Chapter on the Classification of Organic Chemicals: Focus on Bio-Oil Derivatives

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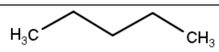
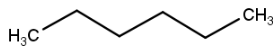
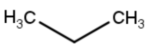
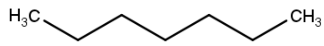
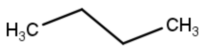
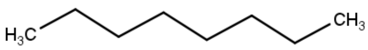
1. Baic Hydrocarbons

The simplest group of organic compounds known as basic hydrocarbons that consist exclusively of hydrogen and carbon (Silberberg and Amateis, 2017). Generally, basic hydrocarbons can be divided into aromatic and aliphatic hydrocarbons.

1.1. Aliphatic Hydrocarbons

The aliphatic hydrocarbons have an important role to play in many chemical processes (Rudolph, 2003). In accordance with IUPAC's nomenclature of organic chemistry, these hydrocarbons are classified as saturated (alkanes) and unsaturated (Favre and Powell, 2013). Alkanes are among the simplest types of this class. They perform many functions as important fuels, including methane, propane, butane, etc. Additionally, alkanes can be classified into straight-chain (n-alkanes) and branched-chain (isoalkane) types. In straight-chain alkanes, all carbon atoms except those at the terminals are bonded only to two other carbon atoms, while in branched-chain alkanes, at least one carbon atom is connected to more than two carbon atoms. (Orchin et al., 2005). Having no double or triple bonds, or rings, straight-chain alkanes follow the general formula C_nH_{2n+2}. The simplest n-alkane is methane (CH4) with only a single carbon. While n-alkanes can contain more than 100 carbon atoms, typically molecules with nine atoms and more are classified as higher alkanes (Niaounakis, 2017), which will be classified as higher molecule weight hydrocarbons. When normal temperatures prevail, alkanes are present as gases (C1-C4), liquids (C5-C17), and solids (C18 and beyond) (Lyons et al., 2016; Yadav et al., 2023). Table 1 provides a list of the basic n-alkanes. Furthermore, it illustrates how these structures are linear in nature. All chemical structures presented in this section were created using MarvinSketch ®.

Table 1. The basic straight-chain alkanes (C_nH_{2n+2})

n	Name		Structure	n	Name		Structure
1	Methane	CH_4	CH_4	5	Pentane	C_5H_{12}	
2	Ethane	C_2H_6		6	Hexane	C_6H_{14}	
3	Propane	C_3H_8		7	Heptane	C_7H_{16}	
4	Butane	C_4H_{10}		8	Octane	C_8H_{18}	

As a result of their high specific energy and low freezing points, isomer molecules have properties that make combustion very efficient. Most importantly, isoalkanes exhibit superior thermal stability (Hamilton et al., 2021). Branch-chain or isoalkanes are special cases of alkanes known as isomers. The formation of isomers occurs when there are four or more carbon atoms in the molecule. When two methyl groups are attached to the terminal carbon atom of a straight-chain alkane, the prefix "iso" is used, while when three methyl groups are attached, the prefix "neo" is used (Lyons et al., 2016). The carbon atoms in saturated hydrocarbons do not have multiple bonds, and every valence orbital on the carbon atom, which is not involved in the C-C bonding, is used in the hydrogen bonding (Orchin et al., 2005). Unsaturated hydrocarbons, on the other hand, are those with one or more multiple bonds between carbons. Here is a list of the basic isoalkanes presented in Table 2. As seen, the

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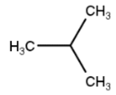
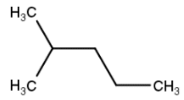
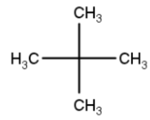
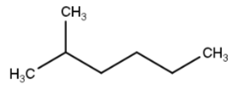
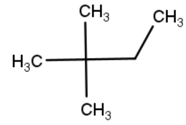
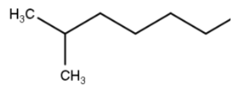
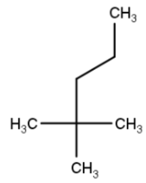
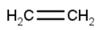
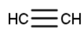
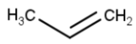
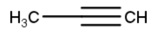
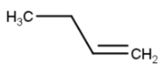
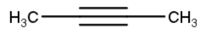
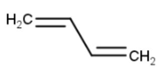
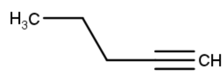
structures of these alkanes are not linear. While n-alkanes and isoalkanes have the same molecular formula, they have different geometrical arrangements of the atoms.

