

Lecture 3: Carbohydrates, buffers and large molecules

Buffers are chemical mixture that maintains relatively constant pH even if large amounts of acid or base are added. It is composed of weak acid and its corresponding base (more common) or a weak base and its corresponding acid (less common). Buffers work by the principles of law of mass action. Which states that the addition of reactants in a chemical reaction drives the reaction in a direction that uses up these reactants.

To see how buffers work in action, it is best to illustrate with an example. Take carbonic acid (weak acid- H_2CO_3) and its corresponding base (HCO_3^{-1}). If strong acid is added, the H^+ from the acid reacts with HCO_3^{-1} to produce H_2CO_3 in the following reaction:



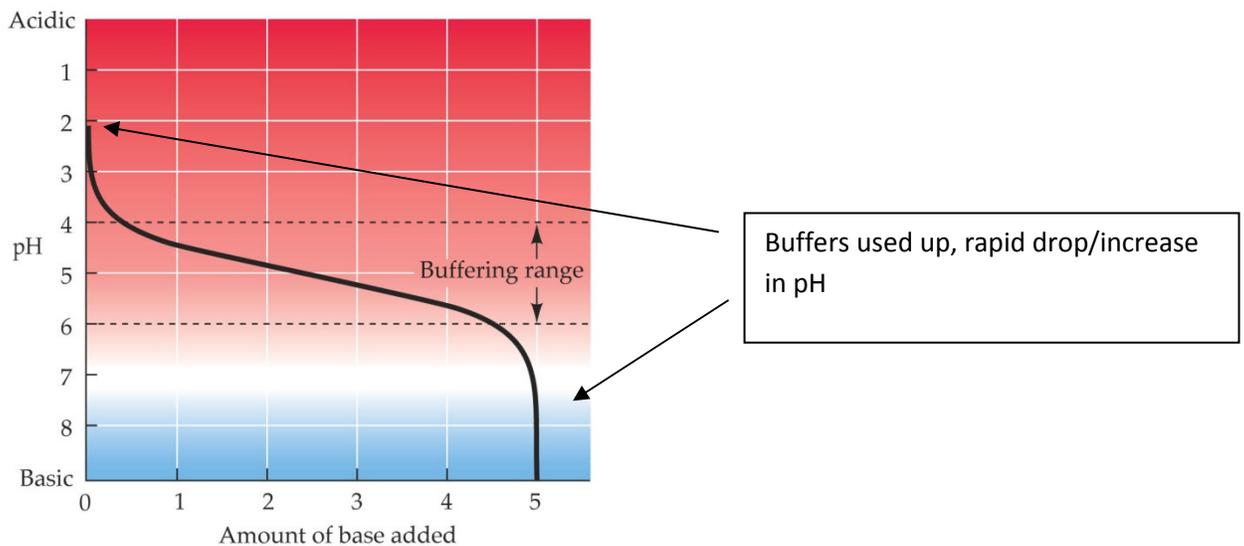
This uses up most of the H^+ released by the strong acid and thus there is little change in pH.

If strong base is added, lots of OH^{-1} ions will be released that react readily with the H^+ ions in the solution. To prevent this, the carbonic acid ionizes to produce H^+ ,



which reduce the effects the base has by replacing most of the H^+ ions that the OH^{-1} ions from the base took.

Buffers only exists in limited amounts. If it is used up due to the addition of too much acids or bases to the solution, then the pH of the solution can drop/increase rapidly.



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 2.19 Buffers Minimize Changes in pH
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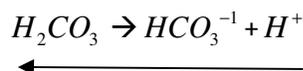
To illustrate this with law of mass action. We consider the following chemical equation



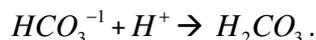
Which shows the dissociation of weak acid in water. On the left is the weak acid and on the right is the weak acid's conjugate base and H^+ ions that are released.

If we add strong acid to the solution, the H^+ concentration of the solution will go up. This means there are more reactants on the right side of the equation. (Reactants doesn't have to be on the left side. Sometimes, the reactants can be products that were just formed)

By the law of mass action, this will that the chemical reaction will proceed towards the left:



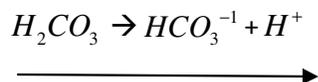
Which is simply this equation:



Lets go back to the equation of dissociation of weak acid in water, which is $H_2CO_3 \rightarrow HCO_3^{-1} + H^+$.

