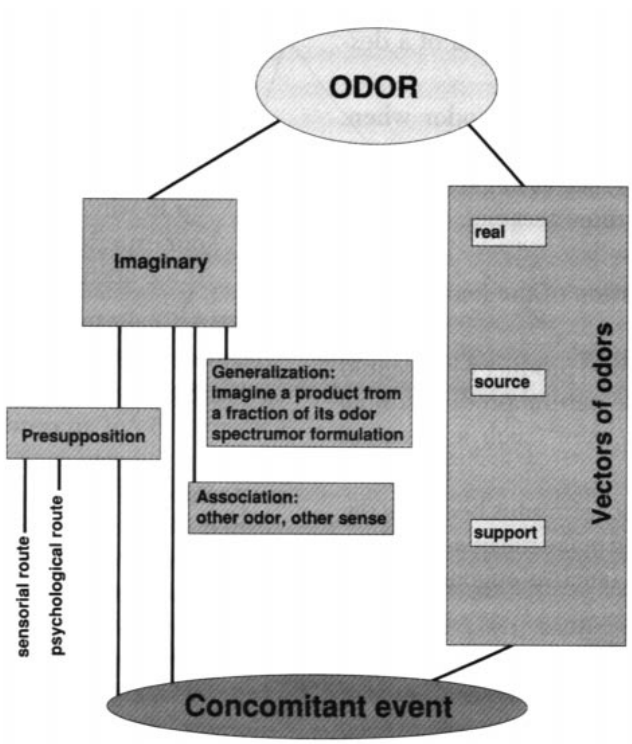
The Field of Odors: Toward a Universal Language for Odor Relationships

By Jean-Noel Jaubert, Université du Havre, Laboratoire de Chimie, Le Havre; Claude Tapiero, Laboratoire de Chimie Bio-organique, Université Montpellier II, Montpellier; and Jean-Christophe Dore, Laboratoire d'Informatique Chimique et Biologique, Muséum National d'Histoire Naturelle, Paris, France

All odors that we smell trigger feelings and sensations that affect our memory and psyche. It is when we try to express the odor in terms that would be universally understood that we find ourselves limited by the poverty of language. As a result, we try to conjure up this experience in our mind and express it in readily understandable terms. These terms may, to our benefit, describe our own personal reaction to the aroma, but more often they are based on empirical and more commonly used descriptive terms, while the feelings that are triggered by the stimulus are more often than not lost in the words. As a consequence we, as human beings, have a natural tendency to associate and connect an aroma stimulus with an actual material source whether this is real or a "force-fit." However, the notion of a non-material source for the odor stimulus is still present in our informational data bank of past events and feelings.



The origin of the aroma, which can stimulate an emotion, event, memory, previous situation or object association, gives us, at least in the imaginary sense, a free hand in odor association. However, subjective (intuitive) and personal characterization of the odorous space usually makes it impossible to share the information with others. This is true even among professionals such as designers, researchers, perfumers and product developers, who find themselves facing this problem daily.

I. Failure of Current "Descriptive" Systems

In a previous study in which we examined the pre-existing descriptive systems,[1] we were able to show that the denominations of odors were schematically related in two separate domains, both of which relate to the memory stimulus of an event concomitant with the perception of the odor (Figure 1).

One domain is based on an actual reference point that contains the "odor vectors," which can be subdivided into three levels:

- *A mere base for the odor.* The object used as a reference has either systematically or accidentally received the odorous substances. Examples of this are newspa-

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pers, which have the odor of the solvents associated with the printing inks (an unpleasant but somewhat unavoidable situation), or a food product that has become assimilated with the odors of its packaging.

- *An odor transmitter.* The object considered actually produces the odorous substances, and is generally well-defined and identifiable. An example is the odor released from a rose.
- *An odor vector.* An odor vector consists of the odorous molecules themselves. For instance, the characteristic odor of benzaldehyde actually consists of odorous benzaldehyde molecules.

The other domain that is associated with an odor stimulus is that of imagination, i.e., what image is evoked by the stimulus. This image can be the result of the following thought patterns:

- It can be directly produced by the event with which it is concomitantly associated, as illustrated in Figure 1.
- It can be triggered by presuppositions that can arise from:
  - Another sensorial perception (such as the image of an object, like an apple).
  - An idea that was present in the mind at the time of the olfactory stimulus (such as the idea of a dessert).
- It can be an association with another odor when, previously, the odor stimulus and a second odor were experienced simultaneously (such as might be experienced on smelling a warm crême caramel, e.g., caramel, vanilla, milk and egg).
- It can be dictated by possession of the knowledge it can represent:
  - The composition of a natural product which could lead to imaging the whole natural product from a fraction of its odor spectrum (such as geraniol smells like rose).
  - The formulation. The odor stimulus becomes the seed for the imagination to make the quantum leap to the whole formulation (such as eugenol has the fragrance of carnation).