Table 2. The basic branched-chain alkanes (C_nH_{2n+2})

n	iso group		Structure	n	neo group		Structure
4	Isobutane (2-methylbutane)	C_4H_{10}		4	-		-
5	Isopentane (2-methylpentane)	C_5H_{12}		5	Neopentane (2,2-dimethylpropane)	C_5H_{12}	
6	Isohexane (2-methylhexane)	C_6H_{14}		6	Neohexane (2,2-dimethylbutane)	C_6H_{14}	
7	Isoheptane (2-methylheptane)	C_7H_{16}		7	Neoheptane (2,2-dimethylpentane)	C_7H_{16}	

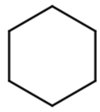
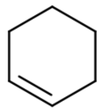
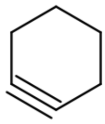
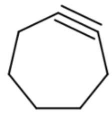
Other types of aliphatic hydrocarbons include unsaturated hydrocarbons such as alkenes and alkynes (Table 3). As they contain fewer hydrogen atoms per carbon atom than the maximum possible, they are considered unsaturated (Stauffer et al., 2008). In general, alkenes are characterized by at least one double bond between carbon atoms, resulting in the general formula C_nH_{2n} (Ouellette and Rawn, 2015a; Roberts and Caserio, 1977). There are a few exceptions to this formula, such as 1,3-butadiene, which has the formula C_4H_6. Alternatively, alkynes are compounds containing at least one triple bond between carbon atoms, giving them the formula C_nH_{2n-2}. Since they contain a triple bond which are stronger and shorter than double bonds, alkynes are even more reactive than alkenes (Stauffer et al., 2008).

Table 3. The basic unsaturated hydrocarbons (alkenes and alkynes)

n	Alkenes group		Structure	n	Alkynes group		Structure
2	Ethylene	C_2H_4		2	Acetylene (Ethyne)	C_2H_2	
3	Propylene	C_3H_6		3	Propyne (Methylacetylene)	C_3H_4	
4	1-butene	C_4H_8		4	Butyne	C_4H_6	
4	1,3-butadiene	C_4H_6		5	1-Pentyne	C_5H_8	

According to IUPAC's gold book (McNaught and Wilkinson, 1997), aside from alkenes and alkynes, there are also other unsaturated hydrocarbons such as allenes (containing two double bonds that meet at one carbon atom), dienes (containing two double bonds in different arrangements). Additionally, there exist saturated and unsaturated hydrocarbons such as cycloalkanes, cycloalkenes and cycloalkynes (Banerjee et al., 2017; Buchwald and Nielsen, 1988; Harvey and Sigano, 1996; Hioki et al., 2017; Kissin, 1990; Orchin et al., 2005). They consist of a carbon atom ring with one or more double bonds in the cycle (Moldoveanu, 2019a). These are categorized under aliphatic hydrocarbons. Table 4 provides examples of these cyclic hydrocarbons.

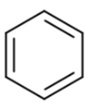
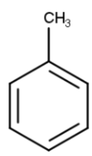
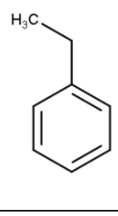
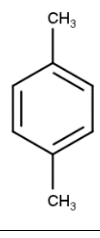
Table 4. The basic cyclic hydrocarbons (cycloalkanes-alkenes-alkynes)

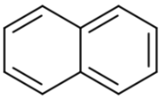
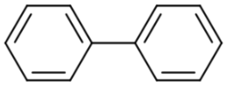
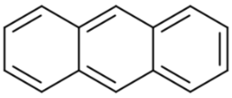
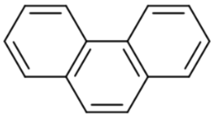
n	Name		Structure	n	Name		Structure
3	Cyclopropane	C_3H_6		6	Cyclohexane	C_6H_{12}	
5	Cyclopentene	C_5H_8		6	Cyclohexene	C_6H_{10}	
6	Cyclohexyne	C_6H_8		7	Cycloheptyne	C_7H_{10}	

