountered by an object depends on its shape and the medium through which it moves.

The Newtonian System - Descartes

5. Rule of Collision: The angle of reflection is equal to the angle of incidence in a collision.

6. Rule of Impulse: The change in motion of an object is proportional to the force applied and the time over which it acts.

7. Rule of Impact: The quantity of motion before and after impact remains the same.

The Newtonian System - Descartes

- RULE (1) If two bodies B and C are completely equal and are moved with equal velocity, B from right to left and C from left to right, then when they collide, they are reflected and afterward continue to be moved, B toward the right and C toward the left, without losing any part of their velocities.
- RULE (2) If B is slightly larger than C, and the other conditions above still hold, then only C is reflected and both bodies are moved toward the left with the same velocity.
- RULE (3) If they are equal in size, but B is moving slightly faster than C, then not only do they both continue to be moved toward the left but also B transmits to C part of its velocity by which it exceeds C. Thus, if B originally possessed six degrees of velocity and C only four, then after the collision they both tend toward the left with five degrees of velocity.

The Newtonian System - Descartes

- RULE (4) If C is completely at rest and is slightly larger than B, then no matter how fast B is moved toward C, it will never move C but will be repelled by C in the opposite direction. For a body at rest gives more resistance to a larger velocity than to a smaller one in proportion to the excess of the one velocity over the other. Therefore there is always a greater force in C to resist than in B to impel.
- RULE (5) If C is at rest and is smaller than B, then no matter how slowly B is moved toward C, it will move C along with itself by transferring part of its motion to C so that they are both moved with equal velocity. If B is twice as large as C, it transfers a third of its motion to C because a third part of the motion moves the body C as fast as the two remaining parts move the body B which is twice as large. And thus, after B has collided with C, B is moved one third slower than it was before, that is, it requires the same time to be moved through a space of three feet. In the same way if B were three times larger than C, it would transfer a fourth part of its motion to C, etc.

The Newtonian System - Descartes

- RULE (6) If C is at rest and is exactly equal to B, which is moved toward C, then C is partially impelled by B and partially repels B in the opposite direction. Thus, if B moves toward C with four degrees of velocity, it transfers one degree to C and is reflected in the opposite direction with the remaining three degrees.
- RULE (7) Let B and C be moved in the same direction with C moving more slowly and B following C with a greater velocity so that they collide. Further, let C be greater than B, but the excess of velocity in B is greater than the excess of magnitude in C. Then B will transfer as much of its motion to C so that they are both moved afterward with equal velocity and in the same direction. On the other hand, if the excess of velocity in B is less than the excess of magnitude in C, then B is reflected in the opposite direction and retains all of its motion. These excesses are computed as follows. If C is twice as large as B but B is not moved twice as fast as C, then B does not impel C but is reflected in the opposite direction. But if B is moved more than twice as fast as C, then B impels C. For example, if C has only two degrees of velocity and B has five, then C acquires two degrees from B which, when transferred into C, become only one degree since C is twice as large as B. And thus the two bodies B and C are each moved afterward with three degrees of velocity. And other cases must be evaluated in the same way.

The Newtonian System - Descartes

- When integrated with Descartes' dualistic philosophy, Cartesianism seemed to provide the promise of a unified philosophical approach to the world which could replace the weakened and discredited Aristotelian philosophy.
- Newton's own ideas about physics were developed, in part, in reaction to the principles of Cartesian physics.
- As Newton and other contemporaries saw, there are a number of difficulties with interpreting and applying Descartes' physical laws and rules.

The Newtonian System - Descartes

- First, there is a problem about the relation between the laws and rules. The rules are supposed to be derivable from the laws, but how this is to be accomplished is by no means clear. In addition, the system fails to have the required generality. The rules, which do all the actual work, apply only to special cases. The laws, of course, are general, but do not seem to be readily applicable.
- (2) Many of the concepts that appear in both the laws and the rules are unclear. Descartes never provides unambiguous and clear cut rules for interpreting such terms as "force," "quantity of motion," and "resistance." Without such guidelines, the applicability of the rules to particular cases if not clear.
- (3) Despite the Cartesian goal of a mathematical physics, Descartes' principles are not very mathematical.

