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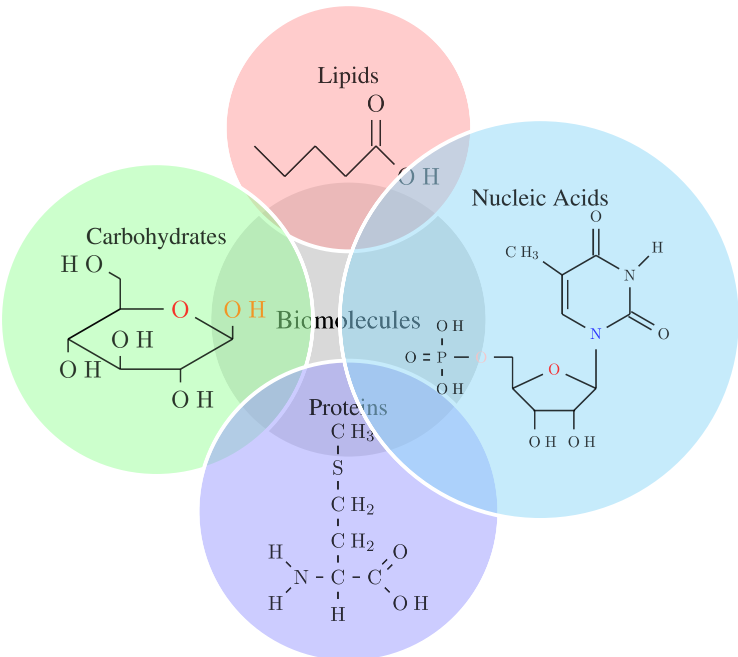
February 15, 2023 (12:25 Noon)

Ch. 11. Biochemistry

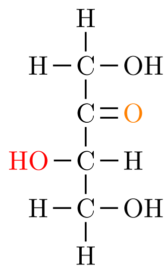
BIOCHEMISTRY applied the principles of chemistry to organic molecules found in living systems. In particular it covers the properties of biomolecules: carbohydrates, lipids, proteins and nucleic acids, perhaps less known biomolecules. You can find carbohydrates in pasta, bread or rice and they give your body quick energy. These molecules are in essence biological alcohols, which contain numerous $-\mathrm{OH}$ groups. Lipids on the other hand are often referred as fats or oils. Cholesterol is for example a lipid found in eggs or milk. The purpose of lipids is to store energy and insulate organs. Proteins have numerous functions in the body such as building muscle or transport oxygen in the blood. Perhaps more importantly is to know what are they made off: amino acids. Finally, if you are not familiar with the term nucleic acids, perhaps you recognize the term DNA. Nucleic acids are large molecules that contains the information for cellular growth and reproduction. Over all, this chapter will briefly cover the structure and composition of these important molecules of life.

11.1 Biomolecules

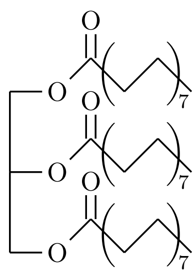
Biomolecules, also called biological molecule, are any of numerous substances that are produced by cells and living organisms. Biomolecules have a wide range of sizes and structures and perform a vast array of functions.



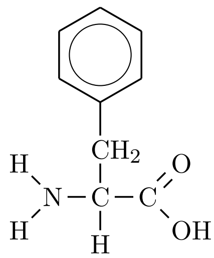
Different types of biomolecules The four major types of biomolecules are carbohydrates, lipids, nucleic acids, and proteins. Carbohydrates (sugars or simply carbs) are organic molecules composed of numerous alcohol groups as well as a ketone or ether group. An example of a carbohydrate is presented below. We can find simple carbohydrates such as glucose and complex carbohydrates such as starch.



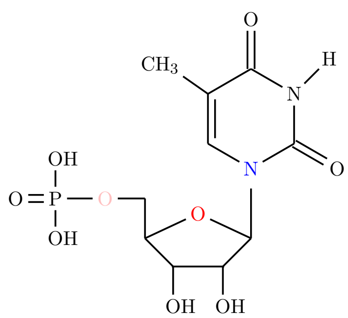
Lipids (fats) tend to contain carboxylic acids or esters. We can find different types of lipids such as fatty acids, waxes or steroids. An example of a lipid is presented below.



Proteins (meat) contain amino or amide groups. Proteins are made of amino acids. We can find complex proteins or simple proteins called peptides. An example of a protein in general is presented below.



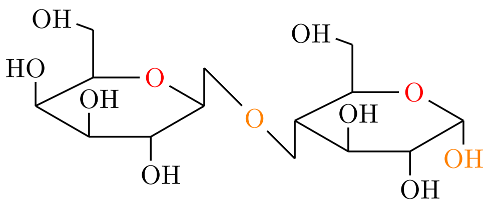
Finally, nucleic acids (DNA or RNA) are made of a sugar connected to an amine, or amide. Sometimes you will find phosphorus atoms on its structure. An example of nucleic acid is presented below.



It is very important to be able to differentiate the different biomolecules as well as to be able to identify each of them.

Sample Problem 1

Classify the following biomolecule as a carbohydrate, a lipid, a protein or a nucleic acid.

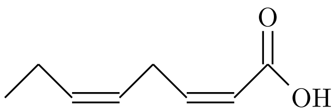


SOLUTION

The biomolecule presented above contains numerous ether groups as well as alcohols. This is a carbohydrate. In particular, it is a complex carbohydrate resulting of the combination of two simple carbohydrates.

STUDY CHECK

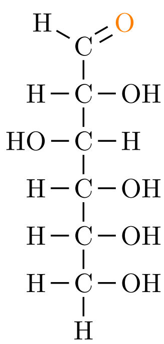
Classify the following biomolecule as a carbohydrate, a lipid, a protein or a nucleic acid.



11.2 Simple Carbohydrates

This first section introduces one of the most important biomolecules: the carbohydrates. If you think about rice, bread, and even fruits, they all contain carbohydrates as their main ingredients. This section cover the rules for their naming of single carbohydrates, called monosaccharides, and will show you how to identify these common molecules in two different forms: a line structure and a cycle, the later called Haworth structure, named after Sir Norman Haworth, a famous english biochemist. Finally carbohydrates can form dimer and polymers and these more complex molecules will also be addressed in this section.

