1

Historical Aspects

1.1 Scents of Time

The use of odors and odorants is, most certainly, much older than the recorded history of mankind, probably even older than *Homo sapiens*, and coincides with the hominid control of fire. Several Middle Pleistocene sites exhibit the exploitation and control of fire some 500,000 years ago. The presence of burned seeds, woods, and flint at the Acheulian site of *Gesher Benot Ya'aqov* suggests that this dates back even to the Lower Pleistocene, some 0.79 million years ago [1]. Thus, *Homo antecessor, Homo erectus*, and *Homo ergaster* were already able to burn resinoid woods and prepare food by roasting, grilling, or cooking. The anthropologist *Richard Wrangham* speculates that cooking consisted a biological requirement for hominid survival and may have begun as far back as 1.7 million years ago [2, 3]. It may very well have influenced our evolution in flattening our facial skull to enable savoring of food by retronasal perception, while carnivores rarely savor their food but rip, chomp, and swallow it [4]. Retronasal perception might even be the key to kissing or the explanation for the evolution of pronounced female breasts that make it possible for babies to taste the milk and smell their mothers upon breastfeeding. Mouth-based smelling is a human trait and led very early on to the discovery of spices that made food tastier but also healthier by acting as preservatives. Fragrant spices also served as the first medicines, and the belief that odors were a cause rather than an effect of illness, or that good smells would cure diseases since they cover bad smells associated with these, extended well into the early 19th century; besides many odorants indeed possess antimicrobial properties.

Apart from the preparation of food, fire also served very early on in human history for the disposal of corpses, which called for neutralization and deodorization of the resulting stench during cremation rituals [5]. This way the burning of fragrant woods, odorous resins, and aromatic plants became linked to religion. Odors became bridges between the here and now and the hereafter. Offered as gift to the gods by all past civilizations, perfume spiritually elevates and renders the body divine and transforms places into sanctuaries [5]. This symbolism is documented in the ancient writings, and the word *perfume* derives in fact from '*per fumum*', meaning '*through smoke*', or by nebulization, the transformation of a substance into something airborne. In particular, the early fumigatory use of burning resins, woods, barks,

Scent and Chemistry: The Molecular World of Odors, Second Edition.
Günther Ohloff, Wilhelm Pickenhagen, Philip Kraft, and Fanny Grau.

and other parts of aromatic plant had widespread appeal. Such odor signals were supposed to possess magical properties and were sent to honor the Gods. The association of odor and sanctity was so explicit that the priests of the cult of Osiris chewed cedar gum to perfume their breath and create a scented aura of sacredness [5]. Odors were also supposed to protect the live and dead from any mishap, as well as to keep the healthy free of disease, to heal the sick, to form a link between man and his ancestors, or simply to give pleasure. Even today, especially in Buddhism, fumigation is synonymous with purification, both in the religious and in the hygienic sense of the word, and this practice soon expanded from the temples into the homes [5].

Incense and myrrh are two of the oldest known odorants [6]. It is written in ancient Assyrian tablets that incense was offered to the God of the Sun in Nineveh. During the reign of *Hammurabi*, one thousand talents (*ca*. 29,000 kg) of incense were burnt in the *Bel* temple of Babylon annually. At the time of the Pharaohs, 3000 BC, the Egyptians prepared incense offerings from a mixture of different resins such as myrrh and opopanax, often combined with cinnamon bark and other aromatic materials [7]. Odorous hardwoods had the same symbolic power. For example, cedarwood is mentioned in the *Epic of Gilgamesh*, 3200 BC, which is considered to be the oldest written document about the genesis of mankind. At that time, Egyptians had already developed the technology of producing cedarwood oil. This was one of the seven oils that the Pharaohs used in combination with tar and odorous resins to prepare balms for their dead [8]. Cedarwood was used because it was thought to last eternally. Sandalwood constitutes also one of the most ancient perfumery ingredients that has been used far longer than 4000 years. The Bible considers sandalwood as one of the most important gifts. One of the oldest citations describes the Queen of Sheba who '*made a gift to Solomon of a great quantity of sandalwood and precious stones*' [9]. Sandalwood is much esteemed in Eastern cultures, especially in India.

From ancient times on, odor has been part of the language of writers, philosophers, and physicians. *Homer*, for instance, reported which odor notes pleased the Greek Gods. In the *Odyssey*, the secret of the '*Bouquet of Venus*' that made *Aphrodite* irresistible was revealed. *Odysseus*, the king of *Ithaca* was held prisoner by the magical odorants used by the sorceress *Circe*. The incredible beauty of *Helen of Troy*, whose abduction brought about the *Trojan* War, was supposed to be due to her cosmetic secrets. She was known to have shared these secrets with her admirers by showing them the recipes of the cosmetic products she used. This supposedly is the beginning of cosmetic and perfumery formulation.

The Greeks were experts in the art of extracting the aromatic principles of plants and resins using olive oil. Fat extraction of floral odors from freshly picked flowers, a technique for the production of concretes that had been known as *enfleurage* and was practiced in southern France from the 17th to 19th century, was already known in Greece at the time of *Homer*. *Antiphanes* described the preparation and use of tinctures, lotions, essences, and creams to scent and moisturize each part of the body. The most important writers of classical antiquity such as *Herodotus*, *Horace*, *Ovid*, *Pliny*, and especially *Martial* often described cosmetic practices and the use of odorant products. According to the book of *Theophrastus*, rose, lily, and violet were the odors that were most liked by the Greeks at that time. It was reported by *Martial* that the Romans preferred the more masculine odors of saffron and balsams. Other odors *en vogue* in classical times were narcissus, iris, calamus, cinnamon, costus, vetiver, quince essence, thyme, and marjoram along with the biblical oil of nardin. In his natural history, *Pliny the Elder* made mention of a cream that contained twenty-seven of these aromatic ingredients. In ancient Greece, *Megallus* and *Peron* were famous Athenian perfumers, while according to *Martial*, *Cosmus* and *Nicero* were the most important *Unguentarii* in Rome. While the Greeks made use of perfumes more moderately, the Romans were lavish with their scents. *Catullus* became an addict to odor orgies and decided to be '*nose-only*'. However, critical voices were also heard. *Pliny the Elder* reminded his followers that '*perfumery was the most redundant luxury*'. *Solon*, an Athenian statesman and lawmaker, forbade the use of perfume by Greek men. In contrast, *Aristotle* praised the aesthetic aspects of the sense of smell. He noted '*pleasant odors contribute to the wellbeing of mankind*'. *Anacreon* recommended that the '*use of lovely perfumes on one's head is the most effective remedy against illness*.' In fact, also in classical times a great number of odorants were used as therapeutic agents. Their use is described in '*Naturalis Historia*' by *Pliny the Elder* and '*De Materia Medica*' by *Dioscorides*.