The Newtonian System - Descartes

- (4) Where the rules to admit of clear mathematical interpretation, they are often wrong. Consider RULE (4), for example. If it were correct, then a speeding bullet would not be able to move a heavier, stationary object. But moving bullets are quite efficient at doing just that, so RULE (4) cannot be right as it stands.
- (5) A deeper problem is that there is no systematic role for the concept of **relative motion** in Cartesian physics. This can be seen quite clearly by reflecting on the phrase "velocity in B," e.g., as it appears in RULE (7). A careful reading of the rules makes it clear that, for Descartes, velocity is an absolute property of a body. This contradicts the Galilean principle of relativity (of which more below; see p.7--45f). Newton saw the failure of Cartesian physics to do justice to the relational character of motion as a fundamental error (For discussion of these criticisms and others, see Blackwell, 1966).

The Newtonian System

- Newton vs. Descartes: Mathematical Principles
  - Newton aimed to create an improved set of mathematical principles
  - Newton's principles widely acclaimed by English scientists, including Halley
  - Newton's principles rejected by continental physicists, including Leibniz
  - Newtonian and Cartesian systems coexisted and clashed into the 1700s

The Newtonian System

- Newtonian Theory: Particle Mechanics
  - Describes and predicts behavior of particles and particle systems over time
- Success of Newtonian System
  - Explains planetary motion, pendulum motion, spring oscillation, and more
  - Some believed Newtonian mechanics were the key to understanding all physical phenomena

The Newtonian System

- Newtonian Paradigm in the 18th Century
  - Movement emerged: Every natural system seen as Newtonian particle system
  - Ideal: Reduce all branches of physical knowledge to Newtonian mechanics
- Challenges in the 19th Century
  - Attempts to reduce various fields to Newtonian mechanics
  - Many fields couldn't be fully explained by Newtonian framework
- Superseding Newtonian Mechanics
  - 20th century: Development of theories of relativity and quantum mechanics
  - Relativity and quantum mechanics replaced Newtonian mechanics
  - Newtonian paradigm no longer comprehensive in explaining all physical phenomena

The Newtonian System - Laws

- Newton's theory rests on three laws of motion plus a law of gravitational attraction.
- The three laws of motion are set forth at the beginning of Book 1 of the Principia, "The Motion of Bodies." The law of gravity appears in Book III. "The System of the World." The laws are:
- **LAW I: (The Principle of Inertia) Every body continues in its state of rest, or of uniform motion [= constant velocity] in a right [= straight] line, unless it is compelled to change that state by forces impressed upon it.**

The Newtonian System – Laws

- **LAW II. (The Definition of Force) The change of motion is proportional to the motive force impressed; and is made in the direction of the light [straight] line in which the force is impressed ($\boldsymbol{F = ma}$).**
- **LAW III: (The Action--Reaction Principle) To every action there is always opposed an equal reaction; or the mutual actions of two bodies on each other are always equal, and directed to contrary parts.**

The Newtonian System - Laws

- In Book III, Proposition VII, Theorem VII concerning the gravitational attraction that all bodies were postulated to have for each other, Newton writes that there is a power of gravity pertaining to all bodies, proportional to the several quantities of matter which they contain.
- **COROLLARY II: The force of gravity towards the several equal particles of any body varies inversely as the square of the distance of places from the particles ($\boldsymbol{F = G\frac{mM}{r^2}}$).**

The Newtonian System - Challenges

- Newton's Three Laws of Motion
  - Foundation of Newton's theory of particle mechanics
  - Enable accurate prediction and description of various physical systems
- Newtonian System: Power and Success
  - Suggested the universe as a vast mechanism explainable by mechanical principles
  - Considered every part as explainable with precision
- Partial Success and Limitations
  - Newtonian approach achieved significant success
  - However, it was never fully successful in explaining all phenomena