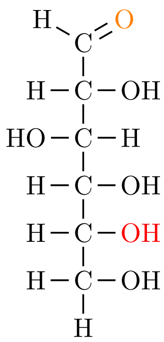
`Carbs are made of C, H and O` Carbohydrates are made of carbon and oxygen and hydrogen, thus their name: carbon hydrates. The simples carbohydrate is glucose with molecular formula $C_6H_{12}O_6$ and with structure



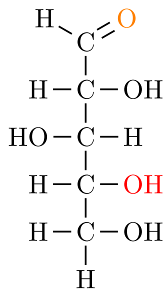
This molecule is produced in plants by means of a process called photosynthesis, in which carbon dioxide and water are added together with the help of sunlight to produce glucose and oxygen. At the same time our bodies burn glucose with oxygen while we breath.

$$6\,CO_2 + 6\,H_2O + \text{☼} \xrightleftharpoons[\text{Respiration}]{\text{Photosynthesis}} C_6H_{12}O_6 + 6\,O_2$$

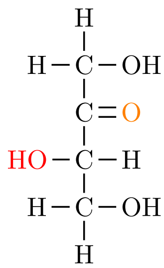
`Monosaccharides: aldo or keto?` The simples sugars are called monosaccharides and their name ends in *ose* like in gluc*ose*. These sugars are made of C, O and H and contain a few functional groups that you should be familiar with. They contain alcohol groups and either and aldehyde ($R-\overset{\overset{\displaystyle O}{||}}{C}-H$) or a ketone ($R-\overset{\overset{\displaystyle O}{||}}{C}-R'$) group in the carbon number one. Depending on the number of carbons, monosaccharides can be classifies in triose, tetrose, pentose, or hexose. Here a few examples:



An aldohexose



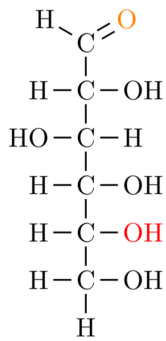
An aldopentose



A ketotetrose

Sample Problem 2

Classify the following monosaccharide as aldo or keto:

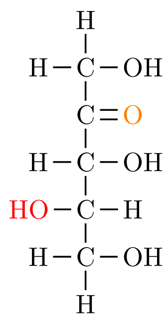


SOLUTION

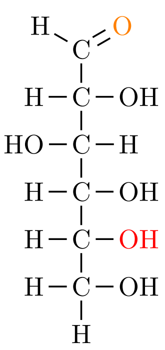
The monosaccharide has a $R-\overset{\overset{\displaystyle O}{||}}{C}-R'$ group on carbon one and therefore it will be aldo. As it also has six carbons, it will be an aldohexose.

STUDY CHECK

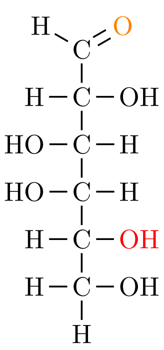
Classify the following monosaccharide as aldo or keto:



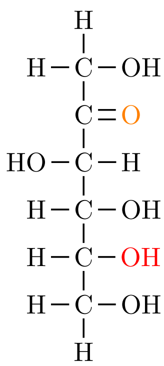
Some important monosaccharides The most important monosaccharides are glucose, fructose and galactose. These are all hexose with six carbon atoms. Glucose and galactose are aldohexose whereas fructose is a ketohexose.



Glucose



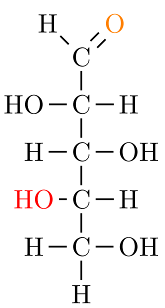
Galactose



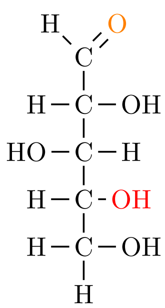
Fructose

Glucose is also known as dextrose or blood sugar, is the most important simple sugar involved in the metabolism of humans. Glucose is found in corn syrup and honey as well as in fruits and vegetables in the form of more complex carbohydrates. Galactose can not be found in free form, but is found in the form of lactose, a disaccharide, in milk. Only when lactose is broken down you can find free galactose. Fructose is the sweetest of all carbs found in fruits–thus its name–and honey.

$d-$ and $l-$ monosaccharides Monosaccharides are classified as $d-$ and $l-$ depending on the position of the second OH group starring from the bottom of the molecule. If that specific OH points to the right we call it $d-$ monosaccharides, whereas $l-$ have the second OH group starring from the bottom pointing left. Here some examples:



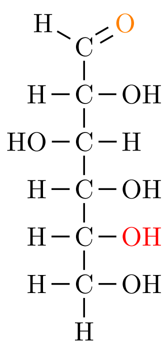
$l-$ monosaccharide



$d-$ monosaccharide

Sample Problem 3

Classify the following monosaccharide as $d-$ or $l-$:

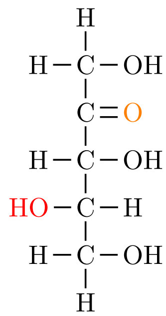


SOLUTION

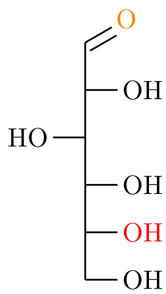
As the second OH group starting from the bottom point to the right, it will be $d-$, in particular it would be a: $d-$aldohexose.

STUDY CHECK

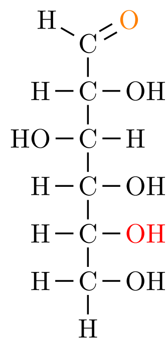
Classify the following monosaccharide as $d-$ or $l-$:



Skeletal structure of monosaccharides Often times, the structure of carbohydrates are represented in skeletal form, ignoring the C and H atoms and showing only oxygen and OH groups. Here an example:

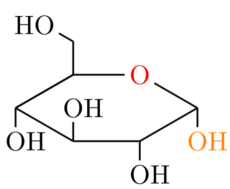


Linear Glucose (Skeletal form)

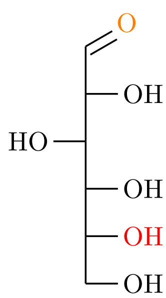


Linear Glucose (Full form)

Haworth cyclic structure of monosaccharides Normally monosaccharides exist in liquid solution. In these conditions its structure is not a linear structure such the one presented before. Instead they exist in a cyclic form called Haworth structure. The goal of this section is just to introduce you to this cyclic form. Here an example:



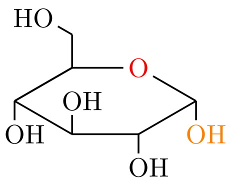
Haworth Glucose



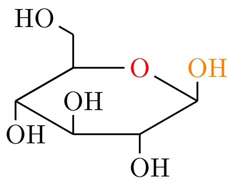
Linear Glucose (Skeletal form)

α or β form of Cyclic monosaccharides The Haworth form of monosaccharides are classified as α or β depending on the orientation of a single OH group:

the OH group of the C atoms directly connected to the O atom in the cycle. If this OH groups points down we call this α and if its points up we call the structure as β . Here some examples:



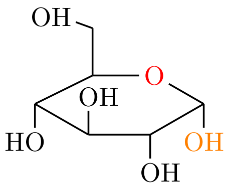
α-Glucose



β-Glucose

Sample Problem 4

Classify the following haworth monosaccharide as α or β :

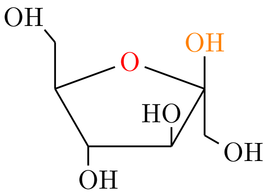


SOLUTION

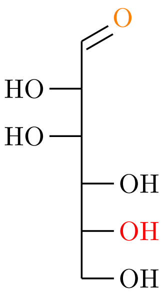
As the second OH group after the -O- in the cycle points down, it will be α.

