Q: What Is the Controlling Force in the Universe?

By Bill Robertson

A: I asked a friend, and his immediate response was, "Your spouse." I've also heard that love makes the world go 'round. And if you happen to be a Jedi, then the controlling force is, well, the Force. But we're looking for a more scientific answer. To get there, let's look at the four known forces in the universe.

For the first force, ask yourself the following question: If the nucleus of an atom is made of positively charged protons and neutrons with zero charge, how come atomic nuclei don't just break apart from the electric repulsion of all those protons? The answer is that there is something known as the *strong nuclear force* that holds the nucleus together. The strong force, which is attractive, is much stronger than electric forces. It's an extremely short-range force, though, so it doesn't extend beyond the size of a nucleus. If the strong force were a long-range force, then everything would slam into everything else in short order. Now, you might be tempted to say that a force that holds nuclei together is the controlling force in the universe, and you would have a decent case for saying that, but I'm going to focus more on what governs interactions between all the planets, stars, and galaxies in the universe.

ART BY BRIAN DISKIN

Since we're ignoring short-range forces, we can also dispense with another force you possibly haven't heard of—the *weak force*, also known as the *weak nuclear force*. This is a force involved in radioactive decay and, like the strong nuclear force, is quite limited in its range. The weak force isn't the same as the strong force, though. It's a force that occurs between very tiny things such as electrons and *neutrinos* (another subatomic particle), and it's also responsible for protons turning into neutrons (yep, that actually happens).

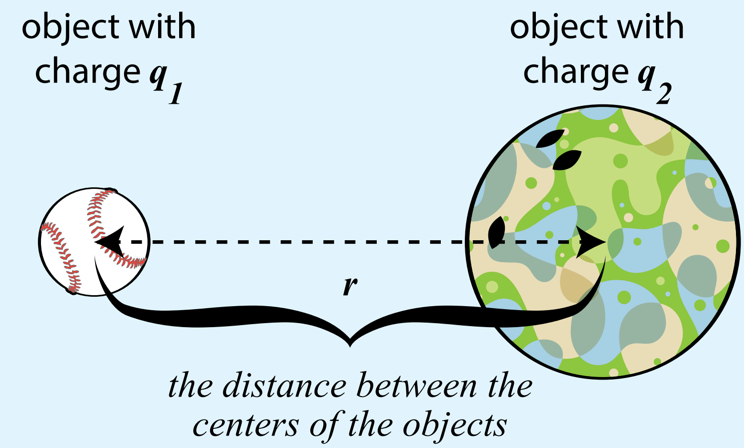
Now we're on to the third force, one with which you are quite familiar. If you aren't familiar with this force, shuffle your feet along a carpet and then touch your finger to something metal. Hurts a bit, yes? This is the force between charged objects, otherwise known as the *Coulomb force* or *electrostatic force*. Sometime in your past, you have probably encountered the following mathematical expression, which gives us the electrostatic force acting between two charged objects. It technically works only for spherical objects, but no need to worry about that now. Figure 1 provides a general illustration of electrostatic forces.

Using just variables, that relationship looks like

$$F = \frac{kq_1q_2}{r^2}$$

Focus on the denominator in that expression. It's the square of the distance between the centers of the two objects. As the objects get farther and farther apart, the electric force between them gets weaker, but it never goes to zero (except at infinite separation). That means that any two charged objects in the universe, no matter how far apart they are, will exert a force on each other. Therefore, this force extends across the entire universe. That makes it a candidate for the controlling force in the universe. Now think about what happens when there's an excess charge on something. When you shuffle your feet on a carpet, you pick up an excess negative charge. But as soon as you touch a drinking fountain or anything else that's metal, you get a shock and you no longer have an excess charge. In fact, if you just stand in place, your excess charge will go away as your body is in contact with water vapor in the air, which conducts the excess charge off your body. With human bodies, or charged-up balloons, or charged-up anything, any excess charge in one place quickly becomes neutralized by charges in other places. So, even though electric forces are quite strong, the quick rearrangement of charges makes those forces not stick around very long. As a result, there isn't an electric attraction or repulsion between different planets, different stars, and different galaxies.

FIGURE 1.



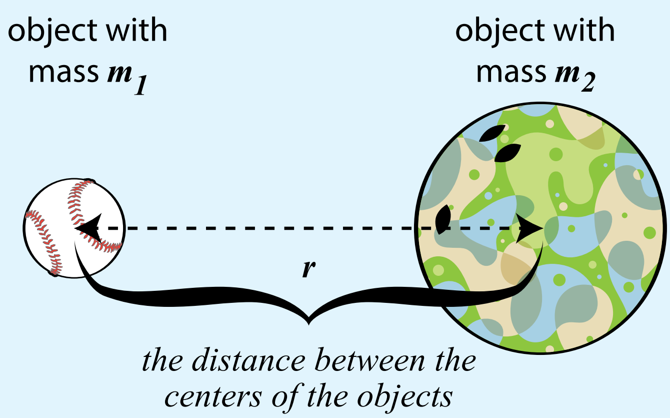
Electrical force is proportional to the charge on each object and inversely proportional to the square of the distance between their centers.

$$\text{Electrostatic force between objects} = \frac{\text{(a constant number)(charge on one object)(charge on second object)}}{\text{(distance between centers of objects)}^2}$$

Before getting on to my candidate for the controlling force in the universe, I should mention magnetic forces. Scientists consider magnetic forces as being lumped in with electric forces, so the proper term for this kind of force is the *electromagnetic force*. Magnetic forces in a sense have a built-in neutralization process, because it's impossible to isolate magnetic "charges" (we don't refer to them as charges because they aren't charges, but rather north and south poles). You can't isolate the north pole of a magnet from the south pole of the magnet—they always come in pairs. If you don't believe that, then cut a magnet in half and notice that the two halves still have both a south and a north pole. The fact that magnetic poles always occur in pairs means that magnetic forces, while having a longer range than strong or weak nuclear forces, do not extend across the universe. And as long as I'm clarifying electric and magnetic forces, I should let you know that physicists have developed a theory that unifies the weak and electromagnetic forces into one model, though scientists still speak of there being four different kinds of forces.

