Cosmic Chemistry: An Elemental Question

Development of a Model: Analyzing Elemental Abundance

TEACHER GUIDE PART I

Background Information

Due to the complexity of our natural world, scientists and students often limit themselves to studying clearly-bounded, small subsystems, creating highly focused investigations. In this case, the system being studied deals with two areas of research: chemical elements and ideas. Both of these areas are fruitful topics for student questioning and class discussion.

Students may expect to understand: 1) the fundamental order that underlies scientific assumptions, and 2) the development of models that allow scientists to predict and explain. The goal of this section is to develop connections between these two understandings.

Part I, "Elemental Order: A Basis for Assumptions," challenges students to think in terms of the ordered system of nature's units of matter. They are: 1) elements, 2) atoms, and 3) isotopes. Students will practice and understand the use of ratios in describing the abundances of isotopes. The order of this chemical system can be described mathematically through studies of the composition and behavior of these particles. It is this model upon which further predictions about our solar system as a whole can be made. Part I of this activity extends students' understanding of modeling, logical questioning processes, and interpolation of information involved in developing the ordered system of the periodic table of elements. Students formally encounter the characteristics of the elements and their isotopes through data plotting, analysis, and interpretation of the compositional relationships of the elements. Additionally, mathematical skills such as determination of ratios are introduced, and a foundation is laid for an understanding that the systems that comprise our universe are not capricious. Through this understanding that scientific studies are built upon principles and laws, a stage is set for modeling and making predictions of elemental abundances in Part II of the activity.

In Part II, "Modeling Elemental Abundance," students utilize elemental and isotopic abundance data to construct mathematical models. Through statistical and graphical manipulation of certain known isotopic abundance data and calculated ratios, students extend the questioning processes initiated earlier in the module. They will attempt to predict what further information is needed to continue NASA's quest for understanding the order and origins of our solar system. The combined processes of mathematical modeling and logic-based decision-making lead students to reduce uncertainty in making predictions and in interpolating, extrapolating and inferring from data.

Standards Addressed (Grades 9-12)

Science as Inquiry

- IDENTIFY QUESTIONS AND CONCEPTS THAT GUIDE SCIENTIFIC INVESTIGATIONS
- USE TECHNOLOGY AND MATHEMETICS TO IMPROVE INVESTIGATIONS AND COMMUNICATIONS
- FORMULATE AND REVISE SCIENTIFIC EXPLANATIONS AND MODELS USING LOGIC AND EVIDENCE
- RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND MODELS
- COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT
- UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY

Science in Personal and Social Perspectives

- SCIENCE AND TECHNOLOGY IN LOCAL, NATIONAL, AND GLOBAL CHALLENGES

History and Nature of Science

- NATURE OF SCIENTIFIC KNOWLEDGE

(For full text of National Standards addressed in this module, see National Science Standards.)

Materials

For each group of three to four students:

- Modern Periodic Table of the Elements (see Teaching Tools)
- Student Activity, "Development of a Model: Analyzing Elemental Abundances on Earth"
- Student Activity, "Development of a Model: Analyzing Extraterrestrial Elemental Abundances"
- Graph paper (see Teaching Tools)
- Protractor
- Ruler
- Calculator
- Optional Student Text, "Atoms, Elements, and Isotopes"
- Notes and completed activities from previous lessons in module, Student Activity, "The Search for Critical Questions," and Student Activity, "Exploration of a Problem: Making Sense of the Elements"

Procedure

Discuss with students the upcoming tasks and the need for them to continue with the questioning and exploration processes they utilized in Student Activity, "The Search for Critical Questions," and Student Activity, "Exploration of a Problem: Making Sense of the Elements." Tell them that this time, the Successful Problem-Solving Process Log should be modified by their group, as each group will begin to bring new perspectives to the questions and problems encountered.

Alternate Strategy Tip

Avoid introducing scientific terms while students are engaged in forming initial concepts. Once conceptualization has begun, it is important to introduce commonly used terms and scientifically accurate definitions to students in order to enhance their communication skills.

Part I. Elemental Order: A Basis for Assumptions

1. *Pose this scenario to students:*

A sample of strange material has been discovered in a remote section of Antarctica. Preliminary tests have shown that the material has an $^{18}O/^{16}O$ abundance ratio of .00196, and an $^{17}O/^{16}O$ ratio of .0372. Scientists have asked your assistance in determining whether this rocky looking chunk is from Earth or extraterrestrial origin. To do this your research team plans to compare the abundance of isotopes of the elements in the sample of the material you were given with the abundance of the same elements on Earth.

