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Foreword

Volatile compounds play an important role in nature as messenger compounds to transmit selective information between species. The ubiquity of these compounds in our everyday environment has initiated a variety of research activities in the life sciences over recent decades. Both biologists and chemists became interested in exploring the role of bioactive volatile compounds in many different aspects. The evolution from molecular to supramolecular science has particularly influenced the research activities on the chemistry and biology of volatiles. The investigation of molecular properties beyond the single molecule required (and resulted in) numerous interdisciplinary efforts to answer important questions related to the role of these compounds in our direct environment.

Molecular recognition is one of the key aspects leading to the understanding of the biological processes involved in volatile signalling. In contrast to the investigation of host–guest interactions typically encountered in the area of pharmaceutical or biomedical research, which usually take place in aqueous solution, volatile compounds have to be diffused into the air and transported over large distances to reach their biological target. The specific feature of their volatility, as compared to other bioactive molecules, characterizes the behaviour of these molecules from their biogenesis, to their emission, analysis, release, transport, recognition and perception, up to their degradation in a specific environment.

The present book summarizes several aspects related to the chemistry and biology of volatile compounds in a structure-based approach and tries to give the reader an introduction to and general overview of the various research areas related to this particular class of molecules. It also provides perspectives along novel avenues of research and development. It should thus be of great interest to all those involved in the various facets of both basic and applied research on volatile compounds.

Jean-Marie Lehn

Strasbourg

November 2009

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Andreas Herrmann

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Abbreviations

Ac	acetyl (in structural formula)
ACC	1-aminocyclopropane-1-carboxylic acid
ACS	American Chemical Society
ACSO	S-allyl-L-cysteine sulfoxide
AE	aroma extract
AEDA	aroma extract dilution analysis
AFNOR	Association Française de Normalisation
AMDIS	automatic mass spectral deconvolution
AMPI	acetylmethyl phosphinate
APC	anterior piriform cortex
approx.	approximately
APS	adenosine-5'-phosphosulfate
aq.	aqueous
ASE	accelerated solvent extraction

ASES	aerosol solvent extraction system
ATP	adenosine-5'-triphosphate
BASF	Badische Anilin und Soda Fabrik
BINAP	2,2'-bis(diphenylphosphino)-1,1'-binaphthyl
BOLD	blood oxygenation level dependent
BOSS	beaver dam offspring study
Bu	butyl (in structural formula)
BVOC	biogenic volatile organic compound
ca.	<i>circa</i>
cAMP	cyclic adenosine monophosphate
CAN-BD	carbon dioxide assisted nebulization with a bubble dryer
CAR	carboxen
cat.	catalyst/catalytic
CBF	cerebral blood flow
CD	circular dichroism (spectroscopy)
CDs	cyclodextrins
CDP	cytidine-5'-diphosphate
CDP-ME	4-diphosphocytidyl-2- <i>C</i> -methyl-D-erythritol
CDP-ME2P	4-diphosphocytidyl-2- <i>C</i> -methyl-D-erythritol-2-phosphate
CDP-MEP	diphosphocytidyl-2-methyl-D-erythritol-2-phosphate
C-GC	conventional gas chromatography
CI	Criegee intermediate
CI-MS	chemical ionization–mass spectrometry
CITAC	Cooperation on International Traceability in Analytical Chemistry
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CoA	coenzyme A
COBEL	children's olfactory behaviors in everyday life
conc.	concentrated
COSY	correlation spectroscopy
Cp	cyclopentadienyl
CPCSP	continuous powder coating spraying process
CRC	Chemical Rubber Company
CS	cysteine synthase
CSO	alk(en)ylcysteine sulfoxide
CTP	cytidine-5'-triphosphate
1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
DADS	diallyl disulfide
DC	direct contact
DCMU	diuron
DEET	<i>N, N</i> -diethyl-2-toluamide
DELOS	depressurization of an expanded liquid organic solution
d.f.	film thickness
D-HS	dynamic headspace
DIBAL-H	diisobutylaluminium hydride
dil.	diluted
DMAPP	3,3-dimethylallyl diphosphate
DMSO	dimethylsulfoxide
DNA	deoxyribonucleic acid
DOX	1-deoxy-D-xylulose
DOXP	1-deoxy-D-xylulose 5-phosphate
DP	dual phase
DSC	differential scanning calorimetry

