Zometool Project Series: the world's most powerful (and fun!) modeling system. Kids, educators, and Nobel-prize winning scientists all love Zometool:

- it's unique, brilliant, beautiful
- all kits are compatible—more parts, more power!
- guaranteed for life!

"The mind, once stretched by a new idea, never regains its original dimensions." –Oliver Wendell Holmes

Pure Carbon

Includes detailed instructions by Dr. Steve Yoshinaga

Parts: 162

64
30
6
40
4
18

CARBON. It's all over our planet: in gas, coal, diamonds, plastics… and all living things.

Compare graphite and diamond. Both are PURE CARBON but their properties are stunningly different. Discover why:

- *Carbon is nature's construction toy*
- *Graphite works in pencils & lubricants*
- *Diamond is the hardest known natural material (and one of the loveliest)*

PLUS: make amazing bubbles to show the structure of carbon atoms and diamond!

MADE IN USA from kid-safe materials

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WARNING: Choking Hazard

SMALL PARTS. NOT for children under 3 years.

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Structure Matters

Different forms of the same element are called *allotropes* (Greek: *allos* "different" + *tropos* "way"). Diamond and graphite, two of the best-known allotropes of carbon, are clearly put together in different ways!

Carbon allotropes include *fullerenes*, which have properties similar to graphite. The ring-like sheets of carbon atoms can form fascinating structures, such as a ball (buckyball), a tube (nanotube), or a wide sheet (graphene).

Diamond structure

Clear, dazzlingly beautiful and harder than anything else on earth, diamond's properties have everything to do with its structure. The 4 hooks of each carbon atom share electrons with one hook from each of its 4 neighbors. Chemists call these connections single bonds, because each side only supplies one electron. Diamond structure is a "natural" for carbon, since the atoms keep their tetrtahedral shape. But it's not easy to achieve: it takes immense pressure, and usually lots of time, for nature to make a diamond crystal. Diamonds are so rare and precious because conditions have to be perfect.

The perfect 10

Diamond is the hardest naturally occurring material on earth. Because it scores a perfect 10 on the hardness scale (graphite scores 1– 2!), diamond is used in dentistry, construction, mining and more. Whether you need a small hole drilled in your tooth, or a large tunnel drilled for a new subway, a diamond will lead the way. They may be a girl's best friend, but without diamonds many industries would "grind to a halt".

Doggie Diamonds

Scientists grow diamonds! Just take a tiny diamond "seed crystal", a little carbon, and subject them to extremely high pressure and temperature. You can even turn your beloved, departed pet into a synthetic memorial diamond. Fido may not be able to fetch your slippers anymore, but he can still put a little sparkle in your life as a brilliant diamond. *www.lifegem.com*

Graphite structure

Soft, grey graphite also owes its properties to its structure. Like a stack of waxed paper, graphite consists of layers of slippery carbon sheets. The difference is the way its carbons bond: atoms in graphite form a grid of hexagons, like bathroom tiles. While diamond's molecular structure is 3-dimensional, a single sheet of graphite is almost 2-dimensional.

See "The Shadow Knows" on the other side to learn how to turn diamond into graphite!

START HERE!

THE GREATEST MOLECULAR BUILDING BLOCK IN THE UNIVERSE!

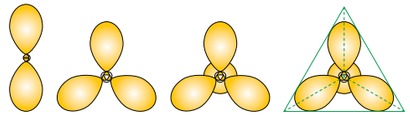
Imagine a building block so versatile it could build almost anything: bicycles, aircraft, houses, books, iPods, fuels, food… even life. *Carbon* practically forms the structural basis of our world. Not only is this kit based on carbon—so are you!

Carbon is so essential, it's earned its own field of study. *Organic chemistry* is a vital sphere of research involving carbon-based compounds as different as petroleum gas, plastics, and your DNA!

Why is carbon so important? It's all about *structure*. With this kit you can build two amazing structures formed solely by carbon atoms, *graphite* and *diamond*. Let's start with a carbon *atom*.

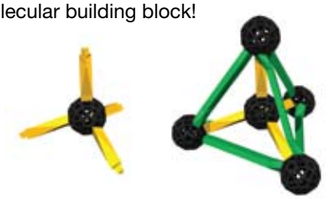
Tricky Tetrahedra!

Imagine tying four balloons together by their "necks" (or open ends). You'd have a nice model of a carbon atom. The balloons represent *electron* "clouds" and the necks, all tied together, represent the dense nucleus of the carbon atom. It takes energy to hold a carbon atom together:



the positively charged nucleus pulls the negatively charged electrons in tight, like string tying the necks together. But the like-charged electrons, like static-electric balloons, try to get as far away from each other as they can.

