Jan 25 - Biochemistry II: Carbohydrates, proteins

Remember chemistry from previous lecture: matter, element, atom, proton, neutron, electron, orbital/valence shell, atomic number, bonds (ionic, hydrogen, single covalent, double covalent, etc.), ion, molecule, compound, molecular formula, structural formula (aka "ball and stick"), electron dot diagram, chemistry of water and the properties of water we discussed and why H_2O is essential for life.

Despite the vast diversity of life on Earth, and the ~92 naturally occurring elements (see periodic table), the large molecules that are built by, are universal among, and are essential to living organisms are relatively few in number. They are called biomolecules:

Biomolecule: any molecule that is essential to cell structure and function and is produced by a living organism.

Some biomolecules are small (e.g., vitamins, hormones), but we will explore four types of large biomolecules, they are:

1) Carbohydrates (today's lecture)
2) Proteins (today's lecture)
3) Lipids (next week in lab)
4) Nucleic acids (later in the semester)

In today's lecture we consider carbohydrates and proteins, and we'll explore lipids and nucleic acids in future lectures/labs.

I. Carbohydrates (can you infer why from the molecular structure?)

There are three different categories of carbohydrates:

1) Monosaccharides* (mono: *one* + sakkharon: *sugar*)
2) Disaccharides* (di: *two* + sakkharon: *sugar*)
3) Polysaccharides (poly: *many* + sakkharon: *sugar*)

As with most other aspects of biology, the form (i.e., structure) of different sugar molecules directly relates to their function (form and function at a molecular scale – how cool!).

** mono- and disaccharides are referred to as "sugars"*
**note that almost all carbohydrates have names that end in "-ose" (see examples below)*

Monosaccharides: (single unit sugars; the smallest sugar molecules).
Fuel source for cells (especially true of glucose). When C-C bonds are broken, energy is released.

Glucose ($C_6H_{12}O_6$): THE primary fuel source for cells – stay tuned!! Glucose is the main product of photosynthesis and is broken down as a cellular fuel during respiration – thus it is found very widely in plant cells (know and recognize simplified "ring" structural formula)

Fructose (**$C_6H_{12}O_6$** – but with a different structural formula than glucose): ("fruit sugar"; sweetest of all sugars listed here…). Found in fruits and in the nectar of some plants – why?

Monosaccharides are the smallest carbohydrate molecules. Larger carbohydrates molecules are constructed by linking together individual monosaccharides.

Disaccharides (two unit sugars) are formed by linking together two monosacharides. One important disaccharide for plants:

Sucrose = glucose + fructose ("table sugar"). Common in many plant parts, sucrose is the "transport sugar" – that is to say sugars are moved about the vascular tissue of a plant primarily as sucrose.

Commercial sources of sugar in include mature stems ("stalks") of sugar cane (*Saccharum* spp., POACEAE) or the fleshy taproot of sugar beets (*Beta vulgaris*; AMARANTHACEAE). [FYI: The former is ~15% fiber, 15% sugar, and 65 % water, the latter is 70% water, 25% sucrose, and 5% pulp. Cane is tropical and beets temperate. The basics of production are as follows: the plant parts are pressed, water is allowed to evaporate out of the liquid that is obtained, and sucrose remains in [high]! The sucrose is crystalized, molasses remains.]

Maple syrup is mostly sucrose, but contains minerals and other sugars. Its production from the sap of maple trees (*Acer* spp., SAPINDACEAE) was described in lecture.

Sucrose is also a major constituent of nectar in flowers of many plants.

Polysaccharides: large carbohydrates that are constructed of many monosaccharides (all of which are glucose in Bot 100). The glucose subunits are bonded together in long chains, or as long chains that branch or become cross-linked.

Polysaccharides serve two important functions:
1) long term storage of energy (sugar molecules)
2) provide physical structure of plant cells tissues

The are many types of **polysaccharides**, we will focus on three in this class:

Starch – Storage polysaccharide in plants. Built entirely from individual glucose molecules. Serve as storage bank from which plants can remove glucose molecules for fuel. [FYI: there are two forms of starch: **Amylose** (unbranched polymer of glucose monomers); **amylopectin** (branched polymer of glucose monomers). I will not ask you about this on quizzes and exams].