STUDY CHECK

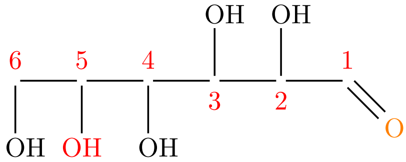
Classify the following haworth monosaccharide as α or β :



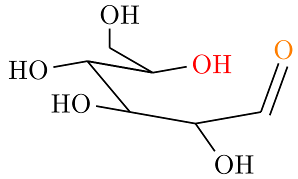
Obtaining Haworth cyclic structure of monosaccharides Linear monosaccharides cycle forming Haworth cycles. In order to obtain a cycle you just need to get the linear structure and turn in clockwise 90 degree until is horizontal, the carbonyl or keto will fall in the right part of the structure and the last C atom in the left part. After that you need to draw the structure in a boat shape, as the Oh from carbon 5 will attach carbon number one and produce a cycle.



D-Mannose

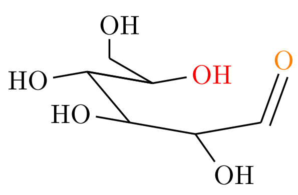


D-Mannose rotated

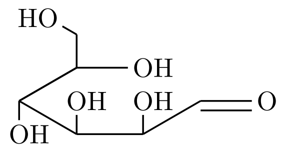


D-Mannose as a boat

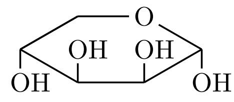
The final cycle looks like:



D-Mannose

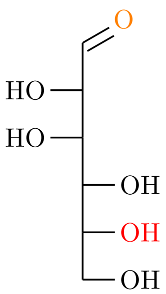


D-Mannose
rotated

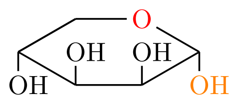


α-Mannose

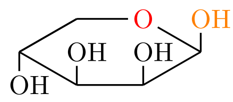
In general the cycles formed from linear monosaccharides can have five of six atoms, depending on the aldo/keto nature of the monosaccharides. Aldo monosaccharides produce six-atoms rings and keto monosaccharides produce five-atoms rings. A six-atom ring example:



D-Mannose

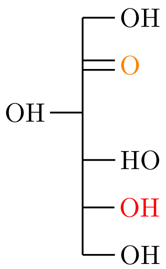


α-d-Mannose

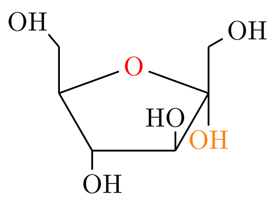


β-d-Mannose

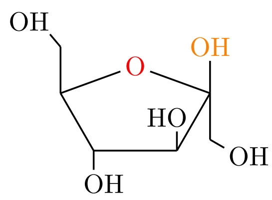
A five-atom ring example:



d-fructose



α-d-fructose

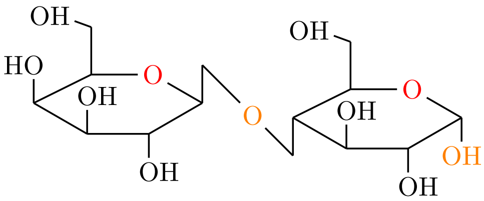


β-d-fructose

11.3 Disaccharides and polysaccharides

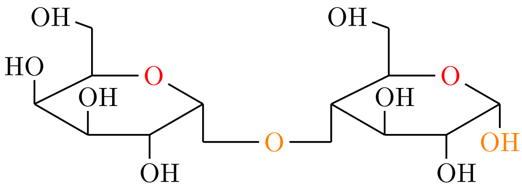
This next section covers the properties of the di and polysaccharides. These are more complex saccharides made of two of more units of sugar. At the same time, these form the most common carbs. For example, sugar cane is a disaccharides, that is, contains two monosaccharides units. Differently, the starch in potatoes is a polysaccharide, made of numerous saccharides units, and cellulose is a structural polysaccharide used by plants. All this complex saccharides have very different properties and for example humans can easily digest sugar cane and starch but not cellulose. The difference is in the way the monosaccharides are connected among themselves by means of a connection names glycosidic bond.

Disaccharides Disaccharides are the combination of two saccharides. An example of a disaccharides is α-lactose, found in the milk:



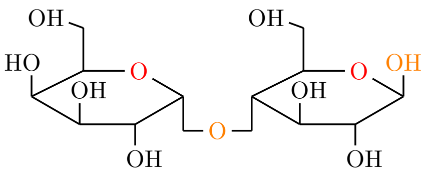
α-lactose

Another example is α-maltose, found in beer:

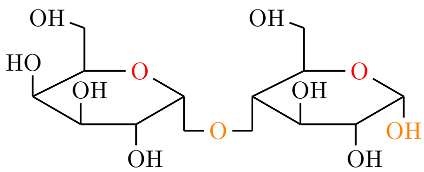


α-maltose

α- and β-Disaccharides Same as monosaccharaides, disaccharides can also be α- and β, depending on the position of the first OH after the -O- atom in the right cycle. For example:



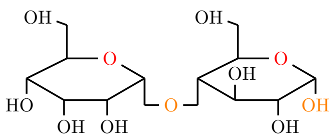
β-maltose



α-maltose

Sample Problem 5

Classify the following disaccharide as α or β:

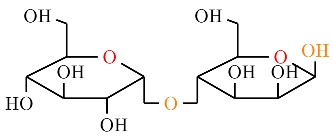


SOLUTION

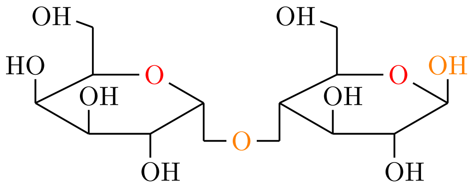
This is an α disaccharide as the first OH after the -O- atom in the right cycle is pointing down.

