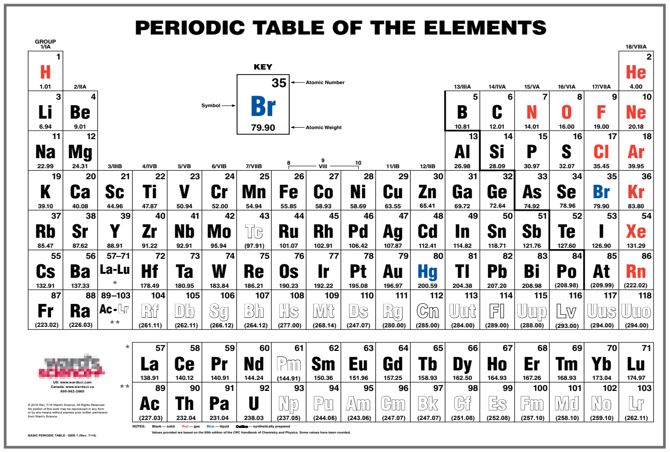
All About Elements:

Carbon

Boreal's All About Elements Series
Building Real-World Connections to the Building Blocks of Chemistry



The periodic table of elements is an essential part of any chemistry classroom or science lab, but have you ever stopped to wonder about all of the amazing ways each element is used to create the world around us? Each of the trillions of substances in our universe can be tied back to just these 118 simple, yet powerful elements.

In our ***All About Elements*** series, we've brought together the most fascinating facts and figures about your favorite elements so students can explore their properties and uses in the real world and you can create chemistry connections in your classroom and beyond.

Look for a new featured element each month, plus limited-time savings on select hands-on materials to incorporate these element in your lessons.

Sign up to receive Boreal Science emails
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Check back often at boreal.com/elements for the latest content and exclusive savings on new teaching tools each month.

Fun Facts About... Carbon

6

C

12.01

1. Graphine, an allotrope of carbon, is the strongest, thinnest, and best conductor of heat known to man. It was created by scientists using ordinary adhesive tape!

2. Carbon was used as the filter in gas masks to purify the air soldiers breathe.

3. Carbon-14 can not only be used for radioactive dating, but also to study abnormalities of metabolism that underlie diabetes, gout, anemia and acromegaly.

4. Diamond is another well-known allotrope of carbon; The largest diamond ever found was 3106 carats—over 10cm long and about 2500 times larger than an average engagement ring diamond!

5. Activated charcoal, another allotrope of carbon, and carbon amide peroxide can both be used to help whiten teeth, yet only the latter is approved by the American Dental Association (ADA).

All About Carbon:

Carbon is the sixth element on the Periodic table found in group 14 (4A), with an atomic number of 6 and symbol C. Carbon gets its name from the Latin word "carbo" meaning charcoal or coal. It is the sixth most abundant element in the universe.

Carbon is an extremely versatile non-metallic element that connects via covalent bonds to other carbon atoms in rings, chains, and networks to make over ten thousand organic compounds. This is in part due to carbon having 4 valence electrons with an electron configuration of $1s^2 2s^2 2p^2$. While carbon is denser than Hydrogen, Helium, Lithium and Beryllium, it is *less* dense than its neighbors Boron, and Silicon. The density of carbon can fluctuate from graphite with a density of 2.25 g/cm^3 to diamond with a density of 3.51 g/cm^3.

Although the amount of carbon in Earth's crust can vary somewhat, the carbon cycle keeps the amount on Earth effectively constant. In addition to all of these properties, carbon has the highest sublimation point of all elements at 3900 Kelvin. The main forms of carbon found naturally are amorphous, graphite and diamond, all with extremely different properties[1]. In addition to these allotropes in nature, there are also manmade allotropes that are becoming more useful by the day. These include fullerenes (buckyballs, buckytubes and nanobuds) as well as carbon nanotubes, graphene, carbon nanofoam, linear acetylenic carbon and Q-carbon, which is supposed to have fluorescence properties. While there are many allotropes, there are only two stable isotopes of Carbon, C-12 and C-13, with all the other isotopes being radioactive. Carbon-14 specifically has a half life of approximately 5,730 years making it useful for dating fossils (more on this isotope later).

