Cosmic Chemistry: Cosmogony

Quarks—Getting Down to Fundamentals

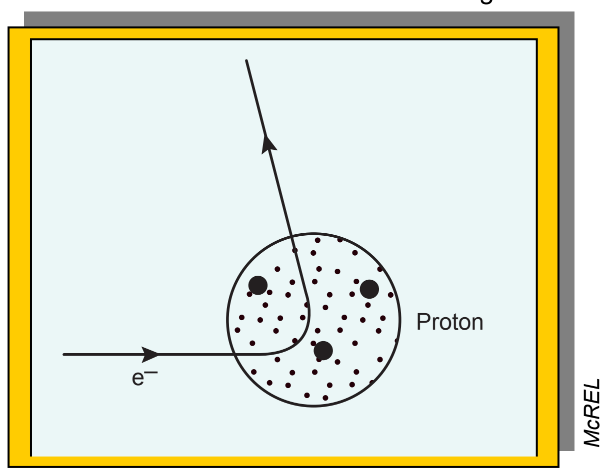
STUDENT TEXT

FUNDAMENTAL PARTICLES

In the activity, "Getting Down to Fundamentals," you modeled the formation of protons and neutrons—nucleons that have net charges of +1 and 0, respectively. Protons and neutrons are called nucleons because they make up the nuclei of atoms.

Forty years ago, protons and neutrons were thought to be **fundamental particles** like electrons. In other words, it was thought that they could not be divided into smaller particles. In the 1960s, physicists working at the Stanford Linear Accelerator Center found that electrons traveling near the speed of light sometimes changed their direction abruptly, losing much of their energy, when they collided with matter. It was as though they were encountering small, but very hard pieces of matter, on their voyage through nucleons. These results (see Figure 1) were similar to Rutherford's experiment using alpha particles showing that atoms were mostly empty space. In this case, observations indicated that protons and neutrons are composed of smaller particles.

Figure 1



An energetic electron (e⁻) is deflected by an electrically charged object in a proton.

Just as you modeled in the activity, protons and neutrons are each made of three quarks. A proton consists of two "up" quarks and one "down" quark, whereas a neutron contains two" down" and one "up." "Up" and "down" are two **"flavors,"** or varieties, of quarks. There are four other "flavors," but they have not been found to form stable matter.

Why are there three quarks in each nucleon?

You have learned that there are two kinds of electric charge—positive and negative—and that like-charged objects repel each other while unlike-charged objects attract. So, a proton with a +1 charge and an electron with a -1 charge can form a stable hydrogen atom.

Quarks possess a characteristic not found in any other type of particle. Each "flavor" of quark is able to carry **three** different types of charges—red, green, and blue **"color" charges**. Quarks of the same "color" repel each other because they have similar forces. And, like trying to balance a three-legged stool on two legs, no two quarks can form a particle because their "color" forces would not be balanced. So it takes one red, one blue, and one green quark to form an object that is stable. These stable particles are said to be "color-neutral" or "white."

Although you used colored rectangles in the activity, the "color" property of quarks is **totally different** from what we usually think of as color because quarks are much smaller than the wavelength of visible light. They do not have any "color" in the normal sense. However, when you combine red, blue, and green light, you get white light. Do you think that maybe this is the reason that scientists used "color" to describe this tripartite quark property?

"Color" charges are also independent of electric charge, as you saw when you were completing the activity. Even a quark's **electric charge** is different from most charges we are familiar with. They are not only positive and negative, but they are also **fractions**, rather than whole numbers. An "up" quark has a charge of +2/3 and a "down" quark a charge of –1/3, in units of electric elementary charge. The charges of protons and neutrons are the sums of their quark charges, just as you calculated in the activity:

a proton charge = up + up + down 2(2/3) + (-1/3), = + 4/3 + (-1/3) = +3/3 = +1

a neutron charge = up + down + down 2(1/3) + 2/3 = -2/3 + 2/3 = 0

Quarks are held to one another by **gluons**, sometimes called the "glue that holds the world together." Just as photons are the carriers of the electromagnetic force, gluons are carriers of the **strong nuclear force**, which is also called a "chromoelectric" force because gluons also have red, blue, or green "color." These "colors" are actually qualities of different gluon particles that make a stable particle. So the gluons in a stable particle must also have colors that add up to "white."

Quarks attract one another with a force that actually becomes stronger the farther the quarks are apart, as if each were joined to its neighbors by means of an unbreakable elastic thread. When quarks are closely packed, they behave *as if* they were free—almost as if they were content that others of their kind were nearby. Yet if any attempt is made to separate them, the quarks immediately counter this by pulling each other more and more powerfully together. Scientists think that this strong nuclear force is the reason that quarks do not exist as free, directly observable particles.

This strong nuclear force acts only through very small distances, like 10^{-13} to 10^{-12} cm, and it does **not** diminish when the distance between the quarks increases. In fact, there is some evidence that it tends to increase with small increases in distance and then it remains constant.

This strong force acts not only between quarks, but also between two or more protons, between two or more neutrons or between neutrons and protons. In other words, the strong nuclear force not only binds quarks into protons and neutrons, but it also holds protons and neutrons tightly together to form the nuclei of atoms. This force is not applicable to electrons.

Why are quarks significant in cosmogony?

At this point you might be asking, "Why are we focusing on these tiny quarks in the study of the origin of the universe?" The reason for this is that quarks and electrons may have been among the first stable particles formed in the early universe. The quarks and electrons that were present in the infant universe could possibly be the same **fundamental particles** that make up the atoms of all matter that we observe today—all matter on Earth, in our solar system, in the Milky Way, and in all the galaxies of the universe. By the way, that includes the matter in you! A 165-pound person is made of 7.0×10^{28} "up" quarks, 6.5×10^{28} "down" quarks, and 2.5×10^{28} electrons.