Now build a Zometool model of the carbon atom. Use a black ball for the nucleus and 4 yellow struts for the electrons. You have to insert them so they're pointing as far away from each other as possible, just like the electron-cloud balloons described above. You've got it when the angle between all the struts is the same (109°, for angle-heads). Put a ball on the end of each strut and connect the balls with green struts, to get a triangular pyramid, called the *tetrahedron.* This shape is why carbon is the best and most universal molecular building block!



Many from one

Electrons shared between carbons are the "hooks" that hold them together. When the carbons bond in different ways, they form very different substances. Diamond and graphite are both pure carbon. One is a dazzling crystal, the hardest natural substance in the world. The other is dull grey, and so soft that it's used as a lubricant and in pencil lead. Carbons connected in a rigid 3-D crystalline lattice make diamond, while carbons bonded in flat sheets form graphite. It's not just the type of atoms, it's how the atoms are put together that determines the properties of a substance. It's all about structure!

Bending bonding rules

Yellow struts in your diamond model are single bonds, while blue struts *usually* represent double bonds. But how can three double bonds in graphite connect to a single carbon? Carbon only has four hooks! Graphite's carbon rings (called aromatic rings, because molecules of many pleasant aromas contain them) use a hybrid of a single and a double bond. Electrons flow around the entire ring, not just between particular atoms. So remember: in flat, aromatic carbon rings, blue struts are hybrid bonds, not double bonds. The bonding rules are intact! The universe is safe!

BOND COLOR CODES

- Single Bond
- Double/Hybrid Bonds
- Triple Bond

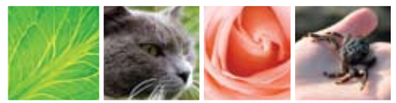
* If blue struts form a ring of atoms in an aromatic ring structure, then each bond acts as a hybrid single/double (=1.4) bond.

Slippery and strong

Graphite is used for strength or lubrication. Sheets of graphite slide on each other, like molecular patches of silk. Graphite works better than oil in machines operating at very high or low temperatures or pressures. When reinforced by epoxy resin, graphite is one of the strongest and most useful materials in the world. "Graphite composites" are extremely stiff, strong, and lightweight, and they expand very little when heated. Bicycles, tennis rackets, and stealth bombers are made from graphite composites.

Carbon builds life

Key to diamond's hard beauty, carbon's tetrahedral structure is also used by many life molecules we know and love. Sugars, fats, hydrocarbons, and the membranes that hold our cells together are just some of the molecules with carbon tetrahedral bonds. The aromatic carbon ring that defines the structure of graphite is also in great demand: nature even uses carbon hexagons to form the structure of DNA, the very backbone of all life on our planet. Carbon *is* the greatest molecular building block in the universe. You could use diamonds and graphite to build a cool robot, but nature uses carbon to build life. We're all carbon-units!



See the other side for step-by-step instructions to build diamond and graphite, activities with bubbles and shadows, and related Zometool projects.

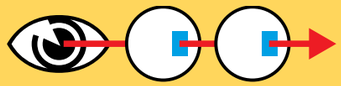
GLOSSARY

Allotrope – each of two or more different physical forms in which an element can exist, such as graphite and diamond
Aromatic Ring – molecule ring (usually carbon) with hybrid single-double bonds, in which electrons flow around the entire ring
Atom – basic unit of a chemical element consisting of a dense, positively charged nucleus surrounded by a negatively charged electron cloud
Bond – strong force of attraction holding atoms together in a molecule or a crystal resulting from sharing (or transfer) of electrons
Crystal – any solid consisting of a symmetrical, ordered, three-dimensional arrangement of atoms or molecules
Diamond – clear, colorless crystalline form of pure carbon that is the hardest natural substance—a precious stone with industrial uses
Electron – stable negatively charged subatomic unit, considered a cloud around the nucleus of an atom that causes chemical bonding
Element – one of more than 100 substances arranged by the number of protons in the Periodic Table; all matter is composed of elements
Graphite – grey, crystalline form of pure carbon that is used as a solid lubricant, in pencils, and in carbon composites
Molecule – two or more atoms bonded together in some fashion; also called a chemical compound
Nucleus – positively charged central core of an atom, containing most of its mass
Structure – systematic arrangement of parts or components in a substance, body, or whole
Tetrahedron – triangular pyramid with four triangular faces; also the structure of a carbon atom

ZOMETOOL RULES!

1 *If it works, it works perfectly.*

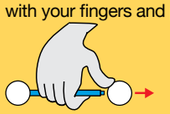
…and if it doesn't work, it doesn't work at all. Don't force Zometool components. You can bend a strut to fit it into a tight spot, but struts in finished models are always straight, never under tension.



Hint: you can tell which strut fits between two balls in a model by lining up the balls and looking through the holes. The holes show you the shape of the strut that fits!