The first research studies on the sense of smell were performed in very ancient times. *Galen*, the founder of *galenism* and personal physician to Emperor *Marcus Aurelius*, discovered the existence of the olfactory nerve. The first theory dealing with structure–activity relationships of odorants is ascribed to the Roman writer and philosopher *Titus Lucretius Carus* (98–54 BC). According to his book '*De Rerum Natura*' [10], pleasant smelling odorants were supposed to be of a smooth round geometry, whereas harsh compounds were supposed to possess rough molecular surfaces. An odor of a compound was thought to be elicited by molecules passing through slots of complementary shape in the sensory organ. Thus, the '*lock-and-key*' principle, which *Emil Fischer* [11] used to describe the interaction of an enzyme with its substrate, was first mentioned over 2000 years ago.

All classical fragrances were scented cosmetics and toiletries, so-called '*unguenta*', and perfumed oils and lotions, and not alcoholic perfumes, as we know them today. The first still was invented by alchemists in Alexandria *ca*. 200–300 AD and then perfected by the Persian philosopher and physician *Alí Sīnā Balkhi* (*Avicenna*, 980–1037) for the steam distillation of rose oil (attar of rose) from *Rosa centifolia* L., a rose highly prized by the Arabs. Rose oil and rose water were soon produced on a large scale and exported around the world. However, only in 1320 Italian distillers invented the serpentine cooler, which allowed the production of high-grade alcohol (from the Arabic *al-kuhūl*), and in 1370 the first alcohol-based perfume appeared in France. It became known as '*L'Eau de Hongrie*' or '*Hungary Water*', since it was allegedly formulated at the command of the Queen of Hungary from her court alchemist. The name emphasizes on the water-clear appearance of this alcoholic perfume in contrast to the then known oil-based fragrance formulations. These '*eaux*' were however not only applied externally as perfume but also internally as medicines against various diseases. This explains the name '*Aqua Admirbilis*' that *Giovanni Maria Farina* (1685–1766) launched in Cologne in 1709. This soon became famous as '*Kölnisch Wasser*' or '*Eau de Cologne*'. Allegedly, *Napoléon Bonaparte*

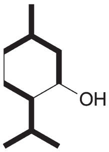
(1769–1821) used up to two bottles of *Eau de Cologne* per day, which he poured over his head and shoulders. Not only did *Napoléon* make *Eau de Cologne* famous all over the world, but he also defined per decree the term *perfume* in 1810. According to this definition, perfumes had to be distinguished from medicines and were no longer allowed to be used internally. The composition of medicines for internal use had to be declared, and thus many perfume makers decided to rather drop any claims of therapeutic effects than to lay open their formulas. Therefore, perfume became a beauty-care product and very soon a fashion item [12].

Despite the success of the *Eaux de Cologne* family, most of the perfumes of the 18th, 19th, and early 20th century were reconstitutions and interpretations of flower scents, so-called *soliflores* [13]. Some prominent examples for such *soliflores* are '*Lily of the valley*' (*Floris*, *ca*. 1750), '*Rose*' (*Molinard*, 1860), '*Jasmin*' (*Molinard*, 1860), '*Rose Jacqueminot*' (Coty, 1904), '*Jasmin de Corse*' (*Coty*, 1906), '*Violette Pourpre*' (*Houbigant*, 1907), '*Narcisse Noir*' (*Caron*, 1912), '*Gardénia*' (*Chanel*, 1925), and '*Le Muguet de Bois*' (*Coty*, 1942). This was due to the fact that the perfumers had only essential oils to compound with, and while they could construct flowers that did not yield an essential oil, such as the lily of the valley (*muguet*), from other essential oils, abstract creations were very difficult to achieve at the end of the 19th century. This technical stagnation was only overcome by the timely and rapid development of Organic Chemistry. The analysis of natural products and efficient synthetic preparation of their smelling principles led to an understanding of the molecular basis of essential oils.

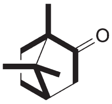
1.2 Chemical Discoveries and Modern Perfumery

The beginnings of the analytical branch of Fragrance Chemistry trace back to 1818, when *Jacques-Julien Houtou de Labillardière* (1755–1834) established by elemental analysis that turpentine oil was characterized by a relation of five C-atoms to eight H-atoms ($((C_5H_8)_x)$) [14]. This relation was found to be identical for all terpene hydrocarbons. In 1833, *M. J. Dumas* [15] classified the essential oils into those containing only hydrocarbons such as turpentine and citron oil, those containing oxygenated compounds such as camphor and anise oil, and those with sulfur (mustard oil) or nitrogen compounds (oil of bitter almonds). He found the correct empirical formula of menthol (**1.1**), camphor (**1.2**), borneol (**1.3**), and anethole (**1.4**).

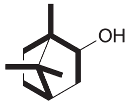
In 1835, *Jean-Baptiste Dumas* (1800–1884) and *Eugène-Melchior Péligot* (1811–1890) isolated and characterized cinnamaldehyde (**1.5**) from cinnamon essential oil [16]. In their groundbreaking work on bitter almond oil, *Friedrich Wöhler* (1800–1882) and *Justus Liebig* (1803–1873) showed in 1837 that its typical odor was due to an enzymatic cleavage of amygdalin (**1.6**) in glucose (**1.7**), hydrogen cyanide, and benzaldehyde (**1.8**), the latter two compounds exhibiting a bitter almond odor [17]. Benzaldehyde (**1.8**), the principal odorant of the essential oil from bitter almonds, can be regarded as the first natural perfume material to be prepared synthetically [18].



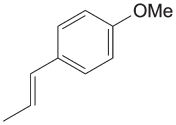
1.1
menthol
$C_{10}H_{20}O$



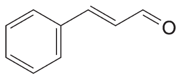
1.2
camphor
$C_{10}H_{16}O$



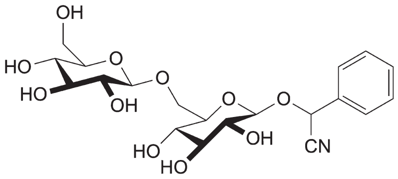
1.3
borneol
$C_{10}H_{18}O$



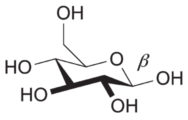
1.4
anethole
isoestragole



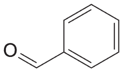
1.5
cinnamaldehyde



1.6
amygdalin

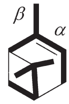


1.7
β-D-glucopyranose

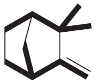


1.8
benzaldehyde

Starting in 1884 *Otto Wallach* (1847–1931) elucidated in over 125 papers the structures of the most important terpenoid constituents of the most important essential oils, including α-pinene (**1.9**), camphene (**1.10**), limonene (**1.11**), sylvestrene (**1.12**), terpinolene (**1.13**), α-terpinene (**1.14**), α-phellandrene (**1.15**), α-fenchene (**1.16**), and the sesquiterpenes α-cadinene (**1.17**), caryophyllene (**1.18**), and clovene (**1.19**) [19]. The exact constitution and stereochemistry of the sesquiterpenes **1.17–1.19** was, however, elucidated only later by the groups of *Ruzicka*, *Eschenmoser*, and *Barton* between 1924 and 1954 [20–22]. The first perfumery raw materials were those that were easy to isolate from essential oils by crystallization, such as camphor (**1.2**), borneol (**1.3**), and (+)-cedrol (**1.20**).

