

Title: Time and Motion

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Abstract: Newton's first law of motion - and the very meaning of inertia - has been described as either completely obvious (D'Alembert) or a 'logician's nightmare' (ex-editor of the American Journal of Physics). Sometimes the simplest things in physics are the most subtle. The first law will be described in historical context, explaining a connection with the ancient Greeks' distinction between natural and violent motion and with Descartes' natural philosophy. You will also learn why it still requires careful handling and what it tells us about time in physics. <kw> 'Time and Motion', Harvey Brown, time, motion, relative, Copernicus, Ptolemy, Galileo, Copernicanism, Descartes, inertia, Newton, standard of time, Fitzgerald, duration, inertial frame </kw>

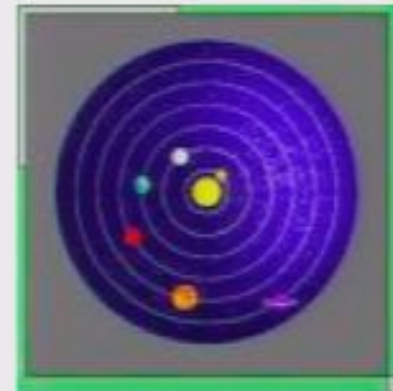
Time and Motion

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“We live on a hunk of rock and metal that orbits a humdrum star in the obscure outskirts of an ordinary galaxy comprised of 400 billion stars in a universe of some hundred billion galaxies ...”

Carl Sagan

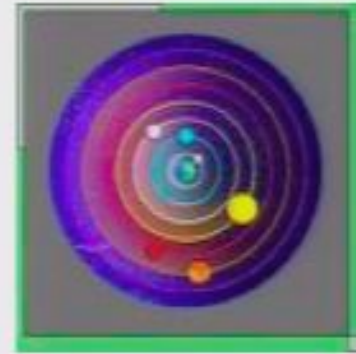


“The first and highest of all is the sphere of the fixed stars, which contains itself and everything, and is therefore immovable. It is unquestionably the place of the universe, to which the motion and position of all the other heavenly bodies are compared.”

Copernicus, *De Revolutionibus* 1543

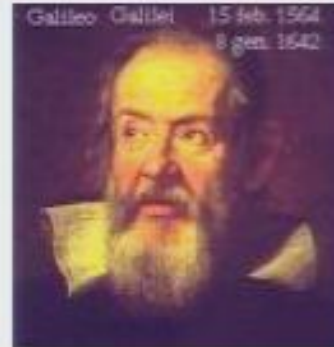
Ptolemy

c. 100 to c. 170 AD



- understood the nature of time in astronomy (used the sidereal not solar day)
- suspected that the “fixed” stars are not fixed; compiled catalogue of star positions (used by Halley in 1718)

Galileo Galilei 1564-1642



- staunch defender of Copernicanism
- either the Earth moves or it doesn't – motion is seemingly *absolute*
- condemned by the Inquisition in 1633

eppur si muove
and yet it moves

Around 1640,

“... the lesson of Copernicanism was beginning to sink in. The great cosmic debate had raged for a century. Just when it appeared to be resolved in favour of Copernicus and Galileo—yes, the Earth does move—Descartes put the whole debate in a totally different perspective. ... From now on the question was no longer: **does she move or does she not?** It was transformed into: **what is motion?**”

Julian Barbour *Absolute or Relative Motion? The Discovery of Dynamics* (1989)

René Descartes 1596-1650



- questioned the framework of the “fixed” stars
- proposed the (modern) principle of inertia
- forced the question: **what is motion?**

The World 1632

Principles of Philosophy 1644

The law of inertia

The law of inertia

Descartes, *Principles of Philosophy* 1644

“The first of these laws [of nature] is that each thing always remains in the same state, as far as it can, and never changes except as a result of external causes. Thus, if a particular piece of matter ... is at rest, we hold that it will never begin to move unless pushed into motion by some cause. And if it moves, there is equally no reason for thinking it will ever lose its motion of its own accord and without being checked by something else ...

The second law is that every piece of matter, considered in itself, always tends to continue moving, not in an oblique path but only in a straight line.”

Early Newton

“A quantity will always move on its same straight line (not changing determination nor celerity of its motion) unless some external cause divert it.”