Now suppose strong base is added. Then the released OH^{-1} ions from the base will consume H^+ ions in the solution. This means that there will be way less H^+ ions. As a result, there will appear to be more of the H_2CO_3 molecules.

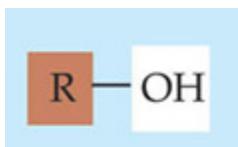
Law of mass action tells us that this reaction will proceed towards the right



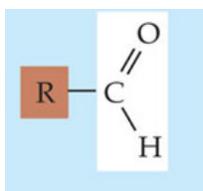
To replace the lost H^+ ions.

Functional groups:

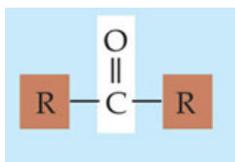
Functional groups are small groups of molecules with specific properties that when attached to large molecules, also give them those properties. The key functional groups you have to memorize are listed below.



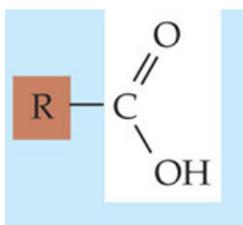
Hydroxyl functional group, commonly found in Alcohol compounds



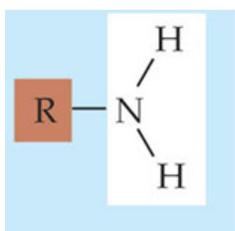
(Aldehyde functional group, commonly found in Aldehyde compounds)



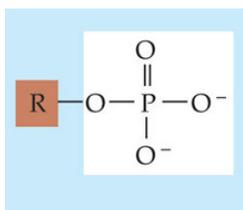
(Ketone functional group, commonly found in Ketone compounds)



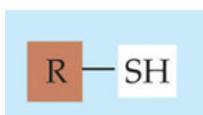
(carboxyl functional group, commonly found in carboxylic acids)



(Amino functional group, commonly found in amines)



(Phosphate functional group, commonly found in organic phosphates)



(Sulfhydryl functional group, commonly found in thiols)

Isomers:

Isomers are molecules with the same chemical formula but differ in their arrangement of atoms. There are two types of isomers, structural isomers and optical isomers. Structural isomers arise when atoms that make up the isomers are joined in different orders. Optical isomers arise when the atoms make up the isomers are joined the same order but still have a different arrangement in space.

A common example of optical isomers is your left and your right hand. They are made the same way but you cannot overlap them perfectly. Thus, they have a different arrangement in space.

In biology, our main concern is that optical isomers arise whenever carbon is attached to 4 different groups or atoms. When that happens, there are two different ways of arranging these groups in space. We call one way L and the other way D.

Amino acids for example, have this optical isomerism. For every amino group that exists, there are the L form of the amino acid and the D form of the amino group. In living organisms however, only the L-form of the amino acid is commonly found.

Macromolecules:

There are four groups of macromolecules: proteins, carbohydrates, lipids, and nucleic acids.

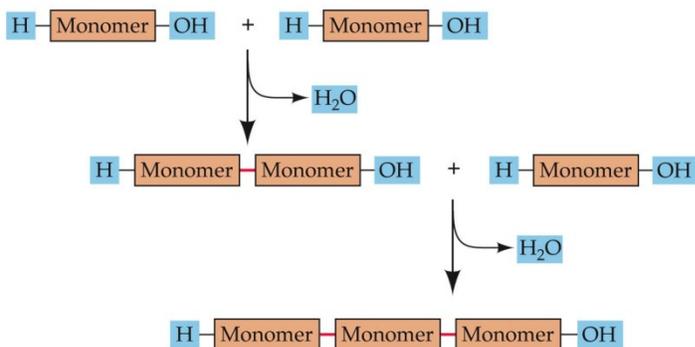
Macromolecules are giant polymers constructed from monomers covalently linked together. A useful analogy is to think of the steel chains that make up a chainmail. The steel chain can be thought of as a polymer made of steel loops (monomer).

A fundamental concept in biology is the idea of biochemical unity. This says that the 4 macromolecules are made the same way and present in roughly the same proportions in all living organisms. This means that organism can acquire the macromolecules they need by eating other organisms.

