NANO-MODULE 3. Carbon Chemistry

Name: _____ Group:_____ Date: _____

Objectives:

- To understand the importance of carbon compounds.
- To visualize carbon compounds in using molecular models.
- To practice using ChemSketch to draw carbon compounds.

Key Concepts: macromolecules, carbon, fullerenes, radioactive, carbon dating, half-life, carbohydrates, saccharides, glycosemia, polysaccharides, lipids, lipophilic, green chemistry, organic chemistry

Vocabulary

radioactive: elements with unstable nuclei that tends to break down at a constant rate over time.
carbon dating: the use of carbon-14 as a tool to age rocks and fossils by analyzing the chemical composition of them.
radiometric dating: use of radioactive isotopes to date objects**.**
monomer: a single small unit.
polymer: a large unit formed by the joining of smaller units (monomers).
macromolecules: "giant molecules," consisting of hundreds or even thousands of small molecules.
carbohydrates: ('hydrates of carbon') s**accharides** (Greek for "sugar") are biological macromolecules that serve as the main source of energy for living things and as a source of structural material for plants and some animals; consist of carbon, hydrogen and oxygen in a 1:2:1 ratio.
monosaccharides: single sugar molecules.
polysaccharides: polymers of monosaccharides**.**
lipids: biological macromolecules that are not water-soluble.
lipophilic: fat-soluble.
phospholipid bilayer membrane: the waterproof covering that selects for what can pass in and out of our cells.

Background:

I.) The Element of Life

Carbon, the sixth element of the Periodic Table, is capable of forming more compounds than many other elements. The 4 valence electrons in a carbon atom can each form a strong covalent bond with other elements including hydrogen, oxygen, phosphorous, sulfur and nitrogen. Carbon's capacity to form many compounds is due to its ability to form single, double, and triple bonds with itself to form long chains and ring structures. Carbon chemistry is important for two reasons: (1) carbon can bond with each other and (2) carbon can bond to many other elements, allowing the formation of millions of different structures.

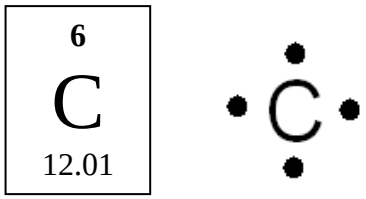

Figure 1. Element carbon and Lewis-dot structure of carbon.

Why is carbon able to form so many different compounds?

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II.) The Many Identities of Carbon

The true versatility of carbon is demonstrated by elemental carbon. The graphite point we use in pencils, the diamond rock that sits on the Queen of England's ring, and the buckyballs (spherical **fullerenes**) that are being used as hydrophobic vehicles for drug delivery[1]. All are just carbon atoms bonded to other carbon atoms. Graphite, fullerenes and diamonds all have different properties because of the different arrangement of carbon atoms.

Structurally, graphite is made up of layers of fused 6-membered rings of carbon atoms. The layers of carbon can slide past one another, which explain why graphite has a slippery feeling. Graphite is soft and is a good conductor of electricity.

Fullerenes are closed shells of carbon. The most famous arrangement is the buckyball, C_{60}, a sphere of 60 carbon atoms forming an array of 12 connecting pentagons and 20 connecting hexagons of carbon atoms.[2] The buckyball looks like a soccer ball and is an extremely stable structure. 70% of the buckyball is hollow and the open spaces in the buckyball allow water to enter.

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[1] Cornell University. "Cornell researchers create DNA buckyballs for drug delivery, demonstrating use of synthetic DNA as building blocks." <http://www.news.cornell.edu/stories/Aug05/DNABuckyballs.ws.html>.

[2] "C-60 - Buckminsterfullerene." H. W. Kroto, J. R. Heath, S. C. Obrien, R. F. Curl and R. E. Smalley. *Nature*, 318, 162-163 (1985).

Figure 2. Diamonds and a pencil with graphite.

Diamonds, the hardest naturally occurring material on Earth, is a crystalline carbon atom surrounded by a tetrahedral arrangement of other carbon atoms. Diamonds do not melt and have the highest thermal conductivity, which means that they do not overheat easily. However, diamonds cannot conduct electricity as graphite does.