Cellulose – Plant structural molecule. In the cell walls of plant cells. A polymer of glucose molecules that are linked together (chemically bonded) in such a way that the individual molecules can NOT be digested by animals! Fungi and bacteria are the only organisms capable of digesting cellulose. So – any animals that derive energy from cellulose do so by harboring bacteria in their digestive system that are capable of breaking the glucose-glucose bond in cellulose – that's how cows and termites do it!!
The fact that no animal can digest cellulose (without the aid of symbiotic bacteria or fungi) makes cellulose a long lasting and durable structural molecule.

Chitin – Structural polysaccharide found in cell walls of fungi.

II. PROTEINS

Proteins: Functioning biological molecules that are long chains of amino acids

Amino acid: the subunit or individual "link" in a protein "chain"; there are twenty different amino acids from which all eukaryotic proteins are constructed (over 100,000 proteins ID'd in Eukaryotes – amazing diversity from just 20 subunits!!). The twenty different amino acids are very similar to each other, and differ only in the side chain, or "R group", attached to the central (aka *alpha*) carbon.

R group (aka: **amino acid side chain**): the atom or molecule bonded to the alpha (*middle*) carbon in an amino acid, and which determines the identity of an amino acid.

> R groups are conceptually important because R groups in an amino acid chain (protein!) chemically attract or repel each other and cause the protein to fold into a specific 3-D shape. This shape then determines the job that the protein does. Again: <u>Form = function</u>!

It is commonly said in biology, especially on exams (!!!) that: <u>A protein's **shape** determines its **function**</u>**.**

Denatured: When a protein loses its shape, it loses its function. A protein in such condition is said to be **denatured**. Common causes are excessive heat, toxins, and cell chemistry imbalances (e.g., pH or ionic solutions).

<u>**Protein function**</u>:

OK, so we now know a little bit about protein structure, but how do they function and what do they do in the tissues of organisms? Proteins have two general functions:

1) **Provide structure** in cells and tissues (mostly in animals – plant tissue is mostly cellulose)
2) **Do work** in cells

In Botany 100 we will really only focus on one class of proteins called *enzymes*. They "do work".

Enzymes: Proteins that catalyze chemical reactions (the making and breaking of chemical bonds – don't worry about how they do this, but we can chat in office hours if you are curious). **Nearly all enzymes have names that end in "–ase**". (EX: **sucrase** – catalyzes reaction of sucrose into glucose and fructose subunits – see sucrose, above).

A single protein (including enzymes!) has **one highly specific function** or job. Organisms can do complex work (such as building large molecules) because they have "assembly lines" of many many specific enzymes – just like Henry Ford's innovation for building the first Model T.

Proteins such as enzymes are fundamentally important biomolecules, and they warrant our attention for that reason. We identified three specific and applied concepts in botany that have to do with proteins. These were:

1) Many plants are adapted to minimize heat stress in order to avoid protein denaturation
2) Glyphosate herbicides (inhibit construction of three amino acids – thus proteins can't form and plants die…).
3) Nitrogen fixation

(*For items 1 and 2 – consult your lecture notes!)*

Plants and nitrogen fixation

Note that every third atom in a protein chain backbone is a nitrogen atom. Organisms must acquire the nitrogen needed to build amino acids, and by linking amino acids together, assemble proteins.
Q: Where do organisms acquire nitrogen to build amino acids?
A: Ultimately, the atmosphere!!…but… the way nitrogen gets form the atmosphere into organisms is an interesting story…

Composition of Earth's atmosphere:
~ 76% nitrogen gas (N_2, aka *molecular nitrogen*)
~ 20% oxygen gas (O_2, aka *molecular oxygen*)
~ 2% water vapor (H_20)
~ 0.03% carbon dioxide (CO_2)

Based upon the composition of Earth's atmosphere, it would appear as though organisms can easily access nitrogen. This is not the case!! The two nitrogen atoms present in molecular nitrogen (N_2) are bonded together with a triple bond (you should be able to see why based upon what you know about the atomic structure and how covalent bonds are formed…what a GREAT exam topic!!).