As can be seen from a review of the above system, which can be considered to proceed from a chronological study of the odor stimulus, the final description terminology used would more often than not be expressed in esoteric language; language which can lead to incommunicability or, worse, confusion. In the long term, with the absence of a set of universal rules that take into account the multitude of private experiences considered referential by the odor stimulus recipient, no real progress can be made with respect to communicating about the odor stimulus. A chronological study of the odor stimulus is really a set of random sequences of unrelated olfactory impressions that are memorized in a pure linear process. This fact makes it difficult to teach and understand what happens when a recipient receives an odor stimulus. Studying odor notes becomes similar to studying history based on a sequence of events and dates. The result is that teaching odor-note identification requires multiple repetitions and is the source of a large number of errors.[2] However, to convey sensorial information on an odor stimulus, one can use a four-stage process:

1. ***Elementary Stage:*** This is the necessary basis for every communication system in a society. For human beings, it is the young child's learning period where stimuli are described in a very objective and rudimentary way. The description is based on a series of references familiar to everyone.
2. ***Evocation Stage:*** This is the association with objects or situations instigated or rediscovered in the memory. It deals with the procedures already presented in this report, and is in fact the only means of communicating information about the stimulus used by people who have already worked on the subject.
3. ***Emotional Stage:*** This conveys the emotions evoked by the stimulus, and on communication the subjectivity of this stimulus is described.
4. ***Behavioral Stage:*** This conveys only simple behavior in which a good deal of data about our being and our experiences is integrated. It is expressed through three attitudes: positive, negative or indifferent.

Various studies have tried to standardize languages corresponding (most of the time with the utmost confusion) to a combination of the last three stages, sometimes with an attempt to put an evocation in concrete form through the use of a substance (or a composition) allowing a certain repeatability.[3] Several individuals and groups have published glossaries and dictionaries that constitute the first endeavors at standardization, but leave much room for subjectivity and personal experience. These remain somewhat inoperative even when it is mentioned that the small group of people who are to work together will have to be trained for a long time in order to speak the same language. But it is, of course, the first stage which is acutely lacking in the domain of odors and puts the sense of smell behind the others for which a complete education has progressively been set up in the course of the history of mankind. Thus, when we tried to carry out a study on the relationship between the structure of molecules and their odorous characteristic, we found ourselves confronted with the lack

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of a single homogenous language to express the odorous characteristics in a universal and reproducible way. This led us to develop a system, which has now been in use for many years, both for the training of professionals (specialists) in the field of aroma description, and for the preliminary training of young children and nonspecialist adults. This system, like all systems of communication, is based on a universal language that takes into consideration the following points:

- A basic glossary; i.e., a body of references from the same field as the one under study. In our case, the field of study is the odor stimulus. The glossary must represent the whole continuum (range of odors).
- An integral organization of these references within the continuum.
- The creation of rules for the system relating to the descriptive terms and a relationship of distance within the continuum between different odor stimuli reference points.
- The control of data flexibility by building in an assimilation of the variations surrounding the reference points.

The model that we have developed to address the above points has been simplistically named the *Field of Odors* which, as we shall see, illustrates Bossuet's main idea on education: "... in the same way as to help one's memory in the knowledge of places, one remembers a few main towns around which others may be located, according to their respective distance. Thus in the succession of centuries one must have some marks, standing out because of some great event and to which everyone else is linked."[4]

II. Discovery of the Field of Odors

Unlike sensorial phenomena such as sight and hearing which tend to deal with perception of only physical dimensions, olfaction, which is based on chemoreception, involves the receipt of disconnected chemical stimuli. Thus the perception of light can be reduced to amplitude (level of gray) alone. Color perception can be reduced to wavelength. Sound perception can be reduced to vibrational frequency (pitch) and amplitude (strength). But, olfaction can be reduced only to a response to the chemical stimuli to which the entire multitude of olfactory receptors (two million) are subjected.

A more sophisticated, integrated organization of odor stimuli within a continuum cannot possibly have as its basis a purely linear organization (univaried) of the various stimuli. Indeed, unlike the classifications used for sensorial perceptions such as visual, auditory and thermal, which use as their basis a one-dimensional physical reality (a gradient of a monotonous function such as wavelength, cycles per second or degrees Celsius), sensorial chemoreception is far more complex in as much as the phenomenon and its perception cannot be reduced to a single dimension. Owing to its multidimensional nature, sensorial chemoreception can use as its basis only an integration of the relative levels of proximity between odor stimuli. These proximity levels cannot be viewed as primary odors in the sense of primary colors, but they can be considered objective landmarks (a multiparametric approach). Even if these landmarks are not accurate, the use of levels of proximity presents a way to relate one odor stimulus to another in a continuum. This approach has led to the development of a taxonomic-based organization of odors similar to the classifications developed by naturalists and systematicians, but relying heavily on the resources used by numerical taxonomists using automatic classifications and factor analysis (a cladistic approach).[5] To achieve this, we organized a structural continuum of odor stimuli based on clearly defined odorous substances (each odor molecule studied separately).

II.A 1,400 Odorous Molecules

As a basis, we selected those odor stimuli (single molecules) with which we are most frequently confronted. It was conceded that natural products, which are mixtures of odor stimuli, release not just a single odor, but several odors which are received differently by different people, each reacting according to a unique sensitivity and current mood. In addition, it was understood that it is very difficult to achieve reproducibility with such composite mixtures.[6] As

a result, in the development of this structural continuum of odor stimuli, mixtures (natural or man-made) were excluded. The molecules thus defined allow us to be sure that, on the whole, all subjects will describe the same stimulus despite the imperfections that might arise from the existence of impurities. As already mentioned, numerous data, varied and diverse, can be collected on odors. The only rational and objective way of classifying odors consists of submitting them to a mathematical procedure known as a reduction of multidimensional data. Indeed, the data with which we are confronted is not just multiparametrical. It is also somewhat variable (noisy data), requiring interpretation through the use of confused (fuzzy) logic.

Through examination of the data and the interrelationships, it can be determined that the shape recognition of molecules meets this requirement. However, this includes the possibility of a certain number of errors, inaccuracies and omissions. This is especially true for the most discriminant elements, from which one can derive a simulation model that, in turn, can be used in the predictive mode. The results thus obtained will not belong to an exact science such as would be found if defined and formal causal relationships between several elements were used. Rather they will be based on probability relationships.

