Molecular Literacy for All

Course Syllabus

Fall 2020

Instructor: Jeff Moore (jsmoore@illinois.edu)

Timetable – Molecular Literacy for All

Session	Topics	Optional Reading
Session 1 Day: Monday, August 31, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Atomic structure; the elements; isotopes; ions; valency – the power of an atom to make molecules	**Week 1 Optional Reading** Composition of the human body; atomic weight calculator; clarifying atomic weights; molecules in space; dietary guidelines; food labels
Session 2 Day: Monday, September 14, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Covalency and a model to combine atoms and make molecules; diatomic molecules; electron pairs; lone pairs; electron pair domains (EPDs)	**Week 2 Optional Reading** Valence, Oxidation Number, and Formal Charge: Three Related but Fundamentally Different Concepts; First Molecule; Methane
Session 3 Day: Monday, September 21, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Patterns of bonding; predicting the geometry of atoms; charge	**Week 3 Optional Reading** Ampicillin; nitrate in beetroot; TMAO; ammonium nitrate;
Session 4 Day: Monday, September 28, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Bonding concepts; connectivity maps; oxidation state; bonding for P and S; the molecular universe	**Week 4 Optional Reading** Why nature chose…carbohydrates; …phosphates; chem space1; chem space2
Session 5 Day: Monday, October 5, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Isomers; spatial relationship of atoms in molecules; chirality	**Week 5 Optional Reading** Thalidomide; Carvone; Red cabbage indicator;
Session 6 Day: Monday, October 12, 2020 Time: 9:00 – 10:30 a.m.	**Topics** Polymers; building blocks of life; lipids; monosaccharides; amino acids; nucleotides;	**Week 6 Optional Reading** As simple as can be;
Session 7 Day: Monday, October 19, 2020 Time: 9:00 – 10:30 a.m.	**Topics** From CO_2 to CO_2: life through the lens of a molecule; photosynthesis, simple sugars; complex sugars; the Milliard reaction; taste	**Week 7 Optional Reading** Maillard Reaction; taste receptors;
Session 8 Day: Monday, October 26, 2020 Time: 9:00 – 10:30 a.m.	**Topics** From CO_2 to CO_2: life through the lens of a molecule; digestion; absorption; fermentation; A1c; metabolism	**Week 8 Optional Reading** Fructose metabolism – new findings; A1c and glycated hemoglobin; Amadori rearrangement

Introduction

Our world is molecular-based and molecular science fills our lives each day. The language of molecules is a communication barrier that prevents us from exploring and understanding topics of interest to us: the food we eat, the medicines we take, the chemicals in our environment, the clothes we wear. This course will guide the learner on a playful journey that introduces the language of molecular science. Our goal is to make learning this language enjoyable, broadly accessible, and useful in everyday life. The course strives to engage the learner in interactive ways to empower the learner with practical tools to explore the world of molecules in whatever direction the learner wishes to pursue.

Aims of the Course

Above all else, this course aims to be an enjoyable and fulfilling learning experience. You all come to the course hoping to get something out of it, but that something is different for each of you. There may be times when you are frustrated, as some of the concepts may seem too technical or confuse you. Who doesn't get frustrated when learning something that challenges thinking in new ways? It's perfectly fine. Set it aside but come back and try again!

I hope the course leaves you with tools, confidence, and interest to explore everyday molecules every single day of your life. For each day you explore, you will get more familiar with the molecular world. I hope the content piques your curiosity and inspires you to view our world through a new lens that's shaped by molecular thinking. I hope your journey of exploration continues to fulfill you long after the course ends.

We will develop simple, but scientifically-grounded principles and models from physics, chemistry and biology and use them as a bridge to link the world we observe with the invisible nanoscopic world of molecules.

Why "Molecular Literacy"?

Words of a language help to form our mental concepts. Sentences are combinations of concepts (i.e., our thoughts). Thoughts are representations that help us make sense of the world. Therefore, the language of molecules helps us to construct concepts about the invisible nanoscopic world.

Expectations – the Learners

"But as I learned more about science, I realized that it doesn't require genius at all. It requires dedication, curiosity, and comfort in going against the grain of society. What all great scientists have in common is not some common innate ability, but the ability to identify what they don't understand and to respond by learning the information already available or by doing the work to uncover the unknown."[*]

- Be engaging, and ask questions
- Questions that clarify concepts for the discussion are best asked during course time. Questions that are tangential and mere curiosities are encouraged but they are best asked privately (by email) to the instructor. Please be mindful of your fellow students and our precious time together.
- Dive in as deep or as shallow as YOU want to go. There's enough content in this course to keep you working an hour or more every day. Maybe you only want a light brush with the subject. If that's your preference, no problem. You're welcome just the same. All you have to do is show up for class every Monday.
- Be respectful of one another.

