Kirk-Othmer Encyclopedia of Chemical Technology.

ODOR MODIFICATION

1. Olfaction

Although the nose houses and protects the cells that perceive odor, it does not directly participate in odor perception. The primary function of the nose is to direct a stream of air into the respiratory passages. While this function is occurring, a small fraction of the inhaled airpasses over the olfactory epithelium, located 5–8 cm inside the nasal passages. This olfactory area occupies about 6.45 cm^2 (one square inch) of surface in each side of the nose.

Olfaction begins when an odorant stimulates the olfactory receptor cells, triggering the opening or closing of the ion channels, which in turn convert this stimulus to an electrical response to the olfactory bulb and ultimately to other parts of the brain. The olfactory neurons send messages to the olfactory bulbs, structures about the size and shape of peach pits, located on the underside of the large overhanging frontal lobes of the cerebrum. Humans have tiny olfactive lobes in comparison with those of most other animals. Olfactory messages do not stop at the olfactive lobes; they also travel to brain regions involved in cognition, emotion, and other activities. These messages are subject to very little rational control. They bypass the thalamus, a group of brain cells that processes and edits most sensory information. The direct route to behavioral areas of the brain may be responsible for olfactory memory. These brain cells are proteinaceous material, and may consist of as many as 1000 different receptor sites. Olfactory neurons are the only nerve cells in the body that regenerate, replacing themselves once every month or two. Thus, people whose olfactory neurons are accidentally damaged, eg, by a blow to the head, may regain their sense of smell when new neurons grow and reestablish links with the proper regions of the brain. The fact that there is a gene responsible for odor receptor proteins was discovered in 1991 (1).

Perception of odor is therefore a physical mechanism by which information is processed in the brain. The nasal fossae are able to detect an unlimited number of dissimilar odor stimuli, sometimes from remote distances and sometimes in dilutions less than one part per trillion of air. In the case of the eye and the ear, the perceiving apparatus is confronted only with a limited and precise range of vibrations in receiving light and sound waves. For taste, there are only four primary stimuli. In contrast, the varieties of odor stimuli, which require evaluation and identification by the brain, are thought to number in tens or possibly hundreds of thousands. Day by day new odors are appearing, all of which are immediately accepted and sorted within the seemingly unlimited categories of the olfactory brain. The brain not only recognizes this information, but evaluates it, sorts it, and associates it with experiences, events, likes, and dislikes (Fig. 1).

The vomeronasal organ (VNO), located in the nose, is a small chemical sensing structure associated with odors and behavioral effects. The vomeronasal system, which is made up of the VNO and a portion of the brain's limbic system, is structurally independent of the olfactory and *nervous terminalis* systems in the nose. It may, however, interact with these systems in a manner dependent on prior experience or learning, and therefore be directly related to the association of smells and experiences. This independent chemosensory system in the nose may prove to open doors to new learning associated with the sense of smell and human behavior.

