

5.2 Newton's First Law of Motion

Newton's First Law of Motion

Key ideas

- Newton's first law states that objects remain at constant velocity unless acted upon by a net external force. That is, an object at rest will remain at rest, and an object moving at a constant speed in a straight line will continue to do so, unless a net external force acts on the object.
- A net force is not required to move an object. A net force is required to change an object's velocity.
- An inertial reference frame is one where Newton's first law holds true. A frame at rest with respect to very distant stars can be thought of as an inertial reference frame. Any reference frame that does not rotate and moves at a constant velocity with respect to this inertial frame is also an inertial frame. No particular inertial reference frame is more special than any other.
- Applying Newton's first law in inertial reference frames allows us to infer the presence or absence of a net force on an object.

Learning objectives

After completing this section, you should be able to...

- describe Newton's first law of motion,
- recognize when a net external force acts on object, and when it does not, from the object's motion, and
- identify inertial and noninertial reference frames.

We have all had the experience of needing to push an object to get it to move. Imagine pushing a large object, like a table, across carpeted floor. The table only moves when you push it--stop pushing the table, and it comes to a stop. This seems to imply that the "natural" state of the table, or any object, is to be at rest--that motion is somehow "special," because it requires a force. Many people today have this understanding of motion because it is so common in everyday life. In fact, for centuries, most scholars in the western world, following the philosophy of [Aristotle](#) (384-322 BC), believed that a force on an object was required to move it.

But is this belief really correct? Let's think a little more closely about the forces acting on the table as you push it across the carpet. Is the force you exert really the only force on the table? The table is in contact with the carpet, so the carpet could be exerting a force on the table that resists its motion (an example of a type of force called friction). This resistive force could be equal in magnitude to the force you exert. In such a case, the net force on the table while it moves might be zero.

To get a better idea of what the actual, "natural" motion of an object would be with no net force acting on it, let's think of examples where we can reduce or eliminate resistive forces. Consider the sport of ice hockey, where a frozen rubber puck lies flat on smooth sheet of ice. Imagine a puck initially at rest on the ice. It remains at rest until it is struck by a hockey player's stick (see [Figure 5.5](#)). The stick applies a force, causing the puck's velocity to change. After the puck loses contact with the stick, the stick no longer exerts a force on the puck. The puck continues at a nearly constant velocity. On a large enough sheet of ice, we would see the puck eventually slow to a stop, after traveling a great distance. But the puck is in contact with the ice, which exerts a small frictional force on it, opposing its motion. The net force on the puck is nearly zero, and the puck moves with nearly constant velocity.

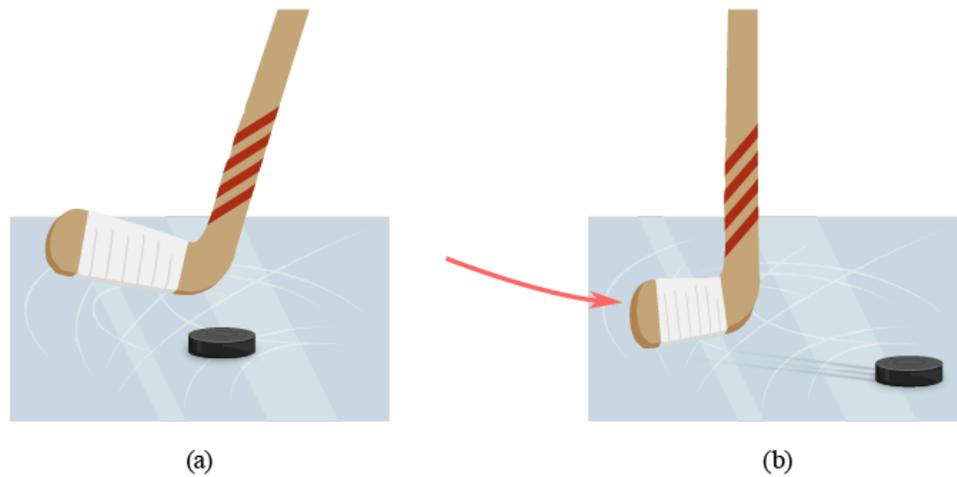


Figure 5.5 (a) A hockey puck is shown at rest. It remains at rest until an external force, such as one applied by a hockey stick, changes its state of rest. (b) A hockey puck is shown in motion. It continues in a straight line until an external force causes it to change its state of motion. Although it is slick, an ice surface provides some friction that slows the puck.

Another example would be an air hockey table, as shown in [Figure 5.6](#), where a puck hovers above a table due to air blown through tiny holes in the surface of the table. The upward force of the air on the puck balances the downward gravitational force, and so it does not come in contact with the table while the air is blowing. Push the puck forward, and it moves with a velocity close to constant. Still, a very small resistive force due to the air tends to slow the puck ever so slightly.