Properties of Carbon

While carbon is the sixth most abundant element in the universe, it is found on Earth in a concentration of 730 ppm, and as high as 2000 ppm at Earth's core[4]. Carbon on Earth is found mainly in coal deposits and must be processed for commercial use, but may also be found in peat oil and methane clathrates. In the earth's atmosphere, carbon is found mainly as carbon dioxide with a concentration of 390 ppm (and rising)[3]. In the human body, carbon is present in organic containing compound at 18.5% by mass[2].

Carbon, like many other elements, is formed from stars. Carbon is specifically created as a star dyes and as helium and beryllium react to form carbon[5]. While carbon is common in elemental form, it also creates both organic and inorganic compounds. Within inorganic compounds, carbon is most often found with oxidation states of +4 and +2. Some examples of these natural inorganic compounds are limestone, dolomite, and carbon dioxide. Because carbon covalent bonds are created so readily and in all organic compounds, all living things contain some type of carbon.

In nature, carbon is found naturally as C-12 and C-13 with abundances of 98.93 and 1.07 percent respectively[6]. Carbon-14, the most commonly known radioactive isotope of carbon, is used to date once living things. This process is based on the idea that there is a small amount of naturally occurring C-14 in the environment that is created by cosmic rays in the upper atmosphere and that the percent of carbon-14 remains constant over time. All living things tend to ingest carbon from the atmosphere, therefore when they die they stop ingesting more carbon and the percent of carbon-14 in the organism begins to decrease as it undergoes radioactive decay. Scientists can use these amounts to determine the approximate age of the organism[7]. In addition to radioactive dating, carbon-14 is also used in a variety of other ways. It can be used to study abnormalities of metabolism that underlie diabetes, gout, anemia and acromegaly[8]. Another use of carbon-14 is for studying the mixing and transporting processes deep in the ocean. This process requires a linear accelerator (a sophisticated mass spectrometer) to determine the ratio of radioactive carbon (14) to stable C-12 and C-13[9].

Discovery and History

The earliest known use of carbon is in the form of charcoal during prehistoric times. The Egyptians and Sumerians also used charcoal, but they used it to reduce copper, zinc and tin ores in the manufacturing of bronze[10]. In addition, charcoal was used for medicinal purposes, to coat barrels so that water could be stored for longer periods of time for travel by sea and was eventually used to refine and decolorize sugar from various sources[10]. Although charcoal had been used since prehistoric times, it wasn't until the seventeenth century, after Robert Boyle suggested that an element was a substance that could not be decomposed into a simpler substance, that carbon was recognized as an element[11]. Numerous tests by René Antoine Ferchault de Réaumur, Antoine Lavoisier and Carl Wilhelm Scheele on graphite, charcoal and soot led to the conclusion that they were all composed of the same element, carbon. Diamond was a more difficult task due to diamond's hardness and rarity. In 1694 Giuseppe Averani, a naturalist, and Cipriano Targioni of Florence first discovered, using a large magnifying glass, that diamond could be destroyed. Pierre-Joseph Macquer and Godefroy de Villetaneuse repeated the same experiment in 1771 and finally Smithson Tennant in 1796 was able to prove that diamond was carbon because when it burned he found only CO_2 as a product[3]. It wasn't until 1789 that the element was named by Antoine Lavoisier.

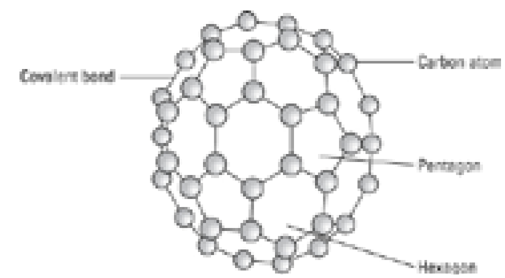
As many chemists now know, the standard atomic mass unit is based on carbon-12, but this standard was originally based on oxygen and hydrogen separating the chemistry and physics world. This became a problem when naturally occurring oxygen was found to contain multiple isotopes of oxygen and therefore the mass was not a whole number. Scientists were trying to determine standard atomic mass of elements on the periodic table and this was difficult with oxygen's mass[16]. This was when Alfred Nier, in 1955, revised all of the physical determinations of atomic weight using mass spectrometry from using oxygen to using carbon, but it wasn't until 1961 that these values from carbon were seen as the accepted atomic mass. Carbon-12 has 6 protons and 6 neutrons giving each subatomic particle a mass of exactly one[13]. Josef Mattauch was able to convince physicists of this new standard while E. Wichers lobbied the chemists to do the same[14].