1.2. *Aromatic Hydrocarbones*

An aromatic compound is a type of hydrocarbon, in which benzene (C_6H_6) is the simplest compound, that consists of bonded carbon atoms forming a ring structure characterized by high resonance energies and stability. (Orchin et al., 2005; Speight, 2017). The aromatic rings can exist as single or double, triple, or multiple fused rings. There are several sources of aromatic hydrocarbons, including petroleum-based fuels, biomass, coal, and solid waste (Huang et al., 2023). Pharmaceuticals, food, cosmetics, dyes, and fragrances are common industries that use aromatic compounds (Sá et al., 2017; Samain-Aupic et al., 2023; Taheri-Ledari and Maleki, 2021; Villa et al., 2005). Aromatic hydrocarbons can be categorized into four classes. Monocyclic aromatic hydrocarbons (MAHs) consist of a single benzene ring with six carbons, six hydrogens, and three double bonds (Moore and Ramamoorthy, 1984). As one of the most volatile and water-soluble aromatic hydrocarbons, benzene, toluene, ethylbenzene and xylenes (BTEX) fall into this class (Asadi and Mirmohammadi, 2017; Kerchich and Kerbachi, 2012; Liu et al., 2018). This class belongs to the basic hydrocarbons category in our classification. Polycyclic aromatic hydrocarbons (PAHs) which benzene rings are present in two or more chains (Macaya et al., 2019). Polycyclic aromatic hydrocarbons found in the environment typically consist of two (naphthalene) to seven (coronene) benzene rings that are fused together. In certain cases, these structures can become even more complicated and comprise up to 10 rings (Boehm, 1964; Huang and Penning, 2014). According to our classification system, light PAHs with two or three rings are classified as basic hydrocarbons. In our classification, high molecular mass PAHs containing four or more benzene rings, such as pyrene and fluoranthene, heterocyclic aromatic hydrocarbons (with five or six membered rings with a single heteroatom), such as furan and pyridine are categorized as fine chemicals. Moreover, class of functionalized aromatic hydrocarbons such as nitroaromatics (e.g., nitrobenzene), aromatic alcohols (e.g., phenol and catechol) aromatic aldehydes (e.g., Benzaldehyde and vanillin), etc. laid under functionalized hydrocarbons or even fine chemicals. Table 5 lists some basic aromatic hydrocarbons.

Table 5. The basic aromatic hydrocarbones (MAHs and light PAHs)

n	Name (class)		Structure	n	Name (class)		Structure
6	Benzene (MAHs)	C_6H_6		7	Toluene (MAHs)	C_7H_8	
8	Ethylbenzene (MAHs)	C_8H_{10}		8	p-Xylene (MAHs)	C_8H_{10}	

10	Naphthalene (2-ring PAHs)	$C_{10}H_8$		12	Biphenyl (2-ring PAHs)	$C_{12}H_{10}$	
14	Anthracene (3-ring PAHs)	$C_{14}H_{10}$		14	Phenanthrene (3-ring PAHs)	$C_{14}H_{10}$	

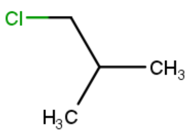
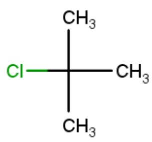
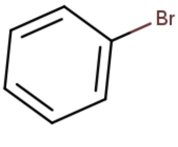
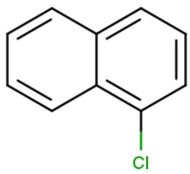
2. Functionalized Hydrocarbons

Organic compounds have several common structural features that are commonly termed functional groups (Roberts and Caserio, 1977). As previously mentioned, simple hydrocarbons are composed solely of hydrogen and carbon atoms. However, there exist hydrocarbons that also include other functional groups, such as hydroxyl (−OH), carboxyl (−COOH), amino (−NH_2), halides (F, Cl, Br, I), and several others. Hydrocarbons can be modified by including various functional groups. Orchin et al. (Orchin et al., 2005), for example, listed and discussed 161 different functional groups. A classification of functionalized hydrocarbons is provided in this section to aid in further analysis.

2.1. Halogenated Hydrocarbons

The presence of halogenated hydrocarbons in the environment is not natural and is due to their synthetic production (Ducrotoy and Mazik, 2011). The reason halogenated hydrocarbons are so common is that they are widely used as a solvent that is both effective and relatively nonflammable, as opposed to kerosene or gasoline (Gerba, 2019). These compounds contain halogen atoms (fluorine, chlorine, bromine, or iodine) in place of one or more hydrogen atoms (McLafferty, 1962; Zheng and Greedan, 2003). There are several types of these compounds depending on the type and number of halogen atoms present and the structure of the carbon skeleton. Alkyl halides are compounds derived from alkanes, where hydrogen atom(s) in the alkane is substituted with a halogen atom(s) (Miguez and Tarazona, 2024; Orchin et al., 2005). Aryl halides, which are aromatic hydrocarbons, are another example. In this case, a halogen directly bonded to a carbon of an aromatic ring (Orchin et al., 2005). In other words, aryl halides consist of halogens directly bonded to aromatic rings (Roberts and Caserio, 1977). A few examples of these classes are provided in Table 6. Compared to table 5 and 1, this table clearly illustrates how halogens are replaced.