STUDY CHECK

Classify the following disaccharide as α or β:

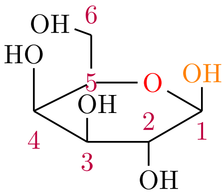


Numbering saccharides Disaccharaides are the result of the connection between two monosaccharides at a specific location of the molecule. Depending on the location of the connection and the orientation of the connection, the disaccharide would be easy or impossible to digest. Is is important to number the carbons in each monosaccharide in order to be able to identify the atoms involved in the connection. Here is an example of a monosaccharide:

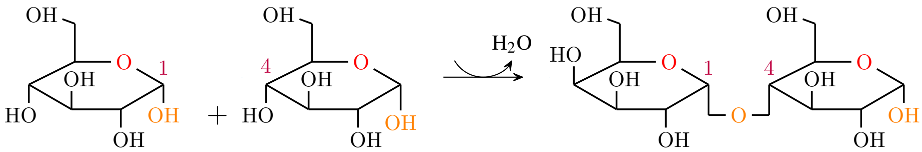


β-maltose

In order to number the chain we start by the -O- atom. This atoms would be zero. After that you continue numbering clockwise. The results is:

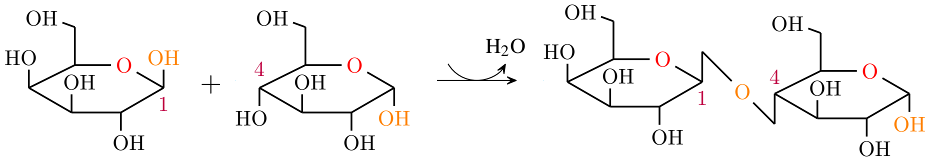


`Glycosidic bond` Monosaccharides connect to form disaccharides by means of very special bond. This bond is the result of combining two OH groups and looks like -O-. This is the glycosidic bond and the formation of this bond produced water. For example, maltose is the result of the connection of two glucose molecules by means of a 1-4-glycosidic bond.



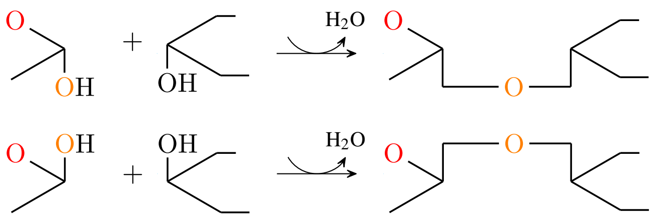
α-glucose and α-glucose Maltose (α-1-4-Glycosidic bond)

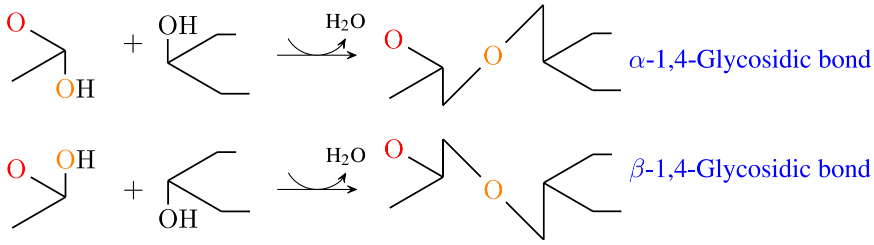
So if you combine an α-glucose molecule with another α-glucose molecule you form a 1-4-glycosidic bond. As the first glucose is α the resulting bond will also be an α bond, and the full name for the bond will be α-1-4-glycosidic bond. Now, depending on the orientation of the OH groups involved in the glycosidic bond we can have four different orientations of the bond. For example, lactose results from combining β-D-galactose and α-D-glucose. The separate monomers are:



β-galactose and α-glucose Lactose (β-1-4-Glycosidic bond)

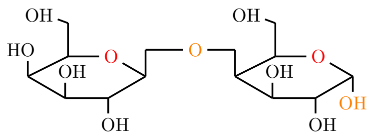
In general the four possible glycosidic bonds are:





Sample Problem 6

Classify the following glycosidic bond:

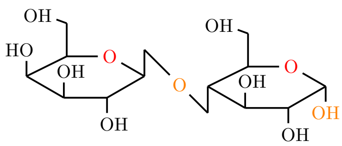


SOLUTION

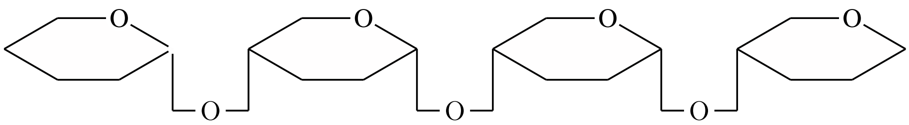
This is a β-1-4-glycosidic bond, as the first bond in the glycosidic bond points up.

STUDY CHECK

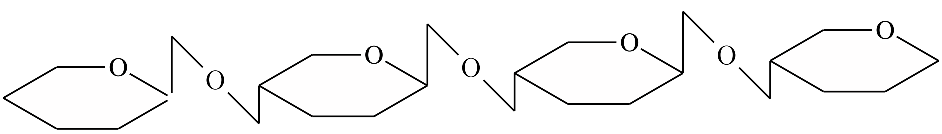
Classify the following glycosidic bond:



`Polysaccharides: starch and cellulose` In the previous section you saw the structure of maltose and lactose and these were made of monosaccharides connected by means of a -O- bond called glycosydic bond. A polysaccharide is a long polymer formed by means of numerous units of sugar connected by means of glycosidic bonds. Starch for example is a polysaccharide found in plants, rice, wheat or potatoes is made of α-glucose molecules connected by means of a α-1-4Glycosidic bond. These bonds are easy to break and humans easily digest starch. Starch hydrolyze in water and acid ultimately producing glucose.

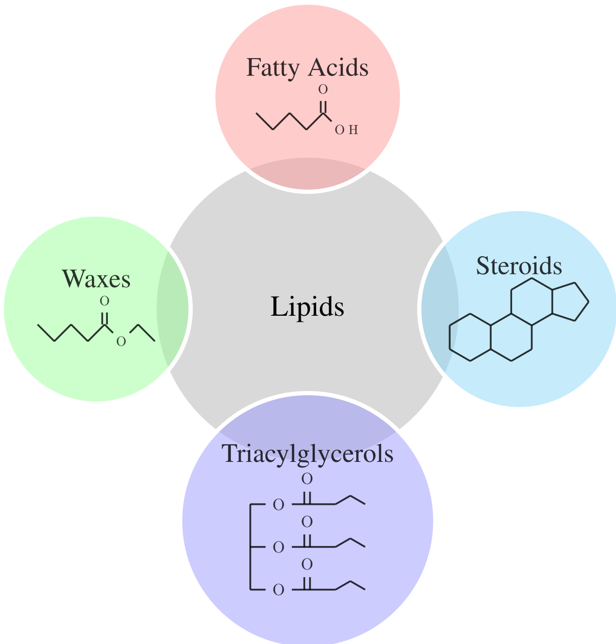


Cellulose is also a polymer of α-glucose molecules. However, this polysaccharide contains glucose molecules bonded by means of a β-1-4Glycosidic bond. These bonds are stronger than the α-1-4Glycosidic bond, and hence humans can not digest cellulose. Only animals can break this polymer with the help of a specific bacteria.