Before developing this olfactive relationship continuum, we had to decide on the number and extent of the olfactory stimuli (odor molecules) that should be selected to develop it. Realize that if all of the data on olfactory stimuli were used, it would be necessary to incorporate data on as many as 40,000 odor molecules even though the number of materials included in existing data banks does not really exceed 10,000. Indeed, one can reasonably assume that the number of odorous molecules is infinite. If ten million organic compounds (molecules) are listed in *Chemical Abstracts* as discreet Registry Numbers, a permutation of the interrelationships between them is neither possible nor practical even when one considers that only a subset of this number can be considered to possess an aroma due to chemical and physical properties such as molecular weight, vapor pressure and chemical function.[7]

After exhaustive examination of lists of odorous molecules that are given in various publications (books, scientific papers, industrial leaflets and catalogs), we determined that a 3.5% representation of the approximately 40,000 odorous molecules would suffice as a basis for developing this olfactory relationship continuum model. The 1,400 compounds that were chosen were selected for their frequency of occurrence in the published material. We also ensured a full representation of all possible odor characters within the cross section of molecules chosen. The development of the olfactory relationship continuum model was based on the data obtained from these 1,400 compounds.

II.B The First Stage of Model Development

Initially we gathered the general structural, physicochemical, toxicological and economic information on each

of the 1,400 chosen odorous molecules (odorants). In addition, we indiscriminately collated all of the odor descriptors that we could get for these same compounds. We used not only the published information, but also descriptive information that we gathered from scientists in the field and creative perfumers and flavorists, as well as personal remarks made by members of our sensory panels who were presented with the odor stimuli from the 1,400 selected odorants.

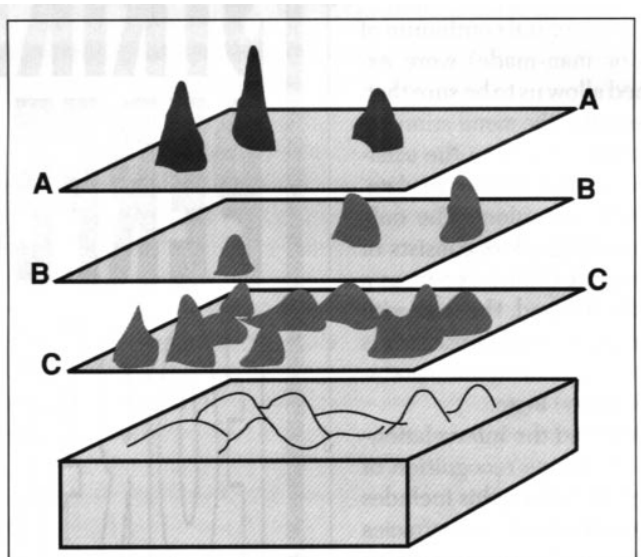


Figure 2. Odorant groups modeled as relief maps.

It was possible to structure the general information in various ways, such as according to the atomic make up, the functional groups, homologous series, physical parameters and other factors. That allowed us to categorize the 1,400 odorants into a structural profile through the intervention of a few dozen descriptors. Using an approach similar to that of Dravnieks,[3] we were able to collect 650 odor evocations, reduced to 135 basic odor evocations for our 1,400 molecules. Following a taxonomic approach to the combination of structural and descriptive information using various factorial treatments, we were able to deduce the results that are presented in this report. This combination and reduction of data was developed along two successive approaches:

1. A double classification of the odorants by the structural data and descriptive data.
2. The classification of the 1,400 odorants based on the frequencies of associations encountered.

Theory and description of the mathematical procedures we used are published elsewhere.[8-11] The present article is intended to show how a system based on that math can be used to teach a method for the identification of odors.

We believe that our approach is original, in that it does not get bogged down in a semantic arena. Instead, we've developed a structural-olfactive relationship continuum that uses the space of vocabulary, only as a medium through which we select the odorants, without trying to make that vocabulary significant. At the level of evocation, this presents minimal danger of confusion or ambiguity. This is in contrast to many studies in which associations are used in odor descriptions, and categorization of the odor is often done to make it fit into a preconceived category based on the association. This "force fitting" may not be right. Nevertheless, it should be noted that the more reduced the "descriptive space" (i.e., the force-fit syndrome), the more difficult it is to develop a model from which a meaningful result can be obtained.

II.C The 42 Reference Odors

The traditional approach to the choice of reference (marker) substances uses a suggestive word as a header, such as *floral* to suggest flowers, and tends to assume that all items classified under that heading are identical. This approach is questionable if one takes into account the points discussed in the first part of this report. We believe that if two odorants elicit evocations without any overlap within the whole group of subjects, then we are entitled to claim that for these subjects the perceptions of these two odorants are in fact different. Now apply that same principle to the volumes of published literature, the descriptive information from scientists and the experiments performed by our own sensory panels, then factor in the 1,400 odorants, and you see that a coherent structure could be proposed.

Unfortunately, the situation is not as clear-cut as one might like. Hence it is better to visualize it as shown in Figure 2. In this Figure, the model is designed along the lines of a geographical relief map that has been cut transversely at different levels. In Section A-A, only very differentiated groups of odorants can be found; that is, odorants that do not share any descriptors. In this differentiated group, we can find 2,5-dimethylpyrazine which is most of the time associated with descriptive terms that conjure up cooked or grilled products. A second member of this group is dimethyl sulfide, which evokes decaying sulfur odors, while a third is isobutylamine, which suggests amine-like characters or rotting fish.