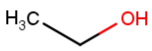
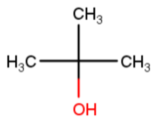
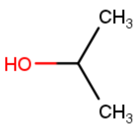
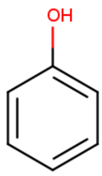
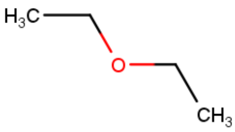
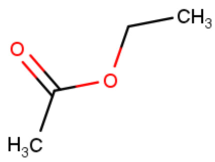
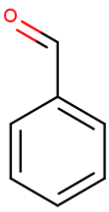
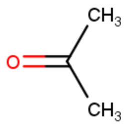
Table 6. Examples of halogenated hydrocarbons

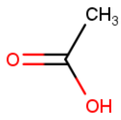
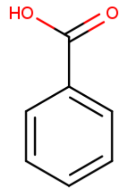
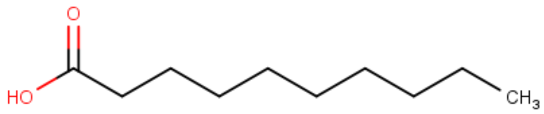
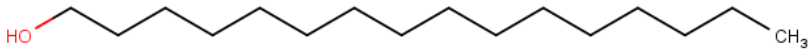
n	Name (class)		Structure	n	Name (class)		Structure
2	Isobutyl chloride (alkyl halides)	C_4H_9Cl		2	Tert-butyl chloride (alkyl halides)	C_4H_9Cl	
6	Bromobenzene (aryl halides)	C_6H_5Br		5	1-Chloronaphthalene (aryl halides)	$C_{10}H_7Cl$	

2.2. Oxygen-Containing Compounds

As indicated by the name of the class, these compounds, which make up a significant portion of functionalized hydrocarbons, contain oxygen as a component of their molecular structure. Different functional groups can form diverse chemicals in a variety of ways. Different classes of these compounds can be categorized based on their functional groups. An alcohol contains a functional group known as the hydroxyl group (-OH) (Orchin et al., 2005; Tisserand and Young, 2014). There are several ways in which alcohols can be classified. There are three categories of alcohols: primary, secondary, and tertiary, according to whether the -OH group is attached to one, two, or three (and complex) carbon atoms (Rabinowitz and Vogel, 2009; Stice et al., 2018; Thrall and Hamar, 2012). From other perspectives, alcohols can be categorized as volatile (e.g. ethanol, methanol) and nonvolatile (e.g. ethylene glycol and other glycols) (Garg and Ketha, 2020). A further important group of compounds is the phenolic group (or phenols), which has unique properties and is not classified as an alcohol (Sparkman et al., 2011). A compound in this class contains a −OH directly attached to the aromatic ring (Orchin et al., 2005; Smith and Tatchell, 1969) where the phenol (C_6H_5OH) is the simplest one. Aldehydes are organic compounds containing carbon atoms attached to a carbonyl group (McNaught and Wilkinson, 1997). Carbonyl functional groups consist of carbon atoms that are double-bonded to oxygen atoms (C=O) (Ouellette and Rawn, 2015b). When carbonyl groups (C=O) are bonded to two carbon atoms, ketone compounds are formed (Orchin et al., 2005). Unlike aldehydes, in which the carbonyl group is located at the end of the carbon chain, the carbonyl group in ketones is always contained within the carbon skeleton (Roberts and Caserio, 1977). A carboxylic acid is an organic compound that contains at least one carboxyl group. This functional group −C(O)OH consists of a hydroxyl group attached to a carbonyl group (Orchin et al., 2005). Commercially available carboxylic acids come in a wide variety of structures and are easy to store and handle using a many well-established techniques (Gooßen et al., 2008). The assessment of food's nutritional value heavily relies on the amount and composition of fatty acids, since they serve as a significant source of energy and important nutrients (Yang and Bai, 2015). Simple esters are compounds in which the hydroxyl group of a carboxylic acid is replaced by an alkoxy group (Ouellette and Rawn, 2015a). An alkoxy group in organic chemistry is a functional group that consists of an alkyl group (e.g., CH_3−) attached to an oxygen atom and alternatively, an oxygen atom can be inserted into a carbon–carbon bond to generate an ether by replacing a hydrogen atom with an alkoxyl (or aryloxyl) group (Orchin et al., 2005). Fatty acids, the primary category of lipids, are carboxylic acids that generally consist of 12-20 carbon atoms (Raymond, 2013). In addition to fatty acids, there are other categories of oxygen-containing hydrocarbons known as fatty alcohols and fatty esters. These compounds have important functions in a variety of biological and commercial processes. Table 7 provides some examples of these functional groups.