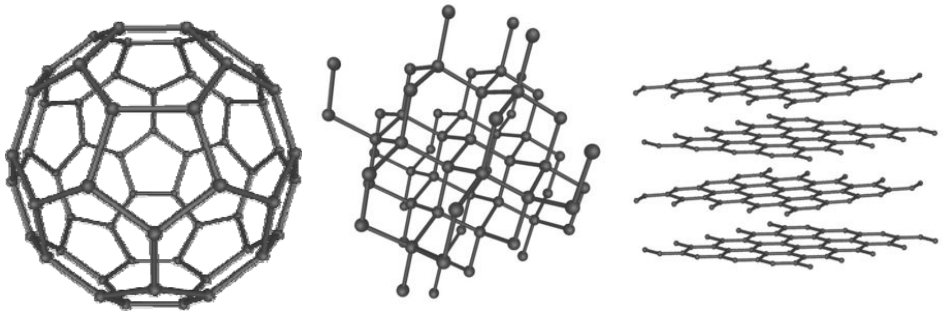

Figure 3. Structures of Buckyball, Diamond, Graphite.[3]

Why do the buckyballs, diamonds and graphite have different properties?

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III.) The Use of Radioactive Carbon Isotopes in Carbon Dating

The carbon-14 isotope of carbon has important applications. Referring back to the Introduction to Chemistry module, we learned that elemental isotopes are atoms of the same element that differ only in the number of neutrons

[3] Buckyball: Image / Michael Strock, released under GNU Free Documentation License.
Original image courtesy Wikipedia
Diamond/Graphite: Image / Itub, released under GNU Free Documentation License.
Original image courtesy Wikipedia

that they have. The most abundant carbon: carbon-12 has two isotopes: carbon-13 and carbon-14. Isotopes of elements may be **radioactive**, meaning that their nuclei is unstable and tends to break down at a constant rate over time. While carbon-12 and its isotope carbon-13 is not radioactive, carbon-14 is radioactive. Since it breaks down into nitrogen at a constant rate over time, scientists use carbon-14 as a tool to age rocks and fossils by analyzing the chemical composition of them. This is called **carbon dating**.

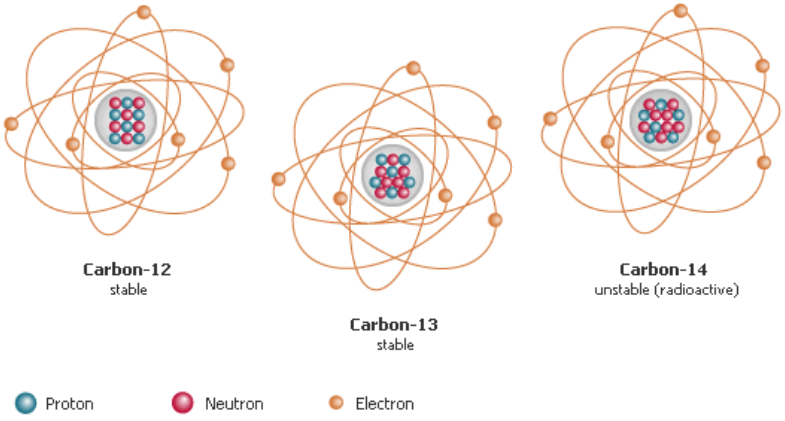

Figure 4. Isotopes of carbon.[4]

How exactly does carbon dating work? In a living organism either plant or animal, there is a constant intake of carbon-14, which is found in carbon compounds. When an organism dies, it can no longer take in carbon-14 and so the amount of carbon-14 constantly decreases as dictated by its half-life. To determine the age of a living thing, scientists then compare the amount of carbon-14 in a living creature today to the specimen being studied. Carbon-dating is not the most accurate and best technique for dating objects beyond 60,000 years of age. Other radioactive isotopes can be used to date objects such as rocks. The use of radioactive isotopes to date objects is called **radiometric dating**.

What is carbon dating?

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[4] http://encarta.msn.com/media_461535237/isotopes_of_carbon.html

IV.) Biomolecules

Macromolecules are "giant molecules," consisting of hundreds or even thousands of small molecules. These large compounds are formed by polymerization, in which the large unit (polymer) is formed by the joining of smaller units (monomers). There are four major classes of biomolecules – carbohydrates, lipids, proteins and nucleic acids.

