Topics for today

Testing Newton's theory

Newtonian space and time

Symmetries of Newton's space and time

First Conservation Laws

What absolutes remain?

Newton, Leibniz, and Mach

Action at a distance and the ether

Themes:

Newton’s metaphysical assumptions

Philosophical interpretations.

Newton review

- 3-Law framework
  - No direct implications, until you start filling in with some less general rules
- One general force law- gravity
  - First real unification of terrestrial and astronomical observations
    - Gives Kepler's laws+ corrections
    - Gives familiar gravity
    - Gives tides, including correct Moon/Sun ratio
  - Provides a nearly complete theory on the scale of planets
    - That allows tests
      - Which it mostly passes, once allowances are made

Newton's Definitions:

- Time*: Absolute, true , and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.*
- Space*: "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimensions or measure of the absolute spaces; which our senses determine by its position to bodies; and which is commonly taken for immovable space; such is the dimension of a subterraneous, an aerial, or celestial space, determined by its position in respect of the earth."* (also it is infinite Euclidean space)
- *Mass or quantity of matter. the product of density and volume. The mass of a body "is proportional to the weight, as I have found by experiments on pendulums" and "by experiments made with the greatest accuracy."*
- Momentum *is defined as mass times velocity.*
- Inertia*: "the vis insita, or innate force of matter, is a power of resisting, by which every body, as much as in it lies, continues in its present state, whether it be of rest, or of moving uniformly forwards in a right line…"*
- Force: *"An impressed force is an action exerted upon a body, in order to change its state, either of rest, or of uniform motion in a right line. Impressed forces are of different origins, as from percussion, from pressure, from centripetal force."*

Resolution of a debate

- Stellar parallax (Bessel, 1838) showed an extra yearly motion of some stars- as expected if the Earth moves, and the stars are at large, different, distances.
  - Does that resolve the Tycho-Copernicus issue?
    - We saw that a reasonable modification of Tycho (stars orbiting Sun, like planets) gives an effect that looks like stellar parallax.
- But: there is no way to fit Tycho's theory into Newton's laws.
  The key role of acceleration in Newton implies that the spin of the Earth should be observable directly on earth- not relative to some other object.
  - It is: (Foucault, 1851; Poisson & Coriolis, 1831).
- Thus our initial question is answered
  - <u>the Earth spins and goes around the Sun</u>,
    - because that fits with the same dynamical theory that explains the rest of celestial and terrestrial dynamics.
      - unless somehow we should have to give up the theory.
- This resolution required empirical evidence and a conceptual framework which were not available to Copernicus or Tycho.
  - Questions that might seem unanswerable may turn answerable.
  - Do scientific issues ever become metaphysical?

On hidden assumptions

- One must be able to assume that there are no other important processes which would complicate the problem. The simple motion of the planets follows from the theory only if there are no other significant forces (*e.g.*, magnetism, hidden planets,..).
- How does one know if anything has been left out? In practice, only "getting the right answer" justifies the assumptions made. This can sometimes be dangerous.
  - Remember the ad-hoc fixes needed to make Newton fit some astronomical data.
- The success of the simple law of gravity in predicting orbits was the key argument (within the modern paradigm) against the geocentric cosmology. The Tychonean theory (remember that Ptolemy has been ejected from the game) contradicts Newton, and there's not some other respectable dynamical theory to fit it.

Symmetries of Space and Time

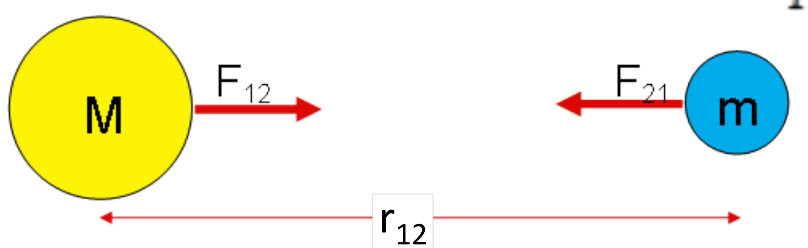
in Newton's Physics

- Space has **translational invariance**. We completely preferred positions. No matter where you do an experiment, you'll get the same answer.
  - Of course, the environment must be the same (near the Earth is clearly not the same as far from the Earth).
  - **Residents of the Andromeda Galaxy presumably see the same laws of physics that we do**. This is not pure conjecture. We can see through telescopes (and other astronomical methods) that the same processes, such as nuclear fusion, are taking place all over the universe.
- Space has **rotational invariance**. You can align your apparatus E-W or N-S, and it doesn't matter.
- **Time** has a similar translational invariance. It doesn't matter *w*hen you do your experiment.
- If space and time did not have these properties, then one could determine an absolute position, orientation, and time. That is, Aristotle would be correct.
- Together with **Galilean invariance** (it doesn't matter how fast you're "moving" or which way), these are the symmetries of Newton's space and time. They are **testable**. One can either do the experiments oneself or watch them being done.

