10 Scientific Laws and Theories You Really Should Know

by Jacob Silverman

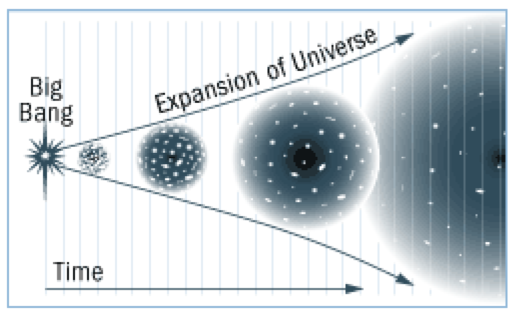
Scientists have many tools available to them when attempting to describe how nature and the universe at large work. Often they reach for laws and theories first. What's the difference? A **scientific law** can often be reduced to a mathematical statement, such as $E = mc^2$; it's a specific statement based on empirical data, and its truth is generally confined to a certain set of conditions. For example, in the case of $E = mc^2$, c refers to the speed of light in a vacuum.

A **scientific theory** often seeks to synthesize a body of evidence or observations of particular phenomena. It's generally -- though by no means always -- a grander, testable statement about how nature operates. You can't necessarily reduce a scientific theory to a pithy statement or equation, but it does represent something fundamental about how nature works.

Both laws and theories depend on basic elements of the scientific method, such as generating a hypothesis, testing that premise, finding (or not finding) empirical evidence and coming up with conclusions. Eventually, other scientists must be able to replicate the results if the experiment is destined to become the basis for a widely accepted law or theory.

In this article, we'll look at 10 scientific laws and theories that you might want to brush up on, even if you don't find yourself, say, operating a scanning electron microscope all that frequently. We'll start off with a bang and move on to the basic laws of the universe, before hitting evolution. Finally, we'll tackle some headier material, delving into the realm of quantum physics.

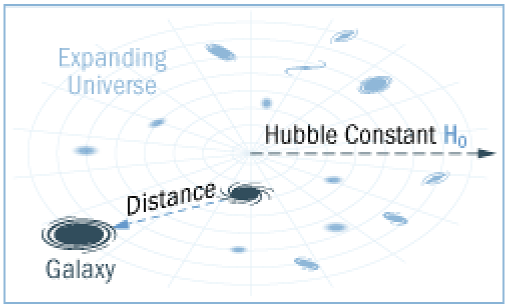
10: Big Bang Theory



If you're going to know one scientific theory, make it the one that explains how the universe arrived at its present state. Based on research performed by Edwin Hubble, Georges Lemaitre and Albert Einstein, among others, the big bang theory postulates that the universe began almost 14 billion years ago with a massive expansion event. At the time, the universe was confined to a single point, encompassing all of the universe's matter. That original movement continues today, as the universe keeps expanding outward.

The theory of the big bang gained widespread support in the scientific community after Arno Penzias and Robert Wilson discovered **cosmic microwave background radiation** in 1965. Using radio telescopes, the two astronomers detected cosmic noise, or static, that didn't dissipate over time. Collaborating with Princeton researcher Robert Dicke, the pair confirmed Dicke's hypothesis that the original big bang left behind low-level radiation detectable throughout the universe.

9: Hubble's Law of Cosmic Expansion



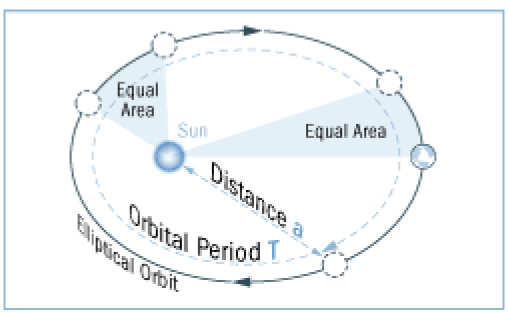
Hubble and his famous law helped to quantify the movement of the universe's galaxies.

Let's stick with Edwin Hubble for a second. While the 1920s roared past and the Great Depression limped by, Hubble was performing groundbreaking astronomical research. Hubble not only proved that there were other galaxies besides the Milky Way, he also discovered that these galaxies were zipping away from our own, a motion he called **recession**.