While charcoal is a natural form of carbon, so are graphite, amorphous carbon and diamond. These are all considered allotropes; structures that are made up of the same element, but have different properties and structures. In 1955, scientists were able to take pure graphite and convert it into diamond under extremely high conditions of temperature and pressure[15]. In 1967, when the meteorite Canyon Diablo impacted earth another allotrope of carbon, lonsdaleite, was found. It is harder than diamond and created when the graphite in the meteorite strikes the earth with a great force. It has also been created in the lab using a variety of techniques, including using explosives, on graphite. In 1969, another allotrope, white carbon, was thought to be formed when tiny crystals of small transparent material clung to the edges of graphite under high temperature and low pressures[15]. Very little is known about this allotrope and many scientists still dispute its existence today.

http://www.meteorite-times.com/Back_Links/2008/january/Meteorite_People.htm

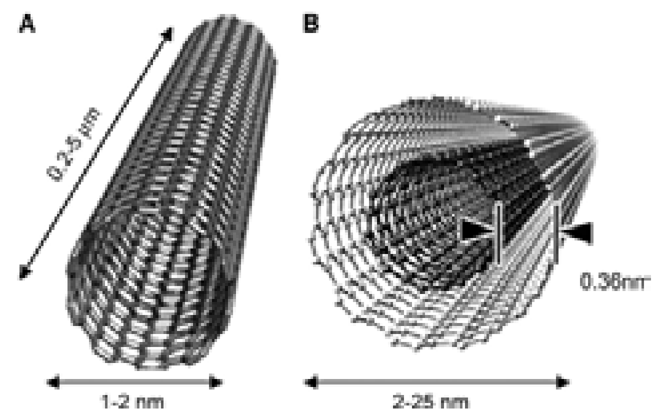
In 1985, a new (and now scientifically accepted) allotrope of carbon was discovered. The buckminsterfullerene was discovered when Harry Kroto from Sussex University in England and Richard Smalley and Robert Curl from Rice University in Texas worked together. Kroto was interested in molecules found in interstellar space, specifically poly-ynes that have several carbon-carbon triple bonds. He reached out to Smalley and Curl because these are difficult to create using conventional methods. He was hoping they would be able to use a laser to blast clusters of atoms off solid targets, create the poly-ynes, and analyze them immediately using a mass spectrometer. Unexpectedly the peaks for mass corresponded to C-60 and C-70 and the scientists had to determine what the structure might look like. They began by trying to use Richard Buckminster Fuller's architectural designs as inspiration, but ended up using a colleague, the chairman of the math department at Rice University, to determine the shape was like that of a soccer ball, football, and other spherical objects depending on the number of carbons[16].

In addition to all the other allotropes, in 1991, Sumio Iijima discovered a graphite needle like structure when looking through an electron microscope that he named carbon nanotubes. These nanotubes are one of the most recent allotrope of carbon found and are now highly researched, especially in the field of nanotechnology[17].



http://www.understandingnano.com/what-is-buckyball-c60.html

The newest allotrope, graphine, was discovered in 2004 at the University of Manchester by Professors Andre Geim and Kostya Novoselov[29]. They used scotch tape to create graphene (a single atom thick layer of graphite. This is possible when graphite is pressed onto it and a new section of tape is used to remove more and more layers until only one layer remains—making graphene.