In Section B-B (Figure 2) three other notes are added: vanillin (sweet), citral (suggesting lemon) and α-pinene (suggesting resinous trees). Section C-C contains a more complex mixture of descriptors in which the fewer the shared descriptors the higher the peak. The lower the altitude, the more summits of lesser importance, and the less and less distinct the odorants are from each other. The more widespread the spatial coverage, the greater the precision. Fortunately or unfortunately, no hierarchy has been found between the various summits, which, it seems, are not interdependent.

It should also be noted that the intensity differences between the odorants in A-A, B-B and C-C are reflected by the number of dots used both within a peak for well-differentiated odorants and on either side of the peak for less well-differentiated ones. Again, the greater the number of dots, the greater the precision. As a result, a compromise

has to be found between the precision and the amount of the data. To accomplish this, several levels of the data have been studied and the results have shown that 42 points (i.e., 45 substances, taking one doublet and one triplet into account) allow both a sufficient coverage of this structural olfactory relationship continuum (odorous space), and an ease of remembering. A list of the 42 points (showing one of the main odorants for each summit) can be seen in Table I. Although the component names listed in this table may appear to be too chemically complicated, they are essential for the precision of the work. Instead of these chemical names, we'd like to use neologisms (new words) that would not divert or influence the respondent's attention. We are looking for those neologisms, but we are not having much success finding them.

We believe, therefore, that our approach to a workable interrelationship model is the most objective one thus far developed, since we have gathered all the available data from all possible sources and treated it in a strictly mathematical way with no subjective (personal) weighting or manipulating. We do not deny that the very complex set of data which constitutes the 42 reference odors may well involve physiological as well as cultural data. At the moment, the list can be considered as a kind of cultural invariant best shared by everyone concerned. This conclusion was confirmed by the results obtained by the treatment of the first matrix, a spatial arrangement of odorants related to their objective chemical characteristics.

Table I. Reference Odorants

1	d-limonene
2	citral ("H" in Figure 3a)
3	linalool
4	7-methyl 3,4-dihydro 2H 1,5-benzo dioxepin 3-one ("calone" in Figure 3b)
5	cis-3-hexenol
6	nonanal
7	a triplet: 2,3-butanedione, butyric acid and 1-octen-3-ol
8	isobutylamine ("A" in Figure 3a)
9	cyclopentanone
10	ethyl isobutyrate
11	γ-undecalactone
12	p-hydroxyphenyl butanone
13	benzyl acetate
14	2-phenylethyl alcohol
15	methyl anthranilate
16	ethyl phenylacetate
17	(E)-anethole
18	hydroxycoumarin ("D" in Figure 3a)
19	a doublet: benzaldehyde and cinnamic alcohol
20	vanillin
21	l-menthol
22	α-pinene ("T" in Figure 3a)
23	terpinyl acetate
24	methyl salicylate
25	d-camphor
26	thymol
27	β-caryophyllene
28	cinnamaldehyde
29	eugenol
30	8-, 12-oxido-13,14,15,16-tetranorlabdane ("ambroxan" in Figure 3b)
31	vetiveryl acetate
32	methyl 3-methyl orsellinate ("evernyl" in Figure 3b)
33	methyl isoborneol
34	isobutylquinoleine
35	omega-6-hexadecenlactone ("ambrettolide" in Figure 3b)
36	3-methyl indole ("skatole" in Figure 3b)
37	ethylmaltol
38	3-(methylthio) propionaldehyde ("methional" in Figure 3b)
39	2,5-dimethylpyrazine ("P" in Figure 3a)
40	phenol
41	diallyl disulfide
42	dimethyl disulfide ("S" in Figure 3a)

II.D Creation of the Field of Odors

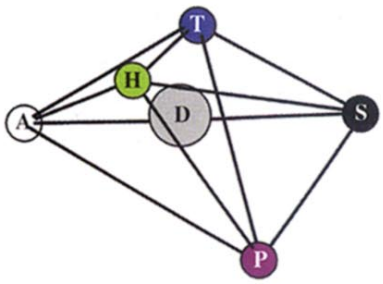
If we consider that the 1,400 odorants can be viewed as dots in a spatial continuum, the information gained from this is both diffuse and impossible to memorize. As a result, we have made use of the structural continuum that we have already defined for the 42 referents identified during the first stage of model development. The heavy concentration of data around six of the referents allows us to imagine a three-dimensional structure, or *Space of Odors* (Figure 3a), that clearly locates the six summits. We shall refer to these six summits as "poles." These poles are surrounded by secondary summits, while other less important summits are distributed here and there. These less important summits are separated by transition platforms, more or less homogeneous, that we call "dominants."

After only elementary training, a group of respondents (subjects) using the structure in Figure 3a can easily find the relative location of each odorant once the identity and position of the six poles mentioned above have been fixed. (For the diagram in Figure 3, we have used simplified language, i.e., "terpenic" instead of "α-pinene"; however, this language must be considered representative of only the simple reference odorants mentioned in Table I.)

The Space of Odors model is uneasy in form and difficult to read so we have reduced the three-dimensional Space of Odors model (Figure 3a) to a two-dimensional Field of Odors model (Figure 3b). If we convert from three to two dimensions, the process undertaken is no longer purely mathematical; blocks are broken, but are represented on the diagram by triangular insertion marks. We believe that this two-dimensional representation is coherent, allowing for a more rapid perceptual understanding and memorization. Only during this last stage of the creation of the Field of Odors were choices made; all other information used represents a summary of all pertinent documented and recorded descriptive data.

