The Journey of a Carbon Atom

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Overview

This unit will introduce students taking Earth and Space Science to the science of Cosmology. Students will first learn about the origin of the universe, beginning with the theory of the Big Bang. This will be followed by an examination of how the subsequent universe developed as a consequence of those first conditions.

This will be followed by the application of what the students have learned to an examination of the stellar cycle. Within this framework will be a review of the age of stars relative to the different types of galaxies, their distances, and compositions.

The nature of space and time will also be studied with particular emphasis on the mystery of the Black Hole and what occurs inside one.

This unit will conclude with an examination of the three theories concerning the ultimate fate of the universe. The so called "Big Crunch", the "Steady State model," and the "Heat Death models."

Rationale

The science course, Earth and Space Science, is characterized by four independent units, each nine weeks long. These four units are Geology, Geomorphology, Astronomy, and Meteorology. These units stand by themselves and require no previous knowledge on the part of the students. This unit will supplement the material in the Astronomy unit.

The students who take this subject are typically mainstream students, who have had problems with abstract thinking in other subjects. They typically have problems with higher math. Many of these students take the course as an alternative to physics or to make up for a failed year in chemistry.

This is a population which benefits from concrete science that is real, immediate, and relevant. If they can see examples of the concepts being presented to them, they can learn the material. What is more significant, they are able to synthesize their new knowledge and apply it to the higher level of understanding indicated by problem solving and critical thinking.

This unit on Cosmology will give the students concrete examples of the processes they will be learning. The learning will be further enhanced by the discussion of some of the great mysteries of science in regards to the nature of time, space, and matter. Reflective thinking and essays will be part of the assessment process.

The proposed curriculum will be applicable to the 11th grade course, Earth and Space Science, which uses the text book "Earth and Space Science" by Spaulding and Namowitz, published by Heath in 1994. The chapters to which this material will be applied are:

Chapter 20	Studying the Universe
Chapter 21	Stars and Galaxies
Chapter 22	The Sun and the Solar System

Introduction

Go out at night and look at the night sky. What do you see? You see immense darkness spangled with stars. In the 19th century a German astronomer saw the same thing as you but went further with his sense of awe. At this time it was thought that the universe was infinite. Regardless of how strong telescopes became, there was no end in sight, no boundary to be seen to the universe.

Heinrich Olbers, however, did a thought experiment. He thought that if the universe went on for ever that there were an infinite number of stars. If this was true, than the further you looked the more stars there would be shining. If this was true, then the night sky should be completely covered with stars, and there would be no darkness. In fact, the night sky should shine with the brilliance of the sun!

This is known as Olbers paradox and implies that there is an edge or finite boundary to the universe. This leads to more questions. What is on the other side of this boundary? Was there a time when the universe did not exist?

Dropping our eyes to the ground we see a piece of coal. There is a connection between those stars above and that common piece of coal, a story that involves the origin, evolution, and final end of the universe.

Earth's History and the Carbon Atom

The origin of that coal can be found in the geologic history of the Pittsburgh region. This history, as recorded in the rocks of the region, began around 445 million years ago. At this time the east edge of the North American continent ran into an island arc, causing intense folding, metamorphism, and volcanism along the edge of the continent.

This period of mountain building is called the Taconic Orogeny (Orogeny means a period of mountain building). Sediment eroded from the Taconic Mountains is carried westward into the basin where Pittsburgh will be and deposited in the Catskill delta. This delta grows to be up to 4,000 feet thick and extended from New York through Central Pennsylvania

Some 115 million years later, during the Pennsylvanian and Permian period, Africa collides with North America which begins the Acadian Orogeny. This forms a new range of mountains east of the deeply eroded Taconic Mountains. These new mountains are called the Acadians and the erosion from them forms an even larger delta as material is carried westward.

At this time the plants grew that would someday become that piece of coal at our feet. Some ancient fern absorbed a molecule of carbon dioxide and through the process of photosynthesis, converted it into plant matter. The carbon atom became locked into plant material that was buried and slowly pressed into coal.

