Cosmic Chemistry: Cosmogony

Dark Matter—More Than Meets The Eye

TEACHER GUIDE

BACKGROUND INFORMATION

In science it is quite natural to engage in thought experiments. Scientists often conduct **thought experiments** as they use current evidence to model the past and future universe. Thought experiments are not just creative science fiction and they are not just models. In this student activity, you will be guiding students as they engage in a thought experiment, focusing on dark matter, a very abstract concept for which we have little, if any, direct evidence. But it is a strategy that is on the very cutting edge of cosmic science and technology and it should be introduced, either using this activity or in an informational class session, if your students will be working on the assessment activity in this module. In that activity, they will, in part, be basing their predictions of the future of the universe on the amount of dark matter they think is present.

You may want to use a copy of Appendix C, "Selected Noteworthy Events in Cosmology" to show students:

a) how long astronomers and cosmologists have been studying the structure of the universe;
b) what types of scientific instrumentation (technology) were used or adapted to make observations of dark matter; or
c) how scientists used "indirect evidence" to find evidence of dark matter.

Emphasize that the information given in the Student Text, "Dark Matter—More Than Meets The Eye" is the result of observations first made in the 1960s. During the period from the 1930s into the 1980s, cosmologists were involved in large-scale mapping that resulted in the description of the structures of the universe. It wasn't until the 1980s, however, that the first evidence of voids was found when astronomers were focused on a very narrow region of our universe. You may want to explore questions like the following with your students:

a) Why was it necessary for cosmologists to change to a narrow "focus" for their observations before evidence of dark matter was found?
b) How confident are scientists now about their evidence for dark matter?

If you think that the background material presented in the Student Text, "Dark Matter—More Than Meets The Eye", is written at too high a level for your students, then you may wish to use it in a follow-up classroom information session, rather than as a reading assignment.

If you wish to do further background reading regarding the technology for detecting dark matter described in the Student Text, "Dark Matter—More Than Meets The Eye," we suggest the following references:

1. *The Whole Shebang*, Timothy Ferris, Simon & Schuster, New York, NY, 1997.
2. *The Dark Side of the Universe*, James Trefil, Charles Scribner's Sons, New York, 1988.
3. *Bright Galaxies, Dark Matters*, Vera Rubin, American Institute of Physics Press, Woodbury, NY, 1997. The chapter entitled, "An Unconventional Career" presents insight into the reason why Rubin decided to study the rotational dynamics of spiral galaxies, the results of which were very controversial, but which laid a foundation for the discovery of dark matter. This text includes a pertinent *Dennis The Menace* cartoon found on page 126.

Cosmology as an Ongoing Science

Notice that the Student Text, "A Milky Way," ends with a statement of the challenge that cosmologists are facing regarding dark matter. Cosmology is a scientific study "in progress." New observations are constantly prompting the asking of more questions, resulting in more explorations and sometimes necessitates new and better observational instrumentation. This activity should be used to stimulate your students to ask questions and to search further for the answers.

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
Science as a human endeavor
Nature of science and scientific knowledge

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

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 student
- Copy of Student Activity, "Dark Matter—More Than Meets The Eye"
- Copy of Student Text, "Dark Matter—More Than Meets The Eye"
- Copy of Appendix C, "Selected Noteworthy Events in Cosmology"

or

For a class
- A transparency of Figure 1 for "Dark Matter—More Than Meets The Eye"

Alternate Teaching Tip

This activity assumes that students know the density of water as 1.00 g/mL. If your students do not know this, demonstrate how to find the density of water by finding the mass (in grams) of 10 mL of water in a graduated cylinder. The mass of the empty graduated cylinder should be subtracted, and this amount should be divided to 10 to find the density of water as 1.00 g/mL.