Start by determining the relative abundances of the isotopes in samples of Earth materials that appear to be similar to the strange material. Table 1: Terrestrial Isotope Data Set gives known information about various stable isotopes of certain elements on the Earth, including the mass of each isotope and the *average* atomic mass of the element. Determine for each element the *rank order* of abundance for each of its isotopes. Since it will be necessary for your team to explain how it came to a conclusion, record each question your teammates ask and what steps your group took to address the questions and problems encountered along the way.

Students will need to be reminded of the process they used for tracking their questions and decisions in the last activity, Student Activity, "Exploration of a Problem: Making Sense of the Elements." They can utilize the same process again. This time, however, tell them that when the class reviews the problems, solutions and processes used by each group, the Successful Problem-solving Process Log will be amended to fit their groups' alterations to the problem-solving processes.

2. Pass out Student Activity, "Development of a Model: Analyzing Elemental Abundances on Earth." Stress that the group must first identify what they know and what they are being asked to discover. Allow them to devise their own methods to find solutions, but remind them to chart their questions and decisions.

3. As students begin to work on the activity, meet with each group to ascertain progress. Eventually, it should become evident to some groups that the *average atomic mass* of each element is closer to the mass of one isotope of the element than it is to the other isotopes for that element. For example, the average atomic mass of Hydrogen (1.0079) is significantly closer to the mass of ^{1}H (1.0078) than it is to ^{2}H or ^{3}H. It is true, as well, that ^{1}H is by far the most abundant isotope of Hydrogen on earth. This is generally true for most isotopes, as is the notion many students will get that the second most abundant isotope is the next closest in mass to the average, and so on.

   There are exceptions. Chlorine (Cl) has an average atomic mass of 35.453, with four known isotopes - ^{35}Cl, ^{36}Cl, ^{37}Cl, and ^{38}Cl. ^{35}Cl is the most common, followed by the only other stable isotope, ^{37}Cl.

   Some students may be distressed that the average atomic mass of ^{16}O, ^{17}O, and ^{18}O is 15.999. After all, it does not seem possible that any number of 16s, 17s and 18s would average to a number less than 16. Discussing this seeming inaccuracy with students will help dispel a common misconception in elementary chemistry. The 16 in ^{16}O, assumed to be the atomic mass, is really a shorthand symbol for expressing the total number of particles, protons plus neutrons, in the nucleus of that particular isotope of oxygen. Since each nuclear particle weighs less than 1.00 amu, the actual atomic mass of an ^{16}O atom is less than 16. Thus the average mass of the three isotopes of oxygen can be a value less than 16.

   See Table 1 for the data set table students are given, and Table 2 for the teacher key containing the measured natural percent abundance of the isotopes for each element.

Alternate Strategies Tip

What is an amu?

An *amu* refers to a relative atomic mass unit, equivalent to one-twelfth the mass of the carbon atom. A carbon atom of the most common isotope has 12 amus. An atom that is said to have a mass of 2 amus has a mass that is one-sixth the mass of a carbon atom, and so on.

To put this into perspective, let us say you have three pets: Sylvester (weighing 10 pounds), Bugs (weighing twenty pounds), and Tweety (weighing 30 pounds). Suppose we make the pmu (pet mass unit) to be one-sixth the weight of Tweety. This makes 1 pmu equal to 5 pounds. Therefore, the *relative* masses of your pets are as follows:

Tweety – 6 pmus
Bugs – 4 pmus
Sylvester – 2 pmus

Table 1: Terrestrial Isotope Data Set

Element Name	*Average* Atomic Mass (in amu's)	Symbols of Isotopes Present	Mass of Isotopes* amu	*Rank Order* of Terrestrial Abundance	Terrestrial Percent Abundance
Hydrogen	1.0079	^{1}H	1.0078250		
		^{2}H	2.0141018		
		^{3}H	3.0160493		
Helium	4.0026	^{3}He	3.0160293		
		^{4}He	4.0026032		
Carbon	12.011	^{12}C	12.0000000		
		^{13}C	13.0033548		
Nitrogen	14.007	^{14}N	14.0030740		
		^{15}N	15.0001089		
Oxygen	15.999	^{16}O	15.9949146		
		^{17}O	16.9991315		
		^{18}O	17.9991604		
Sulfur	32.064	^{32}S	31.9720707		
		^{33}S	32.9714585		
		^{34}S	33.9678668		
		^{36}S	35.9670809		

*Data from Table of the Nuclides, Korean Atomic Energy Research Institute, http://hpngp01.kaeri.re.kr/CoN/index.html