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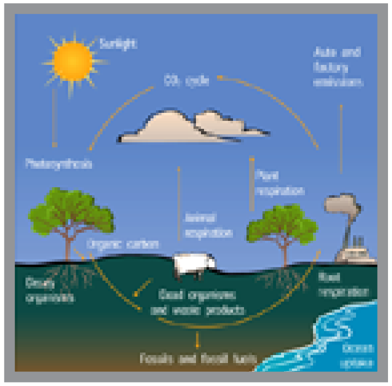
Where in the World is Carbon?

Allotropes of carbon, as well as compounds containing carbon, are widely distributed in nature. The estimation is that carbon forms 0.032% of Earth's crust. Free carbon is found in large amounts like hard coal, amorphous form of the element with other complex compounds of carbon-hydrogen-nitrogen. Pure crystalline carbon is found in the form of graphite and diamond[18]. Graphite is found on every continent around the world except Australia and Antarctica and mined from numerous countries-mostly from metamorphic rocks. China is the largest producer of graphite in the world, producing 800 thousand metric tons, followed closely by India. In countries like the US, Mexico and Ceylon, graphite is obtained by underground mining[19]. Diamonds are generally found in the mineral kimberlite in Russia, Botswana, Democratic Republic of Congo, South Africa, Australia and China. They were formed millions of years ago about 100 miles below the earth's surface. Many were brought to the earth's surface by volcanic activity[20]. All forms of pure carbon are solids, but as compounds are formed gases are produced.

Carbon, in the form of carbon dioxide, is present in the atmospheres of many planets. In theory the carbon cycle here (pictured) on earth is nature's way of keeping the concentrations of carbon constant. Animals, humans, automobiles, and factories all release CO_2 into the atmosphere. The CO_2 is then used in photosynthesis by plants. Decaying organisms and the creation of fossil fuels increase the amount of CO_2 in the earth. This constant back and forth keeps the amounts of CO_2 relatively constant. While carbon dioxide is essential for photosynthesis, the concentration of carbon dioxide and carbon monoxide are increasing in the earth's atmosphere contributing to global warming. Things like burning fossil fuels and methane cause the levels of CO_2 in the atmosphere to increase while deforestation (nearly 18 million acres of forest being destroyed each year) decreases the ability of the environment to cope with increasing levels of carbon dioxide.

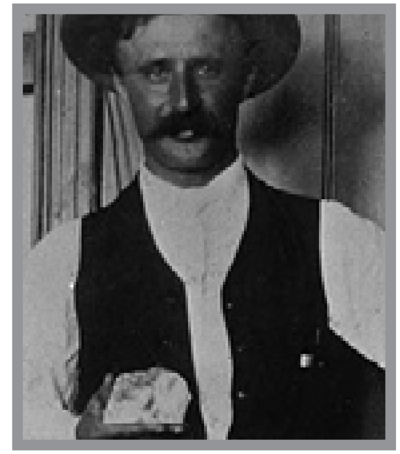


https://eo.ucar.edu/kids/green/images/carbon-cycle.jpg

Carbon is the essential element for life due to its versatility and stability. Carbon chains and rings are the structural basis for many compounds that comprise living cells including DNA, glucose and proteins[18]. In addition, the remains of living plants and animals create deposits of natural resources including petroleum, coal, and natural gases. While the creation and use of pure carbon is essential, minerals including limestone, dolomite, gypsum and marble contain carbonates.

Allotropes: The most well known allotrope of carbon is the diamond which contains only carbon and is typically colorless, but can have slight tinges of yellow, brown, gray or blue shades. It is extremely durable, chemically inactive, a good insulator, has a high melting point, and is the hardest natural substance on earth. Diamonds are used in a variety of industrial applications including polishing tools, cutting and grinding (partially because it has a relatively high optical dispersion)[20]. Researchers are hoping to be able to use man-made synthetic diamonds as semi-conductors. One reason for this is that the diamond carbon-carbon bonds are strongly connected, and have an infinite three dimensional lattice. In this lattice each carbon atom is linked to four other carbon atoms with a distance between atoms of 1.54×10^{-8} centimeters long[15]. In addition to industrial uses, the color and clarity of the diamond, along with marketing, have increased the desire for diamonds for consumers. The largest diamond ever found was the Cullinan diamond in 1905 at the Premier Mine in South Africa. It is over 10 cm long, is 3106 metric carats and has exceptional blue white color due to its clarity. Thomas Cullinan, the chairman of the mining company who found the diamond, presented it to King Edward VII as a token of loyalty. Now the diamond has been cut into nine pieces with two residing within the crown jewels of England while the others are set in brooches, rings and necklace and are on display in the Buckingham Palace State rooms during the summer of 2016[21].