The Newtonian System - Challenges

- Fundamental concepts of the Newtonian system were questioned from the start.
- Newton believed space and time were absolute backgrounds for mechanical motions, but Leibniz and George Berkeley challenged this view.
- Newton's concept of gravity was also challenged by Leibniz.
- Leibniz saw Newton's idea of gravity as invoking mysterious "I-know-not-whats" to explain physical phenomena.
- Leibniz considered Newton's concept of gravity to be based on "occult qualities" and action at a distance.

The Newtonian System - Challenges

- Leibniz viewed Newton's concept of gravity as a return to the discredited medieval philosophy.
- Leibniz followed the Cartesian program, which aimed to explain motion based on contact forces.
- Newton responded by distinguishing between the mathematical description of gravity and its interpretation or explanation.
- Newton acknowledged that the Law of Gravity provided a mathematical description but did not fully explain the essence of gravity.

The Newtonian System - Challenges

- In the General Scholium to Book III, added to the second edition, Newton writes:
- “Hitherto we have explained the phenomena of the heavens and of the sea by the power of gravity, but have not yet assigned the cause of this power. This is certain, that it must proceed from a cause that penetrates to the very centers of the sun and planets, without suffering the least dimunition of its force; that operates not according to the quantity of the surfaces of the particles upon which it acts (as mechanical causes used to do [a reference to Descartes and his view that the important quantity was the size and not the mass of a body?]), but according to the solid matter which they contain, and propagates its virtue on all sides to immense distances, decreasing always as the inverse square of the distances. . .

The Newtonian System - Challenges

- hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and **I frame no hypotheses** [<u>hypotheses</u> <u>non</u> <u>fingo</u>]; for whatever is not deduced from the phenomena is to be called a hypothesis; and hypotheses, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction. Thus it was the impenetrability, the mobility, and the impulsive force of bodies, and the laws of motion and of gravitation, were discovered. And to us it was enough that gravity does really exist [as evidenced by its effects], and act according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies, and of our sea [compare with Galileo]" (Newton, 1962, pp. 546f.)

The Newtonian System - Challenges

- Privately, in a letter to Richard Bentley, written February 25, 1692-1693, but unpublished until much later, Newton wrote:
- “It is inconceivable that inanimate brute matter, should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact, as it must be, if gravitation, in the sense of epicurus be essential and inherent in it. And this is one reason why I desired you would not ascribe innate gravity to me.

The Newtonian System - Challenges

- That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without further mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, could ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I left to the consideration of my readers" (Newton, 1953, p. 54).

What are we to make of this?

- Newton distinguishes between the mathematical expression of a law and its explanation.
- Newton's focus is on providing a mathematical formulation of the effect of gravity.
- The mathematical formulation is used to describe and predict the motion of celestial bodies.
- Newton shares Galileo's view that the physicist's primary concern should be producing mathematical laws of nature.
- Hypothetical understanding of these laws is of secondary concern to Newton.

What are we to make of this?

- Newton is dissatisfied with the current understanding of gravity and acknowledges the need for further explanation.
- However, Newton believes that this additional explanation is not part of the mathematical principles of natural philosophy.
- Newton privately hoped that readers would conclude that God was the ultimate causal agent behind gravity.
- Newton considers gravity and the principles in the Principia as evidence of God's presence and work in the universe, comparable to religious Scriptures.

Newton’s Space and Time

- In the *Scholium* to the definitions preceding Book I, Newton discusses time, space, place, and motion.
- Newton distinguishes between absolute or mathematical time and relative or common time.
- Relative space, time, and motion are those that can be measured by us.
- According to Newton, all measurement involves comparing one thing with another.