Table 2: Terrestrial Isotope Data Set Teacher Key

Element Name	*Average* Atomic Mass	Symbols of Isotopes Present	Mass of Isotopes* amu	*Rank Order* of Terrestrial Abundance	Terrestrial Percent Abundance*
Hydrogen	1.0079	^{1}H	1.0078250	1	99.985
		^{2}H	2.0141018	2	0.015
		^{3}H	3.0160493	3	Not naturally occurring
Helium	4.0026	^{3}He	3.0160293	2	0.000137
		^{4}He	4.0026032	1	99.999863
Carbon	12.011	^{12}C	12.0000000	1	98.89
		^{13}C	13.0033548	2	1.11
Nitrogen	14.007	^{14}N	14.0030740	1	99.634
		^{15}N	15.0001089	2	0.366
Oxygen	15.999	^{16}O	15.9949146	1	99.762
		^{17}O	16.9991315	3	0.038
		^{18}O	17.9991604	2	0.200
Sulfur	32.064	^{32}S	31.9720707	1	95.02
		^{33}S	32.9714585	3	0.75
		^{34}S	33.9678668	2	4.21
		^{36}S	35.9670809	4	0.02

*Data from Table of the Nuclides, Korean Atomic Energy Research Institute, http://hpngp01.kaeri.re.kr/CoN/index.html

Given the mass of each isotope, and the average atomic mass, it is possible to calculate algebraically the percent abundances for elements with only two isotopes. (This is not possible for elements having three or more isotopes, since there are a number of solutions possible.) Note the following procedure as one method for solving the problem.

X = % abundance of isotope A
Y = % abundance of isotope B
(NOTE: x + y = 100; therefore y = 100 - x)

Substitute (100 - x) for y in the equation above to solve for the percent of isotope A (x) and then subtract from 100 to solve for the percent of isotope B (y).

Alternate Strategies Tip

Often students at this grade have not yet mastered the skill of data organization. If this is the case, you may choose to withhold the chart used to organize their data set and challenge them to take the data you give them (as well as the data they will be asked to determine), and organize it in tabular form devised by their group.

Depending on the amount of assistance needed, you may offer ideas regarding set-up of columns and rows, or potential titles for various types of data, (such as *average atomic mass).* Students could also check whether their organization system makes sense by allowing another student or teacher to say what they think is clearly displayed in the data table.

Students should be encouraged to develop their own equations to the extent possible, and be prepared to discuss their use of variables in setting up and solving the problems. Numerous items of interest may be noted by students in their efforts, and these may be added to the record of questions and decisions students make on the first question on their response sheet. Before moving to the next step, students should be given the appropriate data in the right-hand column and should discuss their difficulties and solutions in solving the problem to this point. You may conduct this discussion with the entire class at once, or you may prefer to conduct it on a group-by-group basis when each reaches the point where they are ready to proceed to the next step.

It is of interest to note that the processes and entries in the *Successful Problem-Solving Process Log* up to this point may differ from the log entries in the next step, as well as the step after. You may tell students that each time they feel they are solving a different type of problem, they should begin a new log record of the processes, questions, and decisions they utilize.

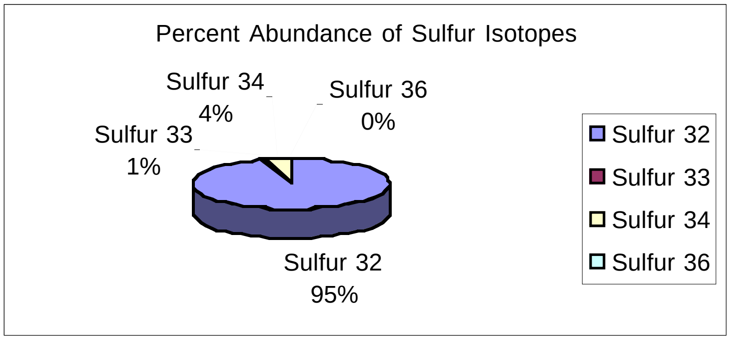
You may wait until Part I is completed in its entirety before discussing the log and attempting to construct a class log of the accumulated records. This would allow for emergence of the fact that different problems often require different types of processes and questions. These, in turn, lead to relatively more or less satisfactory solutions or potentials for error.

4. Read the opening scenario again to the students. Ask them to describe anything else they want to know about the terrestrial isotopic abundance data that would make their analysis of the mysterious material more relevant. Answers will vary. In this case, they would need to know the abundances of oxygen isotopes for a natural Earth material as a benchmark for comparison. Also, students may ask which elements, other than oxygen, might be present in the material. Some students may even want to know what further information can be determined about isotopic abundances of the material, such as the relationships or ratios of other isotopes found to be present.

