Cosmic Chemistry: Cosmogony

Quarks—Getting Down to Fundamentals

TEACHER GUIDE

BACKGROUND INFORMATION

To prepare for teaching this activity, read (or re-read) "The Universe is Expanding" and "Remnants of the Big Bang" in Appendix A of this module.

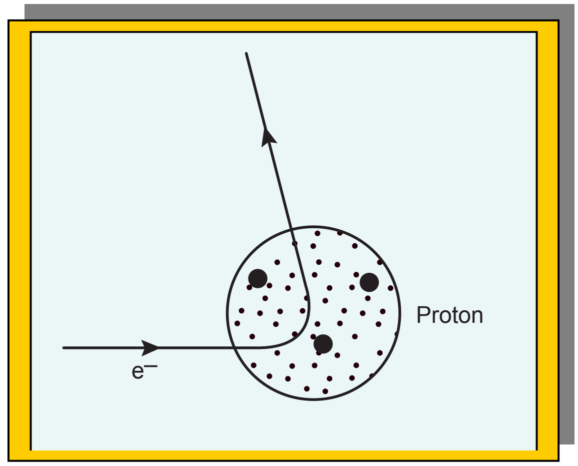
Why study quarks?
For many years, we have known that protons, neutrons, and electrons are the building blocks of atoms, and that atoms are the building blocks of matter. In some references, protons and neutrons have also been called "**fundamental particles**," particles that cannot be divided into smaller particles. It is true that protons and neutrons are stable particles at temperatures that exist in the universe today, but are they really fundamental particles? Not according to some models of the early universe.

In the activity, "Getting Down to Fundamentals," students will discover the combinations of "up" and "down" **quarks** that form protons and neutrons. The use of **flavors** and **colors** to describe the characteristics of quarks will probably be very new uses of these terms. Use the questions in the procedures to help clarify these terms as well as to introduce students to fractional charges and **strong nuclear forces**.

In the Student Text, "Thought Experiments: Tracing Origins," we have chosen to trace the origins of quarks by running the movie of the beginning of the universe "in reverse." We show the universe getting smaller and smaller. If you continue this back in time, you come to a point where the mass of the universe is "crammed" into an infinitely dense point. Matter was a mixture of quarks, **leptons** (particles like electrons that are not influenced by the strong nuclear force), and theoretical particles, which may have been the source of quarks (and **anti-quarks**).

Where did the particles in the "primal stew" come from? If we had an answer to this question, we would have insight into the beginning of the universe. They may have been produced from energy during the second, very brief epoch or during the Mysterious Epoch immediately preceding it (see p. 6 of "Thought Experiments: Tracing Origins) when the universe was very compact and temperatures were very high. This is in agreement with a premise of the standard cosmological model that the early universe was in a state of high density and high energy.

Figure 1



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

> **Teaching Tip**
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> Many first-year chemistry or physics students would enjoy the thought experiment involving a "magical oven" that Harald Fritzsch describes in his book, *The Creation of Matter*. Timothy Ferris does something similar in the videotape, "The Creation of the Universe". Also included in Fritzsch's book is a section in which the reader carries on a "dialogue with a quark." David Darling, in *Deep Time*, takes the reader for a ride with a proton backward and forward through time and space to visualize the birth of stars and the construction of the galaxies—and finally Earth.

If this is the case, then matter is frozen energy. The universe, which began in a high-energy state, has been cooling off ever since. Hot energy congealed into cold matter. So we are studying quarks in this activity because they appear to be the first form of matter in the universe and they are still present today. Not only are they fundamental particles of matter, but they also played a vital role in the formation of atoms and molecules that form the vast structures of today's universe.

As your students work with this model, emphasize that it is consistent with observations of chemical constituents in the universe—from studies of young and old stars; planetary nebulae, shells of gas ejected by unstable stars; glowing gas clouds; lunar soil samples that Apollo astronauts brought to Earth; and particles of solar wind gathered by sheets of aluminum foil deployed on the surface of the moon (see "It Began with Apollo" from *Dynamic Design: A Collection Process*). The observed abundances of hydrogen and helium in space match the abundances predicted from this model.

It is also consistent with known physical laws and properties of **fundamental forces**. Examples include the fact that the temperature of matter decreases as it expands, so the reverse would be true as matter condenses, and that the fundamental attractive forces have different strengths.