To assist in developing the working models to be used to both classify and describe odors and their relationship to each other, we presented a range of odorous substances to a group of kindergarten children to which a set of 16 different colored felt pens were given. After smelling each odor stimulus, the children were asked to describe the odor by marking their ballot sheets with a color. The results of this exercise have been incorporated into the development

of the Field of Odors to assist in memorization of odor types and categories. This color coordination should assist in the categorization by rationalizing some of the uncertainty related to odor description that is partly due to our inability to put feelings and impressions into words that will be universally understood. This difficulty expressing ourselves comes from the absence of shared reference points for odors; shared reference points are well known in other areas of sensory stimulation. In the Field of Odors we show that a structure does, in fact, underlie the unspecified odor and it removes inherent biases based on culture, a fact that will become evident when the subject is studied to a greater extent. (It should be pointed out that there is really no originality in this procedure; the seven colors used to



3a. The Space of Odors

Color/ Abbrev.	Function	Odor
A	white pole (amine)	isobutylamine
H	yellow-green pole (citrus)	citral
T	blue pole (terpenic)	α-pinene
S	black pole (sulphured)	dimethyl sulfide
P	violet pole (pyrogenous)	acetyl methyl pyrazine
D	light gray pole (sweet and benzenoid)	coumarin
L	red-orange dominant (fruit, lactone)	γ-undecalactone
	yellow dominant (grass)	
B	brown dominant (woody, transition)	vetiveryl acetate
	dark green note (menthol)	
	dark gray intermediate zone (Ambroxan)	
	green-yellow intermediate zone (fresh)	
	azure intermediate zone (marine)	
	sandy intermediate zone (skatole)	
M	beige intermediate zone (musk)	ambrettolide
Ph	phenol note	phenol
E	ethereal note	cyclopentanone
PHPB		p-hydroxyphenyl butanone

3b. The Field of Odors

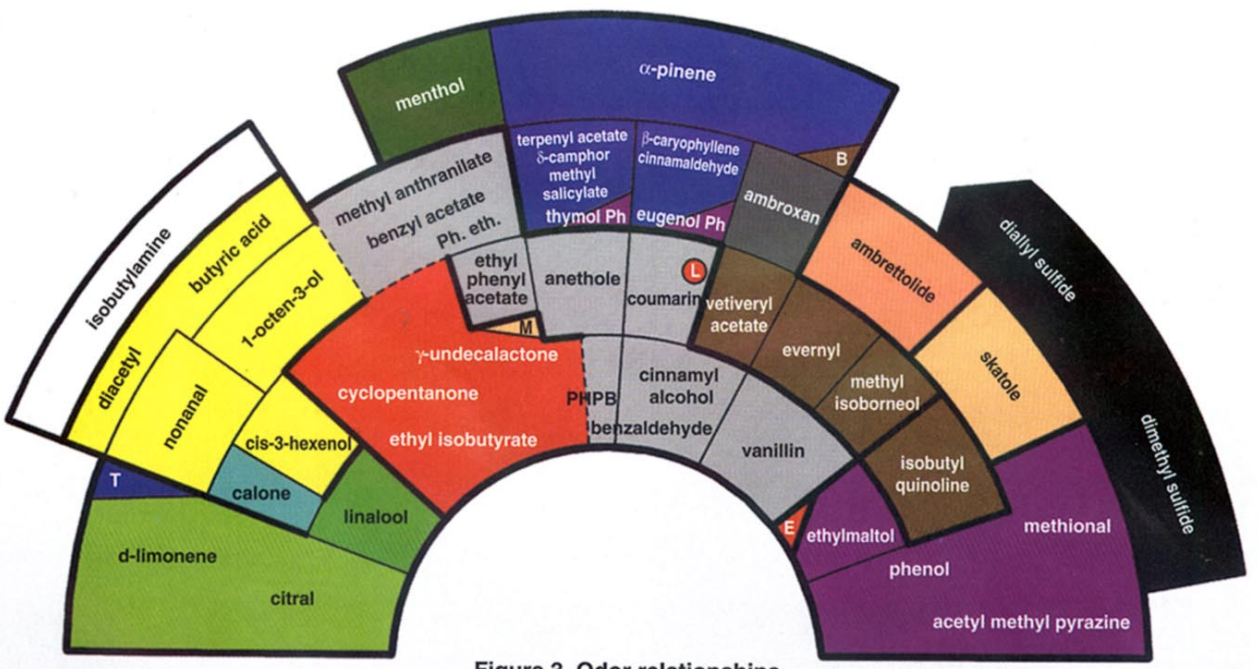


Figure 3. Odor relationships.

visualize the odorous space in Figure 3 are chosen because they are the colors of the rainbow—an infinity, a continuum.)

III. Description of the Field of Odors

Although the Field of Odors remains relatively complex, it greatly simplifies our ability to describe and classify the approximately 40,000 odorous molecules currently identified, as well as the infinite combinations that are found in nature or are artificially combined in new creations. We therefore believe that a detailed description of how we arrived at a working model is necessary to facilitate both its understanding and its use.

III.A General Architecture

The two-dimensional representation of the Field of Odors (Figure 3b) shows the reference odors in boxes arranged in a semicircle. The box positions are determined as much as possible from the mathematical calculations used to produce the three-dimensional Space of Odors. In the manual translation from three dimensions to two, the relative polar positions are retained, but some of the connections had to be broken and are shown in the Field of Odors as triangular insertion points in certain boxes. At the box perimeters, thin lines indicate a continuous flow, thick lines indicate a discontinuity, and dashed lines indicate a change in the chemical family without much change in odor. The colors of the odorant classes are those chosen by kindergarten children in a process previously described.