Graphite is one of the softest substances known on Earth. Instead of a network arrangement, like diamond, graphite contains sheets or layers of infinitely linked carbon atoms that are covalently bonded to one another. Between the layers there are weak intermolecular forces that allow the sheets to slip past one another. This allows graphite to be used as a lubricant, as well as pencil "lead" and slide off onto paper. Graphite comes in two different forms that have identical properties, but different structures: alpha and beta forms. Graphite is also a good conductor of heat and electricity, but is difficult to ignite. A specific form of the allotrope graphite is graphene, which only contains a single layer of carbon atoms and has properties that are still being discovered and hopefully used to replace silicon in semiconductors.

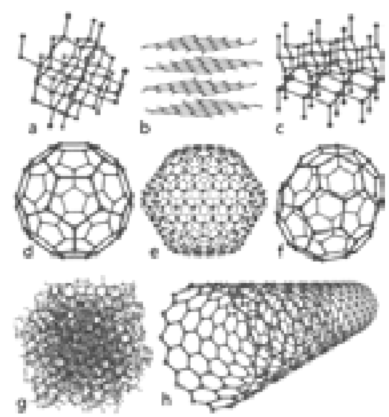


The Cullinan in its rough state

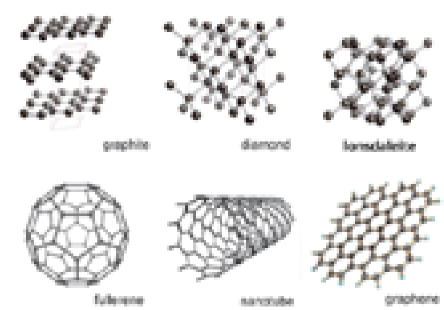
http://orderofsplendor.blogspot.com/2012/04/queens-top-10-diamonds-1-cullinan.html

The last main allotrope of carbon is called amorphous carbon and occurs when materials containing carbon are burned without enough oxygen. Amorphous carbon doesn't have a crystalline structure, but can be used to make paints, inks and rubber products. Things that are considered amorphous are coal, soot, carbon black, lamp black, gas black and channel black[7]. Most of these allotropes are created by substance decomposing under heat.

In addition to the naturally occurring allotropes, other nano-allotropes include buckminsterfullerenes (buckeyballs), nanotubes, and nanobuds. Buckminsterfullerenes are the main class of these nano-allotropes and the other two are made up of these nano-structures arranged in different ways. These fullerenes are joined similar to the individual sheets of graphite, but some of the carbon rings contain five or more carbon atoms therefore the linked rings don't remain flat, but join to form a hollow sphere or tube[15]. A popular fullerene has 60 carbon atoms in it, and takes the form of a "truncated icosahedron", a shape much more commonly recognized as a football![15]



Some allotropes of carbon: a) diamond; b) graphite; c) lonsdaleite; d–f) fullerenes (C60, C540, C70); g) amorphous carbon; h) carbon nanotube.



http://www.mdpi.com/nanomaterials/nanomaterials-04-00267/article_deploy/html/images/nanomaterials-04-00267-g002.png

Uses of Carbon Today:

Carbon is very stable both in its elemental forms (allotropes) and in compounds. These allotropes and compounds exist as functions of carbon's non-metallic character through bonding and intermolecular forces leading to a variety of different properties and uses. Many carbon containing products we encounter on a daily basis. Pure elemental carbon is found in everyday products like charcoal for fires, graphite to write with in pencils, as well as diamonds in jewelry. Common everyday occurrences that have carbon compounds are the carbon dioxide that we breathe out, the installation of carbon monoxide detectors to keep us safe from the poisonous gas, chalk for drawing on the sidewalks (calcium carbonate), limestone that monuments and tombstones are made out of that we visit, and methane (natural gas) to keep our homes warm. Some interesting applications of carbon, its compounds and allotropes are found below.