DTBP	di- <i>tert</i> -butyl peroxide
DVB	divinylbenzene
DXR	DOXP reductoisomerase
DXS	DOXP synthase
EAD	electroantennographic detection
EAG	electroantennogram
Ed.	editor/edition
EDGAR	emissions database for global atmospheric research
<i>ee</i>	enantiomeric excess
EEG	electroencephalogram
EHLS	epidemiology of hearing loss study
EO	essential oil
EPA	Environmental Protection Agency (USA)
<i>er</i>	enantiomeric ratio
ES-GC	enantioselective gas chromatography
ESP	epithiospecifier protein
ET	ethylene
Et	ethyl (in structural formula)
etc.	<i>et cetera</i>
EU	European Union
FACs	fatty acid–amino acid conjugates
FAO	Food and Agriculture Organisation (of the United Nations)
Fd	ferredoxin
FFNSC	flavour and fragrance natural and synthetic compounds
F-GC	fast gas chromatography
FID	flame ionization detector
fMRI	functional magnetic resonance imaging
FPP	farnesyl diphosphate
FQPA	Food Quality Protection Act (USA)
FSOT	fused silica open tubular
GA-3-P	glyceraldehyde-3-phosphate
GAS	gas (or supercritical fluids) anti-solvent
GC	gas chromatography
GC-FID	gas chromatography–flame ionization detection
GC-MS	gas chromatography–mass spectrometry
GC-qMS	gas chromatography–quadrupole mass spectrometry
GC-O	gas chromatography–olfactometry
GGPP	geranylgeranyl diphosphate
γGP	γ-glutamyl sulfoxide peptide derivative
GPP	geranyl diphosphate
GS	glucosinolate
GSH	reduced glutathione
GSSG	oxidised glutathione disulfide
HCC-HS	high concentration capacity headspace technique
HIPVs	herbivore-induced plant volatiles
HIV	human immunodeficiency virus
HLA	human leukocyte antigen
HMBC	heteronuclear multiple bond coherence
HMBPP	4-hydroxy-3-methyl-2-(<i>E</i>)-butenyl diphosphate
HMG	hydroxyl-methylglutaryl
HMPA	hexamethylphosphoramide
HMQC	heteronuclear multiple quantum coherence
HPC	hydroxypropyl cellulose
HPLC	high performance liquid chromatography

HPOD	hydroperoxyoctadienoate
HR	heart rate
HS	headspace
HS-LPME	headspace–liquid phase microextraction
HS-MS	headspace–mass spectrometry
HSQC	heteronuclear single quantum coherence
HSSE	headspace sorptive extraction
HS-SPDE	headspace–solid phase dynamic extraction
HS-SPME	headspace–solid phase microextraction
HS-SMSE	headspace–silicon membrane sorptive extraction
HS-STE	headspace–sorptive tape extraction
IAA	indole-3-acetic acid
IATA	International Air Transport Association
i.d.	inner diameter
IFF	International Flavors and Fragrances Inc.
IFRA	International Fragrance Association
INCAT	inside needle capillary adsorption trap
IOFI	International Organization of the Flavour Industry
IPP	isopentenyl diphosphate
IRMS	isotope ratio mass spectrometry
<i>IspD</i>	CDP-ME synthase
<i>IspE</i>	CDP-ME kinase
<i>IspF</i>	MEcPP synthase
<i>IspG</i>	HMBPP synthase
<i>IspH</i>	HMBPP reductase
ISTD	internal standard
IUPAC	International Union of Pure and Applied Chemistry
JA	jasmonic acid
LC	liquid chromatography
LDA	lithium diisopropylamine
LF	lachrymatory factor
LFS	lachrymatory factor synthase
LMCS	longitudinally modulated cryogenic system
LOD	limit of detection
LOQ	limit of quantification
<i>LOX³</i>	lipoxygenase 3 (gene)
MACR	methacrolein
MAE	microwave-assisted extraction
MA-HD	microwave-assisted hydrodistillation
MAM	methylthioalkylmalate
MBO	2-methylen-3-buten-2-ol
MCSO	S-methyl-L-cysteine sulfoxide
MD	multidimensional
ME	male equivalents
Me	methyl (in structural formula)
MEcPP	2-C-methyl-D-erythritol-2,4-cyclodiphosphate
MeJA	methyl jasmonate
MeSA	methyl salicylate
MEP	2-C-methylerythritol-4-phosphate
MESI	membrane extraction sorbent interface
MGL	methionine-γ-lyase
MHC	major histocompatibility complex
MHE	multiple headspace extraction
ML	maple lactone
MME	membrane microextraction