For a full understanding, the two-dimensional Field of Odors model should not be separated from the more accurate three-dimensional Space of Odors model. Nevertheless, it is essential to keep in mind that the words used are themselves strictly meaningless and should only be considered as the odor of a reference point. We believe that since each color is learned only as part of the whole spectrum and by comparison with other shades, so reference points can be used for odors only if they are all positioned in the continuum of the Field of Odors.

To put this positioning in perspective it is necessary to avoid serious mistakes that could arise from the way in which the odors are considered. For example, in this diagrammatic representation of A and B,

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A          O          B
x ..... x ..... x
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someone standing at O considering alternately A and B will have to perform a 180° rotation each time, which means that A and B are not necessarily very different; they are merely at the extremity of AB. If we now place this page at a distance of 20 meters, we can see at once that the distance between A and B has been reduced; in fact, at this distance, A and B almost appear to merge. Thus, it is necessary to know the distance constraints of the system in which the two points A and B will be placed so that the distance between A and B can be viewed from the perspective of the whole system. This is also true for odors because if A and B were two odorous substances, it is quite likely that they would possess many differences; however, these differences become less significant compared to the global amount of differences that can exist between all odorous molecules. As a result, like the relationship between A and B, the distance between the odors is a function of their differences and, more importantly, the size parameters of the whole system.

The left-to-right odor position in the Field of Odors is based on a time measurement. Each odor was initially diluted to a level where it was readily perceived but not overpowering. It was dipped on a perfumer's blotter (smelling strip) and a measurement was taken of the amount of time required for the substance to reach its maximum odor amplitude. It was found that the time span was 0.1-2.0 seconds, depending on the reference odorant tested.

Although this evaluative procedure sounds unwieldy, it is relatively easy to do as long as the subject has a stopwatch. Also, it does not take very many repetitions to readily identify the sequence of information in a complex odor and reproduce the time. It is worth noting that the order of odorant perception did not vary very much between respondents. Examination of the Field of Odors model from left to right allows us to proceed from the "fastest" odors to the "slowest" ones. The exceptions to this are the "sulfur" notes which cover the whole range of speeds.

Finally, before we proceed to the interpretation of the Field of Odors, we want to emphasize that all substances examined were chromatographically pure materials or solutions. In the case of solutions, the solvent did not cause any odor enhancement (as often happens with ethanol) and it did not smother the odors (as frequently happens with diethyl phthalate) or in any way modify the perception.

III.B Interpretation of the Field of Odors

To fully understand the spatial arrangement among the various odorant classes, it is important to discuss each class individually. To simplify the terminology within the model, we refer to each class by its color. (See Figure 3 color codes.)

III.B.1 The white pole: This pole corresponds almost exclusively to the amine function exemplified by isobutylamine. As a result, the compounds in this odor class are considered "fast" and are readily identified. It can be used to categorize "rotten" as applied to fresh food products. This aroma character forms very rapidly in fish and contributes to its aroma to some extent. As a result, this pole remains very isolated from other poles.

III.B.2 The yellow-green pole: This pole is situated on the extreme left of the Field of Odors. It is grouped around citral and corresponds to a rather homogeneous group of compounds considered to be among the "fastest." For this pole we use the term "citrus" without any reference to its botanical meaning. One of the main components of this pole is made up of the functionalized acyclic terpenes such as aldehydes and ketones. The yellow-green pole is connected to the blue pole, as shown in the three-dimensional Space of Odors, because of the presence of limonene (a monocyclic monoterpene) which, although sharp and fresh in an alcoholic medium, becomes heavier and more aggressive in the pure state. This makes limonene an excellent bridge between the yellow-green pole and the blue pole. Within the blue pole, the terpene esters allow the aroma character to range from fruity to rustic earthy notes.

III.B.3 The blue pole: The focus of this pole can be found around cyclic monoterpene hydrocarbons such as α-pinene. It constitutes a chemically homogeneous class of compounds, although from an aroma-note, it goes from turpentine-like to minty (as associated with l-menthol) with both odor characters leading toward benzenoid compounds. Also found in this odor class are:

- Rustic notes made of terpenic esters (terpenyl acetate) more readily found on the left of the Field, then δ-camphor and at least the phenolic derivatives such as thymol, then methyl salicylate, finally reaching the pyrogenated pole through the floral area.

- Spicy notes that contain, among others, sesquiterpenes (β-caryophyllene) close to woody notes, and that also develop into phenolic notes (eugenol).

III.B.4 The light gray pole: This pole, made up primarily of benzenoid (aromatic) compounds, can be subdivided into (a) an aggressive feature that has links to both the fruity and rusty notes (benzoates, salicylates, anthranilates, phenylacetate) as well as floral notes, and (b) a truly "sweet" feature that can be thought of as comprised of four distinct notes that are close to each other, such as anethole, benzaldehyde, cinnamic alcohol and coumarin/vanillin. The pole situated at the center has a more or less close relationship with the fruity ketone p-hydroxyphenyl butanone, lactones and coumarin, and the caramelic notes of ethyl maltol. There is a gap in this theory, as we have not been able to categorize the linkage between the violet pyrogenic pole and the light gray pole.

III.B.5 The black pole: This is a characteristic group of compounds, all of which possess at least one sulfur atom. Among the notes in this odor class, we distinguish alliaceous notes between the sharpest (diallyl disulfide) and the roundest (dimethyl disulfide). In large amounts, the compounds in this class are unpleasant; however, it is sufficient to know that they are extremely powerful odors that when found naturally occurring in minute quantities can give a crustacean or a vegetable its unique and revered aroma. This pole hybridizes easily with others through the incorporation of a sulfur atom; an example is methional, which has a strong relationship and connection to the pyrogenic pole.

