

08. Newton

De Gravitatione et Aequipondio Fluidorum

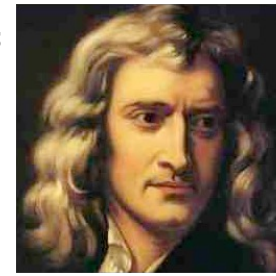
(On the Gravity and Equilibrium of Fluids) (~1670)

Philosophia Naturalis Principia Mathematica

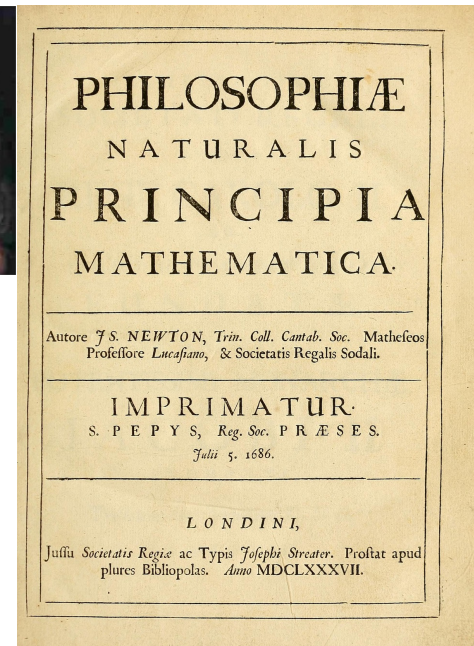
(Mathematical Principles of Natural Philosophy) (1687)

1. Critique of Descartes

2. Newton's Cosmos



Isaac Newton
(1643-1727)



Recall:

- Plato: space = "pure" matter (receptacle).
- Aristotle: space = collection of places.
place of an object = inner-most motionless surface of containing object.
- Descartes: matter = extension = "pure" space

*space is dependent
on matter*

- Newton: space = container of material objects, completely separate from material objects.

1. Newton's Critique of Descartes

Recall Descartes' Relational Theory of Motion:

- True motion:

"...the transfer of one body from the vicinity of the other bodies which are in immediate contact with it, and which are regarded as being at rest, to the vicinity of other bodies."



- All motion is relative:



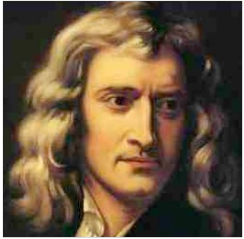
"...it can be said that the same thing moves and does not move at the same time, depending on how we determine its location."

- Motion is defined only with respect to a frame of reference.
- Frames of reference are defined by material objects.
- All frames of reference are equivalent.

Newton Objects:

- (a) Some motions are physically distinguished from others (inertial motions).
 - Thus: *Not* all frames of reference are equivalent.
- (b) Can't define privileged frames by material objects (objects move about).
 - So: There must be a frame of reference *separate and distinct* from material objects in terms of which inertial motions can be defined.

- *Absolute space* = privileged frame of reference separate and distinct from material objects.
- *Absolute motion* = motion with respect to absolute space.
- *Relative motion* = motion with respect to material objects.



"...[Descartes] says that speaking properly and according to philosophical sense the Earth and the other Planets do not move, and that he who declares it to be moved because of its translation with respect to the fixed stars speaks without reason and only in the vulgar fashion. Yet later he attributes to the Earth and Planets a tendency to recede from the Sun as from a centre about which they are revolved, by which they are balanced at their [due] distances from the Sun by a similar tendency of the gyrating vortex. What then? Is this tendency to be derived from the (according to Descartes) true and philosophical rest of the planets, or rather from [their] common and non-philosophical motion?" (*De Grav.*)

Descartes is committed to three claims:

- The Earth is at rest in its immediate surroundings (it is at "true" rest).
- The Earth exhibits a tendency to recede from the sun (rotational motion).
- The Earth is accelerating (Laws of Nature 1 & 2).

