Newton's Laws of Motion

Newton's laws of motion are three statements describing the relations between the forces acting on an object and the motion of the object. They are the foundation of classical mechanics.

1. The Law of Inertia

If an object is at rest
or moving at a constant speed in a straight line,
it will remain at rest
or moving in a straight line at constant speed
unless acted upon by a force.

The law of inertia was deduced by Galileo in his experiments with balls rolling down inclined planes, and was later mathematically generalized by René Descartes. In Newtonian mechanics, there is no real distinction between rest and uniform motion in a straight line. They are treated as the same state of motion, but seen by different observers, one moving at the same velocity as the object, and one moving at a different velocity to the object.

Although the principle of inertia is the starting point and the fundamental assumption of classical mechanics, it is not intuitively obvious. In ordinary experience, in Aristotelian mechanics, and in most other ancient philosophies, objects that are not actively pushed will come to rest. This led the ancients to believe that all things have a natural resting place. For example, earth naturally rests below water, which naturally rests below air, which naturally rests below fire.

Why Invent the Idea of Inertia?

For Galileo, the principle of inertia was fundamental to his scientific search: he needed to explain how it is possible for the Earth to spin on its axis and orbit the Sun, yet without our sensing the motion. The idea of inertia helped answer this riddle.

Since we are in motion along with the Earth, and like all other objects our natural tendency is to retain our motion, Earth appears to us to be at rest. Thus, the principle of inertia, which may seem fairly obvious today, upended millennia of common sense, sacred scriptures, and entrenched authorities.

Galileo found the path, Newton found the math. Newton sorted out the details and created the equations that make it possible to accurately account for even minor deviations in planetary paths.

In the Newtonian formulation, the observation that objects that are not pushed tend to come to rest is attributed to the fact that there are "unbalanced forces" acting on them, such as friction and air resistance.

2. The Law of Acceleration

The time rate of change
of the momentum of an object
is equal in both magnitude and direction
to the force imposed on it.
The momentum of an object
is equal to the product of
its mass times its velocity.

Newton's second law is one of the most important in all of physics. It tells us exactly how much an object will accelerate for a given net force. If an object has a net force acting on it, it is accelerated in accordance with the equation. Alternatively, if an object is not accelerating, then there is no net force acting on it.

We can state it far more clearly in mathematics. For an object whose mass m is constant, it can be written in the form $F = ma$, where F (force) and a (acceleration) are both vector quantities.

$$a = \frac{\Sigma F}{m}$$

Where a is the acceleration of the object, ΣF is the net force on the object, and m is the mass of the object. Momentum, like velocity, is a vector quantity, having both magnitude and direction. A force applied to an object can change the magnitude of momentum, thw direction, or both. This formula shows that:

1. acceleration is **proportional to** the net force (ΣF), and
2. acceleration is **inversely proportional to** the mass, m.

Note: Newton's second law is often written: $F = ma$. This is the same formula, but with acceleration a isolated (by dividing both sides by mass m), and for convenience, dropping the Σ sign, although it is still implied.

$$F = ma$$

Don't Confuse Mathematical Models with Reality!

Don't confuse mathematical equations with reality! Just as the mathematical equation, $1c = 4l$, *"one cat equals 4 legs"*, does not mean that a cat IS "four legs", the mathematical expression ma IS NOT a force, it is what the net force equals. The two sides of the equation have a mathematical relationship, nothing more.

In other words, if the net force is doubled, the acceleration of the object will be twice as large, and if the mass of the object is doubled, its acceleration will be half as large. The equality symbol implies a relationship; it does NOT mean that each side of the equation are the same thing.

Net Force and Vectors

In mechanics, a force is a push or a pull on an object, and a Net Force (ΣF) is the sum of all forces on an object. Both the *average speed* and the *instantaneous speed* tell us how fast something is going, but they don't tell us which direction. As the ancient Chinese sage noted, *"If we don't watch where we're going, we'll end up where we're headed." Therefore we need to understand vectors.

Any force is made up of two scalar values—one for direction and one for distance. Objects can speed up, slow down, and change direction. We need a more complex mathematical idea to describe such situations. This is where *vectors* come in. **Quantities that have both a magnitude (aize) and a direction are called *vectors*.**

$$Average\ speed = \frac{Distance\ traveled}{Time\ taken} \tag{1}$$

$$Average\ velocity = \frac{Displacement\ (change\ in\ location)}{Time\ taken\ (change\ in\ time)} \tag{2}$$

$$v = \frac{\Delta x}{\Delta t} \tag{3}$$

Where Δ is change, x is position, t is time, and v is velocity.

Displacement is a vector quantity. Its *magnitude* is the straight-line difference between the initial and final locations of an object, and its *direction* is the change from the initial to final locations.

The term "velocity" is a vector combining values for *speed* (the magnitude) and *direction*. When we talk about *instantaneous velocity*, we state the instantaneous speed, such as "15 miles per hour" and add the direction, such as "north", "south", or "30 degrees above the horizontal".

3. The Law of Action and Reaction

When two objects interact,
they apply forces to each other
that are equal in magnitude
and opposite in direction.

This law is important in analyzing problems of static equilibrium, where all forces are balanced, but it also applies to objects in uniform or accelerated motion. The forces it describes are real. For example, a book resting on a table applies a downward force equal to its weight on the table. According to the third law, the table applies an equal and opposite force causing the table to push back at the book.

If an object has a net force acting on it, it undergoes accelerated motion in accordance with the second law. If there is no net force acting on an object, either because there are no forces or because all forces are in balance, the object does not accelerate, and thus is in equilibrium. Alternatively, an object that is not accelerating has no net force acting on it.

Newton's Giants

Newton's laws first appeared in his masterpiece, *Philosophiae Naturalis Principia Mathematica* (1687), commonly known as the *Principia*.

In 1543 Nicolaus Copernicus suggested that the Sun, rather than Earth, might be at the center of the universe. Galileo, Kepler, and Descartes laid the foundations of a new science that would both replace the Aristotelian worldview, inherited from the ancient Greeks, and explain the workings of a heliocentric universe.

In the *Principia*, Newton developed his three laws in order to explain why the orbits of the planets are ellipses rather than perfect circles as had previously been believed. He succeeded in this, but he explained far more. He created the modern world. The series of ideas leading from Copernicus and ending with Newton are known as the Scientific Revolution.

Why Stop There?

In the 20th century Newton's laws were augmented by Quantum Mechanics and the Theory of Relativity. Newton's laws continue to provide an accurate account of nature in all situations, except for sub-atomic particles and objects moving close to the speed of light.

Over time, humanity has learned a little. But with each answered question, many new questions emerge. Why does light have a particular speed? Why does light sometimes act like a particle and sometimes like a wave? What is gravity? How is gravity able to affect objects across empty space? Why is gravity there at all? What is matter? What are black holes? What is time? Is the universe conscious or only made of blind mechanical matter? What is consciousness? What is mind? Most importantly, why 42?