Protection from Poisonous Gas During WWI

During World War I poisonous gases were first used in warfare. Scientists needed a quick and efficient way that the air could be filtered for soldiers on the field. They tested many different respirators, many of which used granulated carbons (charcoal) with adequate adsorptive powers that had low resistance to airflow that were activated by wood chips in zinc chloride. They finally settled on coconut shell (while some reports say peach pits) because the combination with zinc chloride resulted in the characteristics required to filter air and the resulting carbon that was necessary.[22]

http://boulderhistory.org/gas-masks-world-war-i/

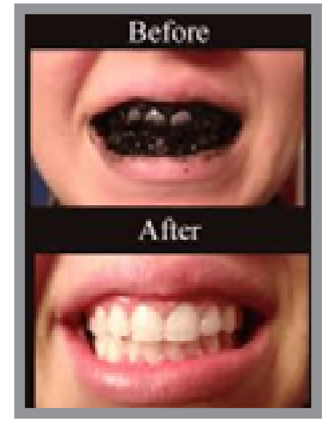
Cleaning up Radioactive Waste at Fukushima

Graphene is an incredibly thin substance being just one layer of graphite thick. Graphene oxide, as researchers at Rice University and Moscow State University found when they worked together, can bind quickly to natural and manmade radionuclides and condense them into solids. This would allow the solids to be filtered out and removed from contaminated water sources.

A new method for removing radioactive material from solutions is the result of collaboration between Rice University and Lomonosov Moscow State University. The vial at left holds microscopic particles of graphene oxide in a solution. At right, graphene oxide is added to simulated nuclear waste, which quickly clumps for easy removal. Image by Anna Yu. Romanchuk/Lomonosov Moscow State University[23]

Teeth Whitening

Let's start by saying this is not an approved American Dental Association method for whitening! But, how do you do it and how does it work? Using activated charcoal, a reheated and oxidized version of charcoal, a paste is created to brush the teeth. Although a very messy process, it has been shown to remove stains and plaque to make teeth appear whiter. How? The adhesive properties of charcoal help it bind to the surface of teeth and remove coffee, tea, wine and plaque and are removed when the paste is spit out. This is safe and harmless to ingest, in fact it is sold in health food stores in tablet form, but the method still isn't approved. Dentists at the ADA are concerned about the abrasiveness of the activated charcoal. Enamel, which once gone can't be restored, is brushed away with the abrasiveness of the charcoal. While activated carbon isn't ADA approved, carbon amide peroxide IS an approved ingredient in many approved bleaching kits both at dental offices and at home treatments.



Teeth whitened with activated charcoal.

Fire Extinguishers

Carbon Dioxide fire extinguishers are important for putting out flammable liquid and electrical fires (class B and C fire extinguishers). These extinguishers don't have a pressure gauge, are easily identified by the horn and use carbon dioxide to both cool and extinguish the substances on fire[25]. These extinguishers are more environmentally friendly than traditional class A extinguisher because the only chemical used is CO_2 which is then safely released back into the atmosphere.

Carbonated Beverages

Carbon dioxide is what allows you to have those refreshing bubbles that fizz when you open a can of soda pop. Under conditions of low temperature and high pressure, carbon dioxide is dissolved into water. This addition creates carbonic acid which decreases water's acidity from neutral to somewhere between five and six making carbonated beverages acidic.

Want to Charge Your Phone in Five Seconds?

New graphene technology that is environmentally friendly and biodegradable could be the answer. These new supercapacitors have the ability to charge phones, computers and even electric cars in a fraction of the time it normally would![27] While this has been done in a lab setting, don't expect it to come out on the market anytime soon. Graphene is still extremely expensive and time consuming to produce.

Teach All About Carbon with these Hands-on Materials:

Save 13% on these items through September 2016 **with promo code EOM16**

SAVE 13%

Click item or search by item number to see complete product details and current pricing available at boreal.com.