Table 7. Examples of oxygen-containing compounds

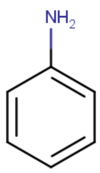
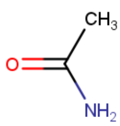
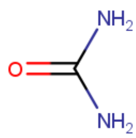
n	Name (class)		Structure	n	Name (class)		Structure
2	Ethanol (Promary alcohol)	C_2H_6O		4	Tert-Butyl alcohol (Tertiary alcohol)	$C_4H_{10}O$	
3	Isopropanol (Secondary alcohol)	C_3H_8O		6	Phenol (Phenols)	C_6H_6O	
4	Diethyl Ether (Ethers)	$C_4H_{10}O$		4	Ethyl acetate (Esters)	$C_4H_8O_2$	
7	Benzaldehyde (Aldehydes)	C_7H_6O		3	Acetone (Ketones)	C_3H_6O	

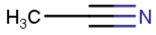
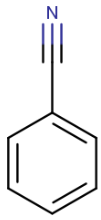
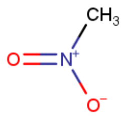
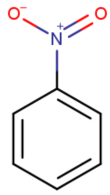
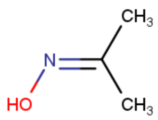
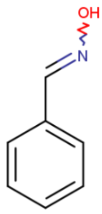
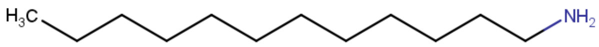
2	Acetic acid (Carboxylic acid)	$C_2H_4O_2$		7	Benzoic acid (Carboxylic acid)	$C_7H_6O_2$	
8	n-decanoic acid (Fatty acids)	$C1_8H_{34}O_2$					
16	Hexadecan-1-ol (Fatty alcohol)	$C_{16}H_{34}O$					

2.3. *Nitrogen-Containing Compounds*

The same way oxygen-containing hydrocarbons were defined, if nitrogen (N) is involved in molecular structure, then nitrogen-containing compounds will be formed. Nitrogenous organic molecules play significant roles in several natural processes. Their structural variety is vast, encompassing both basic functional groups and complex heterocyclic compounds, with the inclusion of nitrogen atoms (Moreno and Peinado, 2012). Based on their functional groups, these compounds can be classified into several distinct categories. Among the organic compounds, amines occupy a distinct and important position. Not only do these molecules exist in many physiologically significant substances, including amino acids, peptides, proteins, DNA, RNA, and many other substances, but they also serve as prominent characteristics of several synthetic substances used as pharmaceuticals and commercial products (Abdel-Magid, 2014). Amines are compounds in which one or more of the hydrogen atoms of ammonia are replaced by an alkyl or aryl group. Primary, secondary, and tertiary amines are formed when one, two, or three hydrogen atoms are substituted with these groups, respectively (Orchin et al., 2005). Fatty amines are compounds that result from the substitution of nitrogen atoms in fatty acids, olefins, or alcohols (Visek, 2003). Most commercially available fatty amines are composed of carbon chains ranging in length from C8 to C22. The term "amides" refers to derivatives of carboxylic acids where the hydroxyl group (−OH) is changed to the NH_2 group (Moldoveanu, 2019b). From a different standpoint, an amide is a chemical molecule that consists of an acyl group (R−C=O) bonded to a nitrogen atom (Speight, 2011). Imines and nitriles are compounds containing double and triple bonds between carbon and nitrogen respectively. Nitro compounds have a nitro group ($-NO_2$) that is attached to either carbon, nitrogen, or oxygen (McNaught and Wilkinson, 1997). Compounds in which the thiocyanate group (−S−C≡N) replaces the hydrogen atom of a hydrocarbon are known as thiocyanates (Orchin et al., 2005). Oximes are compounds that result from the reaction between aldehydes or ketones and hydroxylamine (NH_2OH). They are distinguished by the presence of the functional group −C=NOH (McNaught and Wilkinson, 1997). Table 8 provides some examples of nitrogen-containing compounds.