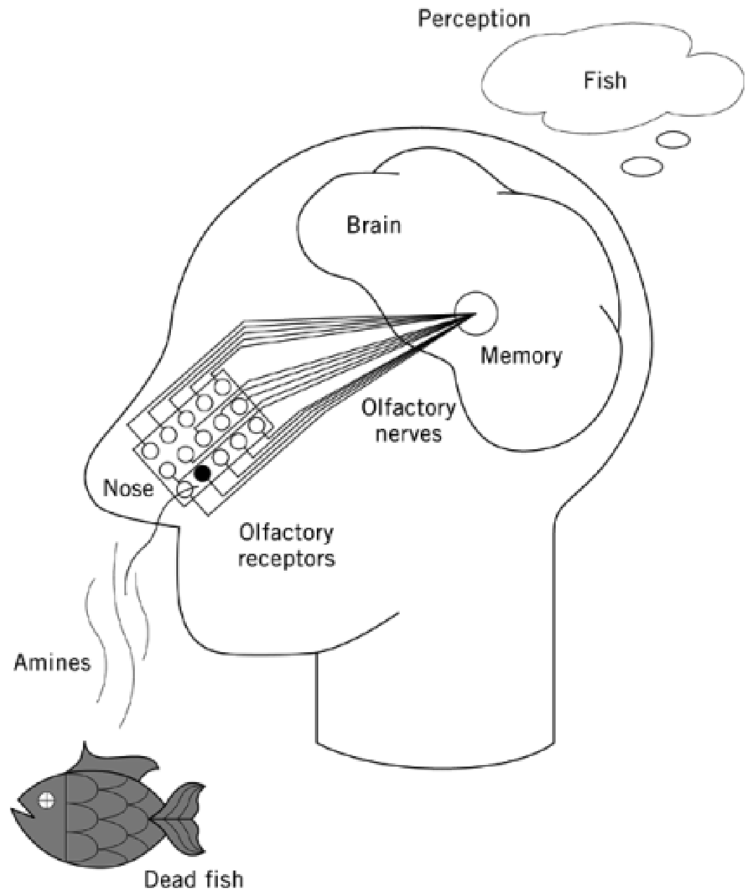

Fig. 1. How the olfactory fingerprint works.

According to the physical theory of olfaction, odorous substances emit radiations of high frequency that directly transmit their energy or vibration to pigment granules in the olfactory receptors. The energy involved in olfactory stimulation is the characteristic molecular vibration of each specific odorous substance; differences in odor are therefore dependent on differences in the wavelength of the radiation emitted. To substantiate this theory, it has been demonstrated that certain odorous substances in the gaseous state have absorption bands in the ultraviolet region of the spectrum (0.20–0.36 μm), whereas the absorption bands of nonodorous compounds fall outside this range (2).

According to the chemical theory of olfaction, the mechanism by which olfaction occurs is the emittance of particles by the odorous substances. These particles are conveyed to the olfactory epithelium by convection, diffusion, or both, and directly or indirectly induce chemical changes in the olfactory receptors.

Researchers at the Monell Center (Philadelphia, Pennsylvania) are using a variety of electrophysical and biochemical techniques to characterize the ionic currents produced in taste and olfactory receptor cells by chemical stimuli. These studies are concerned with the identification and pharmacology of the active ion channels and mode of production. One of the techniques employed by the Monell researchers is that of "patch clamp." This method allows for the study of the electrical properties of small patches of the cell membrane. The program at Monell has determined that odors stimulate intracellular enzymes to produce cyclic adenosine

3′,5′-monophosphate (cAMP). This production of cAMP promotes opening of the ion channel, allowing cations to enter and excite the cell. Monell's future studies will focus on the connection of cAMP, and the production of the electrical response to the brain. The patch clamp technique also may be a method to study the specificity of receptor cells to different odors, as well as the adaptation to prolonged stimulation (3).

There is still some debate regarding the degree of ability in humans to experience the sense of smell. Most people can distinguish between smells that are common odors and perceive the same type of smell. Although a certain smell can be perceived as agreeable or disagreeable to different people, the majority of humans have a fairly uniform sense of smell. The general population can detect the aroma of an apple pie baking in the oven; however, only those who are trained in the study of olfaction are able to detect the components of that aroma, ie, cinnamic aldehyde.

In 1986, the National Geographic Society, in cooperation with the Monell Center, conducted a worldwide survey of the sense of smell. Over 10 million survey forms were sent to readers of the Society's journal, of which close to 1.5 million forms were completed and returned. With responses to 40 demographic and 42 odor-related questions, the results constitute the largest set of data on human olfaction (4).

Both genetics and experience can influence one's olfactive capabilities. The inability of an individual to smell a certain odor is known as anosmia. According to the National Geographic Survey, 40–50% of the population cannot smell androsterone. For those who can smell androsterone, the odor perception ranges from sweet and perfumey to sweaty and urinous. Studies at the Monell Center have determined that genes play a significant role in determining whether a person can smell androsterone, and possibly how it is perceived (5). However, the ability to smell androsterone can be induced in some people, who initially cannot smell it, by repeated daily exposure to the compound.