2 *Don't break it apart; take it apart!*

Take Zometool models apart by grasping a strut with your fingers and pushing the ball straight off with your thumb. Twisting balls, pulling models apart or crushing them can cause parts to break!*



3 *Leave the place cleaner than you found it.*

It's always a good idea to clean up when you're done. If we work together, we can make the world better.

We replace accidentally broken parts for free: visit **www.zometool.com/warranty for details.*

Our mission:
- make learning fun
- create value
- build a better world

zometool®

Whether you want to ask better questions or learn better answers, Zometool is your ticket to discovery and fun. From numeracy to nanotechnology, quasicrystals to quantum mechanics, the destination is always the same: understanding our amazing universe.

Discover more at **zometool.com** or call **888-966-3386** or **303-297-3387**.

Zometool Pure Carbon Project — thanks to Dr. Steve Joshinaga, concept; Dr. Scott Vorthmann, vZome software for images; Anni Wildung, graphic design; Paul Hildebrandt, editing and project management. Contact paulh@zometool.com. Based on the 31-zone system discovered by Steve Baer, Zomeworks Corp., USA.

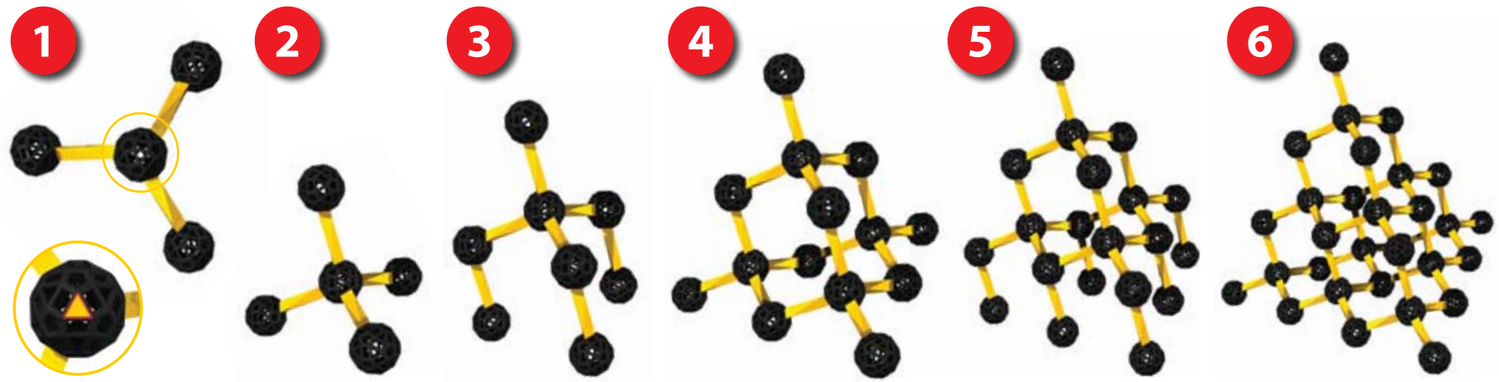
Related Project Kits:

Molecular Mania
Use carbon in concert with a few other elements to model an almost limitless variety of important compounds.

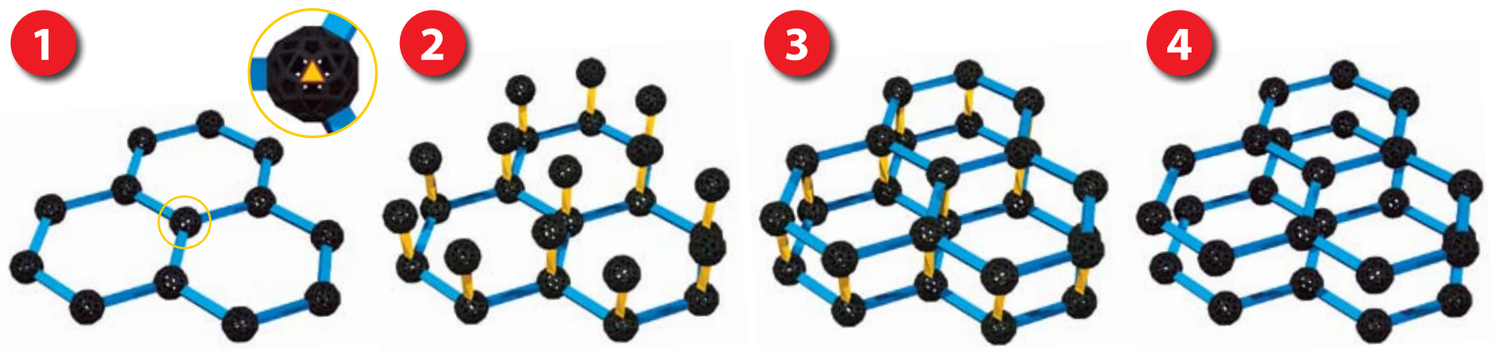
Bio Chemistry
Build the molecules that form the basis of life, and learn the big ideas of molecular biology.

