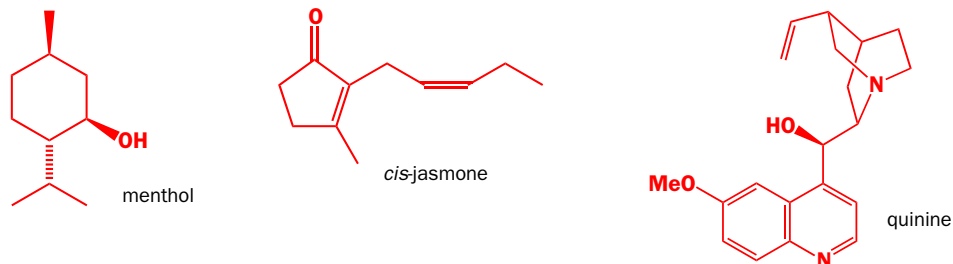


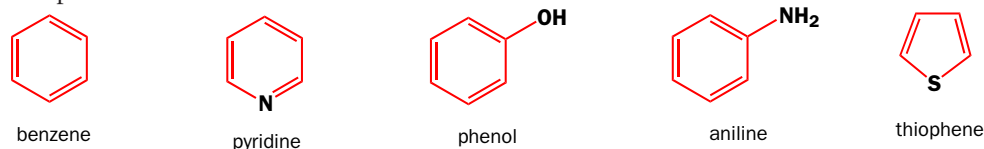
You will be able to read towards the end of the book (Chapters 49–51) about the extraordinary chemistry that allows life to exist but this is known only from a modern cooperation between chemists and biologists.

The organic compounds available to us today are those present in living things and those formed over millions of years from dead things. In earlier times, the organic compounds known from nature were those in the ‘essential oils’ that could be distilled from plants and the alkaloids that could be extracted from crushed plants with acid. Menthol is a famous example of a flavouring compound from the essential oil of spearmint and *cis*-jasmone an example of a perfume distilled from jasmine flowers.

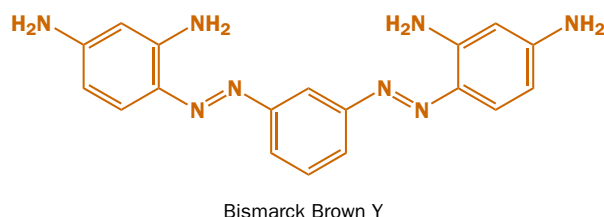


Even in the sixteenth century one alkaloid was famous—quinine was extracted from the bark of the South American cinchona tree and used to treat fevers, especially malaria. The Jesuits who did this work (the remedy was known as ‘Jesuit’s bark’) did not of course know what the structure of quinine was, but now we do.

The main reservoir of chemicals available to the nineteenth century chemists was coal. Distillation of coal to give gas for lighting and heating (mainly hydrogen and carbon monoxide) also gave a brown tar rich in aromatic compounds such as benzene, pyridine, phenol, aniline, and thiophene.



Phenol was used by Lister as an antiseptic in surgery and aniline became the basis for the dyestuffs industry. It was this that really started the search for new organic compounds made by chemists rather than by nature. A dyestuff of this kind—still available—is Bismarck Brown, which should tell you that much of this early work was done in Germany.



In the twentieth century oil overtook coal as the main source of bulk organic compounds so that simple hydrocarbons like methane (CH₄, ‘natural gas’) and propane (CH₃CH₂CH₃, ‘calor gas’) became available for fuel. At the same time chemists began the search for new molecules from new sources such as fungi, corals, and bacteria and two organic chemical industries developed in parallel—‘bulk’ and ‘fine’ chemicals. Bulk chemicals like paints and plastics are usually based on simple molecules produced in multitonne quantities while fine chemicals such as drugs, perfumes, and flavouring materials are produced in smaller quantities but much more profitably.

At the time of writing there were about 16 million organic compounds known. How many more are possible? There is no limit (except the number of atoms in the universe). Imagine you’ve just made the longest hydrocarbon ever made—you just have to add another carbon atom and you’ve made another. This process can go on with any type of compound *ad infinitum*.

But these millions of compounds are not just a long list of linear hydrocarbons; they embrace all kinds of molecules with amazingly varied properties. In this chapter we offer a selection.

You can read about polymers and plastics in Chapter 52 and about fine chemicals throughout the book.



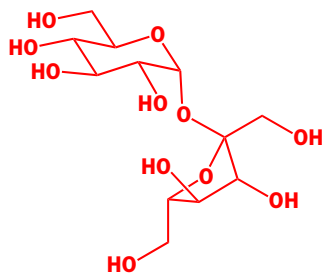
n = an enormous number
length of molecule is *n* + 2
carbon atoms



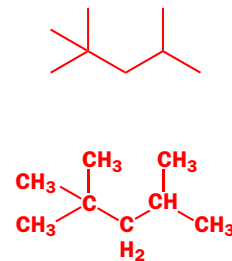
n = an enormous number
length of molecule is *n* + 3
carbon atoms

What do they *look* like? They may be crystalline solids, oils, waxes, plastics, elastics, mobile or volatile liquids, or gases. Familiar ones include white crystalline sugar, a cheap natural compound isolated from plants as hard white crystals when pure, and petrol, a mixture of colourless, volatile, flammable hydrocarbons. Isooctane is a typical example and gives its name to the octane rating of petrol.