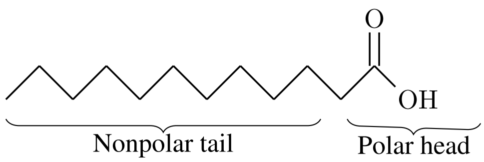


11.4 Lipids

This section covers the chemical properties and structure of lipids. These biomolecules are often referred as fats as they are insoluble in water and soluble in organic solvents. Think about oil, butter or even cholesterol. All these are different types of lipids with distinct structure. One one hand, oil and butter contain fatty acids, which are organic acids–carboxylic acids–with a carboxylic group connected to a very long zigzag hydrocarbon chain. On the other hand, cholesterol is a lipid that do not contain fatty acids. The structure of cholesterol results from an steroid nucleus made of three cyclohexane and a cyclopentane fused together. Perhaps less known fats are waxes and triacylglicerols. Both result from the reaction of fatty acids and alcohols. We will briefly cover the structure of those lipids as well. The following diagrams gives the classification for the different kinds of lipids.



`Structure of fatty acids` Fatty acids are molecules with two different parts: a polar head and a nonpolar tail. On one hand, a carboxylic acid group ($\overset{\overset{\displaystyle O}{\|}}{C}-OH$) make these molecules acidic and polar. On the other hand, a hydrocarbon () chain makes these molecules nonpolar, that means and hence insoluble in water. As the chain tends to be long these molecules over all are nonpolar that means they do not dissolve in water. These fatty acids are called saturated fatty acids, as they only contain simple C-C bonds.



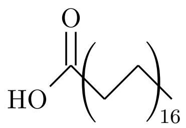
Saturated Fatty acid

Sample Problem 7

Geddic acid is a saturated fatty acid with 34 carbons found in animal fat. Write down its skeletal formula.

SOLUTION

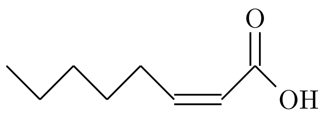
Saturated fatty acids have a polar acid head and a hydrocarbon chain with no double bonds. The polar head has one carbon and hence the tail should have 33 carbons:



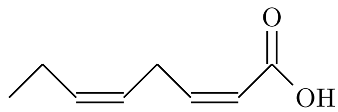
STUDY CHECK

Lignoceric acid is a saturated fatty acid with 24 carbons found in wood tar and peanut oil contain. Write down its skeletal formula.

Mono and polyunsaturated fatty acids Often times fatty acids contains double bonds called unsaturations. They can have a single double bond or more than one double bond. Monounsaturated fatty acids only contain a single unsaturation and polyunsaturated fatty acids have more than one double bond. Examples are palmitoleic acid, a monounsaturated fatty acid found in butter or linolenic acid, a polyunsaturated fatty acid found in corn oil.



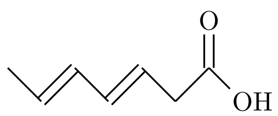
Monounsaturated fatty Acid



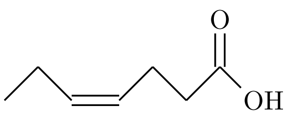
Polyunsaturated fatty Acid

Sample Problem 8

Classify the following fatty acids as saturated, monounsaturated or polyunsaturated:



A



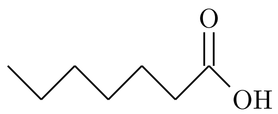
B

SOLUTION

A saturated fatty acid has no double bond on its tail, whereas a monounsaturated fatty acid has a single double bond in the tail and a polyunsaturated fatty acid has more than two double bonds. According to this, the fatty acid A is a polyunsaturated as it contains two double bonds on its tail. The fatty acid A is monounsaturated, as it only contains a single double bond.

STUDY CHECK

Classify the following fatty acid as saturated, monounsaturated or polyunsaturated:



Melting point of fats Some fats such as olive oil are liquid at room temperature. Other such as butter or lard are solid at room temperature. Liquid fats have low melting point so that they are already melted in a liquid form at room temperature. Solid fats have in general larger melting point and hence at room temperature they preserve its solid form. Two different factors affect the melting point of a fat. The first factor is the number of carbons. The larger the number of carbons the higher melting point and hence the fat will most likely be solid at room temperature. For example, lauric acic, found in coconut oil, has 12 carbon atoms and a boiling point of 44°C. Palmitic acid, an oil found in palm, on the other hand has 16 carbon atoms and its boiling point would be therefore higher (63°C).

$$\mathrm{CH_3} \left(\mathrm{CH_2} \right)_{12} \mathrm{COOH}$$

Lauric Acid (MP=44°C)

$$\mathrm{CH_3} \left(\mathrm{CH_2} \right)_{14} \mathrm{COOH}$$

Palmitic Acid (MP=63°C)

The second factor is the presence of double bonds–remember these are called unsaturations. Double bonds decrease the melting point. For example, stearic acid is an unsaturated fatty acid–with no double bonds–with 18 carbons and a melting point of 69°C. On the other hand, linoleic acid is a monounsaturated fatty acid with the same 18 carbons but a lower melting point of -5°C. Due to the presence of a single unsaturation the melting point is highly reduced and hence linoleic acid will be liquid at room temperature whereas stearic acid will be a solid.

$$\mathrm{CH_3} \left(\mathrm{CH_2} \right)_{4} \mathrm{CH{=}CH{-}CH_2{-}CH{=}CH} \left(\mathrm{CH_2} \right)_{7} \mathrm{COOH}$$

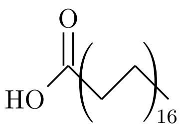
Linoleic Acid (MP=−5°C)

$$\mathrm{CH_3} \left(\mathrm{CH_2} \right)_{16} \mathrm{COOH}$$

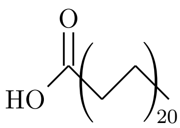
Stearic Acid (MP=69°C)

Sample Problem 9

Compare the melting point of the following fatty acids and predict whether they will likely be solid or liquid at room temperature.



A



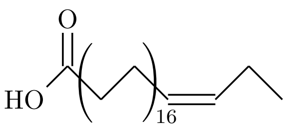
B

SOLUTION

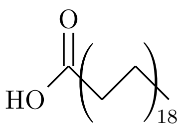
The larger the number of atoms in the fatty acid the higher its melting point and hence the higher the chances the fat is solid at RT. The fatty acid A has 33 carbon atoms whereas B has 41 so B has higher melting point than A and has more chances to be solid at RT.

STUDY CHECK

Compare the melting point of the following fatty acids and predict whether they will likely be solid or liquid at room temperature.



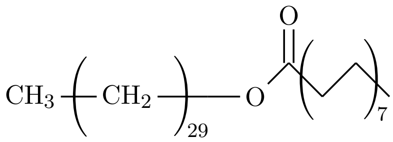
A



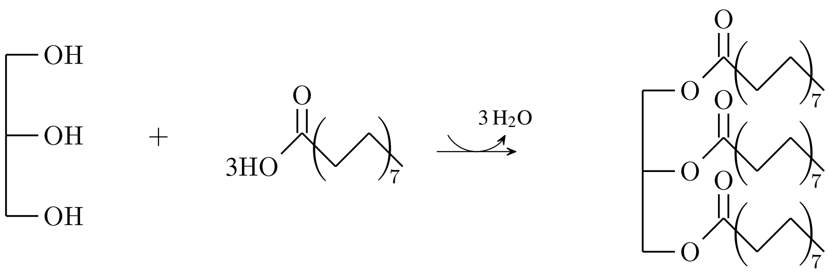
B

Carnauba wax is obtained from the leaves of the carnauba palm.