How are the symmetries manifest?

- Look at Newton's law of gravitation:

$$\vec{F}_{12} = -\frac{GMm\hat{r}_{12}}{r_{12}^2} = -\vec{F}_{21}$$



- The space & time symmetries tell us:
  - Absolute time may not appear in the equation. (time translation)
  - Only the *relative* position, $\mathbf{r}_{12}$ may appear in the equation. (space translation)
  - The forces must point along the line joining the objects, if the forces depend only on relative positions, not velocities. (space rotation)
- Note that if we either rotate the system, or look at it from a different direction, the same laws work. If we rotate the system and ourselves together to some new angular position, everything even *looks* identical. There's no way to know that we'd all been rotated without looking outside, e.g. at the stars.

More symmetries of gravity

- “Galilean relativity”: If you set both objects in the same uniform motion, their distance is unchanged. So the force is unchanged. The predicted acceleration is thus unchanged. Adding a fixed velocity does leave the accelerations unchanged. So Newton's gravity fits Galilean relativity.

- Notice another symmetry: between m and M. The law itself does not distinguish anything qualitative between the objects. If you change the names, you still calculate exactly the same forces.

- There's a peculiarity about the law of gravity: the amount some object (same m) accelerates does not depend on its mass, which cancels out when you combine a=F/m with $F=GmM/r^2$ to give $a=GM/ r^2$.
  - If gravity were the only force law, we would not bother to describe "forces" but would simply say that every object with mass M caused every other object to accelerate by an amount:

$$\vec{a}_{12} = -\frac{GMm\hat{r}_{12}}{mr_{12}^2} = -\frac{GM\hat{r}_{12}}{r_{12}^2}$$

Two more symmetries

(important later in the course)

- **Time reversal**. So long as the forces (like gravity) depend only on positions, not velocities, Newton's laws tell us that every physical process can proceed as well in reverse. If one runs a film backward, nothing impossible happens. Mathematically, if we let t (time) become -t, Newton's equations remain valid, because in calculating acceleration, we divide <u>twice</u> by time increments, so it doesn't matter if we call both increments positive or negative.
  - Later we'll see velocity-dependent forces, but it turns out they also end up looking right in reverse, because the product of <u>two</u> velocities enters into the force laws.
  - Is time-reversal symmetry really correct? The future is not the same as the past. At a microscopic level, T-reversal fails in a very subtle way, but that doesn't account for the gross violations seen at the level of our experience. Stay tuned.
- **Parity** (mirror image). The mirror world behaves identically to ours. This turns out not to be true in a subtle way.

Why is symmetry a good thing to discover?

- It simplifies the math.

- It leads to conservation laws.

- It leads to conceptual connections that were not previously understood. We'll see in relativity that all the symmetries above are aspects of a more encompassing symmetry.

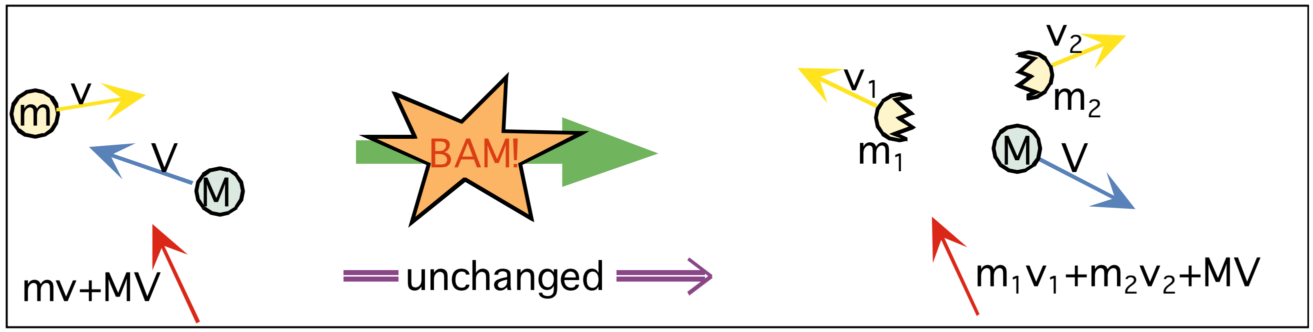
- Symmetry provides a powerful tool for simplifying the analysis of problems. Physicists love it.