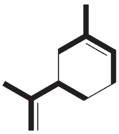


1.9
α-pinene
$C_{10}H_{16}$



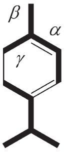
1.10
camphene
$C_{10}H_{16}$

1.11
limonene
$C_{10}H_{16}$



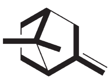
1.12
sylvestrene
$C_{10}H_{16}$

1.13
terpinolene
$C_{10}H_{16}$

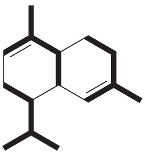


1.14
α-terpinene
$C_{10}H_{16}$

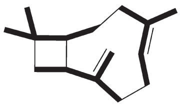
1.15
α-phellandrene
$C_{10}H_{16}$



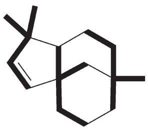
1.16
α-fenchene
$C_{10}H_{16}O$



1.17
α-cadinene
$C_{15}H_{24}$

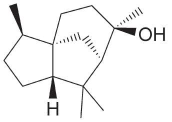


1.18
caryophyllene
$C_{15}H_{24}$

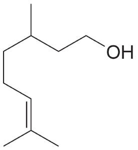


1.19
clovene
$C_{15}H_{24}$

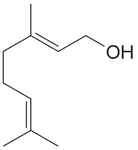
Developments in vacuum distillation techniques and derivatization subsequently allowed the isolation of liquid components from essential oils. Compounds such as citronellol (**1.21**), geraniol (**1.22**), citral (**1.23**), (−)-linalool (**1.24**), cinnamaldehyde (**1.5**), and eugenol (**1.25**) represent a series of natural materials that inspired the perfumers of the 19th century. However, the development of modern perfumery with all of its creativity and artistic freedom became only possible with the commercial synthesis of pure nature identical and synthetic odorants (*Figs. 1.1–1.4*). These synthetic compounds allowed for the creation of fantasy perfumes, some of which are still in fashion today.



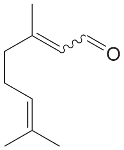
1.20
(+)-cedrol



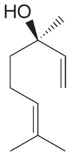
1.21
citronellol



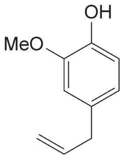
1.22
geraniol



1.23
citral



1.24
(–)-linalool



1.25
eugenol

The age of modern perfumery dawned in 1868 when *William Henry Perkin* (1838–1907) synthesized coumarin (**1.26**; *Fig. 1.1*) by heating the sodium salt of salicylaldehyde with acetic anhydride [23]. Coumarin (**1.26**) with its distinctive note of freshly mown hay and marzipan is the smelling principle of tonka beans, from which *Friedrich Wöhler* had isolated it by extraction with 80% ethanol 12 years earlier [24]. In 1877, the modification of the *Perkin* reaction, involving boiling a mixture of acetic anhydride, anhydrous sodium acetate, and salicylaldehyde [25, 26], made coumarin (**1.26**) industrially accessible, and thus, *Paul Parquet*, chief perfumer and owner of *Houbigant*, could utilize **1.26** in the creation of a fragrance that should evoke the scent of fern – if ferns had any, since most of them are odorless [27]. The result was '*Fougère Royale*' (*Fig. 1.2*), which appeared on the market in 1884 and was such a success that many related fragrances were created around the central accord of oak moss, lavender, and coumarin (**1.26**). Even though '*Fougère Royale*' was discontinued in the 1950s, with an unsuccessful relaunch attempt in 1988, the *fougère* family still constitutes one of the main fragrance concepts, with such representatives as '*Paco Rabanne pour homme*' (*Paco Rabanne*, 1973) by *Jean Martel*, '*Drakkar Noir*' (*Guy Laroche*, 1982) by *Pierre Wargnye*, and '*Cool Water*' (*Davidoff*, 1988) by *Pierre Bourdon* [28]. In December 2010, finally even '*Fougère Royale*' reappeared on the market and was revived and modernized by *Rodrigo Flores-Roux* working alongside *Roja Dove* as creative director.

Ferdinand Tiemann (1848–1899) [29] can be considered the true founder of Fragrance Chemistry. He was involved in improving *Perkin*'s access to coumarin (**1.26**) to industrial applicability [26], but more important even was his structure elucidation and synthesis of vanillin (**1.27**; *Fig. 1.1*) three years before, in collaboration with *Wilhelm Haarmann* (1847–1931). *Haarmann*, who descended from a wealthy old-established family background in Holzminden, had joined the laboratory of *August Wilhelm von Hofmann* (1818–1892) at the University of Berlin at about

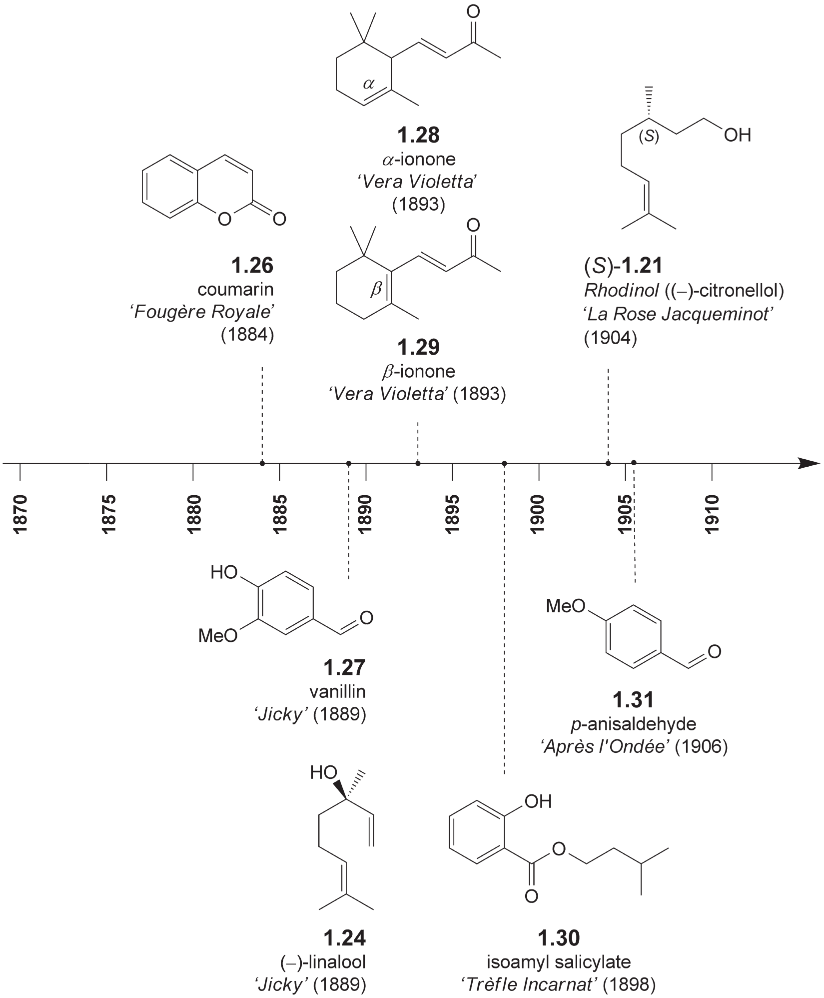


Figure 1.1 Timeline of the initial phase of modern perfumery featuring the most important perfumes in 1870–1910 that were influenced by new odorants