For millions of years this carbon atom was buried under thousands of feet of rock. Then 70 million years ago western Pennsylvania became a broad flat plain across which slow moving rivers meandered. These rivers slowly cut down into the plain, gradually exposing the buried rocks below.

Then 11 million years ago western Pennsylvania began a period of uplift, which caused the rivers to run faster. The present day rivers, the Monoghohela, Allegheny, and Ohio, cut down into the flat plain, dissecting it into valleys. Layers of sandstone, limestone, shale, and coal were revealed along the steep sides of the river valleys. Eventually weathering and erosion caused our piece of coal to break loose and roll down the hill to our feet, once again exposing the carbon atom to the atmosphere.

But where was this carbon atom before it was buried? Our planet was formed approximately 4.5 billion years ago. During the subsequent history of our planet our carbon atom may have been used by thousands of creatures and been part of their bodies. Or perhaps it was buried all that time and was only released by a volcano a short time before it was absorbed by that ancient plant.

However, we are not yet at the beginning of this carbon atom, for it existed before the origin of this planet. In fact it existed before the origin of this solar system. We know this because of our understanding of how atoms are formed. This process is found in the center of stars and within the life cycle of stars.

The Solar System's History and the Carbon Atom

While much of what we understand about the origin of our carbon atom comes from recent scientific discoveries, the theory for the origin of the solar system in which it resides dates back to the 18^{th} century. Two distinguished men came up with the theory at the same time, Immanuel Kant, who was a great German philosopher and the French mathematician, Pierre Simon Laplace.

They both proposed what is called the solar nebula hypothesis. This hypothesis proposed that the solar system originated from a spinning flattened disk of dust and gas. The outer parts of the disk became planets while the center of the disk became the sun. This explains the flattened shape of the solar system and the fact that the planets all move in the same direction around the sun.

This interstellar cloud was probably a few light years in diameter and may have drifted through space for billions of years until something started it on the way to becoming reborn as a star and its planets. We know from studying other clouds that it was probably composed mostly of hydrogen (71%) and helium (27%). But also in this cloud were tiny grains composed of the higher elements. These included our atom of carbon.

This cloud began its transformation into a solar system when the gravitational attraction between particles in the densest part of the cloud became great enough to cause it to collapse inwards. This collapse may have been triggered by the cloud being hit by a shock wave from a nearby exploding star.

As the density of material in the cloud increased, small bits of matter began to collect and grow larger through collisions. Eventually these formed larger objects called planetisimals. Those close to the sun were in an area too warm for ice and frozen gases and so they were composed mainly of rock and iron. Those farther from the sun were able to draw on ice and frozen gases and become composed mainly of these materials.

In the next stage of the solar system these planetisimals began colliding, eventually growing into bodies large enough to be called planets. Once these new born planets were large enough, they had the gravitational attraction to attract material into orbits around them that would grow into moons.

At some point during this accretion phase, our carbon atom became part of the future planet Earth. The continuous bombardment of Earth kept it in a molten state. During this phase, the heavier elements, especially iron and nickel, slowly sank to the center of the earth while lighter elements floated to the surface. This formed the multi layered earth we have now made up of an inner core, outer core, mantle and thin crust. This crust is composed mainly of the lighter elements such as silicon, oxygen, and carbon.

Star history and the carbon atom

We have yet to see the origin of our carbon atom. Where did it come from, floating in space as a part of the interstellar cloud? Although it is supposition that the death of a star and its subsequent shock wave caused the collapse of this cloud to form the solar system, we do know for sure that a star died to make the cloud in the first place.

We know this from our understanding of the life history of stars and the physical processes of fusion that provide the energy that comes from a star. This original star was composed of the atoms which first came into existence at the beginning of the universe. At this point most of the atoms in the universe were hydrogen atoms with the remainder being helium atoms.