Newton’s Space and Time

- When using a measuring tape to determine the dimensions of a room, the measured space is relative to the tape used as a standard.
- The measurement of time involves comparing the duration of a process or activity to the duration indicated by clocks.
- Objects are considered to be in motion only if they move in relation to something else.

Newton’s Space and Time

- Newton proposed the existence of Absolute space, Absolute time, and Absolute motions in addition to relative measures.
- These absolute quantities are not directly detectable by human observers.
- Despite their insensibility, Newton argued for the existence of these absolutes.
- Critics, including Leibniz, vehemently attacked the plausibility and necessity of these absolute concepts.

Newton’s Space and Time

- Newton makes clear (*De Grav.*, this vol., p. Ill) that he takes space to be a geometric object, just as we conceived it in the Euclidean hypothesis.
- It is composed of points, collections of which comprise lines, surfaces and “solids” (in the sense of having volume, not solidity) as in geometry. These geometric objects are possible “absolute places” for material objects, over and above their relative locations.

Newton’s Space and Time

- The points, then, exist independently of material objects: first in the sense that locations exist before they are occupied—“We firmly believe that the space was spherical before the sphere occupied it . (*De Grav.,* this vol., p. Ill); and second in the sense that space would exist even if there were no matter—“we can possibly imagine that there is nothing in space, yet we cannot think that space does not exist . . (*De Grav.,* this vol., p. 113).
- Existence independent from matter is the first sense in which Newton thinks space is absolute, not relative; in contrast, if there were no material objects then there would be no relative distances between objects, and hence no space, according to the relationist.

Absolute space and absolute time are qualitatively homogeneous.

- In the *Scholium*, Newton says, "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable." That absolute space "remains always similar" is just to say that its parts are qualitatively homogeneous.
- Even so, in an unpublished manuscript, Newton puts the case more strongly: "The parts of duration and space are only understood to be the same as they really are because of their mutual order and position; nor do they have any hint of individuality apart from the order and position which consequently cannot be altered (Hall and Hall, 1962, p. 136)." This contrasts with the Aristotelian view, at least with respect to space, since Aristotle, recall, held that space was qualitatively heterogeneous.

Absolute space (time) is infinite (Eternal)

- Newton argues for the infinite extension of space and time based on conceptual and theological reasons.
- Newton states that space extends indefinitely in all directions, as imagining a limit implies the existence of space beyond it.
- According to Newton, straight lines and similar figures continue to infinity and have no bounds.
- Newton's belief in the eternity and infinity of God leads him to conclude that space must also be infinite in extent, and time (or duration) must be infinite as well.

Space and Time are Continuous

- The continuity of time follows from Newton's assertion in the *Scholium* that "Absolute, true, and mathematical time, of itself, and of its own nature, flows equally without relation to any thing external . . .." That Newton takes absolute time to "flow equably" is a good indication that he thought that the flow of time was continuous and not discrete.
- We must, of course, remember that, in Newton's time, to say that an interval was continuous was to say that it was dense but not point-like.

Absolute space and absolute time are object/mind independent

- According to Newton, even in the absence of objects, absolute space would still exist as a receptacle or container.
- Absolute time would also exist regardless of any changes or enduring objects.
- While we can imagine the absence of objects in space, we cannot conceive of space itself not existing.
- Similarly, we cannot conceive of the absence of duration, even though it is conceivable to suppose that nothing endures.

Absolute space and absolute time are immutable

- Immutability of absolute time involves two aspects.
  - First, absolute time flows equably, meaning it ticks off at a regular rate.
  - Second, the individual moments or parts of duration are fixed in their relative order to each other in an intrinsic way.
- This means that if a set of successive events occurring at different instants of absolute time is ordered from earlier to later, the order is unique.
- However, the Special and General Theories of Relativity propose a different understanding of time.

