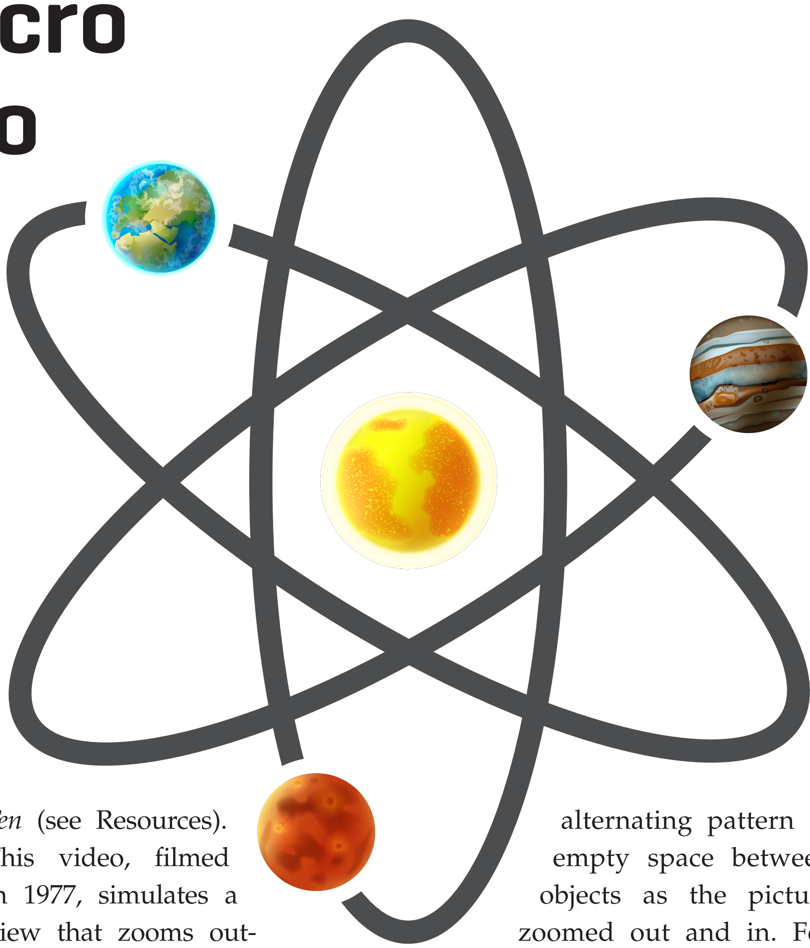
The universe, from micro to macro

BY BOB RIDDLE



For years scientists and theorists encountered a problem—eventually solved by technological improvements—with a subatomic particle known as a *neutrino*. Some middle school students may have trouble understanding subatomic particles and neutrinos, but the topic is suitable for more advanced students. Before students can delve into the neutrino problem, however, they need to take a look at the universe from micro and macro perspectives.

First, the teacher should provide some context of neutrinos with a class discussion of subatomic particles and the energy-producing processes within the Sun and other stars. Then, ask students to name the biggest thing they have ever touched. After reaching the consensus that our planet Earth is the largest thing anyone has touched, discuss the sizes of solar system objects, from micro to macro, and list the largest and smallest objects we are able to see or detect within the universe.

To help visualize these objects, show students the video *Powers of Ten* (see Resources). This video, filmed in 1977, simulates a view that zooms outward to what at the time was the limit of the observable universe, a distance of about 10^24 meters, (100 million light years). The video then zooms down to the subatomic scale, stopping at the edge of the known observable subatomic universe (0.00001 Angstrom; 10^-15 meters), where "quarks" may exist. A quark is an elementary particle that forms protons and neutrons when combined with different types of quarks.

After watching the *Powers of Ten*, students can consider the alternating pattern of empty space between objects as the picture zoomed out and in. For example, space is relatively crowded within the solar system, but beyond the solar system, there is a lot of seemingly empty space between objects in the galaxy. Similarly, there is a lot of empty space within an atom. One scale model of an atom has protons and neutrons with 1 cm diameters. At that scale, the atom, including the space to the outermost electrons, would have a diameter of more than 3.2 km (2 mi.), and more than 99% of that volume would be empty space.

FIGURE 1: Poem by Ralph Waldo Emerson

Atom from atom yawns as far
As Moon from Earth, or star to star.

Next, read a two-line poem by Ralph Waldo Emerson (see Figure 1) from his series of short poems *Fragments of Nature* (Emerson 1904) and then discuss the relative distances in the macro and micro universe with.

