Allotropes of Carbon

Objectives:

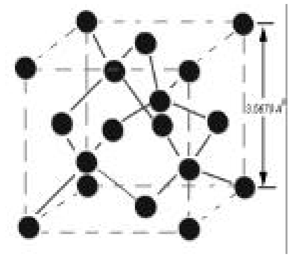
After completing this lab topic you should be able to:

1. Name and describe the properties of each of the allotropes of carbon.
2. Rationalize the mechanical and electrical properties of carbon after inspecting its crystal structure and relate it to bonding.
3. Explain how a pencil writes.
4. Geometrically analyze 3-dimensional shapes.

Introduction:

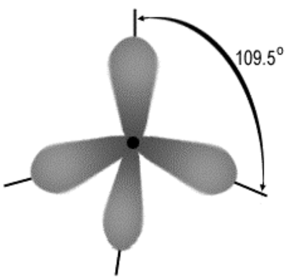
Many of the things we use in our day-to-day lives like wheat, rice, vegetables, fruits, clothes, baking soda etc. all contain carbon. Carbon is in the pencils we use, the diamonds we wear and the drill tips industries use. Carbon is everywhere. Carbon not only makes our lives convenient but, in the form of hydrocarbons, is a crucial component of life itself. Hence it is important for us to know something about this invaluable element.

Carbon is found naturally in different forms – graphite, diamonds, Buckminsterfullerenes and amorphous carbon (like coke and soot). Different forms of an element showing different properties are called allotropes of the element. How can the same element exist in so many different forms? Carbon atoms in the elemental substances (e.g., diamond, graphite, and Buckminsterfullerenes) bond to each other covalently, by the sharing of electron pairs. The covalent bonds have directional properties. This in turn gives carbon the ability to adapt into various molecular and crystalline structures. The nature of these bonds underlies the varied chemical properties and physical properties of the carbon allotropes.



TA to demonstrate
the diamond model

Carbon has 6 electrons, 4 of which are in the outer shell. The s-orbital and p-orbitals of carbon's outer electronic shell have similar energies. As a result, carbon can adapt to form chemical bonds with different geometries. For example, within diamond, one s-orbital and three p-orbitals undergo an sp^3 hybridization. The geometry of the hybridized orbital is tetrahedral. This is the reason why each carbon atom within diamond has four nearest neighbors. We will now study graphite and buckyballs and try to predict their atomic structure from their properties.



The SP^3 hybridized orbital has a tetrahedral symmetry

Lab exercise 1: Properties of Graphite

Materials:

Pencils (H, 2H, 2B, HB)	Paper
Ohmmeter	Microscope(X100)

Introduction:

Activity I

Goal: To study the morphology of graphite crystals and obtain a qualitative understanding of electrical and mechanical properties on the basis of its crystal structure.

Take out a sheet of paper and draw three lines (1 thin, 1 thick, 1 retraced 6 times) on it with a soft pencil. Then answer the following questions:

1. Can you describe the color, darkness and other qualities of these markings?

2. Inspect the lines under an optical microscope. Compare and contrast the lines. At higher magnifications, do the lines appear alike or different? Are they continuous?

3. What is the substance that is causing the color of the line?

4. Notice the 3-dimensional shape of the graphite crystals. Estimate its size.

5. Pick up the pencil and feel its core. Also pick up a piece of pure graphite. Notice what you feel. Can you explain why they feel that way?

6. We learnt that the sp^3 hybridization of the carbon atoms in diamond allows each atom to bond with four other carbon atoms. This leads to its 3-D, tetrahedral structure. Diamond is hard due to this reason. From your observation of the graphite crystals, what do you think is the arrangement of atoms in graphite?

7. What kind of hybridization do you think is present in graphite?

Activity II

Goal: To measure and relate the electrical properties of graphite to its crystalline structure.

Design an experiment to measure the resistance of the leads of the different pencils. Record your observations in the table below.

Pencil Type	Electrical Resistance (Ω)

1. Do you see a correlation between the pencil type and the resistance? Can you explain this relationship?

2. There may be some discrepancies in the above observations. This is because of errors in your measurements. What do you think are the sources of error? How can we avoid these errors?

Discussion:

1. Clay was mixed with graphite to form the pencil's core. What do you think the clay is used for?

2. Writing, drafting, and drawing pencils have number designations that tell about the hardness of the pencil core. A qualitative idea has already been obtained by noticing the variations of the darkness of the pencil line with

the pencil type. What is hardness and can you devise a way to determine this physical property?