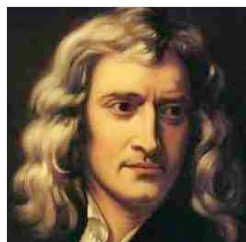
Newton asks: What is the *cause* of the Earth's recession?

(a) "True" (*philosophical*) motion of the Earth?

- *But then Earth is both at rest and accelerating.*

(b) Apparent (*non-philosophical*) motion of Earth with respect to some other body?

- *But which one: fixed stars? Saturn? Jupiter? etc.*



"Unless it is conceded that there can be a single physical motion of any body, and that the rest of its changes of relation and position with respect to other bodies are so many external designations, it follows that the Earth (for example) endeavours to recede from the centre of the Sun on account of a motion relative to the fixed stars, and endeavours the less to recede on account of a lesser motion relative to Saturn..., and still less relative to Jupiter..., and also less relative to Mars... Since all of these endeavours and non-endeavours cannot absolutely agree, it is rather to be said that only the motion which causes the Earth to endeavour to recede from the Sun is to be declared the Earth's natural and absolute motion."

- Newton's claim: The cause must be a *single* motion of the Earth; namely, its "absolute" motion. That is, its motion with respect to *absolute space*.

Two Characteristics of Absolute Space

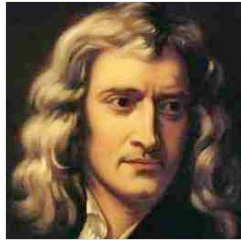
1. *Substantialism*:

(a) Space is geometrical: consists of Euclidean points, lines, surfaces, *etc.*

(b) Spatial points exist independently of matter:

- matter = substance + properties
- space = something else... (*not* a property, not entirely substantial either).

... a precondition for the existence of matter and God.

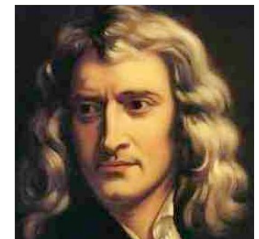


"It is not substance; on the one hand, because it is not absolute in itself, but is as it were an emanent effect of God, or a disposition of all being..."

2. *Immutability*: Space is unaffected by matter.

- Provides the single absolute, immovable reference frame with respect to which absolute motion can be defined.

"The positions, distances, and local motions of bodies are to be referred to the parts of space... space is eternal in duration and immutable in nature, and this because it is the emanent effect of an eternal and immutable being.."