NATIONAL SCIENCE STANDARDS ADDRESSED

Grades 5-8

Science As Inquiry
Understandings about scientific inquiry
Physical Science
Properties and changes of properties in matter
Science and Technology
Understandings about science and technology
History and Nature of Science
Nature of science and scientific knowledge
History of science and historical perspectives

Grades 9-12

Science As Inquiry
Understandings about scientific inquiry
Earth and Space Science
The origin and evolution of the universe
Physical Science
Structure of atoms
Structure and properties of matter
Science and Technology
Understandings about science and technology
History and Nature of Science
Nature of science and scientific knowledge
Historical perspectives

(View a full text of the National Science Education Standards.)

MATERIALS

For each pair of students:

- In an envelope,
  3 squares labeled "red up" and 3 labeled "red down"
  3 squares labeled "blue up" and 3 labeled "blue down"
  3 squares labeled "green up" and 3 labeled "green down"
  (See Teacher Tools)

For each student:

- Copy of Student Activity, Part I "Quarks--Getting Down to Fundamentals"
- Copy of Student Activity, Part II "Tracing Origins"
- Copy of Student Activity, Part III "Quarks and Electrons"
- Copy of Student Text, "Quarks—Getting Down to Fundamentals"
- Copy of Student Text, "Thought Experiments: Tracing Origins"

Alternative Strategy Tip

You may wish to have your students research other models of time or of the universe. The following might serve as an introduction to this kind of assignment.

Did the universe have a beginning? Even the statement that the universe had a beginning has very profound implications and there appear to be two schools of thought about what the statement means. If one considers time to be linear, which is consistent with the thinking of scientists in the Western world, then time has a beginning and one must contend with interpretations of the "Big Bang" model. If, however, you believe as people in some Eastern civilizations do, that time is cyclical, the question of "a beginning" never arises.

There are at least three theories that are based on the assertion that there was no Big Bang or cosmic expansion. One of them is called "**tired light**," which involves the concept that light, as it travels vast distances loses energy, creating a red shift distance relationship that is not due to cosmic expansion at all. (See activity, "Are You Coming or Going?") Another is known as **steady state**, a theory that maintains that matter is constantly created by means of a **"C-field"** that also drives cosmic expansion. A third theory is known as the **plasma universe** model, in which parts of the universe expand while others contract. This would create an ongoing pulsation that occurs when clouds of matter and antimatter collide, generate energy, and, in turn, are repelled from on another.

- Copy of Student Handout, "Thought Experiments: Tracing Origins"

PROCEDURE: PART I QUARKS—GETTING DOWN TO FUNDAMENTALS MAKING ARRANGEMENTS

Before class:

1. Use the teaching tools and colored construction paper to make enough 8.5" x 11" sheets of red, blue, and green rectangles, so that each group of students has a set of rectangles consisting of:
   3 squares labeled "red up" and 3 labeled "red down"
   3 squares labeled "blue up" and 3 labeled "blue down"
   3 green squares labeled "blue up" and 3 labeled "blue down"

   These squares are shown with identifying patterns in the event that colored paper is not available. They may be used in gray scale to accompany this activity.

2. Place each set of rectangles into an envelope for distribution to the groups.

To start the activity:

1. Divide the students into groups of two. Each group should decide who will be the "arranger" and the "recorder."

2. Distribute to each group of students an envelope with a set of squares and a copy of the Student Activity, "Quarks—Getting Down to Fundamentals."

3. Tell the students to complete the student activity by following the instructions given.

4. Have students post their results so that they can be used for further classroom discussion.

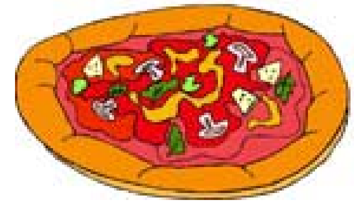
5. During post-activity discussion, center your discussion on questions similar to the following:
   a) Were there any differences in the findings of the different groups?
   b) What do you think is the significance of your instructions to:
      i. Use combinations of three squares?
      ii. Use combinations that included three different colored squares?
      iii. Use combinations that contained specific numbers of "up" and "down" squares?
      iv. Find combinations whose net charge is either +1 or 0?

   If none of your students have already deduced the significance of these characteristics, point out that they have just modeled the construction of protons and neutrons from quarks, the **fundamental particles** from which all matter is made. Emphasize the meaning of the term "fundamental particles," particles that do not decay into smaller particles. Protons and neutrons are not fundamental particles because they decay into other particles. Outside the atomic nucleus, neutrons decay in about 10 minutes. Protons decay in $>10^{30}$ years outside the atomic nucleus.