Conservation Laws

you can predict a few things even in complicated systems

Newtonian physics contains conserved quantities. "Conserved" means that the total value does not change with time.

- N's 3rd law gives us:
  - Linear momentum. m**v**, **v** is **vector** velocity



- The rule that gravity etc. point along the line between the objects gives:
  - Angular momentum. This is a measure of an object's motion around some point. (It turns out that for planetary orbits, this conservation law is just the equal-areas per equal-times law.)
- Tests require the somewhat circular assumption that we have a frame that's not accelerating or rotating.
- Other conserved quantities (not known by Newton):
  - Energy: a conserved sum for Gravity, more to be discussed later
    Electric charge. discovered by Faraday, in the 19th century.

What absolutes remain?

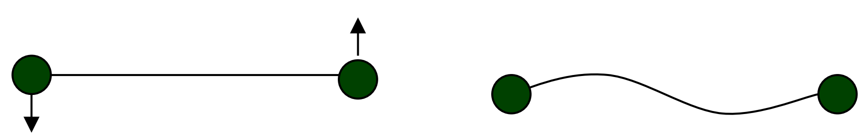
- Both position and velocity have become purely relative. That is, only the position and velocity of one object with respect to another is observable. (Newton himself did not claim that velocity was relative- but in the physical laws he developed, it is relative. In other words, if some fixed velocity were added to every velocity in a description, the new description would obey the same laws of physics. So you can't use the laws of physics to tell which velocity is the "true" one.) Every reference frame (experimental laboratory) is equivalent (i.e. lets you use the same laws) so long as it is not accelerating. “Galilean Relativity”

- Acceleration remains absolute. Newton’s first law (inertia) is violated if the observer is accelerating.

Accelerating with respect to what?

Accelerating with respect to what?

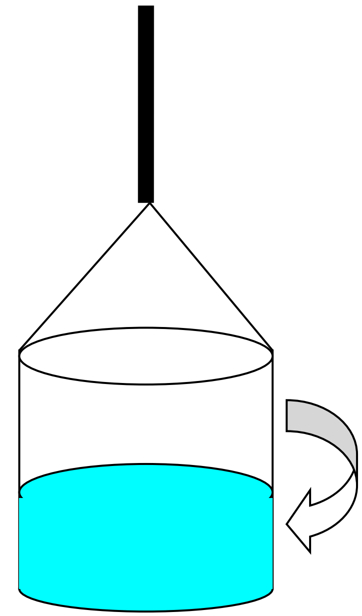
- Newton says: with respect to absolute space.
  - He claims (in effect) that if you were to twirl a string with weighted ends in empty space, it would go taut, because the weights would both be accelerating inward, and that means the string would be pulling on them.



Newton's thought experiments

Rotating bucket: the water is at rest with respect to the bucket. All forces (gravitational etc.) are identical. Inside the bucket we can decide whether or not it is rotating.

If a vessel, hung by a long cord, is so often turned about that the cord is strongly twisted, then filled with water, and held at rest together with the water; thereupon, by the sudden action of another force, it is whirled about the contrary way, and while the cord is untwisting itself, the vessel continues for some time in this motion; the surface of the water will at first be plain, as before the vessel began to move; but after that, the water will recede from the middle and ascend the sides of the vessel, forming a concave figure (as I have experienced). At last the water becomes relatively at rest in the bucket.



- Forces not coming form anywhere are really accelerations.
- Accelerations are always relative to something.
- Absolute space exists.

Metaphysics: some varieties

- Newton's

  For Newton absolute space and time exist. They have reality independent of sensation. Space and time form the arena within which objects move and events take place. (substantivalism) Thus there is no problem saying that absolute accelerations exist.

  - The question becomes: why are there no signs of absolute velocities? Or even of positions?

- Leibniz'

  For Leibniz space and time are merely mathematical devices, convenient for describing the relationships among objects. (relationism)

  - Leibniz view implies that empty space is not a meaningful concept. It has no observable consequences. However, it seems counterintuitive to deny the existence of "something" between the Earth and the Moon. Is "nothing" "something"?
  - In Leibniz' system, it's unclear why absolute acceleration appears in the physical laws.

Sklar's Arguments

- Newton has shown that absolute acceleration exists but that does not prove that absolute positions or velocities exist. Why must accelerations be with respect to something? (semantics issue). There are two types of words:
  - Relative or ordinary acceleration (to the fixed earth)
  - Absolute acceleration. Relative to some inertial reference frame. (in which there are no unaccounted forces.) AA is not relative to anything.
  - "I am at the center of the universe" is not meaningful.
  - "I am accelerated" is meaningful.

semantics depends on experiment!