[*] https://qz.com/work/1286549/imposter-syndrome-lets-toxic-work-culture-off-the-hook/

Expectations – the Instructor

- Be prepared each Monday to deliver a lecture that informs, motivates, and is relatable to everyone.
- Provide lecture notes in advance of each lecture. I will do my best to provide notes on the Friday prior to each Monday's lecture.
- I promise to answer your email questions promptly and thoroughly, insofar as possible.
- I will do my best to promote a learning environment where everyone is welcomed and valued.
- I will do my best to never let arrogance exceed my ignorance.
- Learners who wish to put the coursework into action are encouraged to keep a daily journal that captures his/her thoughts and experiences. Journal entries that match your interests and sustain your enthusiasm are best determined by you. Nonetheless, I am always pleased to provide prompts to challenge your thinking. Just email me if you need a daily prompt. It's no bother at all!

Summary of Intended Learning Objectives

- Increase your awareness of molecules in our everyday world
- To introduce the atomic structure of the elements
- To use covalent bonding models to interpret molecular structure
- To understand the relationship between 2D and 3D representations of molecular structure
- Appreciate why nature chose certain molecule types and not others
- To introduce the structures of the biological macromolecules – proteins, nucleic acids, and carbohydrates
- To put your knowledge to use by following a journey from CO_2 to CO_2: life through the lens of a molecule

Instructor contact information

All questions related to the course content are welcome. While clarifying questions are encouraged during the lecture, please email other questions to jsmoore@illinois.edu

You can follow me on Twitter @mechanophore

Enjoy these books

- *The Same and Not the Same* by Roald Hoffmann
- *Organic Chemistry: Principles in Context* by Mark Green
- *Nature's Robots* by Tanford and Reynolds

Lecture Synopses

Week 1 – *The composition of things.* This lesson introduces learners to atoms as the building blocks of molecules. It teaches the organizational principles of the elements in the periodic table. It introduces isotopes and the concepts of atomic weight. A model to understand electrons in atoms is discussed along with the concept of valency.

Week 2 – *Every breath you take*. This lesson presents a simple but powerful model to describe atomic bonding and the way that atoms come together to make molecules. Bonding in the gasses that we breathe is presented. The concept of the electron pair is introduced. We'll answer the question: What was the first molecule in the universe.

Week 3 – *Molecules intersect our lives every day*. This lesson assists the learner in the interpretation of molecules in our everyday lives. The learner is taught to unpack a molecule as a collection of atoms, each one involved in electron sharing. The geometry and charge of each atom is determined by the covalent bonding model. We'll use this to understand why ampicillin is a unique molecule. Then we will interpret the structure of a molecule in the news – TMAO. An interactive tool for visualizing molecules in 3D is presented.

Week 4 – *Why nature chose…*This lesson summarizes concepts of bonding and uses the model to understand the special characteristics of select molecules in life. We will learn how chemists experimentally determine the structure of molecules. We will look at bonding in sulfur and phosphorus. The concept of oxidation state will be introduced. We will discuss the vastness of the molecular universe.