MS	mass spectrometry, mass spectrometer
Ms	mesyl (SO ₂ CH ₃ ; in structural formula)
MVA	mevalonic acid/mevalonate
MVL	mevalonolactone
MVK	methyl vinyl ketone
MW	molecular weight
MYB	myeloblast
NADPH	nicotinamide adenine dinucleotide phosphate
NB	narrow bore (column)
NIST	National Institute of Standards and Technology
NMO	<i>N</i> -methylmorpholine- <i>N</i> -oxide
NMR	nuclear magnetic resonance
NOESY	nuclear Overhauser enhancement spectroscopy
NPQ	nonphotochemical quenching
NS	nosespace
Nu	nucleophile (in structural formula)
OAV	odour activity values
OB	olfactory bulb
OCO	oral cavity only (exposure)
OFC	orbitofrontal cortex
OP	other phytohormones
OPE	ozone production efficiency
OR	olfactive receptor
ORNs	olfactive receptor neurons
OV	Ohio Valley Speciality Chemical (brand of stationary phases)
OXP-01	2-decyl-1-oxaspiro[2.2]pentane
OXP-04	2-(4-hydroxybutyl)-1-oxaspiro[2.2]pentane
PAN	peroxyacetyl nitrate
PAPS	adenosine-3'-phosphate-5'-phosphosulfate
PCA	principal component analysis
PCSO	<i>S</i> -propyl-L-cysteine sulfoxide
pdf	portable document format
PeCSO	<i>trans</i> - <i>S</i> -1-propenyl-L-cysteine sulfoxide
PEG	poly(ethylene glycol)
PET	positron emission tomography
PBP1	pheromone binding protein 1
PD	Parkinson's disease
PDMS	poly(dimethylsiloxane)
PEP	phosphoenol pyruvate
PG	protecting group
PGA	phosphoglyceric acid
PGSS	particles from gas-saturated solutions
Ph	phenyl (in structural formula)
PLP	pyridoxal-5'-phosphate
PMHS	poly(methylhydrosiloxane)
pp.	pages
PPC	posterior piriform cortex
PTR-MS	proton transfer reaction–mass spectrometer
qMS	quadrupole mass spectrometry (detector)
quant.	quantitative
RA	retinoic acid
ref.	reference
RESS	rapid expansion of supercritical fluids
RNA	ribonucleic acid

RSD	relative standard deviation
r.t.	room temperature
RTL	retention time locking
RubisCO	ribulosebisphosphate carboxylase/oxygenase
SA	salicylic acid
SAA	supercritical assisted atomization
SAS	supercritical fluids (or gas) anti-solvent
SAT	serine acetyltransferase
SBSE	stir bar sorptive extraction
SC	skin conductance
SCC-GC	short capillary column gas chromatography
sc-CO ₂	supercritical CO ₂
SDE	simultaneous distillation–extraction
SDOIT	San Diego odor identification test
SEDS	solution enhanced dispersion by supercritical fluids
SFE	supercritical fluid extraction
SFEE	supercritical fluid extraction of emulsions
S-HS	static headspace
SIM	single ion monitoring
SIM-MS	single ion monitoring–mass spectrometry
SIM-qMS	single ion monitoring–quadrupole mass spectrometry
SiSTEx	solvent in silicone tube extraction
SMP	skimmed milk powder
SMSE	silicon membrane sorptive extraction
SOA	secondary organic aerosol
SPACE	solid phase aroma concentrate extraction
SPME	solid phase microextraction
SROs	stress-related odours
SSI	supercritical solvent impregnation
S&T-HS	static and trapped headspace
TAS	total analysis systems
TCD	thermal conductivity detector
TDS	thermodesorption system
<i>tert</i>	tertiary
THF	tetrahydrofuran
TIC	total ion current
TIC-MS	total ion current–mass spectrometry
TLC	thin-layer chromatography
TMS	trimethylsilyl (protecting group)
TMT	thiol methyltransferases
TOF	time of flight
TPLSM	two-photon laser scanning microscopy
TRGs	temperature-responsive gels
Ts	tosyl (SO ₂ C ₆ H ₄ CH ₃ ; in structural formula)
<i>p</i> -TSA	<i>para</i> -toluenesulfonic acid
UFM-GC	ultra-fast module gas chromatography
UK	United Kingdom of Great Britain and Northern Ireland
UNEP	United Nations Environment Programme
USA	United States of America
UV	ultraviolet (spectroscopy)
UV/Vis	ultraviolet/visible (spectroscopy)
VOC	volatile organic compound
Vol.	volume
WOF	warmed-over flavour