the same time as *Tiemann*, and they remained close friends even during the Franco–Prussian War of 1870. After the war they both returned to *Hofmann*'s laboratory to continue studies on coniferin, which was isolated from the cambium juice of conifers, especially pinewood. Upon degradation experiments of coniferin, their former colleague *Wilhelm Kubel* had observed a characteristic vanilla scent. In 1874, *Tiemann* and *Haarmann* synthesized vanillin (**1.27**) by hydrolysis of coniferin with the enzyme emulsin and oxidation of the resulting coniferyl alcohol with a mixture of potassium bichromate and sulfuric acid [30]. *Haarmann* decided to exploit this invention in his hometown Holzminden, where pinewood was in plentiful supply, and founded in 1874 the *Haarmann's Vanillinfabrik* (now *Symrise*), which later inspired the foundation of several other Flavor and Fragrance companies all over

Figure 1.2 Flacons of early milestone fragrances: '*Fougère Royale*' (*Houbigant*, 1884), '*Jicky*' (*Guerlain*, 1889), '*Trèfle Incarnat*' (*L. T. Piver*, 1898), '*Floramye*' (*L. T. Piver*, 1905), '*La Rose Jacqueminot*' (*Coty*, 1904), '*Quelques Fleurs*' (*Houbigant*, 1912), and '*Nuit de Noël*' (*Parfums Caron*, 1922). Source: Courtesy of *Philip Goutel*

Europe. *Tiemann*, on the other hand, wanted to continue his academic career but decided to dedicate his scientific work to the chemistry of fragrant materials. He immediately saw the use of a new reaction that was discovered in 1876 by *Karl Reimer* (1845–1883) in *Hofmann*'s laboratory for the industrial production of **1.27** from guaiacol by heating with chloroform and 4 equivalents of sodium hydroxide [31]. This *Reimer–Tiemann* reaction made vanillin (**1.27**) available at very attractive costs, which revolutionized perfumery.

Aimé Guerlain was the first to use **1.27** in his famous creation '*Jicky*' (*Guerlain*, 1889; *Fig. 1.2*) [32], in an accord with coumarin (**1.26**) and (−)-linalool (**1.24**), isolated from rose wood, as well as bergamot, lavender, sandalwood oil, and civet. Because of its sophisticated composition, '*Jicky*' can be regarded as the first modern perfume [28], and not taking the *Eaux de Cologne* into account, it is the oldest fine fragrance still on the market. *Frédéric Beigbeder*'s protagonist *Marc Maronnier* famously uses '*Jicky*' in his '*Mémoires d'un jeune homme dérangé*', albeit today it is considered a female fragrance [33]. At the end of the 19th century, '*Jicky*' was, however, found too *avant-garde* for women and thus had first been introduced as a male fragrance.

Perhaps the most precious and popular perfumery materials in the 19th century was violet flower oil ('*fleur de violette*'), for which *von Soden* estimated production costs exceeding 80,000 German gold marks per kilogram [34] due to the low content of essential oil in violet flowers (*Viola odorata* L.) [35]. The structure elucidation of the smelling principle of violet flowers was therefore of high economic interest. Yet, even the quantities of violet flower oil necessary for this work at that time turned out to be too expensive. Therefore, *Tiemann* and his co-worker *Paul Krüger* used the similarly smelling but much cheaper orris root oil (*Iris pallida* LAM.) in their investigations on the smelling principle of violets, assuming that the odor of both oils was due to the same natural product [36, 37]. An incorrect elemental analysis of the

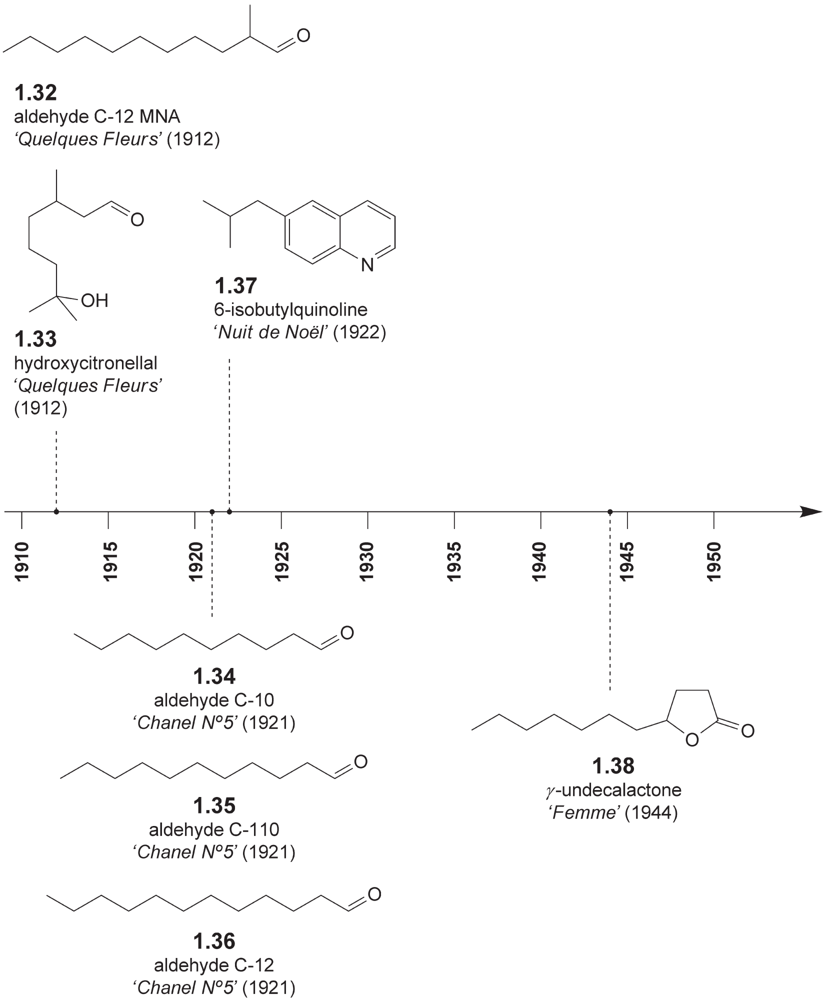


Figure 1.3 Continuation of the timeline of modern perfumery featuring the most important odorants that influenced perfumery in 1910–1950