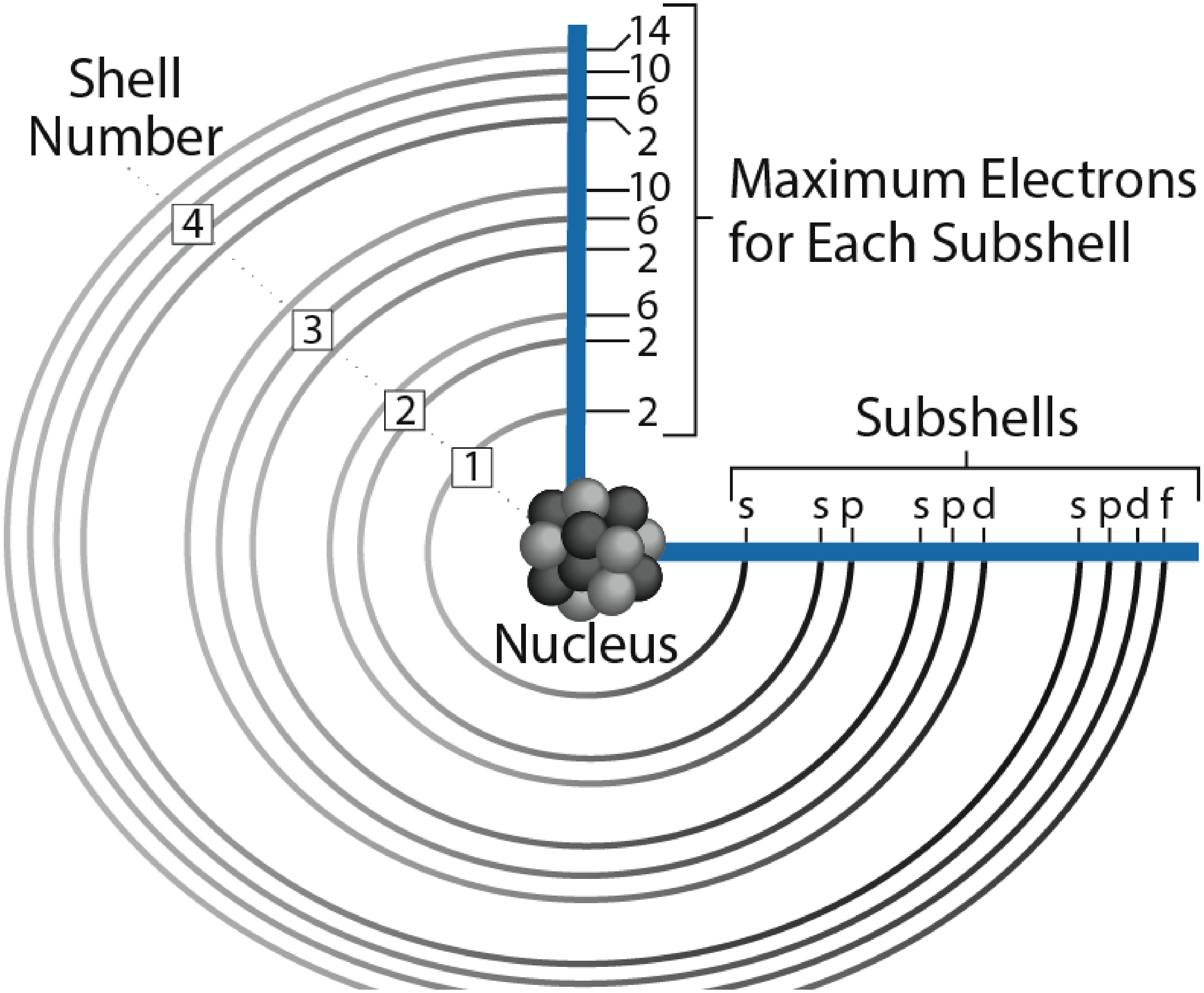
Week 5– *The Same and Not the Same*. This lesson motivates the concept of stereochemistry – how atoms in molecules are arranged in three-dimensional space. We'll talk about molecules that may appear to be the same on paper, are not the same when visualized as three-dimensional objects.