III.B.6 The violet pole: This group is very homogeneous because all of the odors classified therein cause the respondent to recall the aroma of cooked, roasted, grilled or burnt materials, including food products. Many of the compounds found in this class are heterocyclic materials containing nitrogen, oxygen or even sulfur, or they are phenols and their derivatives. The caramelic notes associated with compounds such as ethyl maltol are mainly due to oxygenated compounds converging with both sweet and ethereal notes. The phenolic notes found within this group are quite characteristic, while the grilled notes of 2,5-dimethylpyrazine converge with the musty, earthy notes. Within the group of so-called cooked notes can be found some sulfur compounds such as methional.

III.B.7 The yellow dominant group: The compounds in this odor class can be considered as having their evolution in fats. The compounds found here are functionalized aliphatic chains: acid (butyric acid), alcohol (1-3 octenol), ketone (diacetyl) and aldehyde (nononal). The green aspect of this group, exemplified by cis-3-hexenol, should not be classified with compounds such as styrallyl acetate because even though they cause grass-like evocations, they are heavy and thus not similar to the rest of the yellow dominant group. This group is closely associated with the fruity notes, through ethers and esters, and the marine-like notes associated with long-chain, unsaturated aldehydes.

III.B.8 The red-orange dominant group: This is a rather heterogeneous group comprised of a number of odor notes such as ethereal, furfuralic, lactonic, ketonic and esters. The ethereal group contains compounds such as cyclopentanone as well as the various ethers. Those in the furfuralic group, which is represented by furfuryl aldehyde, possess both fatty ester as well as slightly burnt (pyrogenic) connotations. As one might expect, the lactonic group, containing compounds such as γ-undecalactone, possesses aroma notes ranging from slightly ester-like and fatty-like through coumarin-like to a musky character. The notes associated with the ketonic group, within which can be found both aliphatic and aromatic representatives such a p-hydroxyphenyl butanone, range from being ester-like to sweet. The ester note is associated with a fruity note. "Ester" notes often suggest the aroma of a specific fruit whose aroma for the most part they constitute. A typical member of this group would be ethyl isobutyrate; however, it must be free from isobutyric acid. Also found in this group are the floral notes associated with the aromatic esters, and the fresh to musty/rustic notes associated with the terpene esters. The aroma notes of the esters are generally influenced by the alcohol or acid found within their molecules, although, according to Bassiri,[12] the chain length of the esthers' acid or alcohol moiety seems to interfere with this association.

III.B.9 The brown dominant group: This group, a transitional group without a great deal of specificity, is situated between the terpenic or sesquiterpenic notes represented by vetiveryl acetate and the benzenoid compounds. The former group can be classified as being woody and oakmoss-like (represented by the "evernyl") or moldy (such as methyl isoborneol), whereas the latter, benzenoid, group (excluding compounds such as benzoic acid) contains compounds that possess moldy or earthy notes such as isobutylquinoline.

III.B.10 The dark green notes: Components found within this dark green note category are closely related to the notes of the blue pole, as mentioned earlier. One compound categorized as being a dark green note is l-menthol. Before this compound is smelled, it should be well diluted to avoid the occurrence of a pseudothermal effect.

III.B.11 The dark gray intermediate zone: The so-called amber-note represented by "ambroxan" is, in fact, very close to the sesquiterpenes of the woody and spicy notes.

III.B.12 The green-yellow intermediate zone: As this is an outgrowth of the citrus note, it includes many alcohols such as linalool and terpenic aldehydes. At the same time, olfactively "heavy" compounds such as geraniol bridge the citrus note to the sweet floral note. Primarily this zone can be referred to as "fresh," since it includes materials such as citronella oil and odors associated with the lighter, fresher aroma of certain flowers such as rose. Some terpenic alcohols

with musty/rustic notes can be found in this area, close to the fruity notes.

III.B.13 The azure intermediate zone: This is not a very clearly defined zone since it is a hybrid between the so-called "fatty" and "fresh" zones. Components found in this zone often evoke an aroma character which can be described as marine-like or sea-spray-like (often wrongly called an iodine-like aroma). Compounds found in this zone are long-chain unsaturated aliphatic aldehydes and the monoterpene alcohols such as nerol and "calone."

III.B.14 The sandy intermediate zone: Within this zone can be found the animalic note associated with skatole. Other components, that are found here, which also possess long lasting aroma notes, are the benzenoid heterocyclic compounds.

III.B.15 The Beige Intermediate Zone: The compounds found in this zone are long-lasting aromas such as ambrettolide and other high molecular weight lactones. The characteristic note associated with these large molecules does not necessarily include all of the compounds referred to as musks by the perfumers.

III. C Chemical Basis

As can be seen from the above, we have described the Field of Odors without prejudging why the compounds have been categorized as they were. We wonder whether their classification is the result of chemical phenomena or whether it is just the subconscious result of training. Are the odorous features of a compound memorized only by association with the base with which that compound is connected? Does the analysis of an odor require that another one of our senses (such as sight) confirms what the nose tells us? We believe that all the elements of odor association converge toward a unique, structured system. As a result, we believe that olfaction, being a chemical sense, has to be based on chemical elements even if the latter do not correspond to simple linear relationships.