isolated irones (*cf. Chapt. 6.1*) led them to believe that these could actually be condensation products of citral and acetone, yet these pseudoionones turned out to be odorless. Upon cleaning the reaction flask with sulfuric acid, they, however, observed an intense smell of violets in bloom. They had accidentally discovered what they were initially looking for, the smelling principle of violets. However, only in 1972, an in-depth analysis of violet flower oil using modern analytical tools established that its odor was actually due to a mixture of α-ionone (**1.28**) and β-ionone (**1.29**) [35]. Nevertheless, the ionones **1.28**/**1.29** had an immense impact on perfumery right after *Tiemann*'s discovery of 1893, since they made violet notes suddenly affordable, even as main themes of a composition. Already in 1894, *Roger & Gallet* launched the *soliflore* perfume '*Vera Violetta*', created by *Henri Roger*, one of the founders of

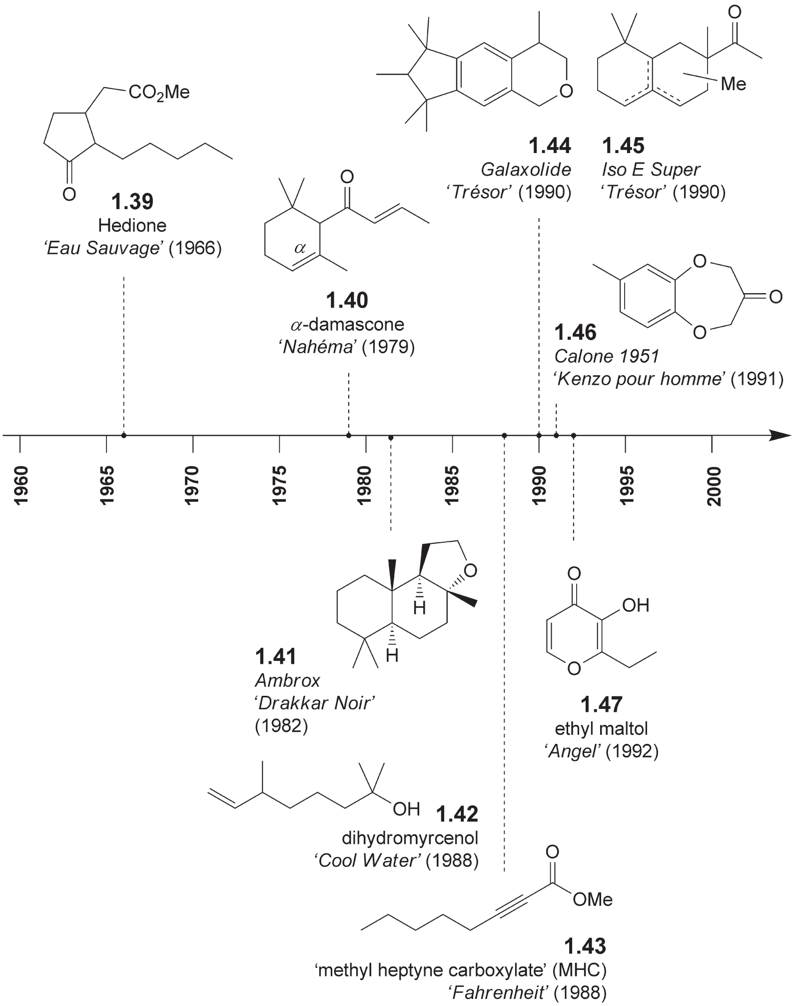


Figure 1.4 The most important odorants that influenced perfumery in 1960–2000

the company. It became the archetype of many violet scents that followed. α-Ionone (**1.28**) has a fresh violet scent, while the β-ionone (**1.29**) is more orris-like woody [28]. Due to their very cheap price today, ionones **1.28**/**1.29** are a main theme in the area of soaps and toiletries, but there is hardly any female fine fragrance without them.

Another famous fragrance chemist of that time was *George Darzens* (1867–1954) [38], who had studied at the *École Polytechnique* in Paris with unbridled energy. After astronomy studies, a B.S. degree in mathematics, and a diploma in physics, *Darzens* enrolled in medical school and obtained an M.D. degree, paralleling his studies in chemistry and serving as assistant to his teacher *Éduard Grimaux* (1835–1900). In the *Dreyfus* affair of 1896, both *Grimaux* and *Darzens* supported the case of Captain *Alfred Dreyfus*, which brought them into discredit [38]. *Grimaux* was dismissed from his chair, and *Darzens* moved into industry. He was recruited by *Jacques Rouché*, perfumer and administrator of *L. T. Piver*, the oldest perfumery house of Paris that had been founded by *Michel Adam* under the name '*A la Reine des Fleurs*' on July 8, 1774. From 1896–1920, *Darzens* served as director of the *Piver* laboratory and discovered and introduced several new odorants, which were carefully guarded secrets that made their creations unique. He also developed and generalized the glycidic ester condensation that was named after him. Saponification of the resulting α,β-epoxy esters, and decarboxylation upon distillation lead to aldehydes that proved valuable as odorants, for instance, methyl nonyl acetaldehyde (aldehyde C-12 MNA, **1.32**; *Fig. 1.3*) from the *Darzens* condensation of undecane-2-one and ethyl 2-chloroacetate. Together with *Jacques Rouché* he also compounded perfumes, such as '*Floramye*' (*L. T. Piver*, 1905; *Fig. 1.2*) featuring aldehyde C-12 MNA (**1.32**) before it became famous with '*Quelques Fleurs*' (*Houbigant*, 1912) [32]. The first odorant *Darzens* discovered was isoamyl salicylate (**1.30**), which recalls '*a blossoming clover field in the warmth of August*' [28]. *Darzens* and *Rouché* added **1.30** to a *fougère* skeleton, and thus created '*Trèfle Incarnat*' (*L. T. Piver*, 1898; *Fig. 1.2*), which was such an incredible success that even today it is hard to find a *fougère* theme without any isoamyl salicylate (**1.30**). Even later when *Darzens* became a professor at the *École Polytechnique* (1913–1937), he continued perfumery formulation with *Grenoville* (1921–1924). While at *L. T. Piver*, *Darzens* curiously also constructed automobile prototypes for car races, which shows what a multitalented inventor he was.