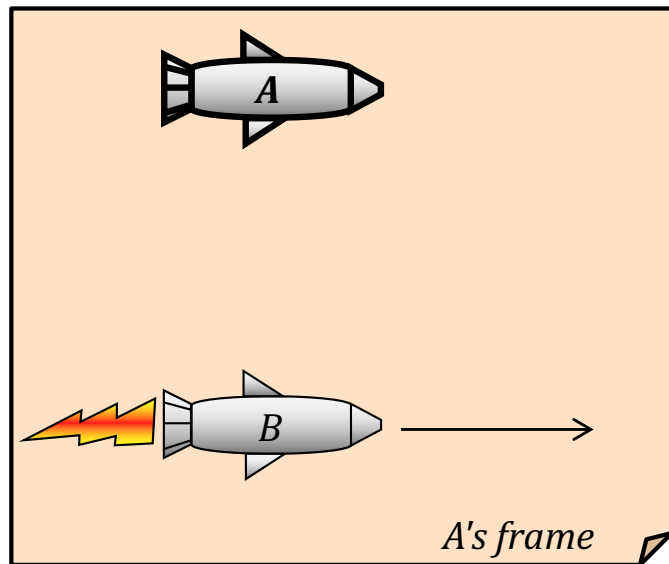


Reference Frames and the Principle of Inertia

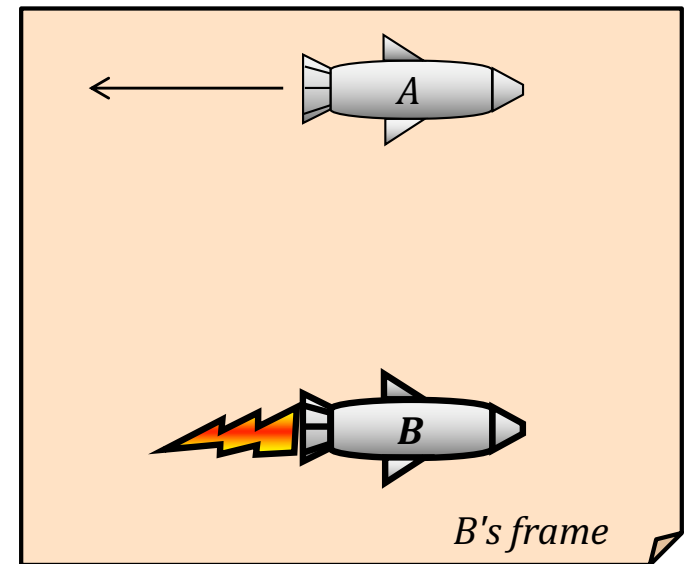
The Principle of Inertia (Newton's 1st Law; Descartes' 1st and 2nd Laws)

Every body continues in its state of rest, or of uniform motion in a straight line, unless acted upon by external forces.

- Newton's insight: The Principle of Inertia only holds in certain reference frames.



A and B accelerating with respect to each other. A experiences no force (engines off). B experiences a force (engines on).



- In A's frame, the Principle of Inertia holds:
 - A is at rest under no external forces.
 - B is in non-uniform motion (acceleration) to right under external forces.
- In B's frame, the Principle of Inertia does not hold:
 - A is in non-uniform motion (acceleration) to left under no external forces.
 - B is at rest in presence of external forces.

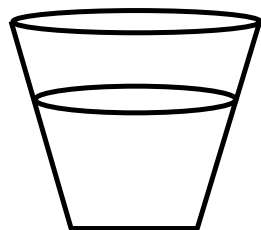
- *Inertial reference frame* = reference frame in which the Principle of Inertia holds.
- *Newton claims:*
Absolute space defines an inertial reference frame required by the Principle of Inertia.

Issues to Consider:

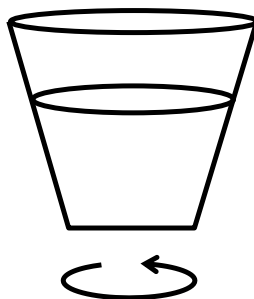
- i. Inertial frames allow *absolute acceleration* to be uniquely defined for all material objects.
- ii. A *single* privileged inertial frame (absolute space) *in addition* allows *absolute position* and *absolute velocity* to be uniquely defined for all material objects.
- iii. The Principle of Inertia requires the existence of privileged inertial frames, but do they have to be defined in terms of Newton's notion of absolute space?
 - *What about an unchanging reference body?*

The Bucket Thought Experiment (Scholium to Principia)

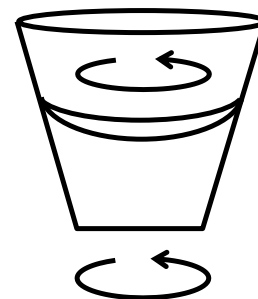
- Claim: Rotational motion is best explained as motion with respect to absolute space, and not as motion with respect to other physical objects.
- Set Up: Consider a water-filled bucket suspended from a rope. Twist up the rope and release the bucket. Observe its motion at various stages:



Stage 1
water at rest
bucket at rest



Stage 2
water at rest
bucket rotating

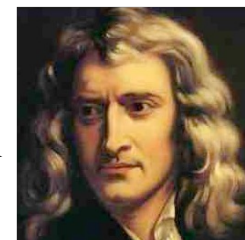


*surface of water
is concave*

Stage 3
water rotating
bucket rotating at same rate.