Table 8. Examples of nitrogen-containing compounds

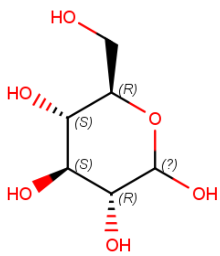
n	Name (class)		Structure	n	Name (class)		Structure
6	Aniline (Amines)	C_6H_7N		1	Methylamine (Amines)	CH_5N	
2	Acetamide (Amides)	C_2H_5ON		1	Urea (Amides)	CH_4N_2O	

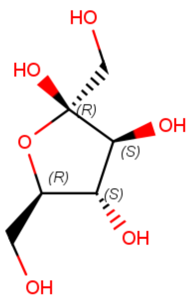
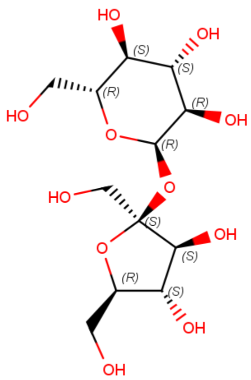
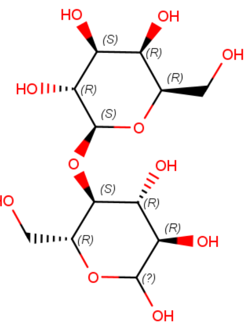
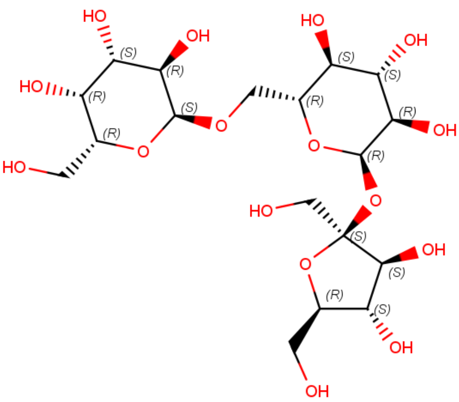
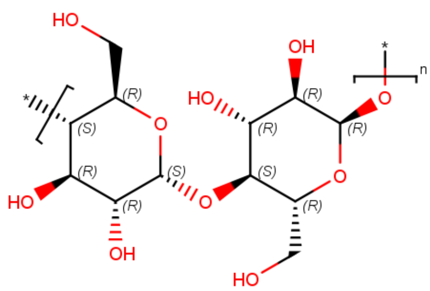
2	Acetonitrile (Nitrils)	C_2H_3N		7	Benzonitrile (Nitrils)	C_7H_5N	
1	Nitromethane (Nitro compounds)	CH_3NO_2		6	Nitrobenzene (Nitro compounds)	$C_6H_5NO_2$	
3	Acetone oxime (Oximes)	C_3H_7NO		7	Benzaldoxime (Oximes)	C_7H_7NO	
12	1-Dodecanamine (Fatty amines)	$C_{12}H_{27}N$					

2.4. Carbohydrates

In nature, carbohydrates are probably the most abundant organic compounds (Jørgensen, 2009). Many vital functions of living organisms are performed by carbohydrates. Since carbohydrates are the immediate products of photosynthesis, they serve as the main energy storage components (Pallardy, 2008). Additionally, they are the precursors of most other organic compounds in plants. General classifications of carbohydrates include monosaccharides, oligosaccharides, and polysaccharides (Kaushik et al., 2022; Leong et al., 2019; Ouellette and Rawn, 2015a; Yahia et al., 2019; Zeece, 2020). Since monosaccharides cannot be hydrolyzed into smaller carbohydrates, they are the simplest carbohydrates. These compounds are aldehydes or ketones with several hydroxyl groups, and they play a crucial role in the production of nucleic acids and serve as fuel molecules in glycolysis (Carrey and Simmonds, 2005). Living organisms rely on nucleic acids, long-chain polymers composed of nucleotides (Khedkar et al., 2016). Oligosaccharides are carbohydrates composed of three to ten monosaccharides (Ahnen et al., 2020; Laurentin and Edwards, 2013; Stylianopoulou, 2023). According to the number of monosaccharide units that are linked, oligosaccharides are called disaccharides, trisaccharides, and so on. A polysaccharide contains thousands of monosaccharides that are covalently linked together (Orchin et al., 2005). Aside from these, there are also some types of modified hydrocarbons. In the classification, they are grouped under the fine chemicals category, even though they can be classified under carbohydrates and functionalized hydrocarbons (see section 4.4.5). Some examples of three classes of carbohydrates are given in Table 9.