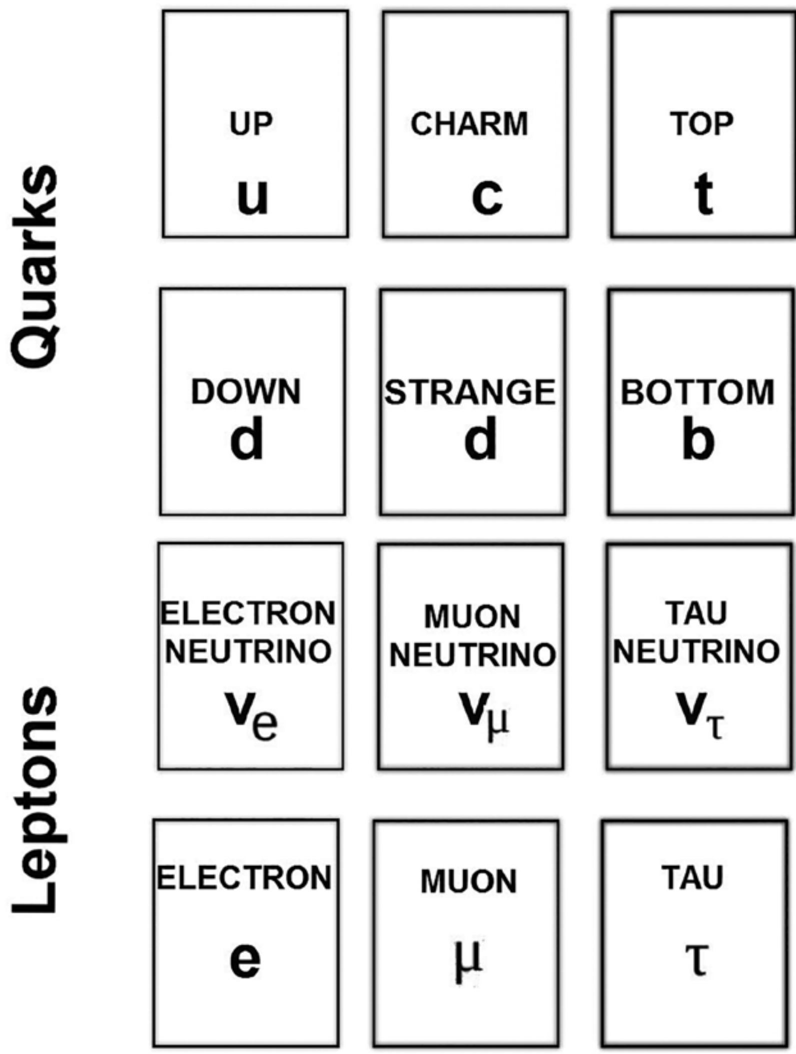
Atoms make up everything

Our universe contains myriad objects of all shapes, sizes, compositions, and even states of matter. Most students have already learned that matter is composed of tiny particles called *atoms*, which are composed of even smaller particles known as *protons*, *neutrons*, and *electrons*. There are at least 12 smaller elementary particles called quarks and leptons. Elementary particles are considered to be the smallest indivisible building blocks of matter. Protons and neutrons are each made of three different types of quarks while electrons, also an elementary particle, are a type of lepton. *Leptons*, like quarks, are an elementary particle of which matter is made. There are six types of leptons, including the electron.

Figure 2 depicts the *Standard Model*, a table-like display of the 12 known elementary particles, known as the building blocks of all matter. According to a theory by particle physicists, the arrangement of particles also explains how the four fundamental forces (gravity, electromagnetic, strong nuclear, and weak nuclear) control the interaction of all matter. Gravity is more involved with the macro universe. The other three forces are more involved at the micro level. *Electromagnetism* holds electrons in their orbits around the nucleus of an atom. A strong nuclear force holds the protons and neutrons together. A weak nuclear force is involved with radioactive decay and nuclear fission.

For the sake of simplicity, Fig-

FIGURE 2: Simplified "Standard Model" of Leptons and Quarks



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ure 2 is an incomplete drawing. There are actually two additional columns to the right containing recently discovered elementary particles called bosons, of which there are five types of bosons, including the recently discovered Higgs boson. A boson's interactions and properties make up the mass of the elementary particles.