Carbohydrates ('hydrates of carbon') or **saccharides** (Greek for "sugar") are biological macromolecules that serve as the main source of energy for living things and as a source of structural material for plants and some animals. They consist of carbon, hydrogen and oxygen in a 1:2:1 ratio. The cell breaks down sugars (i.e. glucose) to supply immediate energy for its activities. Extra sugar is stored as **starch**, which is a polymer of glucose. Single sugar molecules are called **monosaccharides**. Other monosaccharides include **galactose** (in milk) and **fructose** (in fruits). Our bodies can only use glucose, so our cells convert galactose and fructose from our food into glucose.

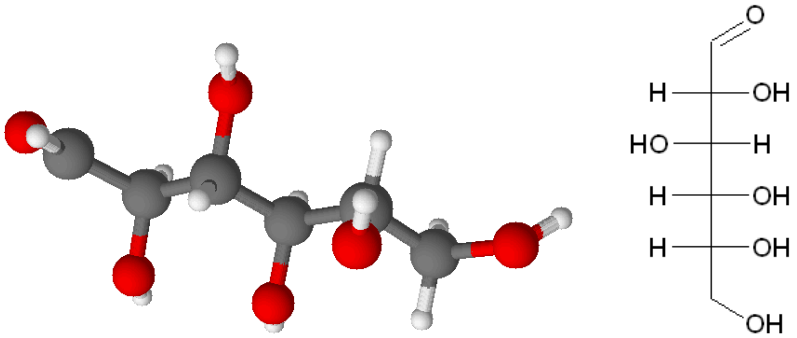

Figure 5. Glucose (Ball-stick model and Fischer projection).

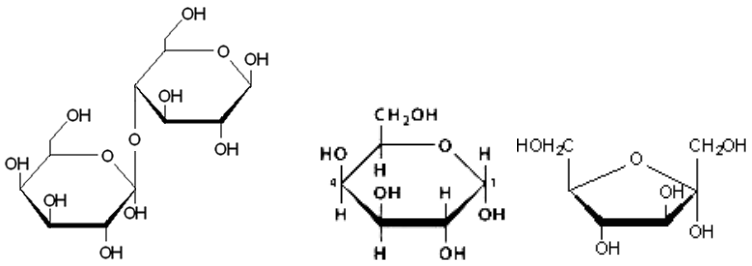

Figure 6. Lactose, galactose, and fructose.

Lipids are biological macromolecules that are not water-soluble. Instead they are **lipophilic**, which means that they are fat-soluble. Lipids include fats,

oils, waxes, steroids, cholesterol, fat-soluble vitamins (vitamins A, D, E, K), monoglycerides, and phospholipids. Lipids consist of mostly carbon, hydrogen and oxygen. Lipids serve as energy storage, structural material, and participate as signaling molecules in the cell. Our cells have a semi-permeable **phospholipid bilayer** membrane, which serves as a waterproof covering that selects for what can pass in and out of our cells. The phospholipid bilayer is home to many other biomolecules such as carbohydrates and proteins.

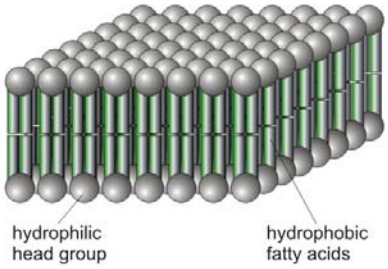

Figure 9. Phospholipid bilayer diagram.[5]