Carnauba wax

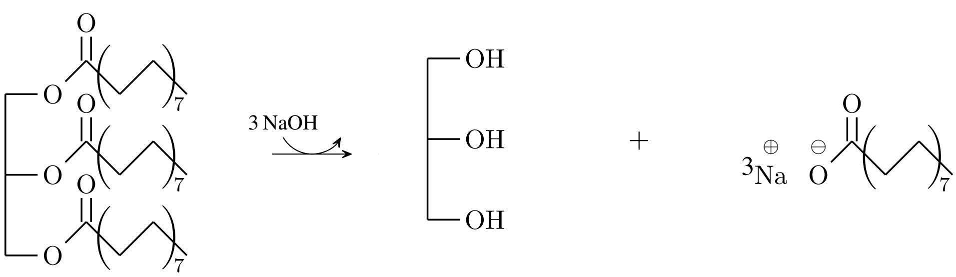


`Waxes, animal fat and soaps` Waxes and animal fat are the results of a reaction between fatty acids and alcohols. Waxes are ester of a fatty acid produced by mixing a fatty acid with long chain alcohols. Waxes are found in animals and plants. Plants secrete waxes in order to control evaporation, reduce wettability and increase hydration. The most important commercial plant wax is carnauba wax, a hard wax obtained from Brazilian palm employed for example in car and furniture polish, floss coating, and surfboard wax. Animal fat is also known as triacylglycerols as they result of the reaction between fatty acids and glycerol, an alcohol with three carbon atoms. Animals store energy in the form of fat. For example, during hibernation they survive by consuming fat.



Glycerol Fatty acids triacylglycerol

Soap results from the treatment of fat with a strong base such as NaOH or KOH. Due to this basic treatment fats break down into glycerol and a salt of the fatty acid. Soaps are indeed salts of fatty acids. Depending on the nature of the base employed in the saponification and the nature of the oil one can produce solid or more more liquid soaps.

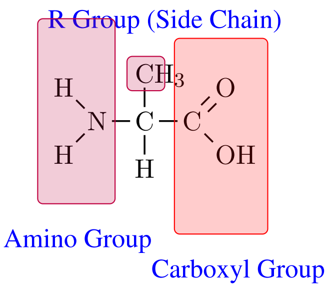


triacylglycerol glycerol Soap

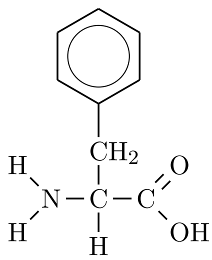
11.5 Proteins

This new section covers the chemical properties of proteins, which are polymers amino acids. Amino acids are molecules with both an amino (NH_2) and a carboxylic acid group (COOH). Amino acids have also a side chain (R)–this is a organic group different than amino or acid group. Side chains give amino acids acid-base hydrophilic-hydrophobic properties and properties. Amino acids bond together by means of a peptide amide bond producing small peptides or large proteins.

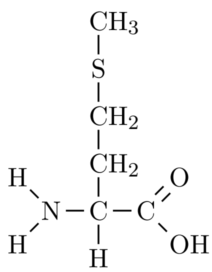
`Amino acids` Proteins are made of amino acids. Amino acids have the following parts: (1) a central carbon called α carbon; (2) an amino (NH_2) group connected to the α carbon; (3) a carboxylic acid (COOH) group connected to the α carbon; (4) a hydrogen atom (H) connected to the α carbon; (5) a side chain (R). All amino acids have the same α carbon, amino group and acid group as well as hydrogen connected to the α carbon. They differ in the side chain. Here is an example of an amino acid called Alanine, indicating the amino, the acid and the side chain.



Two more amino acids examples:



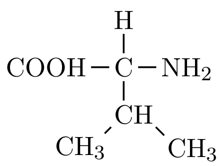
Phenylalanine



Methionine

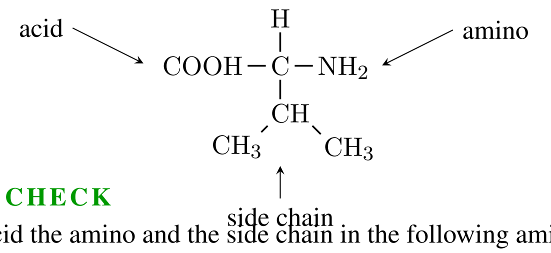
Sample Problem 10

Identify the acid the amino and the side chain in the following amino acid:



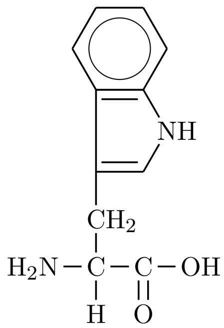
SOLUTION

The acid group is COOH and the amino is NH_2. The side chain is the other group connected to the central C different than hydrogen:

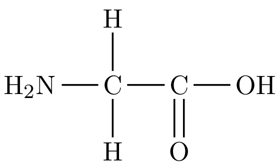


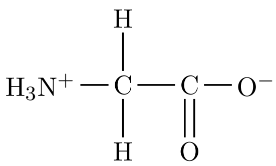
💎 **STUDY CHECK**

Identify the acid the amino and the side chain in the following amino acid:



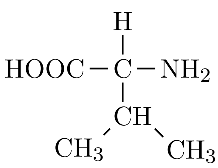
Amino acids as zwitterions Amino acids are acid and basic, that means they have two different PK_a. For example the two different PK_a values for Glycine is 2.34 and 9.60. This means that in solution amino acids will exist in a protonated form in which the acid group looses its proton H^+ becoming negatively charged and the amino group has an extra proton and becomes positive. This positive and negative state of an amino acid is called zwitterion.


Neutral Glycine (Gly)


Glycine as zwitterion

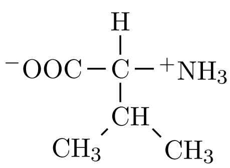
Sample Problem 11

Write down the zwitterion state of the following AA



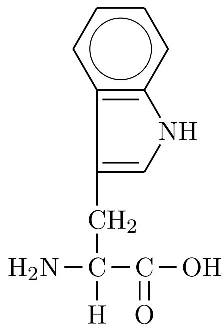
SOLUTION

In its zwitterion state an AA has a netaive acidic group and a positive amino group. The acid group has one less H and the amine gains that proton:

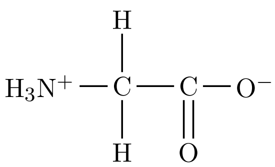


💎 **STUDY CHECK**

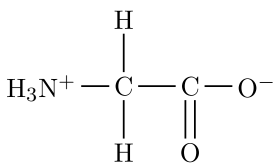
Write down the zwitterion state of the following AA



Hydrophilic and hydrophobic Amino acids There 20 common amino acids. They can be classified according to they hydrophilic and hydrophobic. Hydrophilic means that they solve in water whereas hydrophobic means that they do not solve in water. The classification is result of their side chain, as some of their side chains are hydrophilic whereas others are hydrophobic. For example, Glycine is an hydrophobic amino acid as its side chain is mainly made of carbon and hydrogen and is hence nonpolar. Differently, Serine is an hydrophilic amino acid as its side chain contains oxygen and is hence polar.