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1

Volatiles – An Interdisciplinary Approach

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1.1 Introduction

Volatiles, and in particular biogenic volatile organic compounds (VOCs), are everywhere. They directly and indirectly influence the lives of many plant and insect species, and even human beings in many ways. Transported by diffusion through the air, they perform numerous functions, for example as so-called 'semiochemicals', 'infochemicals' or 'pheromones' for the communication between insects and/or plants,^{1,2} for (insect) mating^{2–4} or even, as a consequence of their pleasant taste or smell to humans, as flavours and fragrances.^{4,5} Without volatile compounds, life on earth as we know it would be impossible. The structural variety in these compounds, which are generally based on a hydrocarbon skeleton with oxygen, nitrogen and sulfur as the most common heteroatoms, is almost infinite and always perfectly adapted to the specific role these molecules play in nature.

Biogenic VOCs are usually highly selective for a given target. This selectivity is presumably the most important property of these different compounds which, of course, is defined by their molecular structure (and the spatial arrangement of the different functional groups from which they are composed) and usually results in a very low 'detection threshold' of a given compound to its target species.⁶ This means that the receptor of the receiving species can selectively detect specific molecules at very low concentrations in the air (typically expressed in ng l⁻¹ of air) which, in some cases, can be a few molecules.

In contrast to many other target-specific compounds found in nature, volatiles are characterized by (relatively) high vapour pressures, allowing their efficient evaporation from various surfaces. This enables their transport through the air and thus to reach their biological target. Nevertheless, the term 'volatile' is usually not well defined, and the vapour pressures of compounds considered to be volatile can vary over several orders of magnitude.⁷ Some representative volatile compounds such as **1–18** are listed in . Their vapour pressures span nine orders of magnitude, ranging from the highly volatile methane thiol (**1**) to the relatively nonvolatile insect pheromone bombykol (**18**) from the silkworm moth *Bombyx mori*.

Furthermore, biogenic VOCs are generally characterized as being rather 'hydrophobic' which facilitates, among others, their efficient evaporation from water-based media into the air. The polarity of different compounds is usually expressed as the logarithm of their octanol/water partition coefficients ($\log P_{o/w}$);^{7,8} the corresponding values for compounds **1–18** are indicated in . Once again, one can see that these data vary considerably, ranging from values below 1 for relatively polar compounds **1** and **3** to highly apolar molecules such as **13** with a $\log P_{o/w}$ above 9.

The numerous areas of research dealing with the investigation of volatile compounds are as varied as their structures and their physicochemical properties. Biologists and chemists have become interested in these compounds for various reasons. Because the same volatile compounds can have different functions, volatiles have been discussed separately by the specialists in different areas. Nevertheless, the same molecular structure is often of interest to a wide variety of quite different research topics such as the biosynthesis of the given volatile in plants, its analysis in compound mixtures by different techniques, its particular biological role as a signalling compound or pheromone, its use in pest control and, if associated with a pleasant taste or smell, as a flavour or fragrance, its chemical synthesis, the mechanism of its perception, its behaviour through encapsulation and processing, its controlled release, right up to its degradation in the environment (). In the following section the different interdisciplinary research aspects associated with a given compound are illustrated with the example of (*E*)-3,7-dimethyl-2,6-octadien-1-ol (geraniol, **11**) as a typical volatile molecule with an average vapour pressure and $\log P_{o/w}$. At the same time, these aspects will allow the introduction of the various topics presented in the different chapters of this book and thus illustrate a typical lifecycle of volatile compounds from their biogenesis, via their release into the air, their role as semiochemicals, their specific recognition, through to their degradation in the atmosphere.

1.2 Geraniol – A Typical Example

Biogenic, bioactive volatiles, such as geraniol (**11**), are generated in plants from small precursor molecules in multistep enzymatic processes. As one of the main constituents of the essential oils of various rose species, monoterpene alcohol **11** is biosynthesized by condensation of isopentenyl diphosphate (IPP, **19**) and 3,3-dimethylallyl diphosphate (DMAPP, **20**) with the help of geranyl diphosphate (GPP) synthetase, followed by dephosphorylation of GPP (**21**),⁹ as depicted in . GPP is of particular importance because it is the precursor of geraniol and of many different monoterpenes. The following chapter (Chapter 2) gives a general introduction to the various mechanisms involved in the biosynthesis of plant isoprenoids and illustrate the structural variety of terpenes generated by plants.