It is theorized that the entire universe is within the Higgs field, where all the matter in the universe interacts with specific bosons depending on the form of matter. For example, the photon is considered to be the boson that transmits electromagnetic radiation across the Higgs field. According to theories dealing with bosons, matter has no mass in itself. Instead, the Higgs boson interacting with the Higgs field gives matter mass. Verifying the existence of the bosons, including the Higgs boson, was an impor-

April

- 1 Waxing crescent Moon near Aldebaran
  Mercury at greatest eastern elongation
- 3 First quarter Moon
- 5 Moon near Beehive Cluster
- 6 Moon near Regulus
  Cassini spacecraft flyby of Titan
- 7 Moon at ascending node
  Jupiter at opposition
- 10 Moon near Jupiter
- 11 Full Moon
- 12 Yuri's Night
- 14 Uranus in conjunction with Sun
- 15 Moon at apogee: 405,478 km (251,952 mi.)
- 16 Moon near Saturn
- 19 Last quarter Moon
- 20 Mercury at inferior conjunction
- 21 Mars near the Pleiades
  Moon at descending node
- 22 Earth Day
  Cassini spacecraft flyby of Titan
  Lyrid meteor shower
- 23 Moon near Venus
- 24 Astronomy Week
- 26 New Moon
- 27 Moon at perigee: 359,325 km (223,274 mi.)
- 28 Moon near Aldebaran
- 29 Astronomy Day

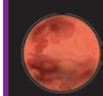
May

- 2 Moon near Beehive Cluster
  First quarter Moon
- 4 Moon near Regulus
  Moon at ascending node
  Eta-Aquarid meteor shower
- 5 National Astronauts Day
  Space Day
  Mars' spring equinox
  Mars near Aldebaran
- 7 Moon near Jupiter
  Cassini spacecraft flyby of Titan
- 10 Full Moon
- 12 Moon at apogee: 406,212 km (252,408 mi.)
- 13 Moon near Saturn
- 17 Mercury at greatest western elongation
- 18 Last quarter Moon
  Moon at descending node
- 22 Moon near Venus
- 23 Moon near Mercury
- 24 *Cassini* spacecraft flyby of Titan
- 25 New Moon
  Moon at perigee: 357,210 km (221,960 mi.)
- 29 Moon near Beehive Cluster
- 31 Moon at ascending node
  Moon near Regulus

Visible planets

Mercury will be visible but low over the western horizon at sunset for the first half of April before moving into inferior conjunction at month's end and will reappear in the morning skies of May.

Venus will be very visible over the eastern horizon at sunrise.



Mars will be visible but low over the western horizon at sunset.

Jupiter will rise around sunset local time and will be over the western horizon at sunrise.

Saturn will rise around midnight local time and will be over the southern horizon at sunrise.

tant milestone in understanding and explaining the interactions of subatomic particles.

Most substances have some amount of mass, and most students probably understand mass as how much matter is in an object. However, it is now believed that the bosons give subatomic particles their mass and the mass that, for example, makes up this journal. The fundamental force determines how bosons interact with other elementary particles. The interactions determine the properties and interactions on the macro scale, of which we are a part. Scientists are able to predict or explain so much of the known universe that the Standard Model, while far from complete, is sometimes referred to as the Theory of Everything.

The neutrino problem

Among the names of the table in Figure 2 are three types of neutrinos, which are produced under extreme situations, such as the fusion reactions in the core of a star or the energy produced during a supernova event. Neutrinos, considered to have little to no mass, move at the speed of light. They stream outward from the Sun and constantly pass through everyone and everything on Earth.

So where do neutrinos come from? In the core of Sun, for example, hydrogen atoms, under tremendous pressure and temperature, are stripped of their single electron, leaving behind the nucleus and one proton. This is the process of *nuclear fusion*, when matter compresses until it fuses together and becomes a different form of matter. This is an ongoing process in the core of the Sun where four hydrogen nuclei (four protons) are fused together to produce the nucleus of a helium atom (two protons, two neutrons) and additional subatomic particles, including two electron neutrinos. Perhaps most importantly, the mass of the four hydrogen nuclei when fused is more than the combined mass of the helium nuclei and other subatomic particles. The difference between the two masses is released in the form of the sunlight we receive on Earth, as well as many other forms of electromagnetic radiation. With that solar energy is a stream of neutrinos.

During the 1960s, scientists developed equipment and techniques for detecting and counting neutrinos. Considering the speed and little to no mass of the objects that basically do not interact with any other matter, detecting neutrinos would prove to be a daunting task. Over time, different types of neutrino detectors were built to minimize the interaction with other particles, so that a neutrino interaction could be detected.

