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Galilean relativity

Imagine a person inside a ship which is sailing on a perfectly smooth lake at constant speed. This passeneger is in the ship's windowless hull and, despite it being a fine day, is engaged in doing mechanical experiments (such as studying the behavior of pendula and the trajectories of falling bodies). A simple question one can ask of this researcher is whether she can determine that the ship is moving (with respect to the lake shore) *without going on deck or looking out a porthole*.

Since the ship is moving at constant speed and direction she will not *feel* the motion of the ship. This is the same situation as when flying on a plane: one cannot tell, without looking out one of the windows, that the plane is moving once it reaches cruising altitutde (at which point the plane is flying at constant speed and direction). Still one might wonder whether the experiments being done in the ship's hull will give some indication of the its motion. Based on his experiments Galileo concluded that this is in fact impossible: all mechanical experiments done inside a ship moving at constant speed in a constant direction would give precisely the same results as similar experiments done on shore.

The conclusion is that one observer in a house by the shore and another in the ship will not be able to determine that the ship is moving by comparing the results of experiments done inside the house and ship. In order to determine motion these observers must look at each other. It is important important to note that this is true *only* if the ship is sailing at constant speed and direction, should it speed up, slow down or turn the researcher inside *can* tell that the ship is moving. For example, if the ship turns you can see all things hanging from the roof (such as a lamp) tilting with respect to the floor

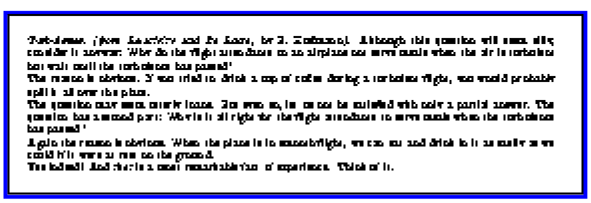
Generalizing these observations Galileo postulated his **relativity hypothesis:**

> *any two observers moving at constant speed and direction with respect to one another will obtain the same results for all mechanical experiments*

(it is understood that the apparatuses they use for these experiments move with them).

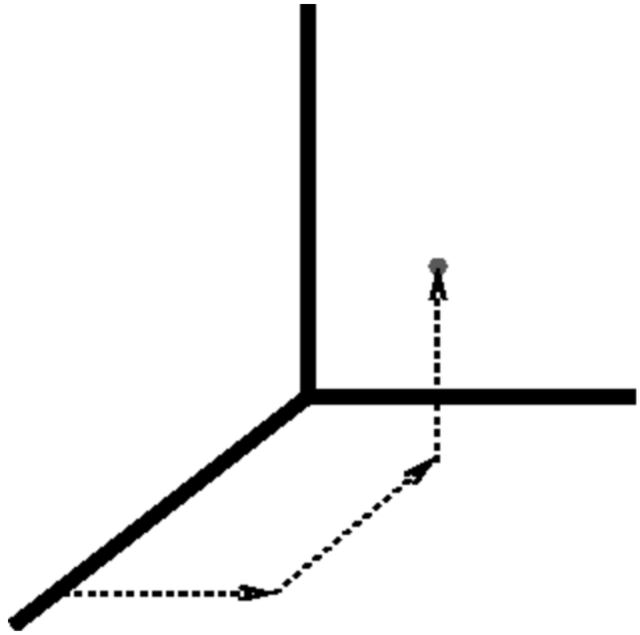
In pursuing these ideas Galileo used the scientific method (Sec. 1.2.1): he derived consequences of this hypothesis and determined whether they agree with the predictions.

This idea has a very important consequence: *velocity is not absolute*. This means that velocity can only be measured in reference to some object(s), and that the result of this measurment changes if we decide to measure the velocity with respect to a diferent refernce point(s). Imagine an observer traveling inside a windowless spaceship moving away from the sun at constant velocity. Galileo asserted that there are no mechanical experiments that can be made inside the rocket that will tell the occupants that the rocket is moving . The question ``are we moving'' has no meaning unless we specify a reference frame (``are we moving with respect to that star'' *is* meaningful). This fact, formulated in the 1600's remains very true today and is one of the cornerstones of Einstein's theories of relativity.



A concept associated with these ideas is the one of a ``frame of reference''. We intuitively know that the position of a small body relative to a reference point is determined by three numbers. Indeed consider three long rods at 90^o from one another, the position of an object is uniquely determined by the distance along each of the corresponding three directions one must travel in order to get from the point where the rods join to the object (Fig. 4.1)

Figure 4.1: A frame of reference.



Thus anyone can determine positions and, if he/she carries clocks, motion of particles accurately by using these rods and good clocks. This set of rods and clock is called a *reference frame*. In short: a reference frame determines the where and when of anything with respect to a reference point.

A prediction of Galileo's principle of relativity is that free objects will move in straight lines at constant speed. A free object does not suffer form interactions from other bodies or agencies, so if it is at one time at rest in some reference frame, it will remain at rest forever in this frame. Now, imagine observing the body form another reference frame moving at constant speed and direction with respect to the first. In this second frame the free body is seen to move at constant speed and (opposite) direction. Still nothing has been done to the body itself, we are merely looking at it from another reference frame. So, in one frame the body is stationary, in another frame it moves at constant speed and direction. On the other hand if the body is influenced by something or other it will change its motion by speeding up, slowing down or turning. In this case either speed or direction are not constant as observed in *any* reference frame. From these arguments Galileo concluded that free bodies are uniquely characterized by moving at constant speed (which might be zero) and direction.

An interesting sideline about Galilean relativity is the following. Up to that time the perennial question was, what kept a body moving? Galileo realized that this was the *wrong question*, since uniform motion in a straight line is not an absolute concept. The right question is, what keeps a body from moving uniformly in a straight line? The answer to that is ``forces'' (which are defined by these statements). This illustrates a big problem in physics, we have at our disposal all the answers (Nature is before us), but only when the right questions are asked the regularity of the answers before us becomes apparent. Einstein was able to ask a different set of questions and this lead to perhaps the most beautiful insights into the workings of Nature that have been obtained.

Galilean relativity predicts that free motion is in a straight line at constant speed. This important conclusion cannot be accepted without experimental evidence. Though everyday experience seems to contradict this conclusion (for example, if we kick a ball, it will eventually stop), Galileo realized that this is due to the fact that in such motions the objects are *not* left alone: they are affected by friction. He then performed a series of experiments in which he determined that frictionless motion would indeed be in a straight line at constant speed. Consider a ball rolling in a smooth bowl (Fig. 4.2).

Figure 4.2: Illustration of Galileo's experiments with friction

The ball rolls from it's release point to the opposite end and back to a certain place slightly below the initial point. As the surfaces of the bowl and ball are made smoother and smoother the ball returns to a point closer and closer to the initial one. In the limit of zero friction, he concluded, the ball would endlessly go back and forth in this bowl.

Following this reasoning and ``abstracting away'' frictional effects he concluded that

Free horizontal motion is constant in speed and direction.

This directly contradicts the Aristotelian philosophy which claimed that

- all objects on Earth, being imperfect, will naturally slow down,
- that in a vacuum infinite speeds would ensue,
- and that perfect celestial bodies must move in circles.

In fact objects on Earth slow down due to friction, an object at rest would stay at rest even if in vacuum, and celestial bodies, as anything else, move in a straight line at constant speed or remain at rest unless acted by forces.

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