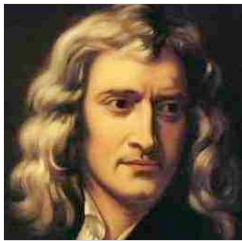
- Question: At what stage is the water in rotation?
- Newton: Stage 3: Presence of force of recession from axis indicates motion with respect to absolute space.

"This ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water... becomes known, and may be measured by this endeavor."



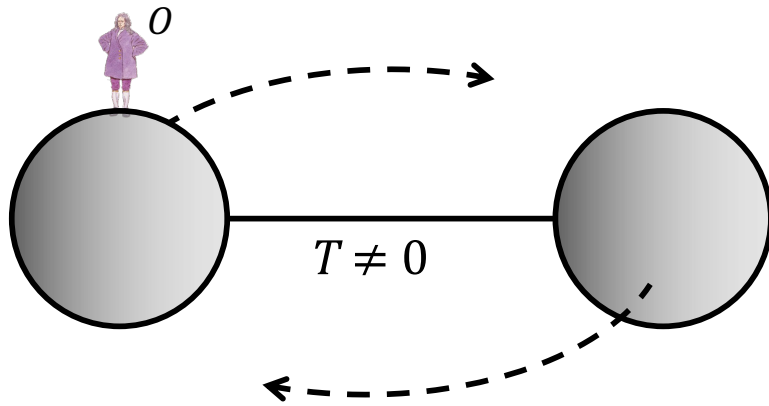
Possible explanations in terms of relative motion:

- (a) Suppose "true" motion is motion with respect to physical objects in immediate contact with the moving object and considered to be at rest.
- Then: The water is in "true" rotation in Stage 2, and "true" rest in Stages 1 and 3.
 - But: Stages 1 and 3 are physically distinct.
- (b) Suppose relative motion between water and some physical object other than the bucket explains the force of recession in Stage 3.
- But: There are many possible objects in many relative motions with respect to the water in Stage 3.
- *Which* relative motion explains the force?

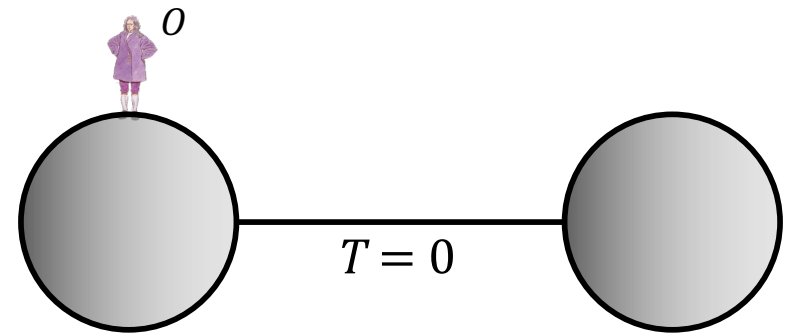


"There is only one real circular motion of any one revolving body, corresponding to only one power of endeavoring to recede from its axis of motion, as its proper and adequate effect; but relative motions, in one and the same body, are innumerable, according to the various relations it bears to external bodies, and, like other relations, are altogether destitute of any real effect, any otherwise than they may perhaps partake of that one only true motion."