Now we look at how polymer is made from monomers.

To combine monomers, a chemical reaction called condensation reaction occurs. This however, will only occur if the right enzyme is present to hold on to the monomers. During condensation reactions, the hydroxyl group on one monomer will combine with the hydrogen group on the other monomer. As a result, a water molecule is released every time condensation reaction occurs to combine monomers in covalent bonds.

(a) Condensation

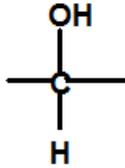


LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 3.3 Condensation and Hydrolysis of Polymers (Part 1)
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To divide the polymer into monomers, the opposite reaction, called hydrolysis, occurs. A water molecule is consumed for every covalent bond that is broken.

Carbohydrates

Carbohydrates are characterized by carbon atoms flanked by hydrogen atoms and hydroxyl groups.



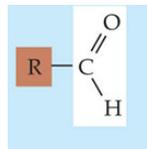
Thus, most unmodified carbohydrates are in the multiples of CH₂O with carbon, hydrogen, and oxygen atoms in a 1:2:1 ratio.

Carbohydrates are used to store energy and act as a carbon skeleton. Carbohydrates are divided into monosaccharides, disaccharides and polysaccharides. Monosaccharides are monomers that make up disaccharides (two monosaccharides) and polysaccharides (many monosaccharides).

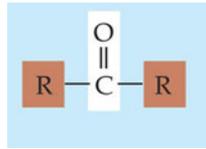
Monosaccharides:

Common monosaccharides are glucose, fructose, ribose, deoxyribose, galactose, and mannose.

Monosaccharides usually contains an aldehyde or ketone functional group in addition to the CH₂O subunits.



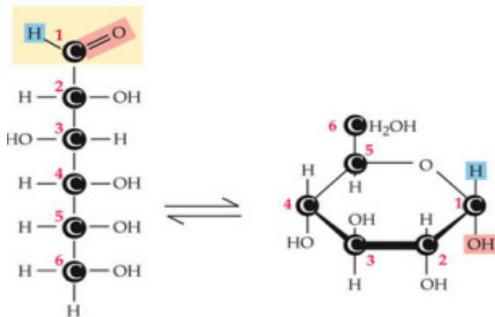
Aldehyde



Ketone

Monosaccharides can exist either in straight chain form or in a ring form under cellular environment.

(Cellular environment simply means the type of environment that exists inside a cell, which is what Biol 112 concerns about)



Straight chain form

Ring form

Monosaccharides composed of 4 carbons or more can exist in the ring form under cellular conditions. Most common monosaccharides exist in the ring form, so we commonly see the ring form of the carbohydrate.

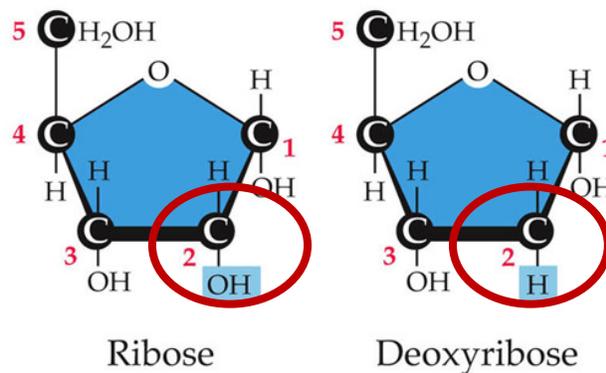
Monosaccharides that are composed of 5 carbons are called pentose. Examples of pentose are ribose, and deoxyribose.

Monosaccharides that are composed of 6 carbons are called hexose. Examples of hexoses are glucose, fructose, galactose and mannose.

Pentose:

The two important pentose are ribose and deoxyribose. Ribose is the carbohydrate component of RNA and deoxyribose is the carbohydrate component of DNA.