There are certain well-established facts about olfaction (6). All normal people can smell. People suffering from brain lesions, injured olfactory nerve, or obstructed nasal passages may be anosmic. Cases of preferential anosmia, ie, ability to sense certain smells and not others, are not well established. Such cases occur, but little is known of them.

Some substances are odorous, others are not. Humans can smell at a distance; if one smells the roses in a garden, it is not ordinarily considered that part of the rose is in contact with the nose. Substances of different chemical constitution may have similar odors. Substances of similar constitution usually have similar odors, eg, in a homologous series; nevertheless, even stereoisomers may have different odors. Substances of high molecular weight are usually inodorous and often nonvolatile and insoluble. The quality as well as the strength of odor may change on dilution.

The sense of smell is rapidly fatigued. Fatigue for one odor does not affect the perception of other dissimilar odors, but will interfere with the perception of similar odors. Two or more odorous substances may cancel each other out; this compensation means that two odorous substances smelled together may be inodorous.

Odor travels downwind. Many animals have a keener sense of olfaction than humans. Insects have such extraordinary keenness of smell that it may be a different modality of the chemical sense from that known to humans.

2. Odors

Odors have been classified according to Carolus Linnaeus, the eighteenth century Swedish botanist who proposed seven odoriferous qualities: aromatic, fragrant, musky, garlicky, goaty, repulsive, and nauseous. Later in the twentieth century, ethereal (fruity) and empyreumatic (burnt organic matter), together with subdivisions of Linnaeus' classification, were added. In the 1990s, researchers concentrate less on categorizing odors, and more on how people detect and interpret them. Although the average person can name only a handful of common odors, this limitation results from memory retrieval failure, rather than a failure to detect the differences.

It was thought previously that there were no inborn odor preferences; that these are learned from experience. However, studies at the Monell Center have indicated that flavors consumed by a mother and transmitted into the milk influence the feeding behavior of her infant. When mothers consume garlic, their infants feed longer than when no garlic is consumed (7).

Odors are measured by their intensity. The threshold value of one odor to another, however, can vary greatly. Detection threshold is the minimum physical intensity necessary for detection by a subject where the person is not required to identify the stimulus, but just detect the existence of the stimulus. Accordingly, threshold determinations are used to evaluate the effectiveness of different treatments and to establish the level of odor control necessary to make a product acceptable (8). Concentration can also produce different odors for the same material. For example, indole (qv) in low concentrations has the smell of jasmine and a low threshold of perception. In high concentrations, it has a strong odor of feces and α-naphthylamine as well as a considerably higher threshold of perception.

3. Evaluation Methodologies

Industry has standardized procedures for the quantitative sensory assessment of the perceived olfactory intensity of indoor malodors and their relationship to the deodorant efficacy of air freshener products. Synthetic malodors are used for these evaluation purposes. These malodors should be hedonically associated to the "real" malodor, and must be readily available and of consistent odor quality. These malodors should be tested in various concentrations and be representative of intensities experienced under normal domestic conditions.

Panelists are trained to evaluate malodor intensity and the degree of modification. It is important that the panelist be able to smell through any extraneous odor(s), such as the fragrance of the product, to evaluate the efficacy of products making elimination or neutralization claims, as opposed to the phenomenon of masking.

Specific scales may be used to rate the perception of intensity of (*1*) the malodor, and (*2*) the malodor along with an odorous material designed to modify the malodor. Rating scales may consist of numerical assignments to words, eg, from $0 = \text{no odor}$ to $10 = \text{very strong odor}$. These same type of scales may be used to describe both the hedonic acceptability of the net result, ie, from $0 = \text{very unpleasant}$ to $10 = \text{extremely pleasant}$, and the degree of modification, ie, from $0 = \text{does not modify}$ to $10 = \text{complete elimination or cover} - \text{up}$.