IV. Use and Interest in the Field of Odors

IV.A Learning the Basics

Like all of the bases of our elementary culture, the Field of Odors requires a systematic approach. To start with, one must acquire a working knowledge of the language. Initially, the relative positions of the reference compounds in the Field of Odors must be memorized. To do this, each compound must be smelled and compared with those with which it is associated, and those with which association is found. It is perhaps easier if the reference compounds are color coded and letter coded so that their association with their position can be readily remembered and reviewed. Practicing odor description by looking for the least possible differences between materials is easier than trying to always associate an aroma with an object. It should be remembered that communication is only possible if a certain amount of inaccuracy is accepted. Too much accuracy leads to worthless complexity. We believe that after about ten sessions, which is far less time than the children required to learn their colors, the Field of Odors concept can be understood and its practical scope can be appreciated.

IV.B Using the Field of Odors

When confronted with a new odorous substance, one needs an accurate analysis repetitively completed in order to communicate the odor experience. If, for example, the substance to be smelled (either a single compound or a mixture) has a single odor character that can be verified by smelling it as it dries down, then through comparisons between it and the reference compounds, the position in the Field of Odors can be pin-pointed. On the other hand, if the substance to be smelled is a mixture whose aroma changes on evaporation, then each aroma character has to be classified or positioned in the Field of Odors, and this positioning is given a fourth dimension, namely a time scale. As a result, a mixture can be "fresh" (green-yellow intermediate zone) initially, after which it can be lactonic (red-orange dominant group) and then finally it can assume an oakmoss-woody dry out note (brown dominant group).

It is easy to understand that most natural oils and extracts fall into the second category, in which the olfactive character, over time, can be associated with a number of different reference compounds. Nevertheless, in spite of this complexity, a more user friendly character description will be realized.

IV.C Value of the Field of Odors

We believe that the Field of Odors reveals what is buried in our subconscious concerning the way odorous substances have been recognized by humans ever since humans evolved. In addition, the Field of Odors gives an intrinsic structure to a sense which we do not normally associate with structure. Even though by definition this approach remains reductory since it does not allow a detailed description of each odorous feature, the model proposed facilitates its memorization and simplifies its use. The mathematical approach to presenting the results yields a pyramid of dots, starting at the top with very few dots and, therefore, a great degree of inaccuracy. Nevertheless, at this point there is a high capacity for memorization. Meanwhile at the base of the pyramid there are a great many dots which are too difficult to assimilate. The cross section of this hierarchy at the 42-point level seemed like a good compromise position; however, we do not exclude the possibility of obtaining more accuracy or of a closer approach to one type of odorous note according to special but as yet undefined requirements.

We believe that our Field of Odors approach to odor classification is the first to propose an odor continuum with an objective structure that discards any hedonic rating or personal choice criteria. It is based on the odor similarities and differences among sets of odors. This amounts to saying that odors are described by odors, which is at least coherent

and logical in its approach. Finally, the Field of Odors proposes that 45 easy-to-learn substances be used as reference points to form the basis for a common language of communication about odors. Such an approach results in the removal of cultural and prior-knowledge prejudices as well as ambiguities in the translation of information. It will also equate or level off the differences in perception found between individuals. Whatever way the reference compound is considered, it will be the same for all and therefore its characterization will similarly be the same.

The Field of Odors presents us with the means to express the characteristics of an odor in an unambiguous, coherent, qualitative way irrespective of our education level. It literally requires little more education than being able to learn and, therefore, differentiate between colors. The teaching tool described in this article is just a little more sophisticated than the multi-colored building blocks to which a young child might compare each new object he or she is given in order to determine its color.

Besides the fact that memorization of the reference compounds and their color-coded positions in the Field of Odors will make communication much easier, because of its structure, the mathematical objectivity which allowed the Field of Odors' evolution is to some extent a guarantee of a universal dimension. This is necessary for communication. Until now an odor was always expressed in terms of associations with objects—sometimes singularly and sometimes in combinations—because of subconscious individual memories. The Field of Odors approach offers a communication forum about odors. Each user of the technique should remember that the reference points found for the reference compounds were determined from probability calculations; one should not look for the strictness of Cartesian order. As with a great majority of natural phenomena, including colors themselves, odors should be considered a continuum with more or less typical summits but always with indefinite borders.

IV.D Applications of the Field of Odors

There are some convenient applications for the Field of Odors. Within our own research on odorous substances or their perception, we use the Field of Odors to obtain consistently reproducible "effects" independent of the subject respondents. It has also allowed us to describe all facets of a complex odor that changes over time. It offers an excellent guide for analysis to identify the various elements that are descriptive of odors. Protocols based on this system have allowed us to analyze and, therefore, control the odor spectrum of formulations.

We use the Field of Odors in our DICT method (Distribution of the Intensity of odors by Character versus Time),[13] which has offered some useful opportunities.[14] We also use the Field of Odors to describe the composition of odors. The various pieces of information can be thought of as analogous to the pieces of a jigsaw puzzle which are put together to create a whole picture. In the creation of odors, each element of the odor is a note that can be located in the

Field of Odors and easily associated with according to its relative position. At a later time, we will publish a formulation method that we already use that is based on this approach.

V. Conclusion

In conclusion, we believe that the Field of Odors approach allows us to discover the knowledge of odors that we all subconsciously possess and gives structure to this. The common aspect of this knowledge is important to the rapid creation of a coherent and easy-to-learn language. This language represents a way for communication on the subject of odors to proceed in a purely objective way. A minimum of learning about a common language (vocabulary) with reference points belonging to the same groupings or space allows the users to share information without formal training.

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Address correspondence to Dr. Jean-Noël Jaubert, Université du Havre, Laboratoire de Chimie, 35 rue Gabriel Peri, 76600 Le Havre, France.

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