A *neutrino detector* consists of a tank that is filled with water, chlo-

For students

1. The neutrino problem is a good example of how theory becomes reality through the processes used by scientists and theoreticians, all of which, in this case, led to a Nobel Prize. See "Solving the Mystery of the Missing Neutrinos" in Resources for a link to this story, as told by John N. Bahcall, one of the scientists involved from the beginning.
2. Detect radiation with a cloud chamber. Most radiation reaching the Earth's surface is measurable with a variety of detectors. Teachers and students can research cloud chambers. An internet search will bring up a variety of cloud chamber kits, or you can build your own cloud chamber (see Resources). *Safety note*: Cloud chambers often involve handling dry ice.
3. Radon gas is a single-atom gas produced by the radioactive decay of uranium. According to the Environmental Protection Agency (see "Radon" in Resources), there are locations around the United States where radon gas is in high enough concentrations to be a health issue. Radon is detected with the use of test kits or detectors. In class, research radon gas, the detection methods, and where radon gas has been determined to be a local health issue.

rine, the element gallium, or other liquids and is encased within a larger tank that is often filled with water. The entire setup is located below the Earth's surface, usually in an abandoned mine shaft. The Earth itself and the outer tank filter much of the incoming forms of radiation so that mostly neutrinos make it through to the inner tank. But how could neutrinos be detected if, by chance, there is an occasional interaction?

Neutrino interactions, or collisions with other charged atomic particles in the solution, produce thousands of light-sensitive photoelectric cells that line the inner tank waiting to catch a flash of light, known as Cherenkov Radiation or Cherenkov Light. Neutrinos have no electrical charge, but when they collide with a charged particle in the solution, such as a negatively charged electron, the charged particle emits the Cherenkov Light (see Super-Kamiokande in Resources). Cherenkov Light is the electromagnetic radiation released by a neutrino, if it is faster through the fluid in the tank than the speed of light.

According to theoretical models, the fusion process should produce a certain amount of neutrinos. Here's the neutrino problem: Scientists were only able to measure between one-third and one-half of the electron neutrinos that the models predicted. Scientists thought that the problem of detecting fewer neutrinos stemmed from:

- a result of the equipment and techniques used,
- theoretical models that needed revisions, or
- something that happens to the neutrinos between the time when they leave the Sun and when they arrive on Earth.

It turns out that the neutrino produced during fusion in the Sun changes to another type of neutrino, either the Muon neutrino or the Tau neutrino, and went undetected. By realizing this and making adjustments to the detection techniques, the theoretical model predictions were matched by detecting and recognizing all of the neutrinos reaching the Earth, thus solving the neutrino problem. ●

REFERENCE

Emerson, R.W. 1904. *The poems of Ralph Waldo Emerson, with notes by Edward Waldo Emerson*. Boston and New York: Houghton, Mifflin and Company.

RESOURCES

Aunt Nan's Missing Star—*www.currentsky.com/articles/nan/index.html*

Astronomy Day—*www.astroleague.org/al/astroday/astrodayform.html*

Astronomy Week—*www.astroleague.org/al/astroday/astroday.html*

Cassini Mission to Saturn—*http://saturn.jpl.nasa.gov*

Earth Day—*www.earthday.org*

How to Make A Cloud Chamber—*www.sciencefriday.com/educational-resources/build-a-cloud-chamber*

International Cosmic Day—*http://icd.desy.de*

International Dark Sky Association—*www.darksky.org*

Jefferson Lab—*www.jlab.org*

Jefferson Lab Coloring Book—*http://education.jlab.org/coloringbook*

Mars Spring Equinox—*www.planetary.org/explore/space-topics/mars/mars-calendar.html*

National Astronaut Day—*http://nationalastronautday.uniphigood.com*

Observing at Night and in the Day—*http://nightsky.jpl.nasa.gov/download-view.cfm?Doc_ID=302*

Particle Adventure—*www.particleadventure.org/index.html*

Powers of Ten—*https://youtu.be/5CKd0aPSWe8*

Quarked—*www.quarked.org*

Radon—*www.epa.gov/radon*

Scale of the Universe—*www.htwins.net/scale2*

Solving the Mystery of the Missing Neutrinos—*www.nobelprize.org/nobel_prizes/themes/physics/bahcall*

Space Day—*www.nationaldaycalendar.com/days-2/national-space-day-first-friday-in-may*

Strange Neutrinos Detected from the Sun—*www.scientificamerican.com/article/solar-neutrinos-detected-borexino*

Sun-Earth Day—*http://sunearthday.nasa.gov/discoveries/multimedia/nasaedge.php*

Super-Kamiokande—*www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html*

Yuri's Night—www.yurisnight.net

Bob Riddle (*bob-riddle@currentsky.com*) is a science educator in Lee's Summit, Missouri. Visit his astronomy website at *www.bobs-spaces.net*.