Protocols allow for at least two vessels to test both the untreated control malodor and the treated malodor(s). The untreated control malodor is used as a reference point for the maximum malodor score. When panelists evaluate each of the two or more vessels, they must wait a period of time (usually 30–60 s) for recovery from adaptation before smelling the next vessel. This step is always repeated between each evaluation.

4. Modification

4.1. Masking

Masking can be defined as the reduction of olfactory perception of a defined odor stimulus by means of presentation of another odorous substance without the physical removal or chemical alteration of the defined stimulus from the environment. Masking is therefore hyperadditive; it raises the total odor level, possibly creating an overpowering sensation, and may be defined as a reodorant, rather than a deodorant. Its end result can be explained by the simple equation of $1 + 1 = >2$ (Fig. 2**a**).

An olfactive evaluation of this phenomenon produces the following outcome:

$$\text{intensity rating malodor} = 6 \text{ (moderately strong)}$$

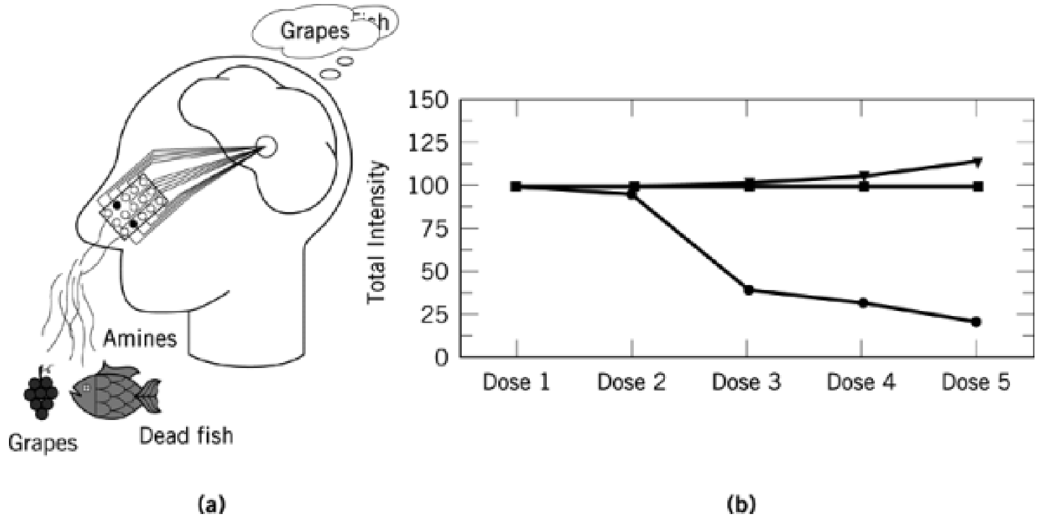

Fig. 2. Odor masking: (**a**) how masking agents work, and (**b**) masking curve for tobacco odor, where (▼) is perceived odor strength (treated); (■) is perceived odor strength (untreated); and (•) is tobacco odor, malodor reduction.

$$\text{intensity rating malodor + odorous material} = 8 \ \text{(strong)}$$

$$\text{degree of modification} = 8 \ \text{(good masking agent)}$$

Odor masking does little or nothing to control malodors; it merely covers them up (Fig. 2**b**). Many materials used in masking odors are aldehydes, which are very chemically reactive and usually comprise the top note of a fragrance. Odor masking has had a long and colorful history. It gave birth to eau de cologne, devised to mask the malodor that was presumed to carry the plague. Odor masking is used in many areas of household, industrial, and institutional use via products that mask such malodors as pet smells, smoke, cooking, and numerous other odors. The forms by which masking is executed vary, and can be solid, liquid, and aerosol.