Saponification of geranium oil with subsequent fractional distillation furnishes (−)-citronellol ((*S*)-**1.21**; *Fig. 1.1*), which was commercialized by *Rhone Poulenc* as *Rhodinol*. It made history when *Francois Coty* (*Spoturno*) launched his first perfume '*La Rose Jacqueminot*' (*Coty*, 1904; *Fig. 1.2*), where it was used together with *rose absolute* and α-ionone (**1.28**). This combination of a complex essential oil with two single perfumery materials provided '*La Rose Jacqueminot*' with an originality, tenacity, and strength unsurpassed by any other rose perfume of that time [28]. With '*La Rose Jacqueminot*' *Coty* introduced a new style in perfumery, where synthetics are the backbones of a composition, while the naturals function as its flesh.

Inspired by the success of *Coty*'s masterpiece '*l'Origan*' (*Coty*, 1905) with its carnation, violet, and heliotrope accord contrasted by a bittersweet anisic top, his biggest competitor *Jacques Guerlain* set out to also create a sweet floriental fragrance. The result was '*Après l'Ondée*' (*Guerlain*, 1906), for which he selected *p*-anisaldehyde (**1.31**; *Fig. 1.1*) with its sweet, warm odor reminiscent of mimosa and hawthorn as central building block. Without knowledge of its chemical structure, *p*-anisaldehyde (**1.31**) had first been synthesized in 1845 by *Auguste Cahours* by oxidation of anise oil [39]. A practical synthesis was then devised by *Tiemann* and *Herzfeld* in 1877 [40]. In '*Après l'Ondée*', **1.31** is combined with orange blossom oil and a violet–orris accord.

Hydroxycitronellal (**1.33**; *Fig. 1.3*) was the next new material that had a major impact on perfumery. Lily-of-the-valley (*muguet*) flowers neither yield an essential oil upon distillation nor *enfleurage*, and their typical odor was hard to imitate by combining the available essential oils. Albeit not found in nature, hydroxycitronellal (**1.33**) combines almost all facets of lily-of-the-valley flowers in bloom. First introduced to perfumery in 1905 by the German *Knoll & Co.*, soon different qualities emerged such as '*Laurine*' (*Givaudan*, 1906) and '*Cyclosia*' (*Firmenich,*1908), distinguishing itself in the content of isopulegol and menthoglycol (*Geranodyl*) formed as by-products. The fragrance to make hydroxycitronellal (**1.33**) famous was '*Quelques Fleurs*' (*Houbigant*, 1912; *Fig. 1.2*) by *Robert Bienaimé*, the successor of *Paul Parquet*. Hydroxycitronellal (**1.33**) adds the muguet part to the complex floral heart consisting of rose, jasmine, ylang-ylang, lilac, and ionones (**1.28**/**1.29**). But '*Quelques Fleurs*' was also groundbreaking for its use of aldehydes, more specifically the methyl nonyl acetaldehyde (aldehyde C-12 MNA, **1.32**) discovered by *Darzens*, which boosts the floral theme and freshens it up.

The fragrance that is, of course, most famous for its overdose of aldehydes (**1.34**–**1.36**; *Fig. 1.3*) is '*Chanel N°5*' (*Chanel*, 1921) created by *Ernest Beaux*. The success and modernity of '*Quelques Fleurs*' had intrigued *Beaux*, and he began to experiment with aldehydes in the creation of '*Rallet N°1*' (1913), a fine fragrance for the perfume factory *Alphonse Rallet & Co.* of Moscow that was initially released as '*Le Bouquet de Catherine*' honoring Catherine the Great on the occasion of the tercentenary of the Romanov dynasty [41]. As gas chromatographs had not been invented yet, it seems likely that *Beaux* did not have a clue about the use levels of the aldehydes **1.34**–**1.36**, and initially dosed too high. Therefore, he must have discovered that the novel materials **1.34**–**1.36** could counterbalance the fattiness of jasmine absolute and rose oil, as a consequence of which he increased the level of the jasmine–rose accord and the aldehyde complex **1.34**/**1.35**/**1.36** incessantly [41]. After the Russian revolution, *Ernest Beaux* (1881–1961) moved to *Chiris* in La Bocca, Côte d'Azur, where he was introduced to *Coco Chanel* (1883–1971) in 1920 by her then lover, the *Grand Duke Dimitri Pavlovitch*, first cousin of *Tzar Nicolas II*. Allegedly, *Beaux* showed *Chanel* 10 samples, numbered 1–5 and 20–24, from which she selected the N°5 because it was her lucky number. If this was true, we may assume that these samples were all reworks of '*Rallet N°1*' that *Beaux* adapted for the available raw materials at the Côte d'Azur [41]. As that may be, the resulting '*Chanel N°5*' structurally resembles '*Quelques Fleurs*' with an enhanced jasmine–rose accord counterbalanced by 2% each of aldehyde C-10 (**1.34**) , aldehyde C-110 (**1.35**), and aldehyde C-12 (**1.36**), all at 10% dilution. And this aldehydic overdose changed perfumery forever, with '*Chanel N°5*' dominating the top 10 selling charts all over the world for almost a century. Without any doubt, it is the most successful fragrance of all times.

Ernest Beaux became the first perfumer of *Parfums Chanel*, and one of his first creations in this function was '*Cuir de Russie*' (*Chanel*, 1924), a composition that evolves from a shimmering dry aldehydic top and his signature rose–jasmine–ylang ylang heart to a warm, ambery leather fond. Leathery fragrances became very fashionable after *Parfums Caron* had launched '*Nuit de Noël*' in 1922 (*Fig. 1.2*), in which *Ernest Daltroff* tried to capture the luxurious scents of incense and fur coats around Christmas Eve. Like many leathery creations that followed, '*Nuit de Noël*' was built on '*Mousse de Saxe*', a base that had the reputation to resemble the smell of a tiger's lair. *Madame Edgard de Laire* had created '*Mousse de Saxe*' around 6-isobutylquinoline (**1.37**; *Fig. 1.3*) [28], a very powerful and long-lasting odorant that at low concentration exerts a warm, sweet, and earthy-mossy leather note. *George de Laire* and his companion *Charles Girard*, the founders of *de Laire & Co.* in Paris, were friends of *Ferdinand Tiemann* and initially produced vanillin (**1.27**) for *Haarmann & Reimer* in France, since the French patent law required national patents to be exerted in France. Later *de Laire & Co.* developed their own products; many of them incorporated into bases not only for easy use but also to disguise their chemical identity. Quinolines became easily available after *Zdenko Hans Skraup* (1850–1910) had published his synthesis from anilines with glycerol in 1880 [42]. '*Nuit de Noël*' pioneered the use of quinolines and inspired many other creations that followed, such as '*Shocking*' (*Schiaparelli*, 1937) by *Jean Carles*, '*Bandit*' (*Robert Piguet*, 1944) by *Germaine Cellier*, and '*Calèche*' (*Hermes*, 1961) by *Guy Robert*. Allegedly, *Karl Lagerfeld* (1933–2019) did wear '*Nuit de Noël*' every December until his death.