6. It is possible that one or more of your students knows something about quarks and recognized the significance of this activity. If so, use his or her expertise to spark the interest of others in the class and/or distribute copies of the student text entitled "Quarks" as their reading assignment for the next class period.

7. During the follow-up discussion of quarks, use questions similar to the following:
   a) What are some properties of quarks? [Flavor, color, fractional electric charge, associated with gluons.]
   b) How are these properties similar to those of another fundamental particle, the electron? [Have mass, electric charge, respond to attractive/repulsive forces.]
   c) How are these properties different from those of the electron? [See answer to a) above.]
   d) What four fundamental forces are now recognized by scientists? [Gravitational, electromagnetic, weak, and strong nuclear.]
   e) Which of these four fundamental forces plays the most important role in the behavior of quarks? [The strong nuclear.]

PROCEDURE: PART II TRACING ORIGINS – PIZZA INGREDIENTS



8. Have students participate in a modeling activity, "Tracing Origins," using a pizza as the topic. Students will go back in time to visualize how a pizza "came to be" and they will be using the same process that scientists use as they trace the known components of today's universe back to the "beginning."

   This activity can be done as a written assignment with students completing "Part II – Pizza Ingredients" of the Student Activity, "Tracing Origins" or as a classroom discussion with you guiding their thinking by asking the following questions:
   a) What are the ingredients in your favorite pizza?
   b) What observations can you make regarding the appearance of the pizza after it is baked and ready to eat?
   c) How might these observations be different from the appearance of the pizza before it was baked?
   d) What observations might you have made regarding the ingredients of your favorite pizza before the pizza was assembled?
   e) Trace one of the ingredients of your favorite pizza—the cheese, the meat, the tomato sauce, or the dough—backward as far as you can to its "beginning." [You may want to give the students an example, using a book as the object whose beginning is being traced. The book contains a cover and pages covered with ink. The cover and the pages are made of paper products, which came from cellulose, which came from trees (or other plants), which came from seeds, which absorbed water and minerals from the soil and energy from the sun.]
   f) What previous knowledge did you use as you traced your ingredient back to its "origins?"

9. Continue post-activity discussion by telling students that cosmologists and cosmogonists use the same type of thought process to model what the universe looked like early in its development. Scientists use modeling and **thought experiments** when it is not possible to actually conduct real experiments with real equipment. In today's terminology, these could be called "virtual experiments," because these simulations are often carried out using computer programs into which all available information has been input.

   Clarify the difference between cosmologists and cosmogonists. **Cosmologists** are scientists who study the structure and changes in the present universe in order to predict the future of the universe while **cosmogonists** are scientists concerned with the origin of the universe. Practically speaking, the work of these scientists overlaps. Observations about the structure and changes in our present universe may not only allow predictions to be made about the future, but they also have provided clues to events that happened long ago when the chemical evolution of the cosmos began.

   Students will be acting as cosmologists as they make observations regarding the structure of a pizza. When they start tracing the origins of the pizza ingredients, they are acting as cosmogonists. Help them make the same distinctions with regard to tracing the origins of quarks.

PROCEDURE: PART III QUARKS AND ELECTRONS THOUGHT EXPERIMENT

10. Distribute the Student Text, "Thought Experiments: Tracing Origins" and copies of the Part III Student Activity, "Quarks and Electrons" and from Part II, Student Activity, "Tracing Origins – Pizza Ingredients." Assign these to be read and completed for the next class period.

11. Follow-up the reading of the Student Text, "Thought Experiments: Tracing Origins." Assign these with classroom discussion focused on the following questions:
    a) What is the basis of the descriptions of the different epochs of the universe? [Models that incorporate observations of the universe today, descriptive mathematics and fundamental physical laws]
    b) Do we KNOW that these descriptions are accurate? What questions do we have concerning their accuracy? [No, we can only say that these descriptions are consistent with what we know about the universe today and the physical laws that are in operation today.]
    c) Have the students determine the amount of time quarks can exist:
       i. as free particles
       ii. as a part of free neutrons and protons
       iii. as a part of atoms
    d) During what epoch(s) were electrons found as free particles?