So, now we come to the gravitational force, which clearly is going to be the answer to the question I've

FIGURE 2.



Gravitational force is directly proprotional to the mass of each object and is inversely proportional to the square of the distance between their centers.

$$\text{Gravitational force between objects} = \frac{\text{(a number)(mass of one object)(mass of second object)}}{\text{(distance between centers of objects)}^2}$$

raised. Figure 2 illustrates this force. The expression for the strength of the gravitational force (which technically applies only to spherical objects) is shown in Figure 2.

Using just variables, the expression is

$$F = \frac{Gm_1m_2}{r^2}$$

Look familiar? Though the quantities are different, this is exactly the same formula as for an electric force. That r in the denominator means the force never goes to zero, except at infinite separation.

At this point, you might expect that we could make the same argument that we did with electric forces—that although the force extends across the universe, things tend to neutralize. But that's not true. There are positive and negative charges in electric forces, but mass doesn't come in positives and negatives. Mass is mass, and when you bring two masses together, they don't become neutral overall. What that means is that even the most distantly separated objects in the universe exert a gravitational force on each other.

Compared to the other three kinds of forces, the force of gravity is extremely weak. It's about 10^{32} (that's a 1 followed by 32 zeroes) times weaker than the weak nuclear force, about 10^{37} times weaker than the electromagnetic force, and about 10^{39} times weaker than the strong nuclear force. Although all objects with mass have a gravitational attraction for all other objects with mass, the force is so weak that we generally don't notice it. Your cup of coffee is attracting you (and not just with its aroma), but the cup doesn't go flying toward you, nor does it cause you to fall over when you walk past it. The Earth's gravitational force attracts you (this is a good thing). You notice that because the mass of the Earth is so large and you're so close to it. The Sun has a much larger mass than the Earth, but it doesn't have much effect on you because it's so far away.

So, gravity is the controlling force in the universe not because it's so strong, but because it's the only force that acts over very long distances and doesn't get neutralized. The formation of galaxies, the formation of stars, the formation of planets, plus just about all the large-scale motion in the universe, are all governed by the force of gravity.

I'd like to end with a quick discussion of the scientific discipline of astrology. I call it a scientific discipline because I came across a Pew Research quiz of scientific literacy, and one of the questions had to do with astrology. If they say it's a scientific discipline, then it must be one. Okay, no, it's not a scientific discipline. Silly that people offering up a scientific literacy quiz would include that topic, no? Just for kicks, though, take a look at what astrologists tell us—that the positions of the planets and stars can affect our lives. I'll leave it to you as a homework exercise to calculate the gravitational force exerted on you by the planet Jupiter, and compare that to the gravitational force exerted on you by various food items in your refrigerator. Guess which one exerts a stronger gravitational force! So, unless there's some unknown force besides gravity that planets and stars exert on us, astrology is, well, astrology. Einstein had a quote that seems appropriate: "Falling in love is not at all the most stupid thing people do, but gravitation cannot be held responsible for it." ■

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Science 102

Exercises to challenge content knowledge

This Month's Question

On dry days, static charge buildup can cause you to get shocks when touching metal surfaces. It happens to me all the time when I'm at the store, and the shopping cart manages to get charged up. It's also common to get a shock when touching a metal drinking fountain when you're on a carpeted surface. Try the following ways of avoiding such shocks. One is to touch the metal surface with the back of your hand instead of the tip of your finger. You'll still get a minor shock but not much. Another way is to hold car keys in your hand and touch the surface with the keys before touching it with your finger. Do that, and you don't get a shock at all. Why do these two shock-avoidance methods work?

Find the answer here next month. Or, go to the digital version of *S&C* to read the answer now. If you do not already receive a digital edition, find it at *www.nsta.org/publications/digital.journals.aspx*.

A Coffee Conundrum

Last month, we asked you about the changes in pitch you experience when tapping a coffee cup. Vibrating objects produce sounds. A vibrating guitar string, a vibrating column of air (as in a flute), and a vibrating speaker all produce sounds. How fast something vibrates determines the pitch of the sound. A high frequency (faster vibrations) produces a high pitch, and a low frequency (slower vibration) produces a low pitch.

When you hit the side of an empty coffee cup, the coffee cup vibrates and produces a sound. When you hit the side of a coffee cup containing liquid, the cup plus liquid vibrate, producing a sound. How fast the cup plus liquid vibrates, and thus the pitch produced, depends on how easy it is for the cup plus liquid to vibrate. A "sluggish" cup plus liquid will vibrate relatively slowly and produce a low pitch, and a "less sluggish" cup plus liquid will vibrate relatively fast and produce a high pitch. When you stir hot chocolate or creamer into a liquid, the powder helps trap air bubbles in the liquid. Air bubbles make the liquid more sluggish with respect to transmitting sound waves (this is because air is easily compressed, while liquids aren't), which makes for a lower pitch when you tap on the side of the cup. After you stop stirring, the air bubbles gradually escape from the liquid. This makes the liquid less sluggish with respect to transmitting sound waves, and results in a higher pitch. Stirring things up again starts the process over.

You can find various explanations of the "hot chocolate effect" on the internet. Most of them refer to changes in the speed of sound in the liquid. Though they might seem different from my explanation, they really aren't. They're just more mathematical (using the relationship between speed, frequency, and wavelength) in nature.