When this original star formed, it began fusing hydrogen atoms into helium atoms with a subsequent release of tremendous amounts of energy. If this star was about the size of our sun, this process would have been as follows;

2 protons fuse -> heavy hydrogen + proton -> 3He + proton -> 4He

After some 10 billion years this sun would have exhausted its supply of hydrogen and swollen to a red giant. During this phase it begins burning the helium converted from hydrogen. As the helium is fused into carbon its radius shrinks. However, the core does not become hot enough to burn the carbon, however, this compression increases the rate of helium fusing and it swells again.

At this point the outer layer of the sun cools enough for the carbon atoms to condense into flakes and be blown outward by the flood of photons. This forms an expanding gas shell called a Planetary Nebula. Eventually, the Helium is exhausted and this sun will collapse into a white dwarf.

However, our planet is made up of more than carbon. It is rich with heavier elements such as iron, gold, and uranium. These elements cannot be created in an average size sun such as ours. Our birth star had to have been larger to provide our planet with these valuable heavy elements.

If this star had been a giant or super giant, a whole different life cycle occurs, one which can grow these heavier elements. When this star had finished burning its supply of Hydrogen, it began to burn helium into carbon. However, being a giant it had the mass to generate the temperatures at its core to ignite the carbon and continue the release of energy.

This process of creating heavier elements is called nucleosynthesis. The following table shows the formation of some of these key heavier elements.

4 Hydrogen -> Helium	3 Helium -> Carbon
2 Carbon -> Neon + Helium	Neon + Helium -> Magnesium + gamma ray
2 Carbon -> Magnesium + gamma ray	2 Carbon -> Oxygen +2 Helium
2 Oxygen -> Silicon + gamma ray	2 Oxygen -> Silicon + Helium + gamma ray

As each fuel is exhausted, the core compresses to the point where it is hot enough to burn the "ashes" of the last fuel, hydrogen, helium, carbon, and so on. This leaves the star with a series of layers or nested shells like an onion, made up of these elements created at the different stages of the star's life.

It is interesting to note that the most common elements that make up the earth are the same elements that are at the base of nucleosynthesis. Below are listed these most common elements and their per cent in mass and volume and how they make up the earth.

Element	Percent of Earth's Mass	Percent of Earth's Volume
Oxygen	46.6%	93.8%
Silicon	27.7 %	0.9%
Aluminum	8.1%	0.8%
Iron	5.0%	0.5%
Calcium	3.6%	1.0%
Sodium	2.8%	1.2%
Potassium	2.6%	1.5%
Magnesium	2.1%	0.3%

It is believed that the reason there is so little hydrogen or helium on the terrestrial planets is that the solar wind cleared the inner solar system of the volatile gases. Only in the colder outer solar system do we find large quantities of the volatile gases hydrogen and helium. Somewhat more mysterious is the paucity of carbon. Our carbon atom is precious indeed due to how little of it there is on the planet compared with the other elements.

At the end stage of its life this star is burning silicon and forming a core of iron. However, at each change of fuel, less energy is released and so the star must burn more fuel faster to counter the force of gravity trying to collapse the shells inward.

This great star is at the end of its life, for its core is becoming choked with iron which it cannot burn. As the energy produced drops, gravity will take over and at some point the electrons and the protons that make up each iron atom will be forced to fuse into neutrons. In this moment of gravitational collapse, the star will go super nova and momentarily outshine the light of an entire galaxy.

This destruction will spread outwards a cloud of gas and dust containing our carbon atom as well as a bounty of atoms of higher atomic weights. Out planet earth is composed of these elements which could only have been created in a giant star which died in a tremendous super nova.

The Early Universe

We know our carbon atom came about in the heart of a great star as a part of the fusion process. Ultimately it came from some combination of helium atoms in that furnace. Where then did those helium atoms come from?

There are two possibilities at this point. One is that the helium atoms were formed in the heart of that star from the fusion of hydrogen atoms. The other is that the helium atoms were created at the moment of the birth of the universe, the "Big Bang."