Vapour pressures and (logarithmic) octanol/water partition coefficients ($\log P_{o/w}$) of a series of representative volatile compounds

^aNote: Values calculated according to ref. 7.

The identification and quantification of the individual constituents isolated from plants is an important aspect in the understanding of the biochemical processes involved in their generation. Volatiles are analysed mainly by gas chromatography (GC), usually coupled with mass spectrometry (GC-MS), and some other more specific techniques. The volatility of such compounds allows specific sample preparation methods such as static and dynamic headspace analysis to be employed.¹⁰ Chapter 3 gives an account of the numerous methods used for the analysis of volatile compounds emitted from plants by discussing the scopes and limitations of the different techniques.

Biosynthesis of geraniol

Plants, insects and other animals use volatile compounds for their communication with the environment.¹ Besides its emission from flowers to attract pollinators, geraniol (**11**) is also a member of a class of so-called 'herbivore-induced plant volatiles' (HIPVs). Plants emit these compounds to defend themselves against herbivore attack by attracting natural enemies of the herbivores responsible for the plant damage. As an example, geraniol was found to attract wasps and flesh flies of the Braconidae and Sarcophagidae families, respectively.¹¹ The specific aspects and implications of volatile signalling for plants and insects are discussed in Chapter 4.

Geraniol (**11**) has also been identified in the secretions of the Nasonov gland of honeybees, where the compound, together with a series of other volatiles, serves as a pheromone to mark the entrance of the hive, for mating and orientation, as for example for swarm clustering or guidance to flowers.¹² Using insects and mammals as examples, Chapter 5 presents the classification, structural particularities and roles of pheromones in chemical communication.

Apart from acting as an attractant, geraniol was also found to repel certain insects, such as the malaria-transmitting mosquito *Anopheles gambiae*.¹³ Essential oils (EOs) containing geraniol (and other insect-repellent compounds) have thus been used for protection against blood-feeding insects, whilst other volatiles have been identified as being useful for the protection of agricultural crops. The potential to selectively repel or kill certain insects is an important aspect of volatiles in the area of pest control, as documented in more detail in Chapter 6.

Although geraniol (**11**) is readily available from natural sources, several methods for its synthesis have been proposed, some of which are illustrated in . Typically the compound is prepared from other monoterpenes¹⁴ such as myrcene (**22**), citral (**23**) or linalool (**24**) to usually afford mixtures of geraniol (**11**) and nerol (**25**). The selective preparation of specific isomers in high purities is therefore one of the major achievements of organic synthesis. Chapter 7 summarizes some of the challenges encountered in the synthesis of natural and non-natural fragrances. Besides allowing the preparation of natural compounds which are difficult to be accessed in large quantities, organic chemistry has delivered a multitude of new and entirely synthetic compounds, in particular for use in perfumery.

Chemical synthesis of geraniol

Certain volatile molecules are also part of our everyday life as flavours present in our daily nutrition. Monoterpenes, such as geraniol, contribute to the floral aroma of a series of grape varieties used in wine-making.¹⁵ Many flavour volatiles, so-called 'secondary metabolites' in fruits or vegetables, are generated from fats or amino acid precursors during ripening. The mechanisms involved in the biogenesis and metabolism of these compounds are important for food preparation as well as in aspects of nutrition and health. Besides the terpenoid structures, sulfur- and nitrogen-containing compounds are particularly important flavour constituents. Whereas Chapter 8 discusses the biogenesis and the role of a variety of sulfur compounds encountered in onion and garlic, Chapter 9 focuses on the generation of flavours during food processing, as for example in the so-called 'Maillard reaction',¹⁶ with particular focus on the thermal effects detected during cooking. Because not all volatiles have a pleasant taste or smell, the understanding of these processes is also important in allowing the efficient minimisation of undesired malodour formation under various conditions.

Once the volatiles have reached their target, they are recognized by specific receptors, which trigger an electric signal perceived by the brain. The mechanisms of olfactory perception are quite complicated in both insects and humans. The general importance of understanding the mechanisms of olfaction was underlined by the granting of the Nobel Prize in Physiology or Medicine to Axel and Buck in 2004 for their discoveries of odorant receptors and the organisation of the olfactory system,¹⁷ which stimulated a general interest in exploring the chemistry and biology of volatile compounds in the life sciences.¹⁸ Chapter 10 gives a general overview of the basic principles and mechanisms involved in (human) perception.