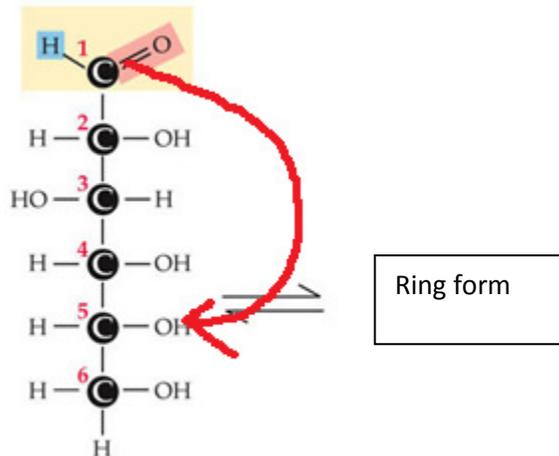
The only difference between the ribose and deoxyribose is that an oxygen is missing from deoxyribose's carbon 2 atom. (Hence why it is called deoxy-)



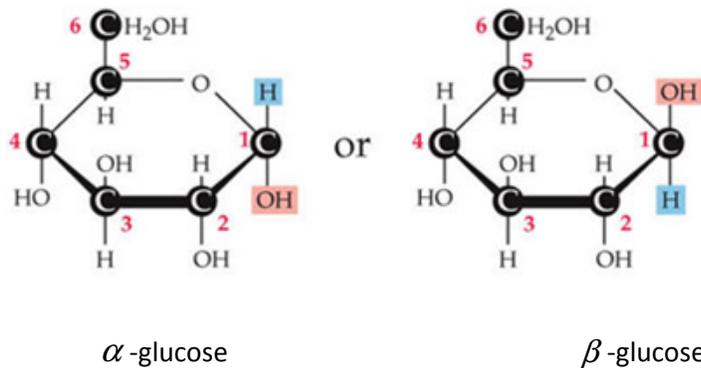
Hexose:

The most important hexose is glucose. Glucose exists in all living cells and provides the cells with energy.

Glucose have a chain form and a ring form under cellular environment. 99% of the time, glucose is in the ring form because it is simply more stable. The ring form is formed by the covalent linking of carbon 1 with carbon 5.

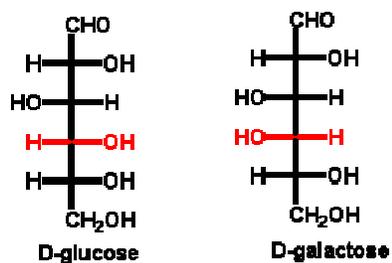


Glucose actually can form 2 ring forms. These two ring forms are called α -glucose or β -glucose. The two forms only differ in the placement of the -OH and -H group in carbon 1. The two glucose ring forms exist in equilibrium with each other.

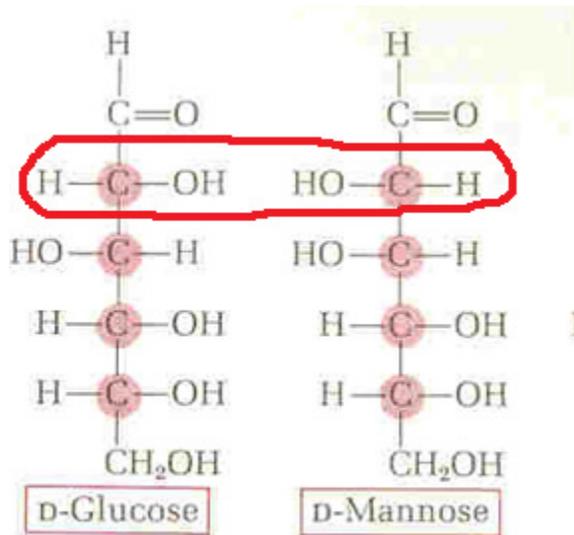


Glucose also has optical isomers. The two optical isomers are called L-Glucose and D-Glucose. Only the D-Glucose is commonly found in organisms and therefore relevant to this course.