The chances are good that the parent helium atoms of our carbon atom originated at the moment of the universes birth. Today, helium makes up roughly 25% of the atoms in the universe with hydrogen making up most of the remaining 75%. The conditions of the Big Bang would have led to this same ratio of helium to hydrogen that we see today.

A second or so after the birth of the universe, it would have consisted of a maelstrom of electrons, positrons, neutrinos, and photons, whirling about at incredibly high temperatures. Within this soup would have been scattered the heavier particles, neutrons and protons.

Frequent collisions with the lighter particles would have made these heavier particles constantly transform in the form of nuclear reactions. Initially, the temperature was so high, that all these flying particles resulted in equal amounts of neutron and proton transformations. However, as the universe cooled off, the ratio started to change to favor protons.

The reason for this is it takes slightly more energy to transform particles into neutrons than it does to transform particles into protons. As a result, protons continued to be made by collisions after the energy and temperature levels dropped below the threshold required to make neutrons.

Finally, when the cosmic expansion had cooled off enough so that there was no longer enough energy to interchange protons and neutrons, we were left with many more protons than neutrons. In fact we ended up with about 7 protons for every neutron.

In the next stage of the universe, atoms began to take form with pairing of protons with neutrons. It takes 2 neutrons and 2 protons to make a helium nucleus. So if we started out with 14 protons with 2 neutrons, we have left over 12 protons. These then became 12 hydrogen nuclei.

So, with a total of 16 particles (2 neutrons and 14 protons), 25% or 4 are tied up as a helium atom (2 neutrons and 2 protons). The same basic ratio that we see in the universe today.

How the Universe will end

Our Carbon atom is safely held in our hands for now, but what of the future? It is believed that our sun is about halfway through its life. In another four billion years it will go through the same sequence of death mentioned above. It will exhaust its hydrogen fuel and then go through its helium.

During this period of time it will expand into a red giant. The fate of the earth as well as the carbon atom will be to be vaporized by this expansion of the sun into the red giant. Whether it will be blown into the outer reaches of the solar system at this point or become part of the sun's outer layer is difficult to say.

What we do know is that in the final hours of the sun, it will start blowing off layers of itself in Novas, leaving an expanding shell of dust and gas. Eventually, it will collapse into a white dwarf and cool off into a dead cinder.

If our carbon atom is fortunate, it will be part of that expanding cloud of dust and gas. If this is the case, it may once more become part of another planet and possibly another life form, stranger than we can imagine.

Its future is inevitably tied with the future of the universe. If we consider the universe's ultimate fate, we are left with three possibilities;

1. It may expand forever, growing colder and more dim.

2. It may slowly stop expanding, and the force of gravity will cause it to collapse inward into what is called the "Big Crunch".

3. It may reach a point of equilibrium where gravity and expansion are perfectly balanced.

The fate of the universe is dependent on an unanswered question. How much matter is there in the universe? Too much and it expands forever, fading away into absolute zero. Too little and it goes back where it came from, compressed into nothingness in a flash of incredible temperature which destroys the fabric of atoms themselves.

In the last decade, discoveries in astronomy and physics have given us the answer. In the words of T.S. Eliot, "This is the way the world ends, not with a bang but a whimper.

The first question regarding the end of the universe was the determination of how much matter there was. Simply counting stars and galaxies turned out not to give the complete answer. As early as in the 1930's astronomers knew there was something out there with mass. It seems that galaxies in clusters were orbiting each other much too fast. They should have been flying off into space at the speeds they were orbiting each other. Clearly there was some hidden mass which was holding things together, some "dark matter."

But, what was it and how much was there? Perhaps the way to see if there as enough matter in the universe to cause the Big Crunch was to see if expansion was slowing down. In 1995 two groups of astronomers set out to do this. Brian Schmidt and Saul Perlmutter led these two groups. The plan was to measure the rate of expansion of the nearby universe and compare it with the rate of expansion of the distant universe.