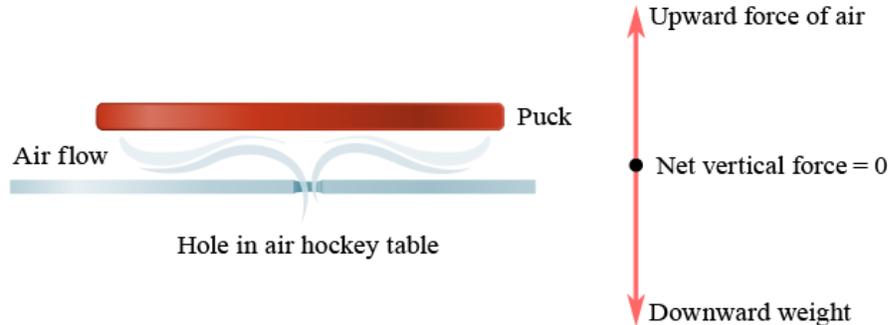


Figure 5.6 Side view of an air hockey table. When the air is off, friction with the table quickly slows down the puck. When the air is on, it minimizes contact between the puck and the table, and the puck glides far down the table.

In practice, it is extremely difficult to eliminate all forces on an object. In the extreme case, we can imagine an object deep in outer space, far from any stars or planets. The density of gases, dust, or other particles is extremely low in outer space, and far from any gravitational forces, an object in motion would continue at an essentially constant velocity. So it seems the closer we get to a situation where there is no net force on an object, the more we can see that the object's motion comes close to remaining at a constant velocity.

One of the first people to realize that an object will remain at a constant velocity if no net force acts on it, at least for the case of horizontal motion on a level surface, was [Galileo Galilei](#) (1564-1642). Later, Isaac Newton generalized Galileo's principle in his landmark treatise, *Mathematical Principles of Natural Philosophy*, where he introduced it as his first law of motion. The law, as Newton originally wrote it, says, "Every body perseveres in its state of being at rest or of moving uniformly straight forward except insofar as it is compelled to change its state by forces impressed" (translated from Latin

by I. Bernard Cohen and Anne Whitman, in *The Principia: Mathematical Principles of Natural Philosophy*, University of California Press, 1999). In more modern language, we can state **Newton's first law** as follows.

Newton's First Law of Motion

Every object maintains a constant velocity except to the extent it is acted upon by a net external force.

Newton's first law tells us several important facts about nature. First, the "natural" or "unforced" motion of any object is *not* rest, but constant velocity. Rest, or a velocity of zero, is a special case of a constant velocity. If an object is at rest, it will remain at rest, unless a net force acts on it. But if an object is moving, it will continue moving in a straight line and at a constant speed, unless a net force acts on it. A net force on an object is not needed for that object to move.

Second, there is nothing inherent within an object that causes it to slow down, or change velocity in any way, on its own. Rather, it is a *net force*, the vector sum of forces caused by *external* objects, that change the object's velocity. Newton's first law effectively defines what a force is and what it does: a force is an interaction between an object and its environment, and it tends to cause (in the absence of other forces) a *change* in the object's *velocity*.

Newton's first law is sometimes called the "law of inertia." Used in this way, the word "**inertia**" refers to the tendency of objects to obey Newton's first law--that is, they remain at a constant velocity (whether that velocity is zero or not) unless acted upon by a net force. However, there is a quantitative aspect to inertia. For example, imagine we apply the same net force over the same amount of time to two different objects, one large and one small. We notice that the small object has a greater change in velocity over that time than the large one. We can then say that the larger object has "greater inertia." However, we also note that the larger object has greater **mass**. Mass, as we introduced in Section 1.2, [Units and Standards](#), is a measure of the amount of matter that comprises an object, but it also turns out to be the "amount of inertia" an object has. The quantitative relationship between an object's mass and how its motion is affected by a net force is described by Newton's second law, which we will discuss in the next section ([Newton's Second Law of Motion](#)).

Inertial Reference Frames

Using Newton's first law, we can detect whether an object has a net force acting on it or not. If we see an object change velocity in any way, then we can infer there must be a net force on the object. Remember that velocity is a vector, so a change in velocity could mean a change in speed (whether increasing or decreasing), a change in direction, or both. In other words, if an object undergoes any type of acceleration (where acceleration is a vector), then by Newton's first law, there must be a net force acting on it. Similarly, Newton's first law can help us infer the presence of forces. Take our example of pushing a table across a carpeted floor. You exert a force forward on the table, but notice that the table's velocity is constant while you push it. Newton's first law says the net force on the table must be zero. So, this implies there must be another force (in this case, due to the carpet) that opposes the force you apply, such that the vector sum of the two forces is zero.

However, there is one important caveat to applying Newton's first law--it must be done in an **inertial reference frame**. In general, a **reference frame** can be thought of as a coordinate system with an origin tied to a physical point in space or a specific object. An inertial reference frame is one where Newton's first law holds true. It turns out that well within experimental error, a reference frame at rest with respect to the most distant stars (sometimes called the "fixed" stars, although the stars are in fact moving) is inertial. For example, think of a point deep in outer space, far from any stars. If an object moves at a constant velocity from the point of view of this reference frame, we are assured that there is no net force acting on it, and Newton's first law holds true. Furthermore, any non-rotating reference frame that moves at a constant velocity with respect to this inertial reference frame is itself another inertial reference frame.

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