3. Why does graphite conduct electricity?
   Hint: Think in terms of hybridization

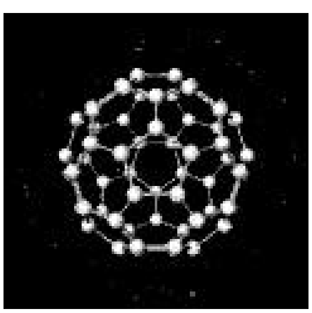
<u>Lab exercise 2: Building a Structural Model of C60</u>

Materials:

Construction paper, scissors, scotch tape, a stencil that has regular (all sides and angles are equal) pentagons and hexagons, and pen or pencil.

Introduction:

The crystalline structure of the C_{60} molecule (nicknamed Buckyball) is different from the diamond or graphite crystal in that distinct molecules form the unit cell of the crystal. The C_{60} molecules are arranged in a face-centered-cubic unit cell. The sides of this cubic cell measure 14 Angstroms. Each C_{60} molecule has a diameter of 10 Angstroms. The molecules are held together in the crystal by weak Van der Waals forces.



As shown in the model, the 60 carbon atoms are bonded together in an array of hexagons and pentagons, like a soccer ball. These molecules are called buckminsterfullerenes in honor of Buckminster Fuller who first designed similarly shaped geodesic domes.

The Buckminsterfullerene molecule is deemed to be the roundest molecule found in nature. A solid figure that most resemble this molecule is a polyhedron known to mathematicians as the Truncated-Icosahedron. We will explore the geometric aspects of the Buckminsterfullerene molecule by performing the following activity. We will also get to use a mathematical concept known as Euler's Rule for convex polyhedrons.

Activity 1:

Goal: Understanding Euler's Rule for convex polyhedrons

Look at the 3-dimensional geometric figures shown below. Note the number of faces, edges and vertices of each figure in the table.

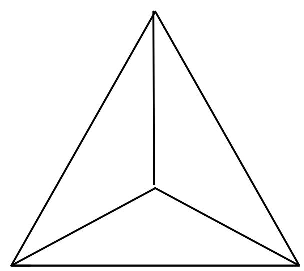


Figure 1

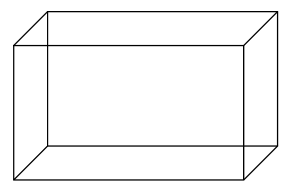


Figure 2

	No. of Faces(F)	No. of Vertices(V)	No. of Edges(E)
Figure 1			
Figure 2			

Now look at the values for figure 1. See if you can find a simple relationship between the values of F, V and E. Write down these relationships in the space below. How many such simple relationships could you find?

Now do the same for figure 2.

Does any relationship between the values of F, V and E occur in both the figures?

Does this relationship work on other geometric figures you know? If it does, then you have just found a relationship that is known to mathematicians as the Euler's Rule (named after Leonard Euler, a Swiss mathematician).

Now lets apply Euler's Rule to C_{60}. If we consider each atom in the molecule to be a vertex, we will have V = 60. We are left with two unknowns, E and F. We can easily determine the number of edges E if we are given that each carbon atom in C_{60} is connected to 3 other atoms. Now, determine the number of edges.

Now that we have only one unknown, F, it is rather straightforward to determine its value. Calculate the number of faces in C_{60}.

Each of the carbon atoms in graphite is bonded to three other carbon atoms. So is the case with C_{60}. In graphite, we saw that the atoms form hexagons. Is this also the case with C_{60}? Explain.

Is the problem solved if there were only pentagons? How about if we had a combination of hexagons and pentagons?

Now suppose that there were H hexagons and P pentagons. Formulate two equations from which we can solve for H and P. Also explain how you obtained the two equations.

Solve for H and P.

Discussion:

1. Can you have two pentagons touching each other?

2. Find out if pentagon sheets that share all their edges with other pentagons can form a flat, unbroken surface.

3. Find out if pentagon sheets that share all their edges with other pentagons can form a flat, unbroken surface.

4. In C_{60}, each vertex is shared by how many pentagons and how many hexagons?

Activity 2: Building a Model of the Buckminsterfullerenes Molecule.

Procedure:

Lay the stencil on a large sheet of construction paper. Trace the figures of pentagons and hexagons from the stencil onto the paper with a pen or pencil.

Cut the paper along the sides of the figures with scissors. Arrange the figures in appropriate configurations and tape them together to make a solid shape.

Activity 3: Chemical properties of graphite and C60

Goal: To compare the chemical properties of graphite and C_{60} and relate it to their atomic structures.

Procedure:

Take a graphite piece and C_{60} powder in separate test tubes and add water to each. Does either of them dissolve? Record your observation in the table. Now, test the samples with toluene. Record your observations once again.

Warning: Inhaling a high level of toluene in a short time can make you feel light-headed, dizzy, or sleepy. It can cause unconsciousness, and in extreme cases, even death

	Water	Toluene
Graphite		
C60		

Can you explain the results with respect to the type of bonding?