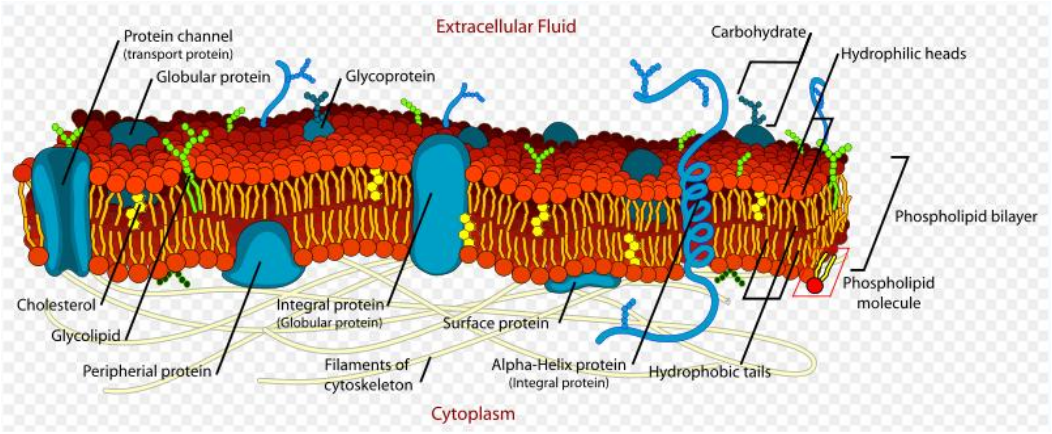

Figure 10. Phospholipid bilayer diagram with embedded proteins and cholesterol.[6]

V.) Organic Chemistry

Due to the importance of carbon chemistry, chemists study **organic chemistry**, which is a special branch of chemistry dedicated to the study of the structure, composition, properties, reactions and preparation of carbon compounds. Organic compounds consist of mostly carbon and hydrogen but they can also contain the halogens, nitrogen, oxygen, silicon, sulfur, and other

[5] http://www.fz-juelich.de/inb/inb-1/ion_channels/
[6] Cell membrane detailed diagram: Image / Mariana Ruiz released under GNU Free Documentation License. Original image courtesy Wikipedia

elements. Organic compounds are classified by the type of functional groups they contain. Functional groups are responsible for the behavior of the organic compound. Compounds containing the same functional groups undergo the same type of reaction.

Important Functional Groups

Functional Group	Name
	Alkane
	Alkene
	Alkyne
 X= (F, Cl, Br, I)	Halogen
	Hydroxyl
	Carbonyl
	Carboxyl
	Ester
	Amine

Table 1. Functional groups (R = H or hydrocarbon).

VI.) The Future of Energy and Green Chemistry

There has been an ongoing concern about the future of energy. With our consumption surpassing our production of petroleum and our strong dependence on oil and other fossil fuels, our world has been hit with issues of decreasing resources and rising costs. In comparison to fossil fuels, we have a low consumption of nuclear and renewable sources of energy such as wind and solar energy. Currently there have been efforts to use corn as a source of ethanol to power our cars instead of diesel fuel. The nature of ethanol and other possible ways of getting energy from organic materials has been a hot area of research bringing together carbon chemistry, engineering, and world economics.

With the limited resources given to us on Earth, there has been a push to enforce recycling, reducing energy use and switching to energy saving appliances. With preservation of our resources in mind, we have looked to the “design of

chemical products and processes that reduce or eliminate the use or generation of hazardous substances."[7] This area of study is called **green chemistry**, or sustainable chemistry. Green chemistry involves every step of developing a chemical product: the design, production, and use.

Currently, researchers are looking for ways to use plants and convert them to usable products or valuable sources of energy. This is particularly promising since plants naturally degrade without leaving harmful waste. Instead, decaying vegetation can be used as compost and fertilizer.

VI.) Plastics!

Biodegradable plastics have use for packaging, gardening and catering products. For example, there are now biodegradable garbage bags and flower pots. Some biodegradable plastics that are already out on the market include starch and starch blends, polylactide acid (PLA), and poly-3-hydroxybutyrate (PHB). The starch plastics make up 80% of the bioplastics market and are being used in the production of drug capsules.[8] PLA is being used for various types of packaging, including foil, cups and bottles. PHB is also being used for packaging plastics and is now being explored for use as a material for tissue engineering and drug-release carriers.[9],[10] The Society of the Plastics Industry has made a resin identification code system used to class different types of plastic so that it would be easier to recycle materials. You probably have seen several of these symbols on the bottom of various plastic products.