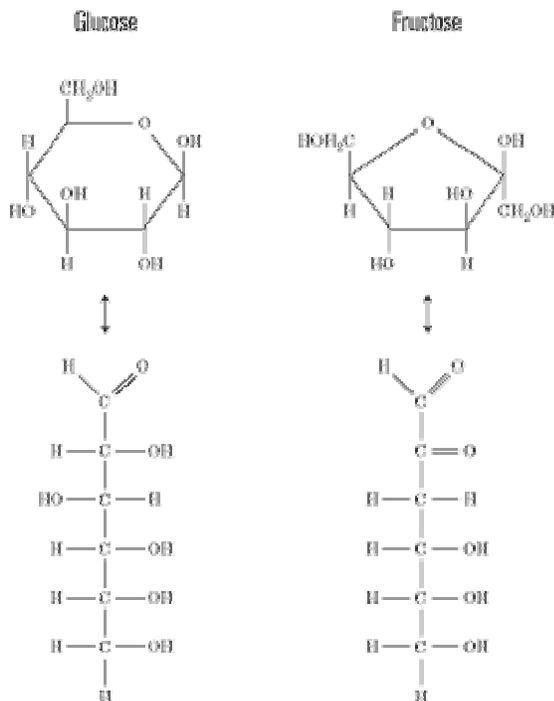
D-Glucose is also an optical isomer with other hexoses. D-Glucose is an optical isomer with D-galactose due to differences on the fourth carbon.



D-Glucose is also an optical isomer with D-mannose due to differences in the second carbon atom.



Glucose is also a structural isomer with fructose due to differences in the second carbon atom. (fructose have both ketone and aldehyde functional group while glucose only have the aldehyde functional group)

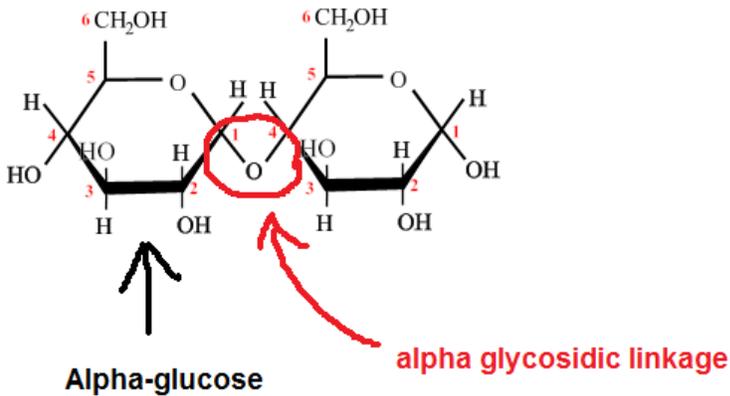


Glycosidic linkage:

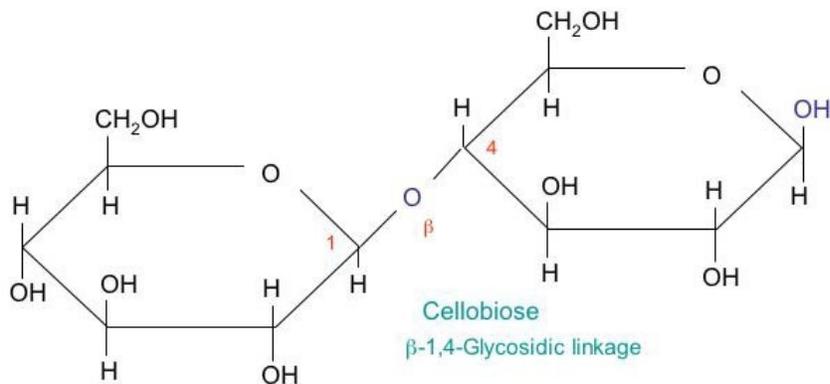
To make disaccharides and polysaccharides, monosaccharides must be linked together. The linkage that is formed by condensation reactions between monosaccharide monomers is called a glycosidic linkage.

When glucose forms glycosidic linkages, it can be either α -glycosidic linkage or β -glycosidic linkage, depending on if the glucose that formed the linkage is α -glucose or β -glucose.

Maltose is formed by the α -linkage on carbon 4 of the α -glucose with the other glucose. This is simply denoted as α (1 \rightarrow 4) linkage.



Cellobiose is formed by the β -linkage on carbon 4 of the β -glucose with the other glucose. This is simply denoted as β (1 \rightarrow 4) linkage.