We can actually measure

- the earth's velocity relative to the big bang radiation. There is a preferred velocity in the universe.
- The time since the big bang, 14 billion years. Hence, there is a natural time origin.
- But the laws of physics don't depend on this velocity or time!

What is the cause of gravity?

How does the Sun affect the planets? More specifically, how is the gravitational force propagated across the void? Similarly, how do other effects, such as electricity, magnetism and light propagate? Do we need to go beyond the mathematics?

- **Descartes:** Gravity is caused by little particles emitted by mass but only occasionally absorbed. When they are absorbed they give an impulse. (drops off as inverse power -good but is velocity dependant—bad. Newton knew this wouldn't work)
- **Newton** thought action at a distance absurd: *"It is inconceivable, that inanimate brute matter should, without mediation of something else, which is not material, operate upon, and affect other matter without mutual contact; as it must do, 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. 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 the mediation of anything else, by and through with 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, can 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 have left to the consideration of my readers."* (from his third letter to Bentley, 1693*)*

- The **ether**, a substance with mysterious properties that filled space; the ether was essential to the propagation of force. (Boyle and Descartes). The ether also provides a possible solution to the question of what constitutes absolute space. background against which acceleration could be determined. But then, why not velocity? The search for the ether led to special relativity.
- Liebniz*: You have made the astonishing discovery that Kepler's ellipses result simply from the conception of attraction or gravitation and passage in a planet. And yet I would incline to believe that all these are caused or regulated by the motion of a fluid medium, on the analogy of gravity and magnetism as we know it here. Yet this solution would not at all detract from the value and truth of your discovery (Janiak 2004, 106-7)* It is the "nature of bodies" to be such that the motion of any body can be altered only by something "contiguous" to that body: no action at a distance
- Gravitational fields carry the force.(definition of the gravitational field: the energy of a test mass at a given position, or equivalently, the work done). Each mass contributes to the gravitational field. How the particles move are dependant only on local field values. **Is the field real? How does fast does it move?**, what maintains the fields? They were thought to be mechanical deformations of the ether.
- **Why is locality of interactions so important?**

Metaphysics: some varieties

- Mach (jumping ahead)
  - In the 19th century, Mach tried to solve the problem raised by Leibniz' views by pointing out that the matter in the universe as a whole (the distant stars) *does* determine the preferred frame. Perhaps there is some unknown effect (a long range influence of some kind) by which acceleration with respect to this matter becomes observable. If so, absolute acceleration would be contingent, not necessary. (More later.)
  - Mach claims that Newton's empty-space twirling experiment would NOT have the string go taut.
    - Why not do the experiment?

Comparisons:

Despite the difficulty in testing these hypotheses, there are indirect implications of each approach which might be testable.

- Newton's view leads naturally to the expectation that absolute position and/or velocity might be observable. The search for an effect of this sort was an important enterprise last century (more on this later).
- Leibniz implies that no such effects should exist.
- Mach suggests that some new long-range effects should be found- hard to test. If the range were infinite, would there be any tests at all?

Some unstated assumptions of Newton's physics

- In addition to absolute space, there is, independently, absolute time. Time intervals between events are independent of who measures them. (Invariant)
- The geometry of space is Euclidean and is independent of any reference to time.

For Newton these were not empirical issues. The answers were assumed. However, Euclidean geometry is not a logical necessity. In particular, Euclid's fifth postulate ("Through a given point there is exactly one line parallel to another line.") always bothered the Greeks, because it required the notion of extending lines to infinity. Consequently, local geometrical measurements can't be reliably extrapolated to infer a universal geometry. This was not fully appreciated until the 19th century (Gauss, Riemann, et al.)

Newton believed that it is possible to acquire truths about things without presupposing any theory of their ultimate nature. Specifically, there are systems whose behavior can be reduced to law without any fear that further investigation will invalidate it. We shall see how well this idea has fared.

Some further questions to ponder

- If geometry describes space, not the objects in space, how can you test it?

- Is there anything more to space than a mathematical framework?

- How is inertia explained? That is, why do objects continue to move? Do we need an explanation?

- Is there a medium which transmits gravitation?
  - Newton was very uncomfortable with his action-at-distance gravity.

- Could that medium provide the "stuff' of absolute space/ How?
  - Boyle and Descartes postulated the ether, a substance that filled space, somehow accounted for inertia and the transmission of forces.