[7] http://www.epa.gov/gcc/
[8] http://www.bioplastics24.com/content/view/248/68/lang,en/
[9] http://www.springerlink.com/content/r775p261703904u3/
[10] http://www.sciencemag.org/cgi/content/abstract/256/5056/520

Symbol	Acronym	Full name and uses
1	PET	Polyethylene terephthalate - Fizzy drink bottles and frozen ready meal packages.
2	HDPE	High-density polyethylene - Milk and washing-up liquid bottles
3	PVC	Polyvinyl chloride - Food trays, cling film, bottles for squash, mineral water and shampoo.
4	LDPE	Low density polyethylene - Carrier bags and bin liners.
5	PP	Polypropylene - Margarine tubs, microwave-able meal trays.
6	PS	Polystyrene - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	Other	Any other plastics that do not fall into any of the above categories. For example melamine, often used in plastic plates and cups.

Table 2. SPI resin identification code system[11]

Useful Links:

"Advances in Drug Delivery Systems"
http://pubs.acs.org/subscribe/journals/mdd/v04/i04/html/MDD04FeatureVogelson.html

"Good things in small packages: Nanotech advances are producing mega-results in drug delivery."
http://pubs.acs.org/subscribe/journals/mdd/v07/i07/html/704feature_willis.html

Energy Information Administration
http://www.eia.doe.gov/

USA Today: "Green Chemistry Takes Root"
http://www.usatoday.com/news/science/2004-11-21-green_x.htm

United States Environmental Protection Agency: Green Chemistry
http://www.epa.gov/gcc/

Green Chemistry At The University of Oregon
http://www.uoregon.edu/~hutchlab/greenchem/

[11] http://www.doitpoms.ac.uk/tlplib/recycling-polymers/printall.php

Greener Education Materials for Chemists
http://greenchem.uoregon.edu/gems.html

American Chemical Society Green Chemistry Institute
http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_TRANSITIONMAIN&node_id=830&use_sec=false&sec_url_var=region1

Green Chemistry Network
http://www.rsc.org/chemsoc/gcn/index.htm

The New York Times: "A Plastic Wrapper Today Could be Fuel for Tomorrow"
http://www.poly.edu/news/_doc/article_103/GrossNYTarticle.pdf

How Carbon-14 Dating Works
http://science.howstuffworks.com/carbon-141.htm

Chronological Methods 8 – Radiocarbon Dating
http://id-archserve.ucsb.edu/anth3/courseware/Chronology/08_Radiocarbon_Dating.html

Green Plastics: the home page for environment-friendly technology in the new millenium
http://www.greenplastics.com/

Bioplastics, Resources, Emission|What are bioplastics?
http://www.bioplastics24.com/content/view/111/110/lang,en/

Earth 911
http://earth911.org/

US EPA Student Center – Waste and Recyling
http://www.epa.gov/students/waste.htm

Plastics Division: Learning Center
http://www.americanchemistry.com/plastics/sec_learning.asp?CID=1102&DID=4256

Plastics Division: resin identification codes
http://www.americanchemistry.com/s_plastics/bin.asp?CID=1102&DID=4645&DOC=FILE.PDF

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Name: _____ Group:_____ Date: _____

Match-up: Match the definition with the term.

A. organic chemistry
B. radioactive
C. lipophilic
D. green chemistry
E. lipids
F. carbohydrates
G. phospholipid bilayer
H. carbon dating

1. biological macromolecules consisting of carbon, hydrogen and oxygen in a 1:2:1 ratio ____

2. describes our semi-permeable cell membrane ____

3. lipophilic, biological macromolecules ____

4. describes atoms with unstable nuclei ____

5. fat-soluble ____

6. the use of carbon-14 as a tool to age things by analyzing the chemical composition of the substance ____

7. the "design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances."____

8. special branch of chemistry dedicated to the study of carbon compounds ____

NANO-MODULE 3. Carbon Chemistry

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Pre-lab Questions

Please answer the following questions to the best of your ability (use your own brain and outside sources if needed) in the space provided below.

1) How many valence electrons does carbon have?

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2) Why is carbon considered to be the most versatile (flexible, for our purposes, in terms of bonding) of all elements?

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3) What are two reasons why carbon chemistry is so important, so important that it has its own branch of study?

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NANO-MODULE 3. Carbon Chemistry

Name: _____ Group:_____ Date: _____

Post-lab Questions

1) Why do you think the element carbon is considered the chemical basis of life?

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2) What are some problems with carbon dating?

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3) Read and summarize in at least 100 words the *New York Times* article*: "A Plastic Wrapper Today Could Be Fuel for Tomorrow"* provided in the useful links section above.

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