Table 9. Examples of simple carbohydrates

n	Name (class)		Structure
6	Glucose (Monosaccharide)	$C_6H_{12}O_6$	

6	Fructose (Monosaccharide)	$C_6H_{12}O_6$	
12	Sucrose (Disaccharides)	$C_{12}H_{22}O_{11}$	
12	Lactose (Disaccharides)	$C_{12}H_{22}O_{11}$	
18	Raffinose (Trisaccharides)	$C_{18}H_{32}O_{16}$	
6n	Cellulose (Polysaccharides)	$(C_6H_{10}O_5)_n$	

2.5. Other Classes

Other classes of functionalized hydrocarbons are also available that are based on specific atoms in their molecular structure. Hydrocarbons containing sulfur, phosphorous, or silicon are examples of such materials. Every living organism contains sulfur-containing compounds (Parry, 1999). Among them, thiols are organic compounds that possess one or more −SH groups in their molecular structure. They may be regarded as similar to alcohols, where the −OH group is replaced by −SH (Moldoveanu, 2019c). A thioether is a compound consisting of a hydrocarbon atom replaced by an alkyl or aryl group or a hydrocarbon atom inserted into a carbon–carbon bond (Orchin et al., 2005). In sulfoxides, an oxygen atom is bonded to a sulfur atom of a sulfide, while in sulfones, two oxygen atoms are bonded to a sulfur atom. As examples of silicon-containing hydrocarbons, like alkanes, silanes have the general formula Si_nH_{2n+2}, and Silicones are polymers with silicon atoms bonding with oxygen atoms.

3. High Molecular Weight Compounds

In the present classification, waxes, and paraffins are high molecular weight compounds. These compounds have a large number of atoms and a large molecular mass. Typically, waxes consist of long-chain aliphatic compounds (Lan, 2019; Tinto et al., 2017) and are generally esters of long-chain fatty acids (C14-C36) and alcohols (C16-C30) (Kumar et al., 2018). The term paraffin refers to an alkane that is solid at room temperature, high molecular weight and contains a considerable amount of carbon atoms (Orchin et al., 2005).

4. Fine Chemicals

The fine chemicals are complex, single, pure chemical substances that have a low volume (less than 1000 tons per year) and a high price (more than 10 dollars per kilogram) (Cybulski et al., 2011; Pollak, 2007). A wide range of industries benefit from the use of fine chemicals, including pharmaceuticals, agrochemicals, dyes and pigments, fragrances and flavors, intermediates, electronic chemicals (Cybulski et al., 2011; Panizza, 2018). Fine chemicals are defined as follows in the present classification:

4.1. Active Pharmaceutical Ingredients

Active Pharmaceutical Ingredients (APIs) are the bioactive constituents of medicines that are accountable for the desired therapeutic effects of medications. Excipients (e.g., lactose or mineral oil), on the other hand, are inactive compounds employed as carriers or to provide form, flavor, or color to the drug (Kumar et al., 2022). An important subclass of APIs, antibiotics (e.g., penicillin) are used to treat and prevent bacterial infections (Patel et al., 2023). A cardiovascular medicine is a broad category of medications that belong to a distinct subclass and are primarily used to treat arrhythmias, heart failure, and coronary heart disease (Kelly, 2021).

4.2. Flavors and Fragrances

The International Fragrance Association (IFRA) (Nikfar and Kharabaf, 2014) defines natural fragrances as complex fragrance compounds made exclusively from natural aromatics (Vijaya et al., 2020). Fragrances are composed of a blend of essential oils or other volatile aromatic chemicals, together with solvents. Essential oils consist of intricate combinations of hydrocarbons, ethers, alcohols, esters, and ketones (Manayi and Saeidnia, 2014). Normally, essential oils are extracted from leaves and other parts of plants other than wood (Park and Tak, 2016). Furthermore, synthetic flavors, which are also known as artificial flavors, play a crucial role in the food, pharmaceutical, and cosmetic industries (PhD and PhD, 2017). They are designed to mimic natural ingredients' tastes. Compared to natural flavors, synthetic flavors are often more cost-effective (Yaylayan, 1991).

