# Physics 419: Lecture 5: Newton Space and Time
# Jan. 29, 2019

## 1 Themes

1.) Newtonian space and time

2.) Newton's metaphysical assumptions

3.) Philosophical interpretations.

## 2 Resolution of earth/sun debate

We discussed last class period how Newton's principle of universal gravitation settles the debate as to whether the sun goes around the earth or the earth goes around the sun. In our solar system, the sun is the most massive object by a considerable margin. Newton's key point is that all objects exert gravitational forces on one another. However, because the gravitational force scales with the mass, the orbit of all the planets is governed (to a large degree) by the most massive entity in the universe. Hence, the focal point of the orbit of most of the planets is centered either in or quite close to the sun. The largest deviation arises in the case of Jupiter. Hence, we can finally rule out the Heraklides/Brahe scheme in which only Venus and Mars revolve around the sun.

There's no reason to exempt the Earth from the force which keeps the other planets in orbit.

Furthermore, the key role of acceleration in Newton implies that the rotation of the Earth should be observable directly on earth- not relative to some other object. It is: (Foucault, 1851; Poisson and Coriolis, 1831).

Thus our question is answered the Earth rotates and goes around the Sun, 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.)

It is important that this resolution required empirical evidence and a conceptual framework which were not available to Copernicus or Heraklides. We will see several more examples of new developments allowing "metaphysical" issues to be turned into scientific ones (i.e. ones with an empirical component).

Does the converse happen; that is, do scientific issues ever become metaphysical?

An important "hidden" assumption:How do we know the theory is correct?

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.

The success of the simple law of gravity in predicting orbits is another argument (within the modern paradigm) against the geocentric cosmology. The Heraklidean theory (remember that Ptolemy has been ejected from the game) contradicts Newton, and at this point there's not some other respectable dynamical theory to fit it.

## 3 Symmetries in Newtonian Mechanics

An important feature of space is translational invariance. This is the ultimate logical consequence of the abandonment of the concept of preferred positions. It says that 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. Or is it? We can see through telescopes (and other astronomical methods) that the same processes, such as nuclear fusion, are taking place all over the universe. But of course, this information is inferred.

Similarly, there is rotational invariance. You can align your apparatus E-W or N-S, and it doesn't matter. (Of course on earth it does matter, but away from any particular object, it doesn't, we think.

Time has a similar translational invariance. It doesn't matter when you do your experiment.

If space and time did not have these properties, then one could determine an absolute position, orientation, and time.

Galilean invariance: Newton's laws of motion remain unchanged in two reference frames that are moving at a uniform speed relative to one another. Note this is a testable statement. A ship moving in calm waters experiences the same laws of physics as does a stationary observer on the shore. In this sense, Galileo was the first person to formulate a relativistic principle. Uniform relative motion does not change the laws of physics.

How do the symmetries manifest themselves?

Look at Newton's law of gravitation:

$$\mathbf{F} = -\frac{\mathbf{GM_1M_2\hat{r}_{12}}}{\mathbf{R_{12}^2}} \tag{1}$$

The space and time symmetries tell us the following:

Absolute time may not appear in the equation. Only the difference in positions, $R_{12}$ appears in the equation. There is no Absolute space. The forces must point along the line joining the objects, if the forces depend only on relative positions, not velocities. Note that if we rotate the system the result looks exactly the same. That is, there is no way for us to tell that we are rotated without looking at some external object.

What about Galilean relativity in gravity?

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 it's 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

$$\mathbf{a} = -\frac{\mathbf{M_1M_2\hat{r}_{12}}}{\mathbf{M_2R_{12}^2}}. \tag{2}$$

# 4 Inertia

Newton's principle of inertia states that a body remains in a state of rest or uniform motion in a straight line unless it is acted on by an external force. If this statement has any meaning, we have to be able to determine when an object is in rest absolutely. This cannot be done. For example, consider two balls dropping from the same height towards the earth. Relative to one another, they are not moving. That is, they are at rest relative to one another. However, there is a force acting on them. Hence, Newton's principle of inertia does not work when one considers a reference frame which is subject to an acceleration. Hence, it is necessary to use a reference frame which is not subject to any acceleration to apply the law of inertia. Such reference frames are called inertial reference frames and were invented by Ludwig Lange to settle this troublesome problem of Newton. Newton got around this problem by stating that his law of inertia applied only to absolute space and absolute time. The center of absolute space was centered at the sun. This does not solve the problem. The sun is accelerating relative to a distant galaxy. Hence, it cannot be the answer to the absolute space problem. Consequently, the only way to implement Newton's laws is to use the concept of relative velocity and position. Velocities are always measured relative to something. There is no absolute velocity. Newton conceded this much. He stated that when it came to a practical calculation, one must resort to the implicit relativity of his laws. We cannot use the laws of physics to tell which velocity is the ”true” one. It is at this point that we should distinguish between Newton's mechanics and Newtonian mechanics. In the latter, Newton acknowledges that Galilean invariance is inescapable. In the former, he denies that such is the case, thereby opening the door for absolute space. It is Newtonian mechanics that we use to solve physics problems. Newton's mechanics is purely metaphysical.