5. Tell students they will now study the abundance of terrestrial isotopes and search for patterns and anomalies in isotopic data. Expect confused looks from the students. Call students' attention to the Terrestrial Percent Abundance column of isotope data on the Terrestrial Isotope Data Set, (Table 1 on the Student Activity). Have students graph the abundance of each element's isotope, requiring that they in some way represent the percent of each isotope of each element, using their choice of graph(s). (See Teaching Tools for blackline masters of graph paper if needed.) Some students may choose to use all pie graphs, some all **x y** graphs with axes. Others may choose to graph all data on one **x y** graph and use a legend to distinguish between isotope data that belongs to different elements. As we are dealing with percent abundance, it is tempting to tell students to simply use this type of graph. At this point, however, learning will be enhanced if students are encouraged to experiment with different ways of representing the data.

6. Urge students to study other students' graphs as well as their own and to make written notes in Question 2 of the Student Activity as to what patterns they observe in isotope percent abundance data. The responses they give will range from noticeable difference between the most abundant isotope of each element and the second most abundant isotope, to the fact that some of the abundance percentages are so small that they round to 0%. Anomalous data will be difficult to spot in this portion of the exercise, but the opportunity is ripe for students to *search* for this data, as well as discuss with each other and with you what is meant by the term *anomaly*.

Figure 1



7. Discuss with the class the value of various types of graphs used to display different types of information, and the various considerations to be made when graphing data. The pie graph in Figure 1 is an example of the most appropriate type of graph for representing percents of a whole. Students will need some help in dealing with problems of scale (large and small numerical data plotted on the same graph), and in scaling the graphs themselves. Resist the urge to create pre-scaled graphs for students.

8. Discuss the meaning of the term *ratio* and use a simple example to illustrate the mathematical process of determining a ratio. For example, if there are 700 students in a school and 28 teachers, then there is an average of 25 students per teacher (700/28). The ratio of teachers to students can be written as 28:700 or 1:25. It can also be represented as a fraction (1/25) to be used in an equation. For instance, suppose another school has 1000 students and wishes to have a 1:25 ratio of teachers to students. The required number of teachers can be found by multiplying the ratio (1/25) and the number of students (1000): (1000 students) * (1/25 teachers per student) = 40 teachers. Challenge students to outline the mathematical steps involved in solving this problem, and for each group to think of another example of ratios that they encounter every day.

Table 3: Terrestrial Isotope Ratios

Name	Symbol	Natural percent abundance	Ratio being calculated	Calculated isotope ratio
Hydrogen	^{1}H	99.985		
	^{2}H	0.015	$^{2}H/^{1}H$	0.0002
	^{3}H	negligible		
Helium	^{3}He	0.0001		
	^{4}He	99.9999	$^{3}He/^{4}He$	.000001
Carbon	^{12}C	98.89		
	^{13}C	1.11	$^{13}C/^{12}C$	0.0112
Nitrogen	^{14}N	99.63		
	^{15}N	0.37	$^{15}N/^{14}N$	0.0037
Oxygen	^{16}O	99.761		
	^{17}O	0.038	$^{17}O/^{16}O$	0.0004
	^{18}O	0.201	$^{18}O/^{16}O$	0.0020
Sulfur	^{32}S	95		
	^{33}S	0.76	$^{33}S/^{32}S$	0.0080
	^{34}S	4.22	$^{34}S/^{32}S$	0.0444
	^{36}S	0.014	$^{36}S/^{32}S$	0.0001

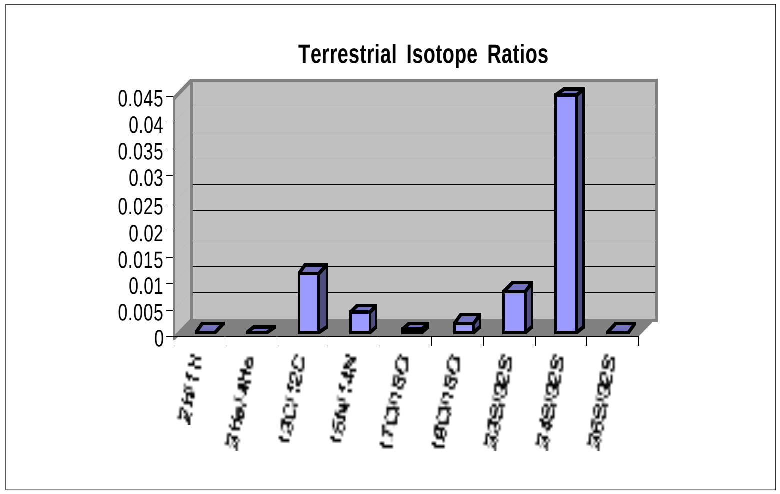
9. Assign each group one element from the data set shown below. Ask students to determine the ratio of each of the less abundant isotopes to the most abundant isotope. Allow them to use calculators and have them plot their data on a class graph that you have posted in the room or drawn on the chalkboard. You can pre-scale this graph and challenge them to deal with the very small numbers (or even scientific notation) used in the graph. More advanced students should be encouraged to develop their own scales.