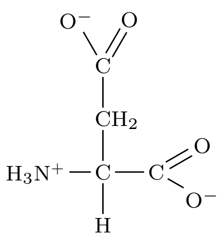


Glycine (Gly)
Hydrophobic AA

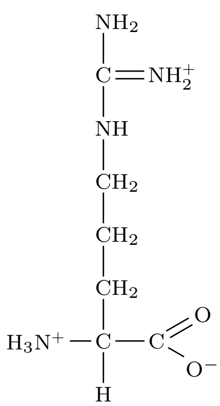


Histidine (His)
Hydrofilic AA

Acid and basic Amino acids Amino acids can also be classified according to their acid-base character. This property depends on the acid-base character of the side group. If this group is acidic then the amino acid will be acidic and basic side chains correspond to basic amino acids. For example Aspartic acid is an acidic amino acid as its side chain is acidic and arginine is a basic amino acid as its side chain is basic.



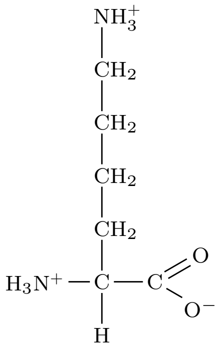
Aspartic Acid (Asp)
Acidic AA

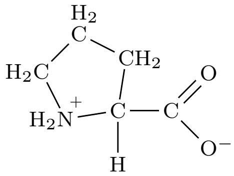


Arginine (Arg)
Basic AA

Sample Problem 12

Classify the following AA as acidic, basic, hydrophilic or hydrophobic:



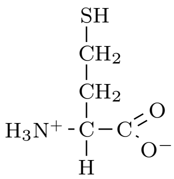


SOLUTION

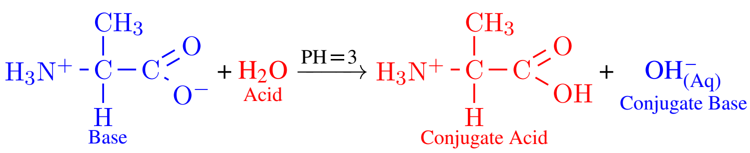
They key to classify the different AA is on its side chain. The AA on the left has a nonpolar side chain made of C and H and hence it will hydrophobic. The AA on the right has a polar side chain with N and at the same time a basic side chain. This AA will be hydrophilic and at the same time basic.

STUDY CHECK

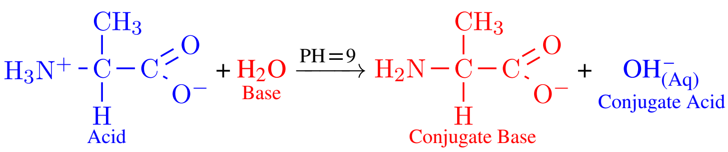
Classify the following AA as acidic, basic or neutral, and hydrophilic or hydrophobic:



Isoelectronic point of an Amino acid Amino acids have acid-base character and that means one can modify its charge by modifying the PH. There is a specific PH value at which an AA is neutral. This is called the isoelectronic point (IP) of an Amino acid. For PH value above this point the AA will have negative charge (will be in the form of a conjugate base) and for PH values below this point the AA will have positive charge as the AA will be in a conjugate acid form. For example, the IP of Alanine is 6.1. This means that for PH lower than 6.1 the AA will have positive charge and will be in the form of a conjugate acid:



Differently, if the PH is above 6.1 the AA will have negative charge as the medium will be basic:

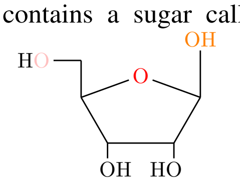


Finally, at the isoelectronic point the AA will be neutral.

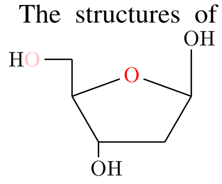
11.6 Nucleic acids

Nucleic acids are long polymers of a unit called nucleotide connected by means of a bond called phosphodiester. There are tow different types of nucleic acids: DNA and RNA. The term DNA stands for deoxyribonucleic acid, whereas the term RNA stands for ribonucleic acid. A nucleotide ies made of a phosphate acid and a nucleoside, and at the same time a nucleoside is made of a sugar and a base. This section cover the properties of nucleic acids.

`Sugars in nucleic acids` The structure of nucleic acids is indeed sugar. Two different sugars can be found in nucleic acids. Deoxyribonucleic acid (DNA)contains deoxyribose, hence its name, whereas ribonucleic acid (RNA) contains a sugar called ribose. The structures of ribose and deoxyribose are:



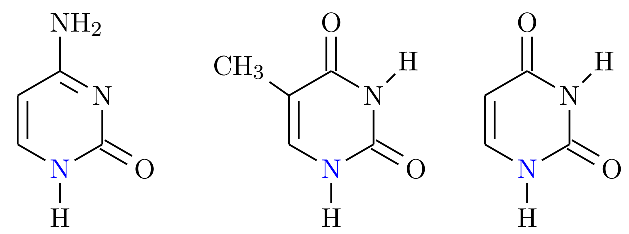
Ribose (R), RNA



Deoxyribose (DR), DNA

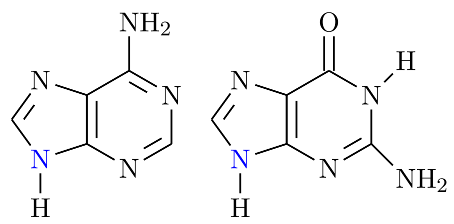
`Bases in DNA and RNA` Nucleic acids contain a sugar, and also contain a base. Remember that bases are chemicals that produce hydroxyls in water. There are tow different types of nucleic bases: purine bases and pyrimidine bases. At the same time, there are three pyrimidine bases: Cytosine, Thymine, and Uracil. There are two purine bases: Adenine and Guanine. Some of these bases can only be found as part of DNA such as thymine, whereas others can be found only in RNA such as Uracil. Other nucleic bases can be found either on DNA or on RNA. An example of the later is Cytosine. Because of the complex name of these bases often times we refer to them by the first letter. For example, Uracil is also referred as U.