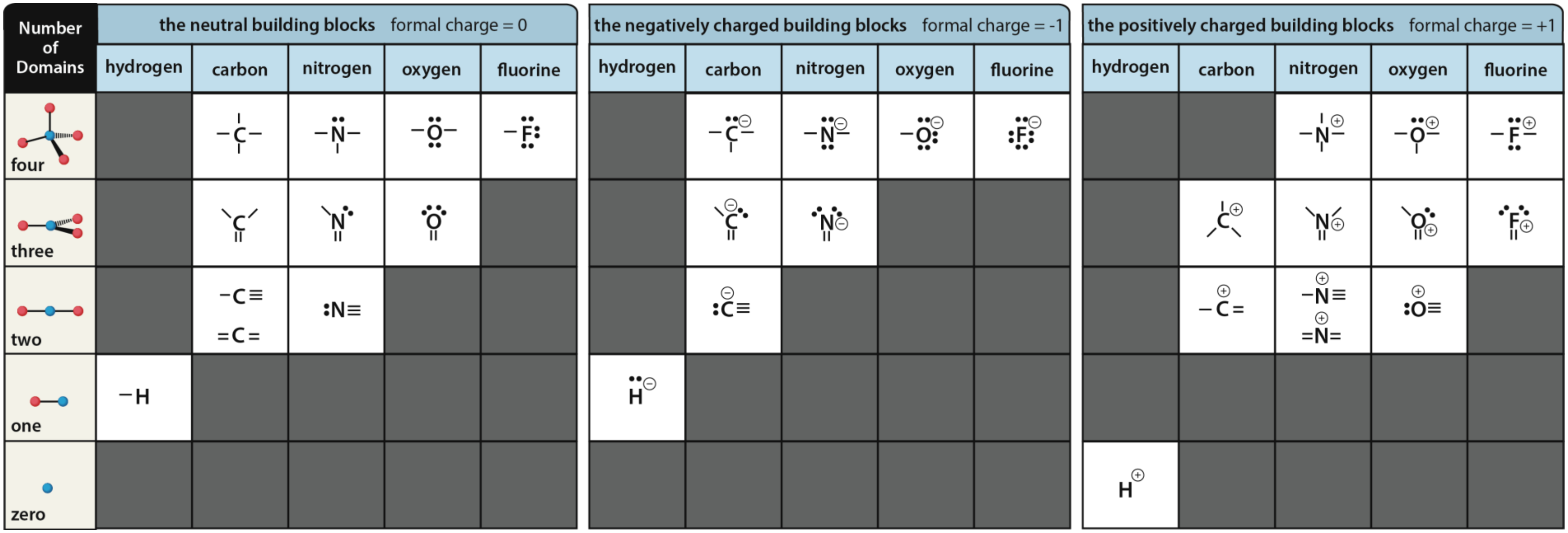
Week 6 - *From Starch to Dietary Fiber to Wood.* This lesson introduces learners to polymer molecules. The molecular building blocks of natural polymers – carbohydrates, proteins and polynucleic acids (e.g., DNA and RNA) are presented. These three natural polymers are made from the molecular building blocks of monosaccharides, amino acids, and nucleic acids.

Week 7 – *From CO_2 to CO_2*. In the next two lessons we'll follow the journey of a CO_2 molecule, from photosynthesis to respiration. From simple sugars (like fructose) to complex sugars (like starch) as plant products that get cooked and undergo the Milliard reaction and profoundly influences taste. Molecules exhibit properties that impart an almost social presence. They interact with one another through their size, shape, and attractive and repulsive forces. These features give molecules information-rich surfaces that allow their interactions to be selective. Molecular recognition occurs on our tastebuds and it stimulates a pleasure response that keeps us coming back for more.

Week 8 – *From CO_2 to CO_2.* We'll continue the journey of a CO_2, now having been consumed and tasted. Armed with molecular literacy, the learner will be able to follow the journey taken by a fructose molecule, from ingestion to chemical conversion that provides the cell with energy and raw materials. Along the way, the fructose may be converted to glucose. Glucose is absorbed and transferred to the blood. Most glucose goes on to fuel the body. But glucose in the blood might react with hemoglobin to raise your HbA1c number. Eventually it gets consumed by respiration to produce CO_2 and the cycle begins again.

This graphic provides the primary postulate on which we will base our understanding of molecular structure and bonding. When combined with the idea that atoms seek to bond to other atoms in order to fill their electron shells to maximum capacity, we'll develop a model that will help you see why atoms of different elements bond with certain patterns to other atoms. Interested learners may wish to understand the theoretical basis of this postulate. However, in this course, we will accept it as truth. We will encounter and discuss a few important exceptions. But by and large, we will gain a richer understanding of the molecular world because of the predictive power that this postulate and its models provides.





The patterns of bonding atoms in molecules. These patterns are like the building blocks of a LEGO set. This table provides a concise summary of the building blocks of molecules. Any molecule can be deconstructed one atom at a time. Each atom must follow one of the arrangement of electrons seen in this table. The number of domains (electron pair domains or EPDs) determines the geometry at that atom.

Number of Domains	the neutral building blocks formal charge = 0					the negatively charged building blocks formal charge = -1					the positively charged building blocks formal charge = +1				
	hydrogen	carbon	nitrogen	oxygen	fluorine	hydrogen	carbon	nitrogen	oxygen	fluorine	hydrogen	carbon	nitrogen	oxygen	fluorine
four		C	N	O	F		C	N	O	F			N	O	F
three		C	N	O			C	N				C	N	O	F
two		C C	N				C					C	N N	O	
one	H					H									
zero											H				

This page gives you a blank table so that you can print it and practice drawing the building blocks yourself.