When choosing the best method to graph isotope ratios, an x y graph is helpful when you have enough isotopes to derive more than one ratio. Most of the elements in Table 3: Terrestrial Isotope Ratios have only two isotopes, which is enough to calculate only one ratio. If we had two variables to plot against each other, we could create a scatterplot. If we were comparing percentages as parts of 100%, we might choose a pie graph. Since our data are discrete, we chose a histogram (see Figure 2) as an appropriate method for visually portraying the results. As shown in the diagram, the histogram better allows us to compare a number of discrete values for different materials.

In this activity we are asking students to work with histograms. It is important that they understand why particular types of graphs are more appropriate for explaining certain types of data. The graphs we choose for communication are selected on the basis of what we are trying to communicate.

Discuss the manner in which your students have just used *derived data* to create a model. Explain to them that Genesis scientists have used derived data in many instances to search for patterns and explanations that would not be clear through the use of simple raw data.

Figure 2



10. Discuss the patterns and anomalies that students observe in the graphs of isotope abundance ratios, as well as their responses to the questions in Student Activity, "Development of a Model: Analyzing Elemental Abundances on Earth" before moving on to the second part of this activity. You may choose to review the progress and notes the groups have taken by creating a class Successful Problem-Solving Process Log, or you may prefer to wait until Part II of this exercise.

Part II. Modeling Elemental Abundance

11. *Tell students*:

    Recall that the strange Antarctic material discussed in Part I of this activity had an $^{18}O/^{16}O$ ratio of .00196 and a $^{17}O/^{16}O$ ratio of .000372. Review the characteristics of extraterrestrial materials in Table 2 of Student Activity, "Development of a Model: Analyzing Extraterrestrial Elemental Abundances." Compare its characteristics to those you calculated for Earth materials in Student Activity, "Development of a Model: Analyzing Elemental Abundances on Earth."

    As a team, assess the likelihood that this rocky material originated on Earth.

12. *Ask students*:

    Would it be possible for your team to determine with any certainty from where the material originated? Do we know with any real certainty what differences exist among the planets and other solar system objects?

    Tell students:

    Diversity among the bodies of our solar system holds what scientists feel is a key to our understanding of the origins of the solar system. In Part II of this activity, you will try to extend the types of questioning and mathematical models you used in earlier activities to the study of numerous materials present in our solar system.

    The mystery sample ratios of .00196 ($^{18}O/^{16}O$) and .0000372 ($^{17}O/^{16}O$) were provided to students as a reference point for their thoughts. However, it may be of interest to teachers at this point to know that this ratio for the oxygen isotopes corresponds roughly to those found in some meteorite samples.

13. You may break the class into different groups of three to four students, or you may use the same groups as in Part I of the activity. Call each group's attention to the Extraterrestrial Isotopic Abundance Data Set, given in Table 2 in the Student Activity, or (Table 4 in the Teacher Guide). Teachers can point out that the percent abundances of oxygen in this data set was based on realistic information. The oxygen isotope abundances, and particularly the ratios of these abundances, are of interest to the Genesis mission scientists. The abundance data, though generalized, is based on measurable data.

    Ask students to reconsider the various types of questioning and mathematical modeling they used in Part I of this activity. Challenge them to determine what types of models could be constructed with the present data that would resemble the modeling used in Part I. Responses will vary, but for the most part, students will feel that the new data lends itself to the isotopic abundance ratio modeling used in the last portion of Part I. Now is a good time to briefly review that process, from calculation of abundance ratios through construction of models.

    This manner of calculating and modeling abundance ratios is in fact interesting to Genesis scientists. However, the additional oxygen data for different bodies in our solar system provides students with a far more extensive opportunity for making a variety of comparisons and models and should not be overlooked.

Table 4: Extraterrestrial Isotopic Abundance Data Set

Oxygen Isotopes	Asteroidal Material	Moon	Mars	Meteorite B	Meteorite A
^{16}O	99.758	99.76077	99.76077	99.76505	99.76854
^{17}O	0.0385	0.03821	0.03821	0.03741	0.03691
^{18}O	0.2035	0.20102	0.20102	0.19754	0.19455

Teacher Key: Oxygen Isotope Ratio

Oxygen Isotopes	Asteroidal Material	Moon	Mars	Meteorite B	Meteorite A
$^{17}O/^{16}O$	0.00038593	0.00038302	0.00038302	0.00037498	0.00036996
$^{18}O/^{16}O$	0.00203994	0.00201502	0.00201502	0.00198005	0.00195001

14. Ask each group to begin the process of determining what we really know and what we can do with that information. Most students will approach this task by calculating oxygen isotope ratios, then constructing histograms that compare oxygen ratios for the same or different extraterrestrial sources. This is appropriate, but students should also begin to consider additional ways to model derived data for certain elements. For example, students will find, that there are two isotope ratios that can be calculated for oxygen. Challenge students to find ways to model comparisons of these two ratios, and remind them that there are other types of graphs besides histograms that could be of assistance. As they progress through various ways of calculating information based on data given and representing that data in various graphical formats on their own graph paper, they should remain aware of the questions that are asked, why they are asked, what decisions the group made, and what the outcome of these decisions were. This information can be recorded in Question 1 of Student Activity, "Development of a Model: Analyzing Extraterrestrial Elemental Abundances." They may choose to record some of this information in a format similar to the Successful Problem-Solving Process Log.