The Rotating Globes Thought Experiment (Scholium to Principia)



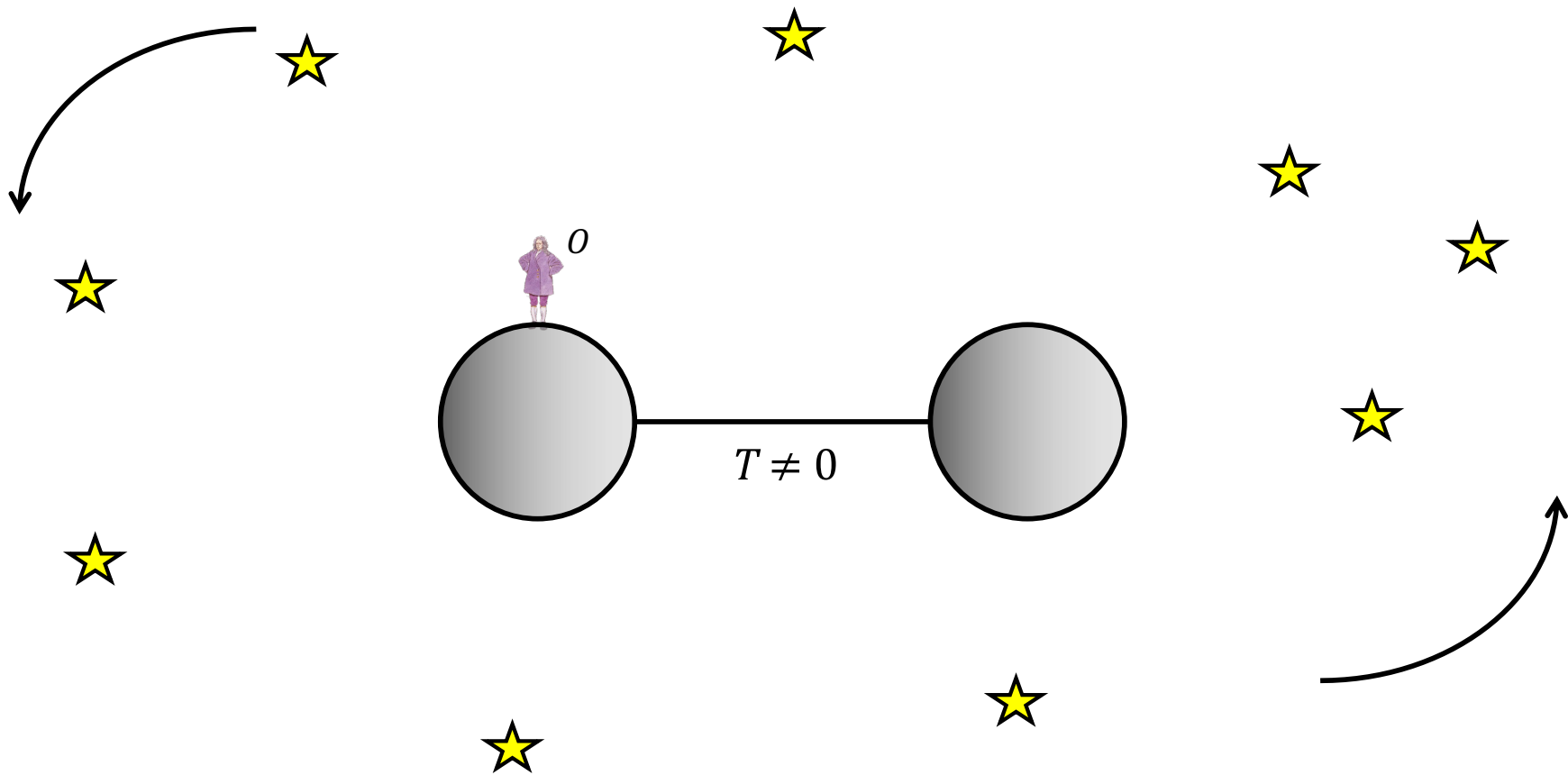
(A) Rotating globes



(B) Non-rotating globes

- In O 's reference frame, can a judgement concerning the motion of the globes be made?
- Newton: Globes are in absolute rotation just when the tension in the string is non-zero.

- On a relationalist view, Scenario (A) is physically indistinguishable from:



- But: Is it plausible to suggest that the fixed stars, simply by rotating about the globes cause a tension to appear in the string?
- Moreover: Newton will claim that in an otherwise empty universe (A) can still be distinguished from (B).