Absolute space and absolute time are immutable

- Newton emphasized the immutability of parts or positions of absolute space.
- He was particularly concerned about the Cartesian view that identified space with the occupying bodies, suggesting that positions or parts of space could move relative to each other.
- Newton did not consider the possibility of non-Euclidean geometrical structure in physical space, so he was not concerned with the idea that the geometrical structure of space could change.

Absolute space and absolute time are causally inert

- According to Newton, space and time serve as frameworks or containers for actions and events in the world.
- Space and time, in themselves, do not causally interact with the material or mechanical processes occurring in the world.
- Newton's view is that the gravitational attraction between two bodies does not affect or is unaffected by the structure of absolute space and absolute time.
- This is similar to how the structure of a rigid container is not affected by objects or processes within it.
- However, the General Theory of Relativity (GTR) will present a different understanding and abandon this view.

Absolute space is a void

- According to Newton, absolute space exists independently of the presence of any bodies within it.
- This means that empty spaces can exist in Newton's view.
- Both absolute space and most of the observable relative space, such as the space between planets, are considered empty.
- However, this posed challenges for Newton, particularly regarding the gravitational force between two planets, as it implied action-at-a-distance without any intermediate medium.
- Newton was consistently unhappy with the concept of action-at-a-distance.

Absolute space is a void

- In his work "Optics," Newton suggests the possibility of an omnipresent aether that could serve as a medium for the gravitational force.
- This concept of aether should not be confused with the 19th-century aether proposed for the transmission of light.
- Newton did not require an optical aether since he believed that light consisted of particles that could travel across empty space as easily as through a luminiferous aether.
- Newton and subsequent Newtonian thinkers did not fully resolve the problem of reconciling the need for a medium in gravitational force.

Relative Space

- What is relative space?
- Position and motion require knowledge of location relative to other things.
- Examples: driving to work, landing a plane, high-energy physics experiments, sending rockets to the moon.
- Understanding relative positions is crucial for navigation, tasks, measurements, and predictions.

Relative Space

- In various situations, a "frame of reference" is defined relative to a specific object called the "reference body."
- Examples include oneself as the reference body when assessing personal safety, the Earth's surface when measuring the speed of a runner, and the Sun or our galaxy when studying the Earth's orbit.
- Newton refers to these reference frames when discussing relative spaces.
- Understanding and defining reference frames are essential for analyzing positions and motions in relation to specific objects or systems.

Relative Space

- Given such a frame, we can introduce relative motion as the change of position relative to the reference body.
- We can distinguish states of relative motion in a reference frame more precisely: a body is said to be **at rest** in a frame if it remains at a fixed distance in a fixed direction (so that it is not orbiting) from the reference body, and it is said to be in **constant relative motion** in a frame when it moves in a straight line and covers equal distances in equal times in that frame.
- Otherwise—that is, if an object changes its speed or travels along a curved trajectory relative to the reference body—it is **relatively accelerating**.

Relative Space vs. Absolute Space

- Newton presents two arguments in the Principia to distinguish between absolute space and relative spaces.
- The "bucket argument" is based on an experiment that can be conducted in any laboratory and involves the observation of water in a rotating bucket.
- The "two globe experiment" is a thought experiment where Newton asks readers to imagine the outcome of an experiment that cannot be practically performed.
- These arguments aim to demonstrate the distinction between absolute space (independent and unaffected by objects or motions) and relative spaces (defined in relation to reference bodies or frames).
- These arguments contribute to Newton's concept of space and its relationship with motion and objects.

Newton’s Bucket Experiment for Thursday

- During Thursday’s tutorial, we will describe and talk about Newton’s bucket and globe experiment (thought experiment) in groups.
- Please read the uploaded “Scholium to the Definitions” section XII and XIV, carry out Newton’s bucket experiment and write it up as you would a piece of lab work, with a description of the apparatus, the method, the results, and conclusion. Does Newton draw the correct conclusion? What other explanations could there be of the phenomena observed?
- Show the best drawings/write up and explain them.

Bucket Experiment