See Representative Graphs for some examples of models that students may construct.

15. When each group decides that they have devised the most revealing and useful mathematical model comparing isotopic abundances in Table 2 of the Student Activity (Table 4 of the Teacher Guide). Ask them to search for and make note of any anomalous data present in the dataset.

As students search for anomalous data, it is important for teachers to emphasize that different types of models will show different anomalies. There is no single significant anomaly that they are looking for as a group. Rather, what is important is to recognize students' abilities and pose possible explanations for data that does not fit (*anomalous data*) in any model they construct.

Say to the class:

Recall that during the activity, "Connecting Models and Critical Questions," you looked at the data set for interesting information. Sometimes this information just does not seem to fit in with the other information. This data is called an anomaly. If your group identifies an anomaly, you should study this data and determine as best you can why it occurred and what effect you believe it has on the accuracy and utility of your overall model. This correlates with Question 4 on Student Activity, "Development of a Model: Analyzing Extraterrestrial Elemental Abundances."

16. *Pose this scenario*:

Look at the data regarding the mysterious material. Decide if you must use interpolation or extrapolation to compare it to the extraterrestrial abundances in Table 2.

Review the meaning of the terms *interpolation* and *extrapolation* with students. Give a simple example of how they might be accomplished in practice with a simple graph. Recall the use of these skills in their earlier activity and how Mendeleev did much the same in his original construction of the periodic table of elements. (See Question 5 in Student Activity, "Development of a Model: Analyzing Extraterrestrial Elemental Abundances.")

Students will find that in order to interpolate and extrapolate data, they must first identify trends and patterns in the data. Now is a good time to work with students on techniques for identifying and characterizing data trends. Some students may have determined a useful way to model using an **x y** graph, such as Genesis mission scientists used to compare ratios of $^{18}O/^{16}O$ to $^{17}O/^{16}O$ (see *The Science* on the Genesis Web site). If so, this is an appropriate point to discuss *best fit lines* and their usefulness in studying data trends. Using techniques such as this, it should become clear that the ratios of the mystery material place it somewhere between the data for Meteorite A and Meteorite B. Therefore, they are using the skill of interpolation.

17. Briefly discuss the idea that as students are making models and keeping records of their decisions, they should be thinking about how to communicate this to their peers. The reason for this is that the overall outcome of their investigation is to convince others of their findings. This means communicating not only the model, but the reasoning that resulted in creation of the model.

The final section of this activity allows students to consolidate their understanding of the concepts and skills learned in the module by speaking extemporaneously about the rationale for further data collection. Their position will be that it is or is not important for NASA to fund other missions that collect information on elemental and isotopic abundances in environments throughout the solar system. The Genesis principal investigators had to convince NASA of this importance before the project was funded. If they had not presented strong models and convincing arguments, there would be no Genesis mission.

Students who engage in science communication activities increase their abilities to think, understand, explain, argue, and conclude. For more information on rationale and strategies for incorporating impromptu speaking into the science classroom, see "Off the Cuff" in the *Creator's Kitchen* section of this Web site.