In order to quantify the velocity of this galactic movement, Hubble proposed **Hubble's Law of Cosmic Expansion**, aka Hubble's law, an equation that states: **velocity = H_0 × distance**. **Velocity** represents the galaxy's recessional velocity; **H_0** is the Hubble constant, or parameter that indicates the rate at which the universe is expanding; and **distance** is the galaxy's distance from the one with which it's being compared.

Hubble's constant has been calculated at different values over time, but the current accepted value is 70 kilometers/second per megaparsec, the latter being a unit of distance in intergalactic space [source: White]. For our purposes, that's not so important. What matters most is that Hubble's law provides a concise method for measuring a galaxy's velocity in relation to our own. And perhaps most significantly, the law established that the universe is made up of many galaxies, whose movements trace back to the big bang.

8: Kepler's Laws of Planetary Motion



Kepler's law of areas

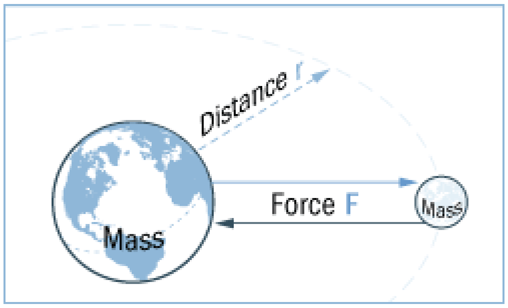
For centuries, scientists battled with one another and with religious leaders about the planets' orbits, especially about whether they orbited our sun. In the 16th century, Copernicus put forth his controversial concept of a heliocentric solar system, in which the planets revolved around the sun -- not the Earth. But it would take Johannes Kepler, building on work performed by Tyco Brahe and others, to establish a clear scientific foundation for the planets' movements.

Kepler's **three laws of planetary motion** -- formed in the early 17th century -- describe how planets orbit the sun. The first law, sometimes called the **law of orbits**, states that planets orbit the sun elliptically. The second law, the **law of areas**, states that a line connecting a planet to the sun covers an equal area over equal periods of time. In other words, if you're measuring the area created by drawing a line from the Earth to the sun and tracking the Earth's movement over 30 days, the area will be the same no matter where the Earth is in its orbit when measurements begin.

The third one, the **law of periods**, allows us to establish a clear relationship between a planet's orbital period and its distance from the sun. Thanks to this law, we know that a planet relatively close to the sun, like Venus, has a far briefer orbital period than a distant planet, such as Neptune.

7: Universal Law of Gravitation (Law of Gravity)

Thanks to Newton's universal law, we can figure out the gravitational force between any two objects.



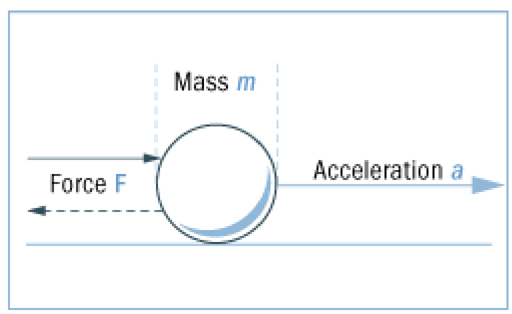
We may take it for granted now, but more than 300 years ago Sir Isaac Newton proposed a revolutionary idea: that any two objects, no matter their mass, exert gravitational force toward one another. This law is represented by an equation that many high schoolers encounter in physics class. It goes as follows:

$$\mathbf{F = G \times [(m_1 m_2)/r^2]}$$

F is the gravitational force between the two objects, measured in Newtons. $\mathbf{M_1}$ and $\mathbf{m_2}$ are the masses of the two objects, while **r** is the distance between them. **G** is the gravitational constant, a number currently calculated to be 6.672×10^{-11} N m² kg^{-2} [source: Weisstein].

The benefit of the universal law of gravitation is that it allows us to calculate the gravitational pull between any two objects. This ability is especially useful when scientists are, say, planning to put a satellite in orbit or charting the course of the moon.

6: Newton's Laws of Motion



Newton's second law of motion

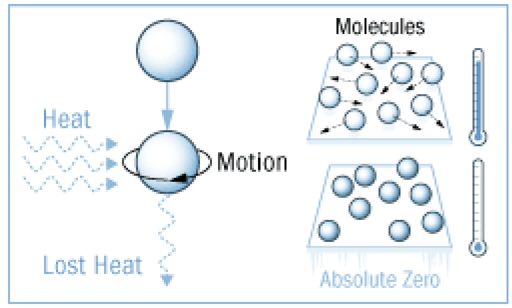
As long as we're talking about one of the greatest scientists who ever lived, let's move on to Newton's other famous laws. His three laws of motion form an essential component of modern physics. And like many scientific laws, they're rather elegant in their simplicity.