Graphite

CAS Number: 7782-42-5

Formula Weight: 12.01

Formula: C

Density (g/mL): 2.26

Freezing Point (°C): Sublimes

Synonyms: Carbon, Black Lead

Shelf Life (months): 36

Storage: Green

Item Number: 470301-190

Charcoal

CAS Number: 7440-44-0

Formula Weight: 12.01

Formula: C

Hazard Info: Flammable

Density (g/mL): 0.4-0.7

Shelf Life (months): 36

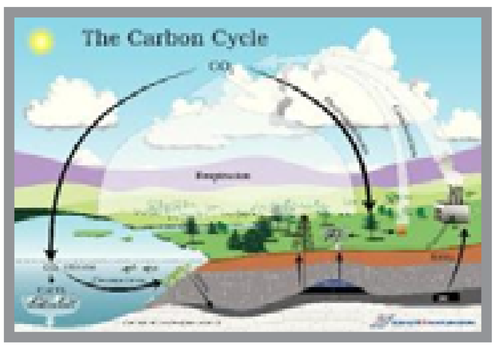
Storage: Green/Red

Item Number: 470300-688

Wards® Limestone (Gray)

Fine, common limestone; massive. Ward's offers different specimen sizes to meet your various needs: Student Specimens. Ideal for students to use for study and identification. Specimens range in size from 1" x 1" to 1" x 2" and come in packages of ten.

Item Number: 474602



Carbon Cycle Poster

A Perfect Lead-in to Lessons on Global Warming

Exceptional full color poster tracks the flow of carbon through the biotic and abiotic parts of the ecosystem. It includes illustrations of respiration, combustion, photosynthesis, mimicry, sedimentation, and decay. Size of poster: 24" x 36".

Item Number: 331601

Global Warming and The Greenhouse Effect Lab Activity

What Affects Global Warming?

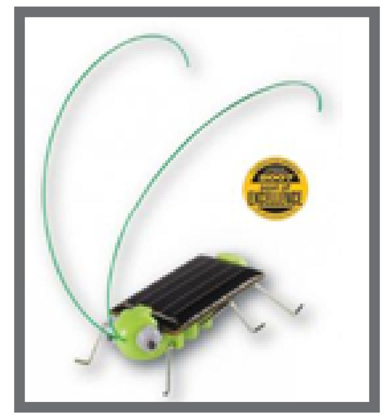
- NGSS Earth/Life Science DCIs ESS2, ESS3, LS1, and LS4
- Pre- and post-laboratory assessments
- Links to real world concepts
- Estimated class/lab time required: 180 minutes over 2–3 days

Using a plastic "greenhouse" and various other materials, students will study the causes of global warming. This will investigate the effect of different surfaces on heat absorption and greenhouse gases and suggest possible ways to reduce the greenhouse effect on our planet. An optional demonstration is also included that examines carbon dioxide's absorption of infrared radiation as compared to air.

This kit has been aligned with all published National Standards. Pre- and Post-laboratory assessments and vocabulary words all target specific Science and Engineering Practices and common core standards. The teacher guide also contains specific "Did You Know" concepts that link the real world with the scientific standards explored. A student copymaster is also included. This kit includes enough materials for five setups.

Item Number: 470213-410

Frightened Grasshopper



Teach Solar energy in a fun way with this moving grasshopper

- Solar energy activity
- Easy to assemble

Eyes jiggle; legs wiggle; and antennas sway to-and-fro is the combo tango-jitterbug-frightened-grasshopper dance. It is unmistakably an attention-grabber. This frolicking fancy is easy to assemble and demonstrates an alternative energy principle. No batteries and tools required and less than ten parts to snap together.

Item Number: 470220-176

Wards® Activated Carbon

Specially Prepared for Proper Mesh Size and Density

Add this activated carbon to your filter to help remove organic substances, chlorine residue, and other contaminants. It can be used in both freshwater and saltwater aquariums. Standard 20- to 30-gallon tanks require approximately 1 lb. of carbon.

Item Number: 214665

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