e) What was the trend in the temperature of the universe from the 1st to the 8th epoch? Why do we think that the temperature decreased? [We have observed that the universe today is expanding and that this expansion is accompanied by a decrease in temperature, consistent with the laws of thermodynamics. We assume that this trend is consistent with what happened in the early universe.]
f) What role do you think decreasing temperature played in the change of the constituents of the universe from the beginning to the present epoch? [Help students chart the temperature, processes, and constituents of the different epochs. You might assign different epochs to different groups of students for further research, since the student text dealt primarily with quarks and electrons.]
g) What is the trend in the length of time for each succeeding epoch? [The epochs got longer and longer, but there doesn't appear to be a strict mathematical relationship.]
h) What is happening to the size of the universe as we go backward from the current epoch to the first epoch? [The size decreases.] Ask students how they "visualize" the size of the universe during the first epoch. [There are models that say that the universe was just a speck of matter. There are others that say that the universe was all energy from which matter was formed. See the "Background" section of this Teacher's Guide.]
i) Which of the four fundamental forces now recognized by scientists—gravitational, electromagnetic, weak, and strong nuclear—played the primary role in each of the following universe phenomena?
    i. The formation of the large structures during the present epoch? [gravitational]
    ii. The formation of atoms and molecules? [electromagnetic]
    iii. The decay of neutrons? [weak and strong nuclear]
    iv. The formation of protons and neutrons? [weak and strong nuclear]
    v. The formation of quarks? [??]
j) Ask students whether or not they think this epoch model of the universe is plausible or not? They should have reasons for their answers, rather than just "yes" or "no" responses. Accept their answers without bias, asking only questions regarding their reasons for clarification.
k) Ask students what other information they might want to have before giving unqualified support to this epoch model.
l) The last sentence in the Student Text, "Thought Experiments: Tracing Origins" reads "Keep tuned to the Genesis Web site for the newest information."

12. Read excerpts of the news story by James Glanz, *The New York Times*, dated February 10, 2000, and ask students whether this new discovery changes their mind regarding support of the epoch model.

*****Below are highlights from the article.**

Excerpts from "Primordial Form of Matter Believed to Have Existed at Big Bang Re-created: Achievement confirms prediction of theoretical particle physicists"

The new material is a highly compressed gas of the particles called quarks and gluons, which are the building blocks of ordinary particles like the protons and neutrons within all the atoms in the universe today.

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The finding moves experimental physics closer than it has ever been to the presumed moment at which the universe came into being and could help cosmologists better understand the driving forces behind the primordial explosion itself.

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Quarks, and the gluons that powerfully bind them together, are normally joined to form protons and neutrons and cannot be shaken loose individually no matter how hard pairs of the ordinary particles are smashed together. To create the new materials, the scientists have, in effect, compressed and heated a ball of protons and neutrons so that they melted into their constituent quarks and gluons, which then floated freely in a laboratory for floated freely in a laboratory for the first time.

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It does indicate that a new state of matter is created.

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This new state we think the universe was in until about 10 microseconds after the Big Bang, and then crystallized into the particles as we know them now.

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Seven different particle detectors examined the residue of millions of lead collisions for evidence that the quark-gluon matter had in fact been created.

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Oddly, the strength with which gluons bind quarks together turns out to be weak when the quarks are close together and increasingly powerful when they are more distant from one another, as if they were connected by elastic.

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Quarks could roam free if enough protons and neutrons could be heated to a temperature about 100,000 times higher than the center of the sun and compressed to a density roughly 10 times that of an ordinary atomic nucleus.

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To test whether this state of matter can exist in reality, the scientists in Geneva used their Super Proton Synchroton to accelerate lead nuclei to an energy of 33 trillion electron volts. Traveling at nearly the speed of light, those nuclei were smashed into a stationary lead foil to produce hot, dense matter in resulting collisions.

For further study:
There have been other models put forward in the recent past and earlier cosmological history. These sources from the bibliography could be of special interest if you assign students to research some of these different models:

A Brief History of Time by Stephen Hawking
Cosmic Dawn by Eric Chaisson
The Creation of Matter by Harald Fritzsch
The Whole Shebang by Timothy Ferris
The Big Bang Never Happened by Eric J. Lerner

Call students attention to the following URL listed in the reference section of this module:
http://particleadventure.org/

Learn about the fundamental building blocks of atoms: quarks and leptons. Here's an interactive learning tool that contains a Quicktime movie introduction and tutorials on the evidence that physicists have found to support the Standard Model of the Atom.