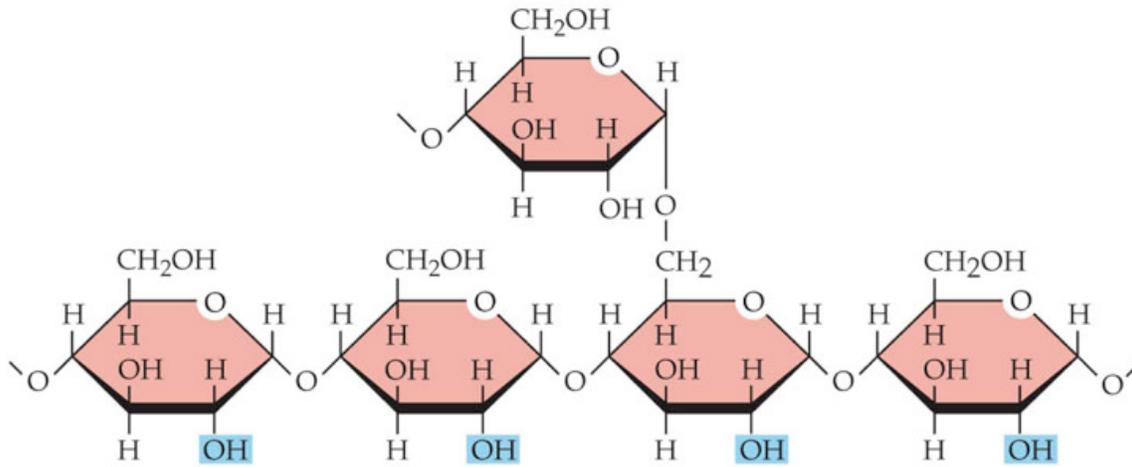
Disaccharides:

Maltose and Cellobiose mentioned above are all examples of disaccharides. Other important disaccharides are sucrose (table sugar) and lactose (milk sugar). Sucrose is formed when glucose joins with a fructose. Lactose is formed when glucose is joined with galactose.

Polysaccharides:

There are three main polysaccharides: starch, glycogen, and cellulose.

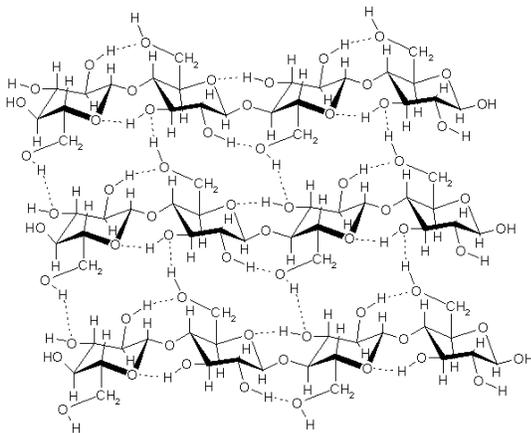
Starch is how plants store glucose. Glucose monomers are joined by α (1 \rightarrow 4) linkages to form starch. There are two types of starch: **amylose and amylopectin**. Amylose is a straight chain of glucose monomers with no branching (side chains). Amylopectin is a glucose chain with moderate branching.



Section of amylopectin with branching on the second glucose monomer

Glycogen is the starch equivalent in animals. Glycogen, however, differs from starch in that it is highly branched (more side chains) and more water soluble.

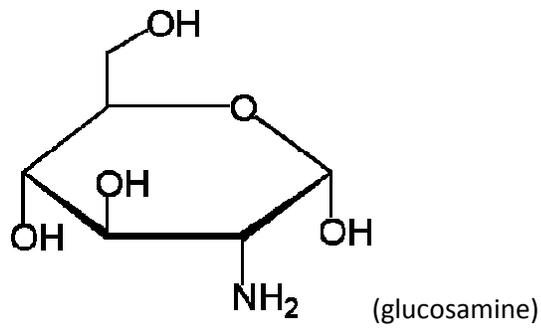
Cellulose is formed by glucose monomers joined in β (1 \rightarrow 4) linkage. It is insoluble in water have no branching (side chains) of any kind. It cannot be broken down into monomers by normal enzymes. Chains of cellulose can also hydrogen bond with each other to form excellent structural material like fibers.



(Cellulose chains hydrogen bond with each other)

Chemically modified carbohydrates:

Carbohydrates like glucose can be modified by replacing the -OH group on the second carbon atom with an amino group (-NH_2). This creates glucosamine, a modified glucose.



Glucosamine can be chemically modified further by adding N-acetyl group to the amino group. This creates N-acetyl glucosamine or NAG for short. This is the subunit that forms chitin, a very tough material present in insects, crabs, lobsters and fungi.