The method these two groups used was a special type of supernova called a Type Ia. These are so bright, they can be seen across the universe and are uniform enough to have their distance from earth measured accurately. Thus the two teams were able to measure the distance to these supernovas based on brightness and their speed of recession based on the red shift of their light from the Doppler Effect.

With these two pieces of information they could determine the universe's rate of expansion both now and in the past. To their surprise and dismay, they did not get the results they expected. If the universe's expansion was slowing down, the distant galaxies should be brighter than you would expect compared with galaxies that are closer. In fact, the distant galaxies were dimmer than expected which indicated that not only was the universe's expansion not slowing down, but, in fact, was actually speeding up.

It appeared that there was something countering the force of gravity, some dark energy. The final composition of the universe turned out to be 5% ordinary matter, 35% dark matter, and 60% dark energy. All the matter put together is not enough to stop the expansion of the universe and the dark energy is actually speeding up the expansion. What's more, the dark energy amount will grow as space grows larger, thus increasing its influence.

Eventually all the galaxies will shrink out of sight and we will only be able to see our home galaxy, the Milky Way. By this time our sun will have shrunk to a white dwarf and entered into a long slow death of some 100 trillion years. The same will happen to the other stars in the galaxy until all that is left will be black holes and cold dead stars.

The next step may see all the dead stars eventually swallowed by the black holes. One theory sees even the black holes evaporating after 1 trillion trillion trillion trillion trillion trillion years into stray particles. These particles will in turn bind into individual "atoms" larger than the size of today's universe. Eventually these will decay and there will be nothing but an infinity of emptiness.

Objectives

Students will be able to:

1. Describe the stellar evolution of the sun from origin to white dwarf and relate each stage to the nucleosynthesis of elements.

2. Correctly list the evolutionary steps in the history of the universe from the "Big Bang" to the present.

3. Explain the three possible futures of the universe and identify the scientific basis for the currently accepted model of accelerated expansion.

4. Relate the composition and structure of the planet they live on to the evolution of the universe.

Strategies

Students will be given a series of lectures using the material provided in the rationales section to give them the background material needed for the learning objectives. Interspersed between lecture sections, classroom activities and assignments will be given. These will include hands on labs and written assignments.

Classroom Activities

Activity 1: Students will construct a timeline using data tape. Students will develop a scale for the timeline, (for example one centimeter equals 1 million years) and plot the major geologic events listed below on the geologic history of Pittsburgh. Students will illustrate the major geologic change points with appropriate pictures on their timeline.

1,000 million years ago (mya) - Eastern US collides with Europe resulting in the Grenville Orogeny. These mountains rose and then were eroded away. The roots of these mountains remain as deeply heated and twisted basement rock.

650 mya- Eastern US and Europe pull apart, forming the ocean, Iapetus. This ocean widens for the next 200 million years.

450 mya- The ocean, Iapetus, begins to close. As the ocean plate subducts, an island arc of volcanoes forms, fed by the melted subducted ocean plate.

445-435 mya- The US runs into the island arc, causing intense folding, metamorphism, and volcanism. This period of mountain building is called the Taconic Orogeny. Sediment eroded from the Taconic Mountains is carried westward into the basin found where Pittsburgh will be and deposited in the Catskill delta. This delta grows to be up to 4,000 feet thick and extended from New York through Central Pennsylvania

300-220 mya- During the Pennsylvanian and Permian period, Africa collides with North America which begins the Acadian Orogeny. This forms a new range of mountains east of Pennsylvania and the deeply eroded Taconic mountains. Erosion from the Acadians forms an even larger delta as material is carried westward.

220-70 mya- No geologic history available for what was happening in Western Pennsylvania.

70 mya- Western Pennsylvania consisted of broad flat plains with slow moving rivers meandering across them.

11 mya- Western Pennsylvania began a period of uplift, which caused the rivers to run faster. The current rivers cut down into the flat plain, dissecting it into valleys.