This triple bond is extremely difficult to break, and therefore the N atoms in N_2 are inaccessible to nearly all biological organisms. Before N atoms can be accessed and used by most organisms, the N atoms must be liberated from the triple bond that holds them together. After this bond is broken, N atoms bond with hydrogen atoms to form ammonium (NH_4^+) , or with oxygen atoms to form nitrate NO_3^- that organisms (plants) can assimilate and/or subsequently dismantle to acquire N atoms.

As with carbon – ALL ANIMALS AQUIRE their N atoms form the plants they eat (or that some other heterotroph has eaten…).

This is a complicated process. For this class, you need to know the following:

1) N_2 is triple bonded and most organisms cannot access N from this molecule
2) N_2 is converted to molecules that are usable to living organisms by a process called **nitrogen fixation.** [By the way, these molecules are ammonia (NH_3) or nitrate (NO_3^-)]
3) All nitrogen in living organisms was once removed from the atmosphere through nitrogen fixation and subsequently absorbed into plant tissues before being eaten by heterotrophs or decomposed by decomposers (fungi, bacteria…)

Nitrogen fixation: The process by which N_2 is converted to molecules that are usable to plants (e.g.: ammonium NH_4^+ or nitrate NO_3^-)

How does N fixation happen?

Human mediated processes of nitrogen fixation:
1) Haber-Bosch process (human performed, important source of N for "conventional" agriculture) complex chemistry…do not need to know!!

<u>Natural process of nitrogen fixation</u>

1) Lightning (natural, very slight contribution to global N cycle)
2) Bacterial fixation – most nitrogen fixation occurs due to special types of bacteria called *nitrogen fixing bacteria*!! **Nitrogen-fixing bacteria and archaea are the ONLY living organisms that can fix nitrogen**!! They are therefore critical to all life on Earth.

Nitrogen fixing bacteria contain the enzyme *nitrogenase*, which catalyzes the reaction of N_2 and H atoms to NH_3 (NH_3 subsequently converted to NH_4 and nitrate…)

nitrogenase: the enzyme in N-fixing bacteria & archaea that catalyzes the conversion of N_2 to NH_3

Many nitrogen fixing bacteria live symbiotically in the roots of plants called legumes (and other plants that are not legumes!). Examples of legumes are beans, peas, vetch, and clover.

Because legumes contain N-fixing bacteria in their roots, they are popular among farmers as a way to maintain high N levels in the soil. These plants are often planted by farmers - not to harvest them, but as a means to enhance soil quality – such plantings are known as **cover crops**.

Cover crops: crops planted primarily to manage soil fertility (N) and quality, water, etc…

<u>Humans and amino acids:</u>

Most (11) we can synthesize – (but to do this we need nitrogen in our diet – <u>remember that every third atom in a protein chain is nitrogen</u>!! - Itis also for this reason that plants must be fertilized with nitrogen-rich fertilizers, or “find” nitrogen in nature).

The acquisition of N atoms and amino acids is the major reason that humans (and other animals) must eat protein-rich foods. For vegetarians and vegans, that means substituting plant-based N sources for meat – legumes are an ideal part of the solution.

Essential amino acids: There are 9 amino acids that the human body cannot synthesize – we must eat these in our diet and they are therefore called the **essential amino acids**.

Animal-based foods usually contain all 9 essential amino acids. No single plant-based food, including legumes, contains all of the 9 essential amino acids, and it has long been held true that a vegetarian/vegan diet must include sources that provide the “missing” amino acids (those not found in legumes). Historically this be accomplished by pairing legumes with corn (in the Americas) or rice (in Asia) – and thereby provide what is referred to as a “complete protein”.

Complete protein: Protein source that contains all 9 essential amino acids necessary for the dietary needs of humans or other animals.

Protein pairing: The practice of pairing plant foods to accomplish a complete protein.

As with many nutritional concepts, there is great debate and misunderstanding swirling about the concept of “complete protein”. The most sane and educated voices in the field seem to agree that vegetarian/vegan foods need not be perfectly paired at <u>every</u> sitting, but that a diverse diet that provides complete protein (and other nutritional needs!) should be a priority.