Super Carbon
Build other spectacular molecules of pure carbon, including buckyballs and nanotubes.

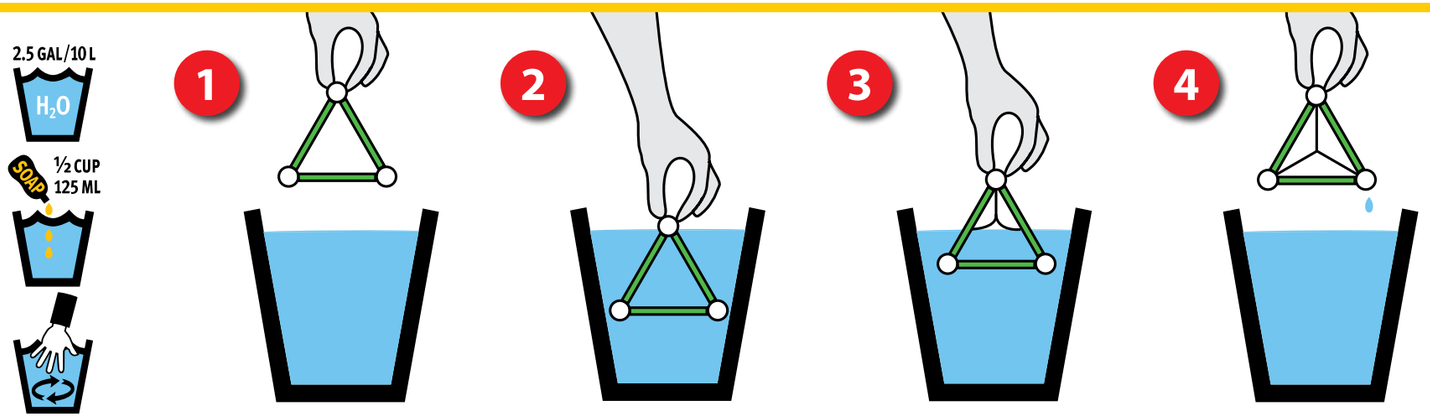
Diamond



Graphite



Bubbles

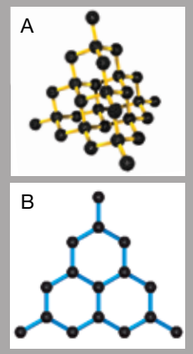


Shadows

The shadow knows...

how to turn diamond into graphite! Check it out!

You need:
- the diamond (A) and modified graphite (B) models (right)
- sunshine
- a projection surface, like a piece of white cardboard at least 30 x 45 cm (12" x 18")

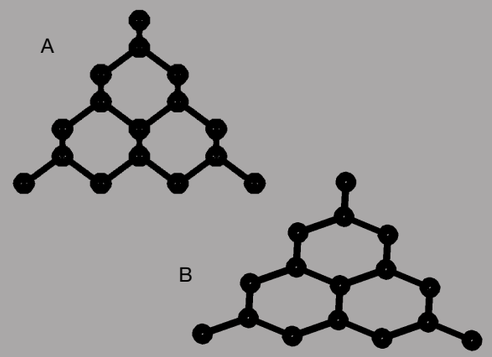


Here's how to do it:

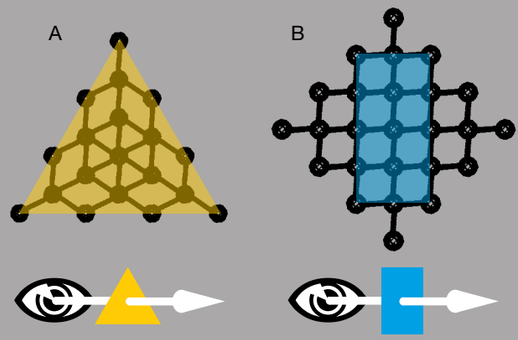
1) Hold the modified graphite model in one hand and diamond in the other.

2) Cast shadows of the two models side by side on the board (best if the board is perpendicular to the light rays so the shadow is not distorted — see pictures!)

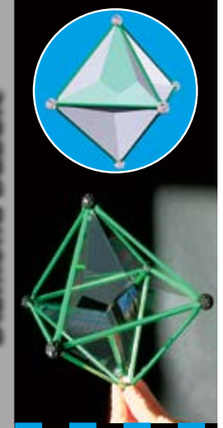
3) Move the models until the two shadows look the same (they won't be exactly the same, but they're close).



Here are some other cool shadows you can make with the diamond model. The colored shape is the same as a strut pointing directly at the sun!



Diamond Bubble



Graphite Bubble

Carbon Atom Bubble