PYRIMIDINE BASES



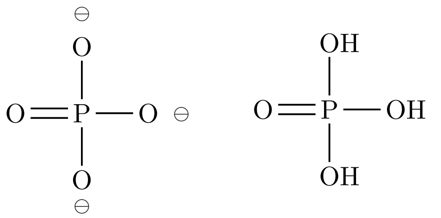
Cytosine (C) DNA & RNA | Thymine (T) DNA | Uracil (U) RNA

PURINE BASES



Adenine (A) DNA & RNA | Guanine (G) DNA

DNA and RNA contain phosphate At this point we saw tow different sugars part of RNA and DNA. We also saw some bases that also are part of the two different nucleic acids. Still, DNA and RNA are complex molecules that also contain a third element: a phosphate unit. Phosphate results from phosphoric acid: H_2PO_4 after removing two hydrogens:

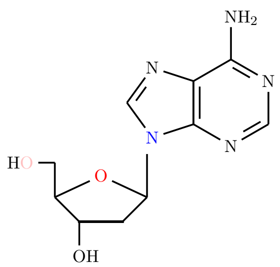


Phosphate Phosphoric Acid

Nucleoside: a base connected to sugar Nucleic acids are polymers. This means the are the result of the connection between smaller units that over all make the nucleic acids. These units are called nucleosides. A nucleoside is the result of connecting a sugar (either R or DR) with a base (C, T, U, A or G). These tow units are connected by means of a bond called N-glycosidic. This is a similar bond that connect sugars in disaccharides, however involved a nitrogen instead of an oxygen:

$$\mathrm{R-OH} \;+\; \mathrm{HN-R'} \xrightarrow{H_2O} \mathrm{R-N-R'} \qquad \text{N-Glycosidic bond}$$

Let us create a nucleoside. In order to do this, we need to select a sugar (for example DR) and a nucleic base (for example adenine). Both will combine be means of carbon number 1 of the sugar and eliminate a water molecule:

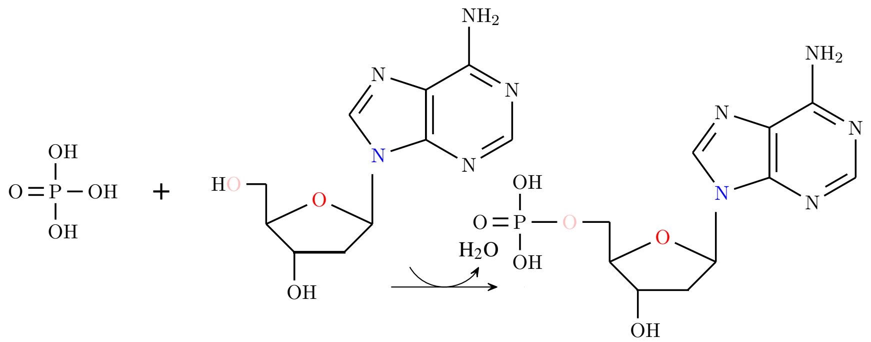


Nucleoside (Sugar+Base)

Nucleotide: a nucleoside connected to phosphate DNA and RNA are composed of numerous units called nucleotides. Nucleotides are the result of a nucleoside reacting with phosphoric acid by means of carbon number 5'. The bond in a nucleotide is called phosphoester bond:

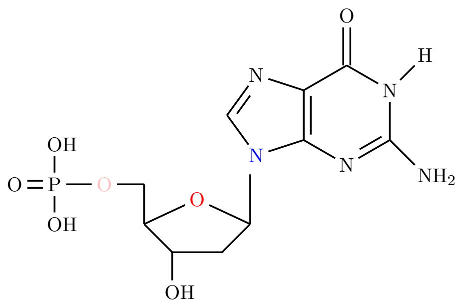
$$\mathrm{R-\overset{\overset{\displaystyle O}{||}}{P}-OH} \;+\; \mathrm{HO-R'} \xrightarrow{H_2O} \mathrm{R-\overset{\overset{\displaystyle O}{||}}{P}-O-R'} \qquad \text{Phosphoester bond}$$

For example, let us consider the nucleoside formed by the reaction of the Deoxyribose sugar and adenide. This nucleoside is called adenosine. After the reaction with phosphoric acid nucleotide is formed called adenosine-5'-monophosphate.

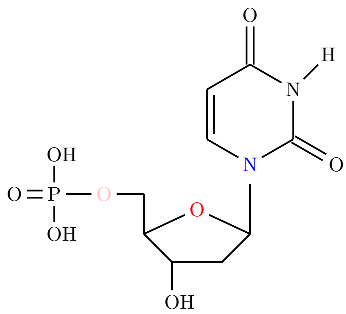


Phosphoric acid Nucleoside Nucleotide (Phosphate+Nucleosite)

Here some other examples of DNA nucleotides. Mind they are all based in Deoxyribose, the sugar that forms only DNA:

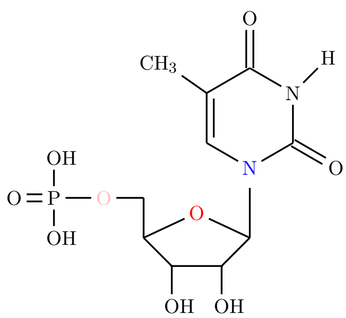


Deoxyguosine-5'-monophosphate

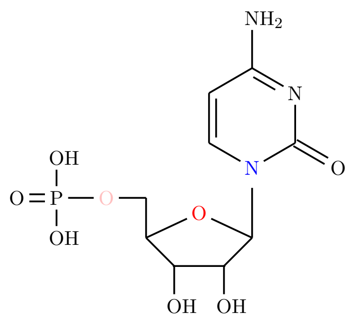


Deoxyuridine-5'-monophosphate

Here some other examples of RNA nucleotides. Mind they are all based in ribose, the sugar that forms only RNA:



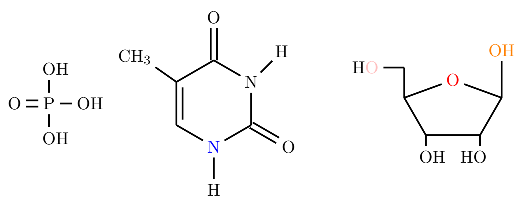
thymidine-5'-monophosphate



cytidine-5'-monophosphate

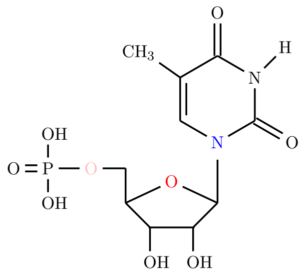
Sample Problem 13

Combine the following molecules to produce a nucleotide:



SOLUTION

A nucleotide is the result of combining a sugar–either ribose or deoxyribose–and a base with phosphate. The sugar given is ribose and the base is thymine, so the nucleotide will be part of RNA:



Thymidine-5'-monophosphate