The first of the three laws states an object in motion stays in motion unless acted upon by an outside force. For a ball rolling across the floor, that outside force could be the friction between the ball and the floor, or it could be the toddler that kicks the ball in another direction.

The second law establishes a connection between an object's mass (**m**) and its acceleration (**a**), in the form of the equation $\mathbf{F = m \times a}$. **F** represents force, measured in Newtons. It's also a vector, meaning it has a directional component. Owing to its acceleration, that ball rolling across the floor has a particular **vector**, a direction in which it's traveling, and it's accounted for in calculating its force.

The third law is rather pithy and should be familiar to you: For every action there is an equal and opposite reaction. That is, for every force applied to an object or surface, that object pushes back with equal force.

5: Laws of Thermodynamics



The British physicist and novelist C.P. Snow once said that a nonscientist who didn't know the second law of thermodynamics was like a scientist who had never read Shakespeare [source:Lambert]. Snow's now-famous statement was meant to emphasize both the importance of thermodynamics and the necessity for nonscientists to learn about it.

Thermodynamics is the study of how energy works in a system, whether it's an engine or the Earth's core. It can be reduced to several basic laws, which Snow cleverly summed up as follows [source: Physics Planet]:

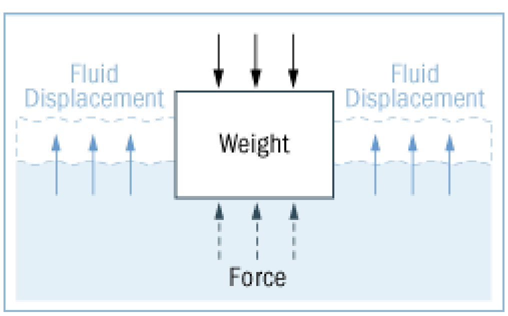
- You can't win.
- You can't break even.
- You can't quit the game.

Let's unpack these a bit. By saying you can't win, Snow meant that since matter and energy are conserved, you can't get one without giving up some of the other (i.e., $E=mc^2$). It also means that for an engine to produce work, you have to supply heat, although in anything other than a perfectly closed system, some heat is inevitably lost to the outside world, which then leads to the second law.

The second statement -- you can't break even -- means that due to ever-increasing entropy, you can't return to the same energy state. Energy concentrated in one place will always flow to places of lower concentration.

Finally, the third law -- you can't quit the game -- refers to absolute zero, the lowest theoretical temperature possible, measured at zero Kelvin or (minus 273.15 degrees Celsius and minus 459.67 degrees Fahrenheit). When a system reaches absolute zero, molecules stop all movement, meaning that there is no kinetic energy, and entropy reaches its lowest possible value. But in the real world, even in the recesses of space, reaching absolutely zero is impossible -- you can only get very close to it.

4: Archimedes' Buoyancy Principle (Law)

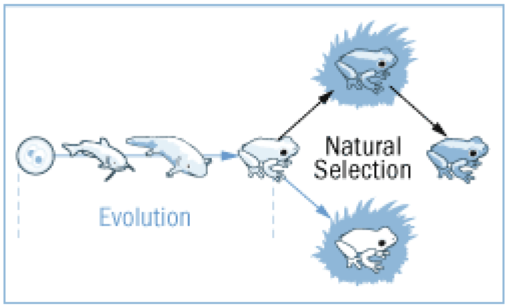


Buoyancy keeps everything from rubber ducks to ocean liners afloat.

After he discovered his principle of buoyancy, the ancient Greek scholar Archimedes allegedly yelled out "Eureka!" and ran naked through the city of Syracuse. The discovery was that important. The story goes that Archimedes made his great breakthrough when he noticed the water rise as he got into the tub [source: Quake].

According to **Archimedes' buoyancy principle**, the force acting on, or buoying, a submerged or partially submerged object equals the weight of the liquid that the object displaces. This sort of principle has an immense range of applications and is essential to calculations of density, as well as designing submarines and other oceangoing vessels.