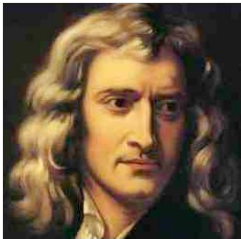
2. Newton's Cosmos (*Principia*)

(a) Characteristics:

- *Space and time are absolute (manifestation of God's omnipotence).*
- *Atomism: matter consists of atoms moving in a void.*
- *Universal action-at-a-distance force (gravity), penetrating matter.*

(b) 3 Laws of Motion

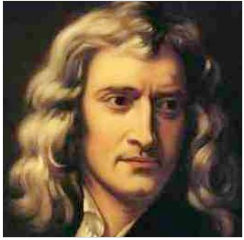
1st Law of Motion



"Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it."

- Describes *natural motion: uniform* motion (rest or constant velocity) in a *straight line*.
- *Encodes the Principle of Inertia* (taken directly from Descartes' Laws 1 & 2).
 - *Inertia* = tendency in an object to obey Law 1.
 - *Inertial motion* = rest or constant velocity in a straight line.

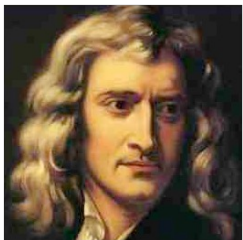
2nd Law of Motion



"The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

- Or: Acceleration (change in quantity of motion) is proportional to force ($F = ma$).
- Describes *Forced motion*.
 - *Accelerated motion = non-uniform motion* (non-constant velocity).
 - *Inertial mass = m = measure of amount of inertia.*

3rd Law of Motion



"To every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts, and takes place in the direction of the straight line along which the force is impressed."

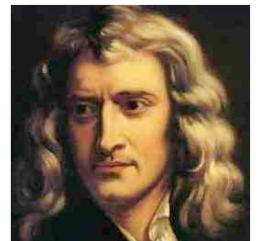
(c) Uniform motion is undetectable:

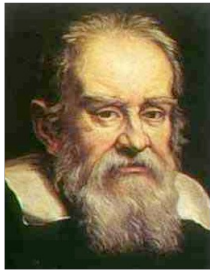


"The motions of bodies included in a given space are the same among themselves, whether that space is at rest, or moves uniformly forwards in a right line without any circular motion."

(Corollary V, Axioms, Laws of Motion.)

"For the differences of the motions tending towards the same parts, and the sums of those that tend towards contrary parts, are, at first (by supposition), in both cases the same; and it is from those sums and differences that the collisions and impulses do arise with which the bodies mutually impinge one upon another. Wherefore (by Law 2), the effects of those collisions will be equal in both cases; and therefore the mutual motions of the bodies among themselves in the one case will remain equal to the mutual motions of the bodies among themselves in the other. A clear proof of which we have from the experiment of a ship; where all motions happen after the same manner, whether the ship is at rest, or is carried uniformly forwards in a right line."





Galileo Galilei

"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals... With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin... [Now] have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still... [T]he ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted."

(Dialogue Concerning the Two Chief World Systems 1632.)

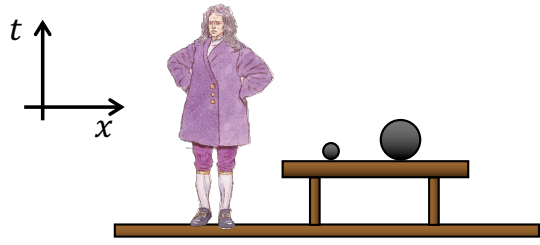
- No way to tell (by experiments with butterflies, *etc.*) from within a closed frame of reference whether a ship is at rest or in uniform motion.