PROCEDURE

1. Before class make copies of the following handouts:
   Student Activity, "Dark Matter—More Than Meets The Eye," for teams of three or four students; or
   make a transparency of Figure 1 for the overhead projector.
2. If students are to do this as an activity, hand out copies of Student Activity, "Dark Matter—More Than Meets The Eye", and tell students to follow the instructions to complete the activity. If you wish to use this as a guided discovery with the whole class, place a transparency of Figure 1 on the overhead projector and set the scenario in the following way:

   A science teacher was preparing for a classroom demonstration. She placed an empty 1 liter beaker on a digital read-out balance and tared the balance to read 0.00 grams. Then she poured 100 mL of ordinary distilled water, H_2O, into the beaker. Imagine the teacher's surprise when the balance readout below the beaker indicated that the mass of the beaker's contents was 1000.00 grams.

3. After students have considered the situation, either as an activity or in a guiding discovery session, ask students for their answers to the following questions, accepting all answers without bias, but questioning students with regard to the reason(s) their answers:
   a) What possible explanations might there be for what the teacher observed?
   b) What might we do to determine the cause of this phenomenon?
   c) On what basis might we decide whether or not we have determined the correct reason for this phenomenon?

   Tell students that these are the same kinds of questions that scientists ask themselves as they observe and explain their cosmic observations.

4. Either hand out copies of the Student Text, "Dark Matter—More Than Meets The Eye," and make the assignment to read it before the next class session; or introduce the topic in a follow-up classroom information.

5. Start the next period's class discussion with questions similar to the following:
   a) What is dark matter? [Matter that we cannot see because it neither emits nor absorbs light.]
   b) What is another term used to describe dark matter? [Non-luminous matter.]
   c) How much of the matter in the universe actually gives off light? [At most, about 10% if scientists have made correct inferences regarding their observations.]
   d) If dark matter does not give off light, how was it discovered? [There was a discrepant event in the Milky Way galaxy. Stars and other luminous matter farther from the center of galaxy than our sun were orbiting the center of the galaxy faster than our sun.]
   e) How willing are scientists to accept what the observations appear to be discrepant events? What usually has to occur before these observations are accepted? [Scientists are usually skeptical of observations that are contrary to prior experience. Duplication of results by other scientists is usually required before credence is given.]
   f) What types of technology have been used to observe dark matter? [Spectroscopes have been used to study galactic dynamics, emission lines, radio emissions, and x-ray emissions. Telescopes with charge-coupled devices, have been used to detect gravitational lensing events. Dark matter can be indirectly detected by observing the luminous matter behind the regions where dark matter exists.]
   g) Can dark matter and light matter coexist in the same space or parts of the universe? [Yes. Remember the density activity, "The Push and Pull of the Universe," that you did earlier in this module? We had materials of different densities in the same box.]
   h) If you had a box that was filled with marbles and basketballs, which of them do you think would model bright, luminous matter and which would model dark matter? [The marbles are much more dense than the basketballs filled with a gas.]
   i) In "The Spongy Universe" activity, we found that one of the basic precepts of the standard cosmological model is that the universe is isotropic and homogeneous. How does the discovery of dark matter support or contradict this precept? [Accept students' answers if the reasons they give are plausible.]
   j) What is the difference between MACHOs and WIMPs? What are some examples of MACHOs and WIMPs that we have studied in previous activities? Are we made of MACHOs and WIMPs?
   k) Based on the evidence that we have now, what do you think that dark matter is made of?

6. Hand out copies of Appendix C, "Selected Noteworthy Events in Cosmology," and discuss some or all of the questions posed in the Background Information above.

Alternate Teaching Tip

This is an alternative discrepant event that you may wish to use in place of the mass discrepancy scenario or as a follow-up demonstration that show volume discrepancy.

Materials needed:

3 clean dry 100 mL graduated cylinders
1 100 mL beaker containing at least 50 mL of water
1 100 mL beaker containing at least 50 mL of ethyl alcohol

Procedure:

1. Fill one graduated cylinder with water to the 50 mL mark. Ask one or two students to come to confirm that the volume is 50 mL. On the chalkboard or overhead projector, write "50 mL water".
2. Fill another graduated cylinder with ethyl alcohol to the 50 mL mark. Ask one or two students to come to confirm that the volume is 50 mL. On the chalkboard or overhead projector, write "+ 50 mL ethyl alcohol" immediately after "50 mL water".
3. Tell them that you are going to add the 50 mL of ethyl alcohol to the 50 mL of water. Have students predict what the total volume of liquid will be after you have poured them together.
4. Carefully pour the contents of both graduated cylinders into the third cylinder.
5. Have two or three students record the resulting volume and record their readings on the overhead or chalkboard. If there is a difference in their readings, calculate an average of their readings.
6. Complete the equation that you have started, "50 mL water + 50 mL ethyl alcohol" by adding "= 98 mL liquid" (or, the average of the students volume readings).
7. Ask students questions like:
   a Why do you think there is a difference between your prediction and the actual reading?
   b) What could have happened to the 2 mL of liquid?
8. Use their answers to lead into a discussion of dark matter.
   a) In the universe, it appears that there is some mass that we haven't accounted for. What appears to be "missing" in the mixture of water and ethyl alcohol?
   b) Do you think that there was a difference between the densities of the water and ethyl alcohol? between the mixture and either the water or ethyl alcohol?
   d) If you had a box that was filled with marbles and basketballs, which of them do you think would model bright, luminous matter and which would model dark matter?

[The explanation for this discrepant event is that the water molecules are so much smaller than the ethyl alcohol molecules, that the water molecules fill the spaces between the ethyl alcohol molecules. Water and alcohol are soluble in each other which is why the "fill in the spaces" between each other's atoms. Another example is that marbles fill the spaces between basketballs in a box. The marbles are much more dense than the basketballs filled with a gas. So you could use this model to explain the apparent difference in total volume, the difference in density.]

For further research:

Whether the universe is made of hot dark matter, cold dark matter, or a mixture of hot and cold would be an interesting problem for students who wish to pursue to topic of dark matter further. This research would help when they complete the Assessment Activity, "Cosmic Tug of War."

Call students attention to the following URL's listed in the Reference section of this module.

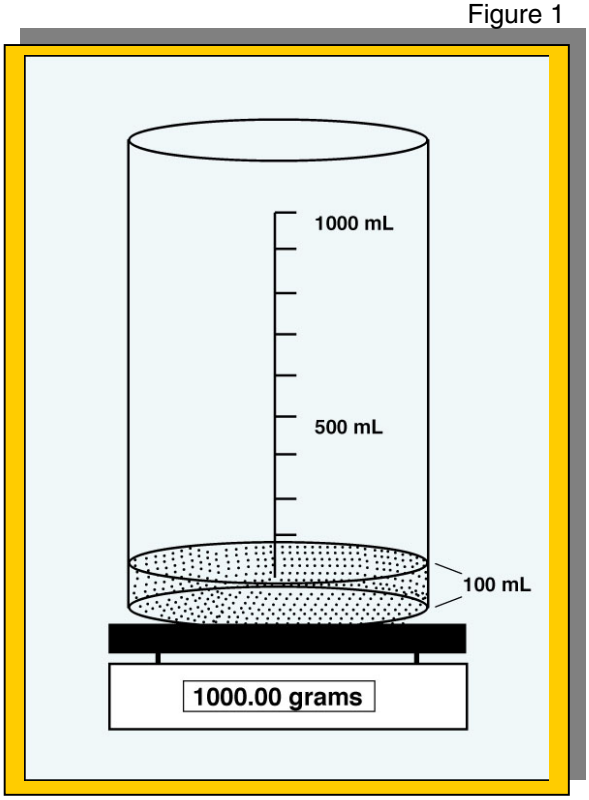
This Canadian site offers information about several cosmological theories, and also has a detailed section on dark matter:
http://www.astro.queensu.ca/~dursi/dm-tutorial/dmo.html

An explanation of gravitational lensing can be found at this site:
http://imagine.gsfc.nasa.gov/docs/features/news/grav_lens.html

The last section of Vera Rubin's book, *Bright Galaxies, Dark Matters*, entitled "The Astronomical Life: Women in Science and Other Heroes, Colleagues and Friends," would make very interesting reading for students considering a career in astronomy or cosmology. The section includes personal interviews, copies of correspondence, and short biographies of many outstanding scientists.

Transparency Master

Figure 1



Beaker containing 100 mL of water on a balance.