Descartes on motion

Descartes on motion

In order to determine *external place* or *situation*

“we must take into account some other bodies which we consider to be motionless; and depending on which bodies we consider, we can say that the same thing simultaneously changes and does not change its place. ... Finally, if we think that no truly motionless points of this kind are found in the universe, as will later be shown to be probable; then, from that, we shall conclude that nothing has an enduring place, except in so far as its place is determined in our minds ...”

Descartes on motion

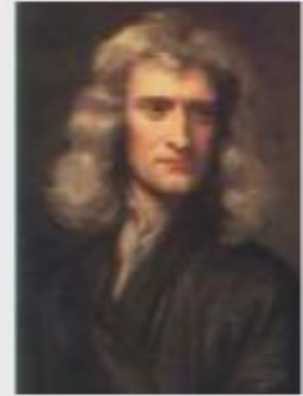
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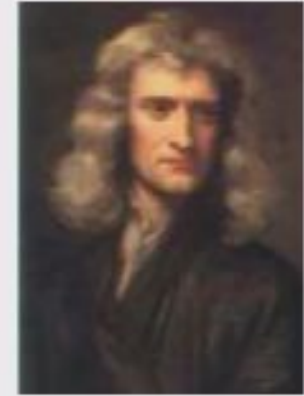
“If ... we consider what should be understood by *motion*, not in common usage but in accordance with the truth of the matter, and if our aim is to assign a determinate nature to it, we may say that *motion is the transfer of one piece of matter, or one body, from the vicinity of other bodies which are in immediate contact with it, and which are regarded as being at rest, to the vicinity of other bodies.*”

Principles of Philosophy 1644

Newton's reaction to Descartes



Newton's reaction to Descartes



De Gravitatione ... (c. 1662)

“I shall venture to dispose of his fictions.”

“For he says that speaking properly and according to philosophical sense the Earth and the other planets do not move ... 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 ... 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?”

“I say that thence it follows that a moving body has no determinate velocity and no definite line in which it moves. And, what is worse, that the velocity of a body moving without resistance cannot be said to be uniform, nor the line straight in which its motion is accomplished.”

Newton's conclusion: “So it is necessary that the definition of places and hence of local motion, be referred to some motionless thing such as extension alone or space in so far as it is seen to be truly distinct from bodies.”

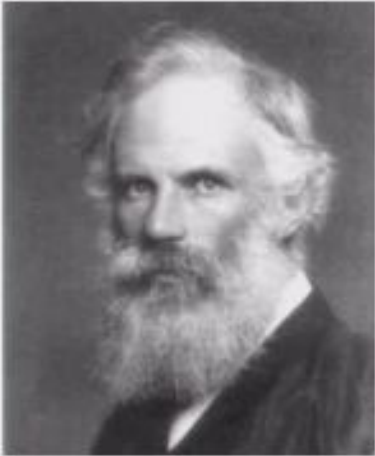
Newton on time

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“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 ...

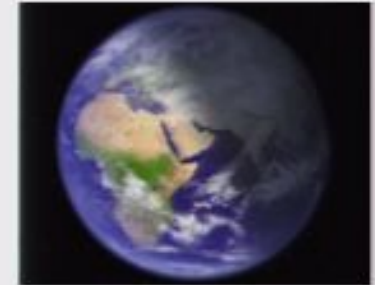
It may be, that there is no such thing as an equable motion, whereby time might be accurately measured. All motions may be accelerated and retarded, but the flowing of absolute time is not liable to any change.”

Scholium to the *Principia*, 1687



G. F. FitzGerald
(1890s) :

The problem of the standard of time



“... there is every reason for assuming that the Earth rotates on its axis more uniformly than any clock we can construct”.

But the rotation rate is changing:

testimony of ancient eclipses
frictional resistance of the tides

So “. . . how on earth can we discover a change in our standard itself?”

How do we find a “more ultimate standard of time”?

What is duration?

Duration is defined by ideal clocks. (Einstein)

What is an ideal clock?

“By a clock we understand anything characterized by a phenomenon passing periodically through identical phases so that we must assume, by virtue of the principle of sufficient reason, that all that happens in a given period is identical with all that happens in an arbitrary period.”

Einstein 1910

VS.

Ideal clocks are defined by duration. (Newton, Fitz-Gerald, Poincaré, Buckingham, Barbour, ...)

What is duration?

The choice of a temporal parameter that makes the basic laws of physics take their simplest form.

There is no ideal clock (apart from the universe as a whole).

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An inertial frame is one relative to which the Descartes-Newton law of inertia holds.

How to avoid circularity? Make the law of inertia **an existence claim**: “There exists at least one inertial frame”.