3: Evolution and Natural Selection (Theory)



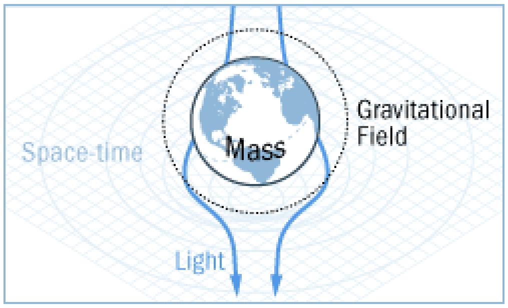
A hypothetical (and simplified) example of how natural selection might play out amongst frogs

Now that we've established some of the fundamental concepts of how our universe began and how physics play out in our daily lives, let's turn our attention to the human form and how we got to be the way we are. According to most scientists, all life on Earth has a common ancestor. But in order to produce the immense amount of difference among all living organisms, certain ones had to evolve into distinct species.

In a basic sense, this differentiation occurred through evolution, through descent with modification [source: UCMP]. Populations of organisms developed different traits, through mechanisms such as mutation. Those with traits that were more beneficial to survival such as, a frog whose brown coloring allows it to be camouflaged in a swamp, were naturally selected for survival; hence the term **natural selection**.

It's possible to expand upon both of these theories at greater length, but this is the basic, and groundbreaking, discovery that Darwin made in the 19th century: that evolution through natural selection accounts for the tremendous diversity of life on Earth.

2: Theory of General Relativity



Einstein's theory of general relativity changed our understanding of the universe.

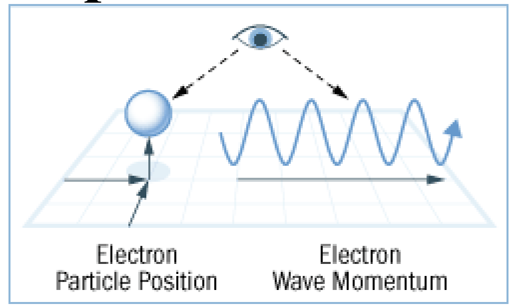
Albert Einstein’s **theory of general relativity** remains an important and essential discovery because it permanently altered how we look at the universe. Einstein's major breakthrough was to say that space and time are not absolutes and that gravity is not simply a force applied to an object or mass. Rather, the gravity associated with any mass curves the very space and time (often called space-time) around it.

To conceptualize this, imagine you're traveling across the Earth in a straight line, heading east. After a while, if someone were to pinpoint your position on a map, you'd actually be both east and far south of your original position. That's because the Earth is curved. To travel directly east, you'd have to take into account the shape of the Earth and angle yourself slightly north. (Think about the difference between a flat paper map and a spherical globe.)

Space is pretty much the same. For example, to the occupants of the shuttle orbiting the Earth, it can look like they're traveling on a straight line through space. In reality, the space-time around them is being curved by the Earth's gravity (as it would be with any large object with immense gravity such as a planet or a black hole), causing them to both move forward and to appear to orbit the Earth.

Einstein's theory had tremendous implications for the future of astrophysics and cosmology. It explained a minor, unexpected anomaly in Mercury's orbit, showed how starlight bends and laid the theoretical foundations for black holes.

1: Heisenberg's Uncertainty Principle



Is it a particle, a wave or both?

Einstein's broader theory of relativity told us more about how the universe works and helped to lay the foundation for quantum physics, but it also introduced more confusion into theoretical science. In 1927, this sense that the universe's laws were, in some contexts, flexible, led to a groundbreaking discovery by the German scientist Werner Heisenberg.

In postulating his **Uncertainty Principle**, Heisenberg realized that it was impossible to simultaneously know, with a high level of precision, two properties of a particle. In other words, you can know the position of an electron with a high degree of certainty, but not its momentum and vice versa.

Niels Bohr later made a discovery that helps to explain Heisenberg's principle. Bohr found that an electron has the qualities of both a particle and a wave, a concept known as **wave-particle duality**, which has become a cornerstone of quantum physics. So when we measure an electron's position, we are treating it as a particle at a specific point in space, with an uncertain wavelength. When we measure its momentum, we are treating it as a wave, meaning we can know the amplitude of its wavelength but not its location.

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