Every reference frame (experimental laboratory) is equivalent as long as it is not accelerating.

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.

## 5 Theories of Space

Early considerations of what space is focused on defining the void. Consider Democritus' view. The void exists among the interstices of the smallest indivisible parts of matter and extends without bound indefinitely. Aristotle and Plato denied the existence of the void. The argument stems from their view of the place of an object. On their view the place of an object is the outermost of the innermost motionless boundary of what contains it. Since no boundary exists for a void, the very notion of the void as a thing is ill-defined. For Aristotle/Plato the universe consisted of the planets, sun and a fixed stars tethered to some shell. There is no place or space outside the fixed stars. That is, the universe is finite. Consider Descartes. Matter has no quality only quantity. Hence, a void (vacuum) cannot exist since there is no way to quantitfy what one has in mind. In William Charletan, we see the first substantivilist claims of space and time as real entities: that time and space are real entities even though they fit neither of the traditional categories of substance or accident (i.e., property or a substance), that time “flow[s] on eternally in the same calm and equal tenor,” while the motion of all bodies is subject to “acceleration, retardation, or suspension”, that time is distinct from any measure of it, e.g., celestial motion or the solar day, that space is "absolutely immoveable" and incorporeal, that bodies, or "Corporeal Dimensions" are everywhere "Coexistent and Compatient" with the "Dimensions" of the parts of space they occupy, that space distinct from body existed before God created the world and that God's omnipresence is his literal presence everywhere, and that motion is the translation or migration of body from one place, as an immovable part of space, to another. (taken from the Stanford Encylopedia of Philosophy) Charleton published his ideas in 1654, twelve years after Newton's birth. His ideas undoubtedly influenced Netwon, though Newton gave no acknowledgement to Charleton.

## 6 Newton/Leibniz Debate

Newton's metaphysics

For Newton absolute space and time exist. They have reality independent of sensation. Space and time are the arena within which objects move and events take place. (substantivalism ) Thus there is no problem saying that absolute accelerations exist. Newton was not sure exactly what absolute space was. He conceived of it as some rather thin all-encompassing fabric–the aether. It was something like a container into which material objects are put. The question becomes: why are there no signs of absolute velocities? Or even positions?

Leibniz's metaphysics

In contrast, for Leibniz space and time are merely mathematical devices which are convenient for describing the relationships among objects. Consider the example that Sklar uses. The relationship between members of a family only has meaning if the family exists. Leibniz conceived of space and time in a similar way. This example is useful in showing the weakness of Leibniz's analysis. Even if the members of the family do not exist, the notion of uncle, mother and father still make sense. That is, the concept of family does not require that a family, namely a particular family, exists. Likewise, there has to be something which grounds the possibilities of space filling for us to make sense of the relationist view. (relationism)

For Leibniz, empty space is not totally a meaningless concept. Space could also be construed as the possible relationship between objects. Does it make sense that we construe empty space as a possible relationship between objects? For Leibniz, everything happened for a reason. So if God were to look at empty space, she would have no reason to put the world in one particular location. But the world does exist. Hence, there must have been some reason why it is where it is. Hence, the view that space is some kind of container waiting to be filled has no meaning. Strictly, for Leibniz, space is only meaningful in an operational level in determining relations between objects. Space does not have substance. Sklar makes a good point about relational space having no meaning in so far as it makes no sense to talk about it in a potential sense. Question: If Leibniz denied that a possible world could exist with the exact arrangement of the physical objects that this world has, must he also deny that two identical objects could not exist in different locations in this world? Is "nothing" "something"?

In Leibniz' system, it's unclear why absolute acceleration appears in the physical laws.

Mach

In the 19th century, Mach tried to solve Leibniz' problem by appealing to the matter in the universe as a whole (the distant stars) as the source of the preferred frame. Perhaps there is some unknown effect (a long range force of some kind) by which acceleration with respect to this matter becomes observable. In this case, absolute acceleration is 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?

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