4.2. Counteraction

Counteraction, sometimes referred to as neutralization, occurs when two odorous substances are mixed in a given ratio and the resulting odor of the mixture is less intense than that of the separate components. The acceptable term to describe this occurrence is compensation. Materials that can accomplish this are basically organic odors which are highly polarized, have a strong affinity for each other, and may also have a low vapor pressure. Some of these molecules have the ability to compensate physiologically for certain malodor materials; others to react chemically with them. Counteraction occurs when the compensating substrate is able to form a coordinate bond with osmophoric sites unique to malodor molecules, such as amino- and thio- moieties. The result is overall reduction in odor; the malodor is transformed into an acceptable state, often with some residual freshening odor. This result lowers the total odor perception and can be exemplified by 1 + 1 = <2 (Fig. 3.

An olfactive evaluation of this phenomenon produces the following outcome:

$$\text{intensity rating malodor} = 6 \ \text{(moderately strong)}$$

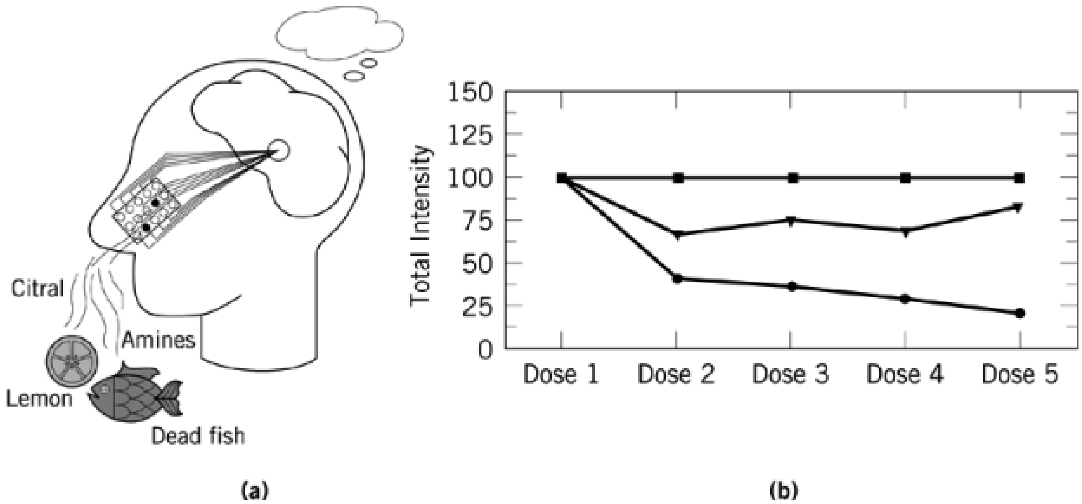

Fig. 3. Odor counteraction: (**a**) how odor counteraction works, and (**b**) counteraction curve, where (▼) is perceived odor strength (treated); (■) is perceived odor strength (untreated); and (•) is kitchen odor, malodor reduction.

$$\text{intensity rating malodor} + \text{odorous material} = 5 \ \text{(slightly strong)}$$

$$\text{degree of modification} = 8 \ \text{(good counteractancy agent)}$$

It is unlikely that two odors when combined will cancel each other and result in no odor, ie, $1 + 1 = 0$; there is always some residual odor. However, reduction of an odor by an oxidation process can destroy the odor molecule permanently and leave no residual odor.

5. Commercial Aspects

Translating odor modifiers into consumer products results in forms, such as solids, liquids, and aerosols, for a market defined as products “for the nose.” This includes products that cover up or eliminate odors, perfume the home, or cleanse the air. Such products thus defined were reported to have sales in 1992 of just under $2 billion. The categories of this market can be broken out as traditional air fresheners, cat litter products, aroma care, air purification, and disinfectant in both consumer and industrial applications.