4.3. Heterocyclic Compounds

Heterocyclic compounds are a significant class of hydrocarbons, which according to our classification are classified under fine chemicals. Heterocyclic compounds are the largest and most diversified group of organic chemicals. Aromatic heterocyclic compounds are commonly found in a wide range of physiologically active synthetic and natural substances, agrochemicals, and pharmaceuticals (Chaudhuri et al., 2021; Kaur, 2022). Heterocyclic compounds have a significant impact on the process of discovering and developing drugs (Tripathi et al., 2021). Heterocyclic rings are present in the majority of current drugs (D’Auria et al., 2023).As a result, extensive efforts have been undertaken to create efficient and environmentally friendly methods for synthesizing these compounds with high yields. Heterocyclic compounds are characterized by a cyclic structure that includes at least one carbon atom and at least one additional element, such as nitrogen (N), oxygen (O), or sulfur (S). Typically, cycles consisting of five or six atoms are the most prevalent, and they possess more stability compared to three, four, seven, or bigger rings (Moldoveanu, 2019d). Based on the number of the rings and the functional groups, these hydrocarbons can be classified in different groups. Pyrrole, furan, and thiophene are the primary basic heterocycles in this category, and their interconnected variations encompass a wide range of naturally existing and artificially produced compounds (Marson, 2003). Pyridines and pyrimidines are important heterocyclic compounds that contain nitrogen (Li et al., 2022). Combining a pyridine with a benzene ring results in the formation of two heterocyclic aromatic structures commonly known as quinoline and isoquinoline (Finley, 2015). Purines and pyrimidines, both nitrogen-containing hydrocarbons, serve as the fundamental components of nucleic acids, namely DNA and RNA (Aaron and Trajkovska, 2005). For instance, adenine, guanine, cytosine, thymine, and uracil, which include tiny aromatic ring structures containing nitrogen, are classified under this group (Glavin et al., 2018). Indoles (a ubiquitous functional group) are heterocyclic ring systems that have diverse uses in many pathophysiological diseases, including cancer, microbial and viral infections, depression, and more (Chadha and Silakari, 2018; Davies and Spangler, 2013). As discussed by Nollet et al. (Nollet et al., 2007) , the majority of flavoring compounds are composed of simple structures that include only one functional group and have a small molecular weight. These structures often include basic aliphatic acyclic and alicyclic alcohols, aldehydes, ketones, carboxylic acids, and related esters. However, there are more complex structures such as heteroaromatic and heterocyclic compounds that exhibit unique organoleptic properties.

4.4. Steroids

Among organic compounds, steroids belong to the large category of compounds that possess a four-ringed molecular structure (one five-membered and the rest six-membered carbocycles) (Jaeger and Aspers, 2012). There are several types of steroidal compounds. As hydroxylated steroids, bile acids are derived from cholesterol in the liver (Engelking, 2015). When a steroid's hydroxyl group is esterified with a fatty acid, steroid ester is formed (Vihma and Tikkanen, 2011).

4.5. Modified Carbohydrates

This class belongs to the group of chemicals such as sugar alcohols, anhydro sugars, and glycosides. As hydrogenated forms of carbohydrates, sugar alcohols are formed by the reduction of their carbonyl groups to primary or secondary hydroxyl groups (Grembecka, 2019). Anhydro sugars are produced from the dehydration of hydroxyl groups in pyranoses and furanoses, resulting in the formation of fused bicyclic or tricyclic ring structures (Pérez, 2007). By using a glycosidic bond, sugar molecules are attached to another functional group to form glycosides (McNaught and Wilkinson, 1997). Generally, a glycosidic bond consists of a covalent bond between a saccharide molecule's hemiacetal group and an organic compounds hydroxyl group (Stylianopoulou, 2023).

4.6. Complex Hydrocarbones

Indeed, there exist intricate hydrocarbons (basic or functionalized) with distinctive characteristics and specific uses, which are categorized as fine chemicals in our classification. These encompass a group of chemical compounds that are manufactured in lesser volumes in comparison to bulk or commodity chemicals. There are the same subcategories of this class as those for basic and functionalized hydrocarbons, except for the higher levels in value pyramid.

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