Representative Graphs

Figure 3

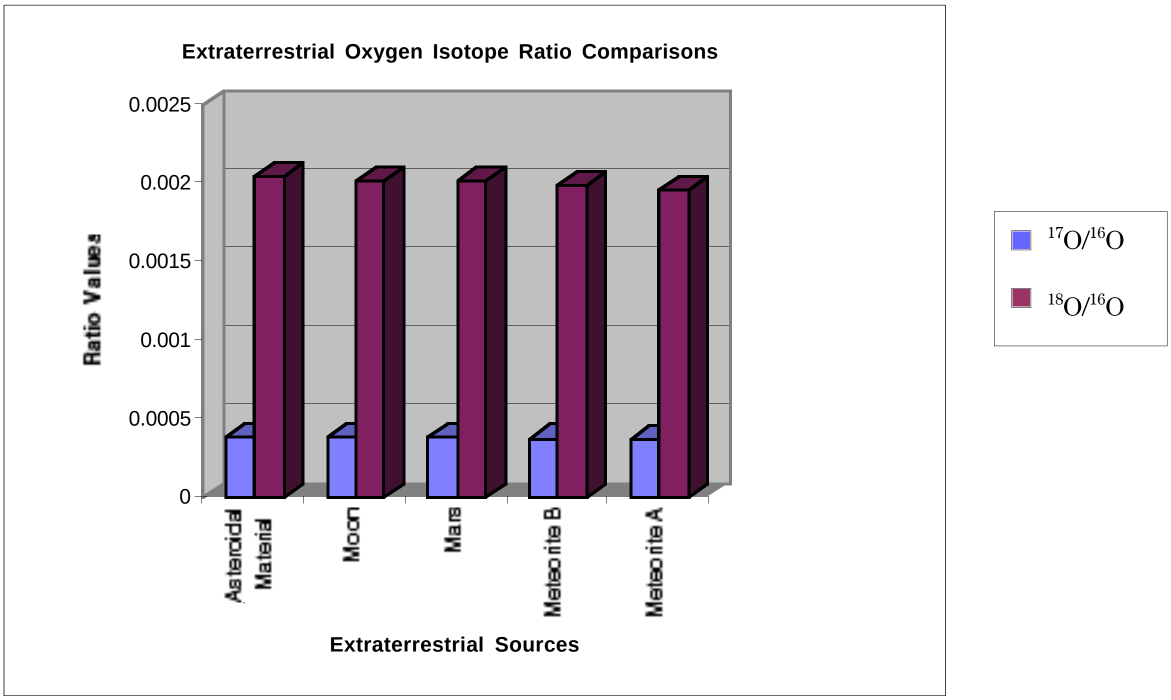


Figure 4

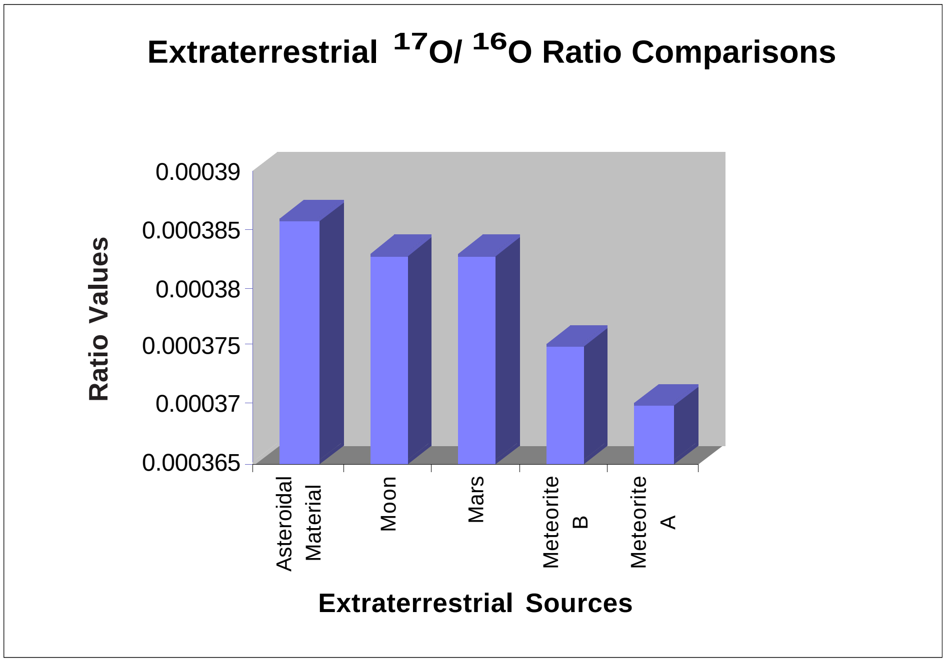


Figure 5

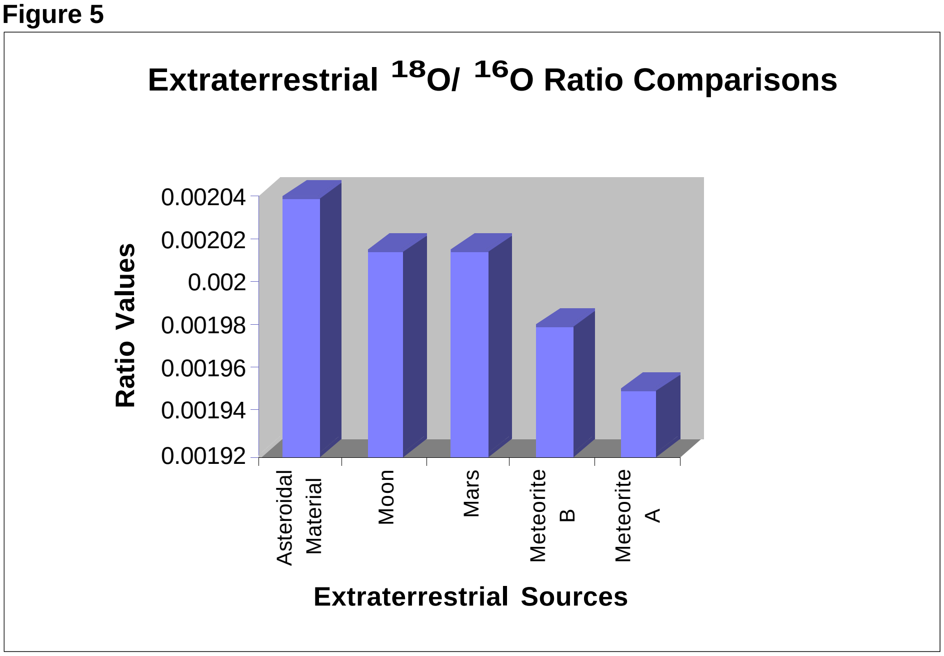


Figure 6*

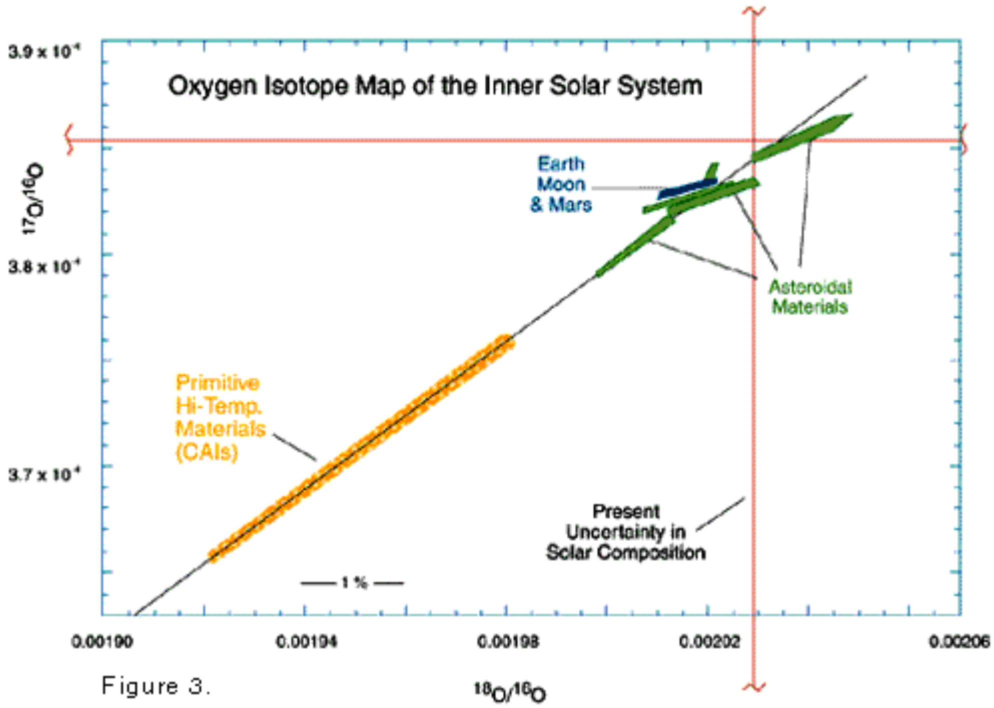


*Figure 6 graph as shown in Genesis Web site: http://genesismission.jpl.nasa.gov

Teacher Resources

http://hpngp01.kaeri.re.kr/CoN/index.html
Table of the Nuclides from the Korean Atomic Energy Research Institute.

http://wulff.mit.edu/pt/
A series of periodic tables showing, for example, specific heat capacities, densities, thermal conductivity, or electronegativity, in tabular and graphic form.

Atoms, Isotopes, and Elements

http://www.nuclear-electric.co.uk/visitors/mn_wotdo1.html
A short article on “Elements, Atoms and Isotopes” from a British nuclear power plant.

http://www.triumf.ca/safety/rpt/rpt_1/node9.html
An excellent short explanation of isotopes.

http://www.carlton.paschools.pa.sk.ca/chemical/molemass/isotopes.htm
An essay with good explanation of how atomic masses are calculated. Also describes the functioning of a mass spectrometer.

http://www.carlton.paschools.pa.sk.ca/chemical/molemass/massnum.htm
An essay with good explanation of how atomic masses differ from mass numbers.

http://www.yk.psu.edu/~jhb3/cotw03_1.htm
A somewhat challenging chapter on stoichiometry which includes a very helpful analogy for calculating atomic and isotopic mass, involving teddy bear heads with different weights of eyes.