1 mya- The ice age caused glaciers to advance to just north of Pittsburgh and block the northward flow of the rivers. A great lake formed and filled to overflowing, causing the current rivers to flow in the southward direction they have now.

Discussion will be held with the students on how much larger their timeline would have to be if they extended it to include the possible history of the carbon atom in their notes.

Activity 2: Students will collect rocks from various areas around their house where the rocks are exposed in situ. These rocks will be brought to class, and the students will use the rock identification table in their books and lab equipment to identify the rock type and the minerals in them. Students will then select one mineral and determine the chemical formula for that mineral. Students will explain how those atoms came to be in that particular mineral in a report.

Activity 3

The Big Bang Theory
An AskERIC Lesson Plan

Author: Judith I. Vandel, McCormick Junior High, Cheyenne, WY
Endorsed by: These lesson plans are the result of the work of the teachers who have attended the Columbia Education Center's Summer Workshop. CEC is a consortium of teachers from 14 western states dedicated to improving the quality of education in the rural, western United States, and particularly the quality of math and science education. CEC uses Big Sky Telegraph as the hub of their telecommunications network that allows the participating teachers to stay in contact with their trainers and peers that they have met at the Workshops.

Students will be able to:

1. Explain how the Big Bang Theory can be used to explain the origin of the universe.
2. Demonstrate, using graphical analysis, how different masses react to the same force.
3. Describe the patterns observed when the force is applied.
4. Identify what material types could represent bodies of the universe.
5. Equate material colors or the visible spectrum as it relates to the elements found in celestial bodies. (Expansion exercise)

Activities:

1. Using masking tape, divide the room or the center of the room into four to six equal parts. Class and room size will help determine this.
2. Take a balloon and insert punch out pieces of construction paper that have the colors of the visible spectrum and white. Use 30 pieces of each color.
3. Have one student stand in the center and blow up the balloon. The expansion of the balloon should be the same for each class so that comparisons can be made between classes. Obviously, the expansion of the balloon corresponds to the energy with which the pieces will spread across the room.
4. Pop the expanded balloon with a pin.
5. Using groups of students, have each group gather the different colored pieces in a particular sectioned off area.
6. Graph the results, noting the number of each color represented in each area.
7. Analyze the results according to the distribution of the colored pieces and how this distribution relates to the Big Bang Theory.
8. Make distribution comparisons for all classes.

Tying it all Together:

It is almost impossible to believe that the variation in the weight of the different colors of construction paper can produce the patterns that continually show up in the different classes if the balloon is blown up to the same diameter in each class. The white pieces very often appear in the outermost areas, while the blue and red are nearer the point of origin. It becomes very evident to the students that the distribution of celestial bodies could be explained by the Big Bang Theory as demonstrated in this activity. It is also possible to expand this activity by using the knowledge of color and its relationship to the presence of different elements to help students determine what elements are represented in each separate area. This is an excellent way for students to become involved in accurate observation, graphing, and analysis of results.

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Appendix A-Content Standards

Pittsburgh Public Schools Science Standards Addressed

1. All students explain how scientific principles of chemical, physical, and biological phenomena have developed and relate them to real-world situations

2. All students demonstrate knowledge of basic concepts and principles of physical, chemical, biological, and earth sciences

3. All students explain the relationships among science, technology, and society

4. All students evaluate advantages, disadvantages, and ethical implications associated with the impact of science and technology of current and future life

5. All students evaluate the impact on current and future life of the development and use of varied energy forms, natural and synthetic materials, and production and processing of food and other agricultural products

Appendix B- Materials list

Activity 1

Student Materials

1. One 7 meter length of tape per two students

2. One meter stick per two students

3. One box of colored pencils per two students

Activity 3

- Teacher Materials
    1. balloons
    2. colored paper punch outs
    3. masking tape
    4. pin
    5. Laboratory sheets with graph paper.
- Student Materials
    1. pencil
    2. straight edge
    3. colored pencils