This article deals primarily with the traditional air freshener category; some product trade names, manufacturers, and forms are listed in Table 1. The active ingredients of these pleasant odors are fragrances composed of both synthetic and natural essential oils. The products themselves can be described as either active (instant action, such as an aerosol), or passive (solids or liquids). The most recent advancement in this product category is that of electrically powered air fresheners. Consumer expectation of the efficacy of these products is increasing, putting greater demand on marketers to develop products that meet their needs. Passive product longevity claims by marketers range anywhere from 30 to 45 days. Active (aerosol) products’ lifespan is minutes.

Table 1. Air Freshener Odor Modifiers

Manufacturer	Trade name	Form
	Industrial	
Walex Products Co.	Metazine, Exodor	liquid
Union Carbide	Abscents	powder
Belle-Aire Fragrances Inc.	Ordenone	liquid
	Consumer	
Armour-Dial	Renuzit	aerosol, solid, electric
Reckitt & Colman	Wizard, Airwick, Love My Carpet, Lysol	aerosol, electric, solid, carpet powder, liquid
Church & Dwight	Arm & Hammer	carpet powder
S. C. Johnson	Glade	carpet powder, aerosol, solid, electric, liquid
Scotts Liquid Gold	Touch of Scent	aerosol

6. Behavior Modification by Odor

Although odorous materials no doubt impact each other, much discussion centers around the ability of odorous materials to influence human behavior. In articles ranging from scientific journals to trade magazines, there is discussion on the potential of fragrances, ie, essential oils, to affect people's moods, their ability to focus and maintain attention, to relax and sleep, and even their sexual capability.

Consider these findings from studies that assess whether fragrance is a powerful mood-altering substance (9):

In scented stores, shoppers look at merchandise longer.

Whiffs of peppermint and lily of the valley improve the alertness of people engaged in monotonous tasks.

A lemon scent pumped through the air-conditioning system of a Japanese office building increased workers' productivity.

Pleasant odors of flowers, fruit, or food can relieve the depression of hospital patients, whether they are aware of the scents or not.

People say they have an enhanced self-image and greater confidence when they think others like their fragrance.

The words aromatherapy, aromachology, and aromakinetics are coinages of the 1990s. Aromatherapy, once based on a tradition of folklore and herbal medicine, is being investigated scientifically.

A technique known as contingent negative variation (CNV) measures brainwave reaction to olfaction. CNV is being conducted by universities as well as fragrance manufacturers (10). These types of studies have shown the effect of materials such as lavender and nutmeg in reducing stress or anxiety, and the ability of oils such as peppermint to stimulate brainwave activity. CNV research was incorporated into the development of the fragrance for a consumer personal care product launched in the late 1980s.

Airlines, such as Air New Zealand and Virgin Air, give their long-distance passengers after-flight regulator travel kits, which contain vials of scents labeled "awake" and "asleep." Sloan Kettering Hospital (New York) has conducted studies using the scent of heliotropin to reduce the anxiety of patients undergoing magnetic resonance imaging therapy.

The interrelationship between fragrance and psychology has been the subject of systematic investigation only recently. Consumer moods can be calculated in both positive and negative directions, and changes can be measured subjectively after exposure to fragrance. Personality traits, such as extrovert or introvert, may in some ways also be determined by fragrance preference.

8 ODOR MODIFICATION

Odors play a much greater role in human behavior than previously thought. The sense of smell provides a direct link with the function of the brain; therefore, the further study of olfaction can only advance the learning of causes and effects of stimuli to the brain.

The future in research will certainly lead to a better understanding of how odors are recognized, sorted, and classified. Studies promise, among other things, to determine whether perceptually similar, but structurally different, odors share the same class of receptor proteins, whether responses to odors can be modified, and possibly why olfactory neurons regenerate but other neurons do not.

Further to this, it should be possible to better understand how odors affect human moods and performance. Studies involving autistic children, severely mentally handicapped persons, and traumatic and stress-related situations where odors are being used to affect behavior may open many more doors to the understanding (4).

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