Contemporary understanding

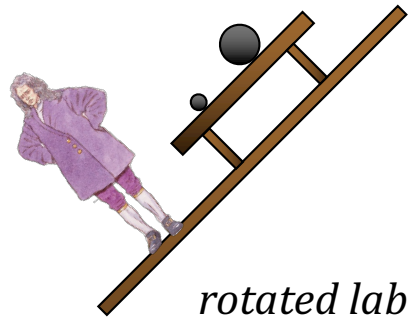
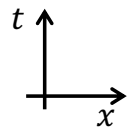
- Newton's laws of motion are the same in all "inertial reference frames" (*i.e.*, objects undergoing inertial motion).

What this means: Any experiment involving moving objects subject to Newton's laws and performed with respect to one inertial reference frame, will produce the same results with respect to any other inertial reference frames: *Inertial reference frames cannot be distinguished by Newton's laws of motion.*

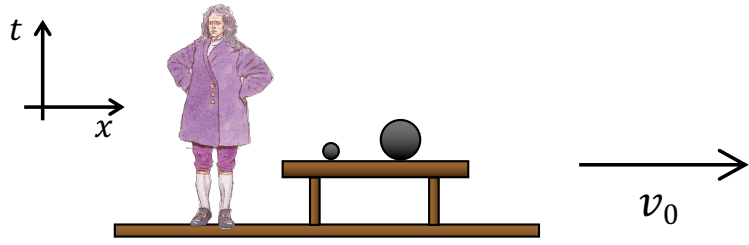
- Question: How are inertial reference frames related to each other?
 - Answer: By the symmetry transformations that leave invariant Newton's laws of motion (in particular, Law 2: $F = ma = md^2x/dt^2$).
 - And: These include rotations, velocity boosts, space translations, and time translations.