In 1905, *Blaise* and *Houillon* [43] treated undec-10-enoic acid with sulfuric acid to obtain after double-bond migration γ-undecalactone (**1.38**; *Fig. 1.3*) [44], which emanates a very powerful and tenacious fruity odor closely resembling that of ripe peaches [45]. *Jacques Guerlain* already used γ-undecalactone (**1.38**) in 1919 to modernize the *chypre* concept. *Chypre* compositions derive from *Coty*'s classical perfume '*Chypre*' (1917) and are constructed from a hesperidic (citrusy) top note, usually containing bergamot and orange oil, a floral heart featuring a rose–jasmine accord, and a somewhat bitter musky–animalic oakmoss fond, often containing in addition patchouli oil or leather notes. *Jacques Guerlain* sweetened the *chypre* theme with a soft peach note by adding γ-undecalactone (**1.38**), thus '*Mitsouko*' (*Guerlain*, 1919) was created. With '*Femme*' (*Rochas*, 1944), *Edmond Roudnitska* went one step further in sweetening the *chypre* concept and brought the peach note of **1.37** to the fore, backed up by a prune accord. The peach–oakmoss accord became one of the most famous in female fine fragrances.

Roudnitska also initiated the next big trend in perfumery, which was about *Hedione* (**1.39**; *Fig. 1.4*) with its transparent, fresh citric jasmine–magnolia note that is so typical for modern perfumery. Despite the enormous significance of jasmine absolute (*Jasminum grandiflorum* L.), only *ca.* 21 of its constituents were known in 1955, and these did not allow for an acceptable reconstitution of the essential oil [46]. It was apparent that something important was missing, and in 1957 *Eduard Demole* of *Firmenich* started an in-depth analysis of an Egyptian jasmine absolute during a stay in the laboratory of *Edgar Lederer* in Paris. The missing link they discovered was methyl jasmonate, methyl 2-(3-oxo-2-((*Z*)-pent-2-enyl)cyclopentyl)acetate (see *Sect. 7.7*) , which was closely reminiscent of the soft floral, herbaceous heart of jasmine absolute [47]. But due to its difficult synthesis, methyl jasmonate turned out to be too costly to be utilized in perfumery. During their work on the structure elucidation of methyl jasmonate, *Demole et al.* had, however, among a number of related compounds also synthesized the dihydro derivative **1.39** [48], which possesses a similar odor note with the additional elegant, fresh floral softness of overripe lemons. It was introduced to perfumery under the name '*Hedione*' (**1.39**) in 1962 at a price of 7500 CHF/kg (2000 US$/kg). This high price was prohibitive for its use, and thus **1.39** was initially only used at low concentration in the reconstitution of jasmine absolute for fine fragrances. However, when *Roudnitska* smelled *Hedione* (**1.39**), he insisted on being given immediate access to this captive new odorant, and not in form of a jasmine base but in pure. It seems he immediately recalled the olfactory memory of passing by a lemon tree with overripe citrus fruits in the sun. This olfactory concept was realized by him in '*Eau Sauvage*' (*Dior*, 1966) with only *ca*. 2% of *Hedione* (**1.39**) and initiated a massive trend in perfumery for transparent notes. With the price of **1.39** dropping due to process improvements and higher production volumes, we find over 20% of *Hedione* (**1.39**) in '*First*' (*Van Cleef & Arples*, 1976) by *Jean-Claude Ellena* [49] only 10 years later. Today *Hedione* (**1.39**) is omnipresent in perfumery, not only in fine fragrances.

A similar case as jasmine absolute was the other fundamental pillar of perfumery, Bulgarian rose oil (*Rosa damascena* MILL.), of which slightly more than 20 constituents were known in the mid-1960s [46], including citronellol (**1.21**), geraniol (**1.22**), (−)-linalool (**1.24**), and eugenol (**1.25**). Again, a reconstitution of the essential oil based on these analytical data was lacking freshness, depth, and naturalness, especially a green-watery, floral-tobacco, and somewhat bread-like note [46]. In collaboration with the GC expert *Ervin sz. Kováts* (1927–2012) at the ETH Zurich, who was working on his habilitation in the group of *Leopold Ruzicka*, *Demole et al.* finally could isolate 0.8 mg of the missing olfactory link [50], which allowed the structure assignment as 1-(2,6,6-trimethylcyclohexa-1,3-dienyl)but-2-en-1-one [51], which they named *β*-damascenone in analogy to the ionones (**1.28**/**1.29**). The corresponding *α*-damascone (**1.40**; *Fig. 1.4*) had already been synthesized by *Günther Ohloff* (1924–2005) and *Gerald Uhde* in the course of structure elucidation of the isomers of *α*-ionone (**1.28**) [52]. However, at first the value of **1.40** for perfumery had not been realized as the weaker, more camphoraceous, and earthy-smelling (+)-(*R*)-isomer ((+)-(*R*)-**1.40**) had been prepared [50]. With the discovery of *β*-damascenone, the real value of *α*-damascone (**1.40**) was however also realized, and as it was also less expensive to produce than the original natural product, it made a big impact on perfumery. The first perfume to feature a high content of *α*-damascone (**1.40**) was '*Nahéma*' (*Guerlain*, 1979) by *Jean Paul Guerlain* [49]. Women were the inspiration for most of the fragrances by *Jean Paul Guerlain*, and in the case of '*Nahéma*,' it was *Catherine Deneuve* in the film '*Benjamin ou les Mémoires d'un Puceau*' ('*The Diary of an Innocent Boy*') with her enchanting mix of icy coolness and smoldering sensuality. '*Nahéma*' is a rich radiant rose resting on a sweet powdery sandalwood base, *Guerlain*'s greatest rose that inspired so many rose accords of perfumes since. Only six years later we find a massive amount of 0.04% of **1.40** in '*Poison*' (*Dior*, 1985) by *Edouard Flechier*, together with even 0.09% of *β*-damascone and 0.09% of *β*-damascenone. Rumor has it that initially the overdose of the damascone accord was due to a mixing error of *Flechier*'s assistant *Nathalie*, who dosed this accord 10 times too high. Safe fact is however that *Maurice Roger* of *Parfums Christian Dior* was already in the conceptualization of '*Poison*' looking for an extremely fruity–spicy note [27] and was thus pushing the damascone accord to higher levels from trial to trial, levels to which '*Nahéma*' had paved the way.