To humans geraniol (**11**) has a pleasant, sweet, floral smell and is therefore among the most frequently used perfumery compounds.^{14,19} Perfumes are usually mixtures of many different volatile compounds created at the interface between art and science. In the general public, perfumery is most commonly associated with 'fine fragrances', but perfumes are also an important ingredient in body care and household products, such as shampoos, soaps, creams, deodorants, shower gels, surface cleaners, detergents, softeners and many others. Chapter 11 illustrates the particular artistic aspects of perfumery creation. For their creations, perfumers require a multitude of different molecules at their disposal. These compounds can be natural compounds extracted from natural raw materials, prepared selectively by biotechnical processes or by organic synthesis.

Many terpenes are sensitive to oxidation, either by oxygen in the air²⁰ or by a variety of bio-oxidation processes initiated by bacteria and fungi²¹ (). To efficiently use susceptible terpenes such as geraniol (**11**) in commercial product formulations they have to be protected against (oxidative) degradation by using various encapsulation techniques.²² Chapter 12 examines a series of flavour encapsulation processes which are most commonly used to increase the stability of food ingredients and to control their release in applications.

Compounds formed by air oxidation of geraniol

Release of geraniol by enzymatic cleavage of its glycoside conjugate

Besides the physical capturing of volatiles within capsules and other matrices, 'chemical' delivery systems have been developed to slowly release small quantities of volatiles to allow the duration of their perception to be increased. Nature stores and transports terpenes, such as geraniol (**11**) as hydrosoluble glycoside conjugates (e.g. **26**) before releasing them by enzymes into the environment,²³ which served as an inspiration to use fragrance conjugates as controlled release systems in practical applications (). Chapter 13 gives an account of the various techniques which have been developed for the release of fragrance molecules via covalent bond cleavage of different natural and non-natural fragrance precursors, so-called 'profragrances' or 'properfumes'. Of course, this concept can be generally applied to the controlled release of volatiles in other areas, as for example to attract or repel insects in pest control.

Another important area of interest concerns the (natural) biodegradation of volatiles in water or soil by the activity of various microorganisms. Nevertheless, as a consequence of their volatility, biogenic VOCs can also reach the atmosphere, where they are exposed to particular reaction conditions leading to their rapid degradation ().²⁴ The investigation of these processes becomes more and more important to understand the lifecycle of natural compounds and to estimate the impact of biogenic volatiles on our planet's climate. This book therefore concludes with a discussion of this important aspect with a summary of the gas phase chemistry of biogenic VOCs in the atmosphere (Chapter 14) as one aspect of their natural biodegradation.

Degradation of geraniol in the atmosphere

1.3 Conclusion

The different topics of research mentioned above for one representative molecule such as geraniol (**11**) indicate the broad variety of interest in volatile compounds. With the structures of the volatiles being the common link to all the different research areas presented in the following chapters, it is on purpose that the reader will find many common molecular structures illustrating the different chapters and thus referring to the different domains of research grouped together in this book. To date, these aspects have mainly been discussed separately by specialists from different areas, and several textbooks and reviews on the individual topics are available. However, the goal of this book is to provide an interdisciplinary approach on the various aspects of the chemistry and biology of volatile compounds to a reader generally interested in this area. The chapters constituting this book are not intended to give an extensive or comprehensive review of each of the specific topics, but rather represent a conceptual and quite general overview of a series of different research areas. They should give the reader the opportunity to discover the basic aspects of the different disciplines, to illustrate parallels between the different domains and, with the numerous references given in the different chapters, to invite further reading.

As depicted in , there is a certain overlap between the different research areas, which of course results from the discussion of similar aspects from different viewpoints in several of the chapters. At the same time, other important aspects of research on volatile compounds might only be briefly mentioned or even entirely omitted. However, to keep this book within a reasonable length, this seemed to be unavoidable.

The respective interest in volatile compounds from so many different angles is an excellent occasion for the exchange and common learning in chemistry and biology, and I hope that the present book will stimulate discussions and collaborations within a highly interdisciplinary research field.

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As well as his research project, Josh planned to write a (7) " Trip to south africa. You will hear a student called Josh Brady talking about visiting South Africa as part of his university course in botany. need to be supplemented by first-hand experience. are attractive because they lead to paid employment. are of little value compared to working on a student newspaper. provide an opportunity for writers to address contentious issues. A B C D. an ambition to gain recognition for their craft. a desire to develop careers outside journalism. a need to prove how versatile they are as writers. a wish to keep their journalism fresh and appealing. Peter and Jenny agree that courses in journalism. A B C D. Peter thinks he got a job on Carp Magazine thanks to.