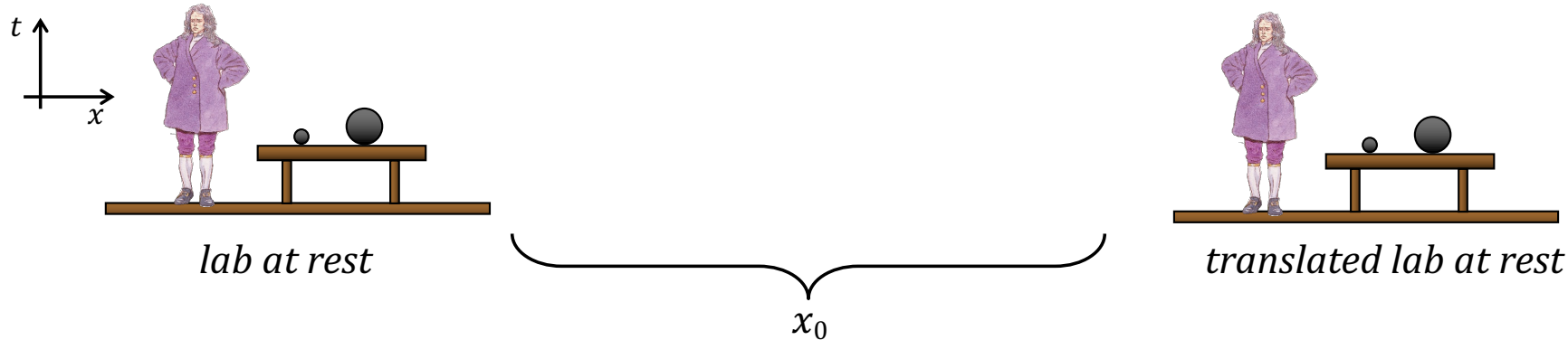
lab at rest

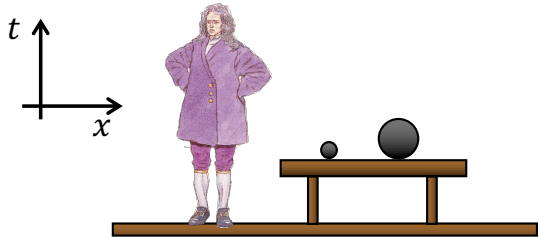


rotated lab at rest

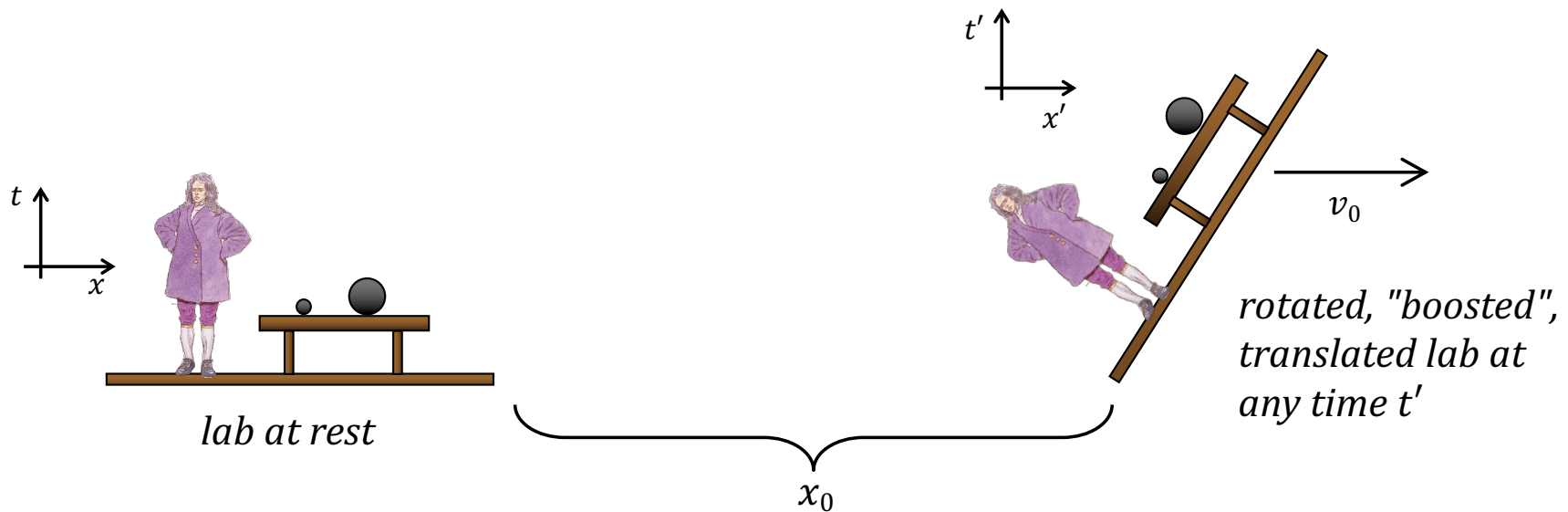


lab in constant velocity





*lab at rest tomorrow
at time t_0*



- Rest lab and rotated, spatially/temporally translated, constantly moving lab are indistinguishable according to Newton's Laws of Motion!

Consequences:

1. Velocity is relative! (No preferred, absolute velocities in nature.)
2. Position is relative! (No absolute positions in nature.)
3. Orientation is relative! (No absolute directions in nature.)
4. Acceleration is absolute! (Any given object has a unique value of acceleration.)

- Problem for Newton (Leibniz-Clarke correspondence 1715-16):
Absolute space entails both position and velocity are absolute!

Recap:

- Newton: Absolute space provides an absolute reference frame with respect to which non-uniform (accelerated) motion that the Principle of Inertia picks out can be defined.
- Absolute space = a single privileged inertial reference frame.

Concerns:

- i. Does absolute space violate Newton's 3rd Law?
 - *Absolute space affects matter (determines the paths that material objects obeying the 1st Law follow). But matter does not affect absolute space.*
- ii. Absolute space is in-principle unobservable.
 - Thus: *Absolute positions and absolute velocities are in-principle unobservable.*