CHEMORECEPTION: THE CHEMISTRY OF ODORS

Our senses provide us with information about our environment. These senses respond to a variety of stimuli. The sense of touch is stimulated by the pressure of physical contact with an object. Hearing responds to rapid fluctuations in air pressure. Sight is produced by electromagnetic radiation falling on the retinas of our eyes. Two of our senses respond to the chemical nature of our surroundings: taste and smell. Because they depend on chemical interactions, these two senses are called chemoreception. Taste is called contact chemoreception, because to experience the flavor of something, we must come into contact with it. Smell is remote chemoreception, for we can sense the odor of an object at a distance.

The sense of smell (olfaction) is both a very simple and a very complex sense. It is simple because relatively few cells are involved in detecting odors. In humans, the olfactory sensors are located at the top of the nasal passages, just below and between the eyes. Each passage contains a small area (about 2.5 cm^2) containing roughly 50×10^6 receptor cells. Each of these cells is connected through a single synapse (junction between nerve cells) directly to the brain. Of all our senses, the sense of smell is the most intimately connected with the brain. In spite of this, the sense of smell is very complex in how it functions. The mechanism by which the odor receptor cells interact with odor-causing molecules is still unknown, but studies of odors and the structure of the odor-causing molecules has revealed some correlations.

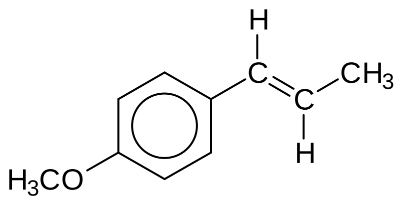
With each breath we take, air is swept over the olfactory sensors. These sensors are covered with a coating of mucous. Molecules from the air dissolve in this mucous and interact with filaments of the olfactory cells. Because odors are sensed only when gaseous molecules dissolve, all odor-causing materials must produce vapors. Materials that release virtually no vapor, such as ionic salts, are odorless. Only volatile materials that are soluble in the mucous and that interact with the olfactory cells produce odors.

Because odors are of significant commercial concern (consider the food and cosmetic industries), the study of odors has been quite extensive. Odors have been classified by a variety of methods, depending on the application. In the food industry, the odors of chemical compounds are categorized by the identity of the edible material of which they are reminiscent. This produces odor classes such as caramel, honey, vanilla, citrus, and butter. In the cosmetic industry, odors are more likely classified by floral and herbal groupings, such as jasmine, rose, balsam, or pine. For purposes of the investigation of how odors are perceived, the classification is more precise.

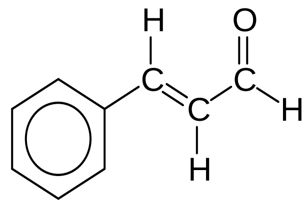
The scientific classification of odors attempts to find so-called primary odors, in analogy to the primary colors of vision (red, green, and blue). To do this, scientists have exploited a common defect in the human sense of smell. In any large group of people, there are some who cannot detect the odor of a particular substance or group of substances. These people are “anosmic” toward a particular odor. This is the olfactory counterpart to color blindness. Just as there are different types of color blindness, there are a variety of anosmias. Scientists investigate which odoriferous substances cannot be detected by certain anosmic persons. These substances are then classified into a single “primary” odor category. So far, eight primary odor categories have been identified: camphorous, fishy, malty, minty, musky, spermous, sweaty, and urinous. The odors of the majority of substances are produced by a combination of these primary odors, just as colors (e.g., yellow) are produced by a combination of primary color responses (red and green). Furthermore, many of the odors we easily recognize are produced by the combination of many compounds. For example, over 90 odoriferous compounds have been identified in jasmine blossoms.

A comparison of the structures of the molecules of materials in each of the primary odor categories reveals similarities among the molecules in some categories. For example, substances having a fishy odor are generally amines containing a nitrogen atom bonded to three other atoms and having a non-bonding pair of electrons.

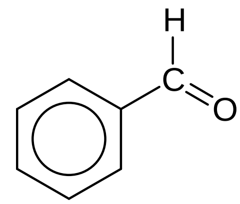
Examples include dimethylamine, $H_3C–NH–CH_3$ and ethylamine, $H_2N–CH_2CH_3$. The molecular structures of several minty materials also reveal some similarity.



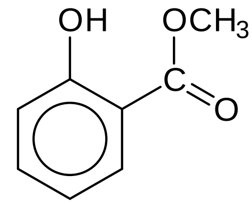
anethole



cinnamaldehyde

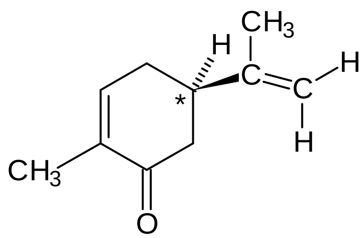


benzaldehyde

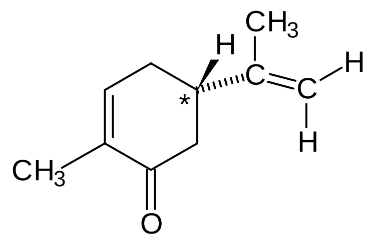


methyl salicylate

However, very subtle differences in structure can produce different odors. For example, the difference between R-carvone and S-carvone is that in R-carvone, the hydrogen near the asterisk is below the double-bonded carbon, but in S-carvone, the H is above the C. In all other respects, the structures are identical. Although both are in the minty category, their odors are distinct.



R-carvone



S-carvone

In some of the categories of odors, especially the musky category, the range of molecular structures is very broad.

Certain structural features of a molecule can be associated with a particular type of odor, although that odor may not be one of the primaries. A good example of such a feature is the mercapto group, –S–H. Most volatile materials that contain this group have strong odors. The simplest such molecule is H–S–H, hydrogen sulfide. This gas produces the characteristic odor of rotten eggs. Allyl mercaptan, $H_2C{=}CH–CH_2–S–H$, produces the characteristic odor of garlic. Tertiary-butyl mercaptan, $(H_3C)_3C–S–H$, and dimethyl sulfide, $CH_3–S–CH_3$, are added to natural gas to produce the characteristic odor that signals a gas leak. Gas companies distribute scratch-and-sniff cards with these compounds in order to teach customers the characteristic odor; once smelled, never forgotten. An indication of the intensity of the odor of these compounds is that only 2.5 grams of them are required to produce 1 million of these cards.

Several theories of how molecules interact with olfactory cells are currently under investigation. One proposes that odorant molecules vibrate at characteristic frequencies, and that olfactory cells contain molecules that vibrate at similar frequencies. When odorant molecules get close to the olfactory molecules in cells, the odorant molecules stimulate the olfactory molecules to vibrate at the characteristic frequency, thereby generating a response. Another theory suggests that odorant molecules penetrate the wall of the olfactory cells, disturbing the electrolyte balance between the exterior and interior of the cell and generating a nerve pulse. Perhaps the most widely accepted theory emphasizes the importance of the size, shape, and electronic arrangement of the odorant molecules. According to this theory, the olfactory cell responds to the size, shape, and electronic arrangement of the odorant molecule. Whether this response occurs at sites specific to certain combinations of size and shape, or whether it is a generalized reaction is still a matter of discussion. However, it is known that olfactory cells are not specific to a particular primary odor, unlike the cells of the retina that respond to only one of the primary colors. A single olfactory cell responds to molecules in several of the primary odor categories.