Leopold Ruzicka (1887–1976) [53–55] is besides *Tiemann* and *Darzens* another groundbreaking pioneer of Fragrance Chemistry. After initial work on irone, fenchone, and linalool (*rac*-**1.24**) with *Haarmann & Reimer* during his habilitation at the ETH Zurich, he collaborated since 1921 with *Chuit, Naef & Co*, the later

Firmenich SA, from 1925–1927 even as their research director. *Ruzicka* is best known for his work on muscone and civetone (see *Sect. 8.1*), which in 1926 overturned *Baeyer*'s theory of ring strain and established the chemistry of macrocycles. This was honored by the award of the *Nobel* Prize for Chemistry in 1939. In the 1940s, *Ruzicka* started to work on ambergris (see *Sect. 8.4*) and reported to his former student *Max Stoll* of *Firmenich* the isolation and structure elucidation of a tricyclic 3,4-dihydro-2*H*-pyranyl enol ether with strong and typical ambery odor [56]. This initiated *Stoll* and his co-worker *Max Hinder* to prepare related analogs, and in the course of which, *Ambrox* (**1.41**) was discovered [57] some 30 years before *Mookherjee* found it in ambergris tincture. To date *Ambrox* (**1.41**) remains the most typical and most esteemed ambergris odorant. Due to its high price, **1.41** is rather difficult to overdose, but the high amounts in '*Drakkar Noir*' (*Guy Laroche*, 1982) by *Pierre Wargnye* had a major impact on the *fougère* family and paved the way for the high quantities used even in feminine fine fragrances today.

Besides **1.41**, '*Drakkar Noir*' (*Guy Laroche*, 1982) is remarkable for containing already 10% of the fresh citrusy-floral, lime- and lavender-like-smelling dihydromyrcenol (**1.42**). But the real revolution of the *fougère* family happened six years later, when *Pierre Bourdon* doubled the amount of **1.42** in '*Cool Water*' (*Davidoff*, 1988), which became a major success still heavily influencing the masculine perfumery of today. Dihydromyrcenol (**1.42**) is easily accessible by hydrogenation of α-pinene (**1.9**), pyrolysis of the resulting *cis*-pinane and subsequent hydroxylation, and was initially conceived as intermediate *en route* to hydroxycitronellal (**1.33**) [58]. But with its successful incorporation in '*Azzaro pour homme*' (*L. Azzaro*, 1978), dihydromyrcenol (**1.42**) outgrew **1.33** in volume in the late 1970s and is today ubiquitous as fresh modern top note not only in the lavender but also the citrus context from fine to functional perfumery.

For dihydromyrcenol (**1.42**) it took almost 30 years from introduction to the overdose level in '*Cool Water*' (*Davidoff*, 1988). For methyl heptyne carboxylate (MHC, *Folione*, **1.43**), it was, however, even longer. This dry, green astringent odorant, which recalls violet foliage and freshly cut cucumber, almost believed to not exist, had already been discovered by *Moureu* and *Delange* in 1901 and was found to be powerful and penetrating [59, 60]. Initially being one of the few green odorants on the perfumer's palette, the use of MHC (**1.43**) declined in the 1960s due to its limited stability and its skin irritation potential. But then in 1988 *Jean-Louis Sieuzac* created with '*Fahrenheit*' an MHC monument by adding the massive dosage of 0.6% of **1.43** to a sketch of '*Grey Flannel*' (*Geoffrey Beene*, 1976) that had been created by *André Fromentin*. The success of '*Fahrenheit*' (*Dior*, 1988), which sold 1.4 million bottles in the first three months in Europe alone, revived this note and inspired many similar creations, albeit **1.43** is now severely restricted in use and its effect is today created by such materials as *Violettyne* (undeca-1,3-diene-5-yne), *Neofolione* (methyl non-2-enoate), or *Undecavertol* (4-methlyldec-3-en-5-ol).

What '*Cool Water*' and '*Fahrenheit*' were in the 1990s for masculine perfumery was '*Trésor*' (*Lancôme*, 1990) for feminine fine fragrances, a new style of monolithic compositions that became associated with the name of their creator *Sophia Grojsman*. The *Grojsman* accord of '*Trésor*' contains 21.4% of the polycyclic musk

Galaxolide (**1.44**) [61], 18% of the woody-ambery *Iso E Super* (**1.45**) [62], 18% of γ-methyl ionone, and 6% of *Hedione* (**1.39**). '*Trésor*' grew out of a personal perfume that *Sophia Grojsman* created for herself with the idea for the perfect fragrance. She was inspired by '*Nahéma*', the cosmetic rose theme of which she found interesting but too strong [49]. With her background in cosmetics and toiletries perfumery, she increased the comparatively inexpensive and long-lasting materials to very high levels to incorporate the rose theme in a central sensual, semi-oriental, but otherwise uncharacteristic accord that she refers to as '*hug me*' accord. This style that provides a lot of '*silage*', as the trail of a perfume waft is called, was only possible by new transparent synthetic odorants like **1.44** and **1.45**.

Likewise, marine scents like '*Kenzo pour homme*' (*Kenzo*, 1991) by *Christian Mathieu* were only possible because of *Calone 1951* (**1.46**; *Fig. 1.4*), which was discovered by *John Joseph Beereboom*, *David Pryde Cameron*, and *Charles Robert Stephens* of *Pfizer* back in 1966 [63, 64]. For more than 20 years, *Calone 1951* (**1.46**) played a marginal role in perfumery and was only used as a trace component in, for instance, muguet accords. '*Kenzo pour homme*' on the male and '*Escape*' (*Calvin Klein*, 1991) changed this overnight and initiated a marine trend with such follow-ups as '*L'eau d'Issey pour homme*' (*Issey Miyake*, 1994) composed by *Jacques Cavallier* [27], '*Polo Sport Woman*' (*Ralph Lauren*, 1996) by *Jim Krivda*, '*Cool Water Woman*' (*Davidoff*, 1997) by *Pierre Bourdon*, and '*Aquawoman*' (*Rochas*, 2002) by *Michel Almairac* [49].

Also the next big trendsetter, ethyl maltol (**1.47**; *Fig. 1.4*), came out in the 1960s from the laboratory of *Charles Robert Stephens* at *Pfizer*, with *Bryce Eugene Tate* and *Robert Pierce Allingham* as coinventors – and again way ahead of its time. Maltol, also known as *Veltol*, occurs widely in nature and had already been discovered back in 1862, yet, the homologous ethyl maltol (**1.47**), which is not found in nature, is not only more than twice as powerful, but it also conjures the smell of crème caramel with far greater fidelity. In '*Angel*' (*Thierry Mugler*, 1992), *Olivier Cresp* used a massive overdose of 0.5% ethyl maltol (**1.47**) to recreate the caramel–chocolate–honey scent of a funfair, on the suggestion of *Yves de Chiris* juxtaposed and contrasted with patchouli oil to tame the overwhelming sweetness [27, 49]. Thus, the first gourmand perfume was created, which gave birth to a whole new family of fine fragrances, both female and male. So far '*Angel*' has been the only perfume to drive '*Chanel N° 5*' (*Chanel*, 1921) off its first place in the perfume bestseller charts in France and seriously rival its fame. The overdose of ethyl maltol (**1.47**) in '*Angel*' (*Thierry Mugler*, 1992), again the main odorant that caused the gourmand trend, proves *Ernest Beaux*, creator of '*Chanel N° 5*', right when he said in 1952 the following [27, 65]: '*The future of perfumery is in the hands of the chemists. We'll have to rely on chemists to find new odorants if we are to make new and original accords.*'

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