The compounds need not lack colour. Indeed we can soon dream up a rainbow of organic compounds covering the whole spectrum, not to mention black and brown. In this table we have avoided dyestuffs and have chosen compounds as varied in structure as possible.



sucrose – ordinary sugar
isolated from sugar cane
or sugar beet
white crystalline solid



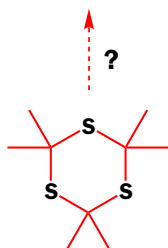
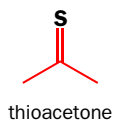
isooctane (2,3,5-trimethylpentane)
a major constituent of petrol
volatile inflammable liquid

s	Colour	Description	Compound	Structure
red	dark red hexagonal plates		3'-methoxybenzocycloheptatriene-2'-one	
orange	amber needles		dichloro dicyano quinone (DDQ)	
yellow	toxic yellow explosive gas		diazomethane	$\text{CH}_2=\text{N}^{\oplus}=\text{N}^{\ominus}$
green	green prisms with a steel-blue lustre		9-nitroso julolidine	
blue	deep blue liquid with a peppery smell		azulene	
purple	deep blue gas condensing to a purple solid		nitroso trifluoromethane	

Colour is not the only characteristic by which we recognize compounds. All too often it is their odour that lets us know they are around. There are some quite foul organic compounds too; the smell of the skunk is a mixture of two thiols—sulfur compounds containing SH groups.

skunk spray contains:

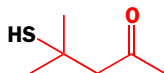




trithioacetone;
Freiburg was evacuated
because of a smell from
the distillation this compound



propane
dithiol



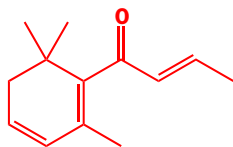
4-methyl-4-
sulfanylpentan-
2-one

two candidates for
the worst smell in the world

no-one wants to find the winner!



the divine smell
of the black truffle
comes from this compound



damascenone - the smell of roses

But perhaps the worst aroma was that which caused the evacuation of the city of Freiburg in 1889. Attempts to make thioacetone by the cracking of trithioacetone gave rise to 'an offensive smell which spread rapidly over a great area of the town causing fainting, vomiting and a panic evacuation—the laboratory work was abandoned'.

It was perhaps foolhardy for workers at an Esso research station to repeat the experiment of cracking trithioacetone south of Oxford in 1967. Let them take up the story. 'Recently we found ourselves with an odour problem beyond our worst expectations. During early experiments, a stopper jumped from a bottle of residues, and, although replaced at once, resulted in an immediate complaint of nausea and sickness from colleagues working in a building two hundred yards away. Two of our chemists who had done no more than investigate the cracking of minute amounts of trithioacetone found themselves the object of hostile stares in a restaurant and suffered the humiliation of having a waitress spray the area around them with a deodorant. The odours defied the expected effects of dilution since workers in the laboratory did not find the odours intolerable . . . and genuinely denied responsibility since they were working in closed systems. To convince them otherwise, they were dispersed with other observers around the laboratory, at distances up to a quarter of a mile, and one drop of either acetone *gem*-dithiol or the mother liquors from crude trithioacetone crystallisations were placed on a watch glass in a fume cupboard. The odour was detected downwind in seconds.'

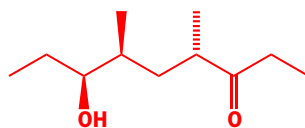
There are two candidates for this dreadful smell—propane dithiol (called acetone *gem*-dithiol above) or 4-methyl-4-sulfanylpentan-2-one. It is unlikely that anyone else will be brave enough to resolve the controversy.

Nasty smells have their uses. The natural gas piped to our homes contains small amounts of deliberately added sulfur compounds such as *tert*-butyl thiol ($(\text{CH}_3)_3\text{CSH}$). When we say small, we mean *very small*—humans can detect one part in 50 000 000 000 parts of natural gas.

Other compounds have delightful odours. To redeem the honour of sulfur compounds we must cite the truffle which pigs can smell through a metre of soil and whose taste and smell is so delightful that truffles cost more than their weight in gold. Damascenones are responsible for the smell of roses. If you smell one drop you will be disappointed, as it smells rather like turpentine or camphor, but next morning you and the clothes you were wearing will smell powerfully of roses. Just like the compounds from trithioacetone, this smell develops on dilution.

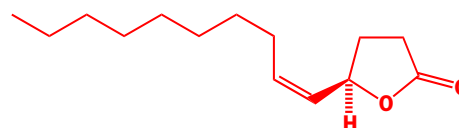
Humans are not the only creatures with a sense of smell. We can find mates using our eyes alone (though smell does play a part) but insects cannot do this. They are small in a crowded world and they find others of their own species and the opposite sex by smell. Most insects produce volatile compounds that can be picked up by a potential mate in incredibly weak concentrations. Only 1.5 mg of serricornin, the sex pheromone of the cigarette beetle, could be isolated from 65 000 female beetles—so there isn't much in each beetle. Nevertheless, the slightest whiff of it causes the males to gather and attempt frenzied copulation.

The sex pheromone of the Japanese beetle, also given off by the females, has been made by chemists. As little as 5 μg (micrograms, note!) was more effective than four virgin females in attracting the males.



serricornin

the sex pheromone of the cigarette beetle
Lasioderma serricorne

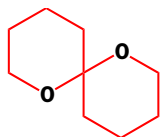


japonilure

the sex pheromone of the Japanese beetle
Popillia japonica

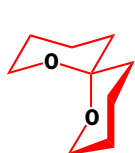
The pheromone of the gypsy moth, disparlure, was identified from a few μg isolated from the moths and only 10 μg of synthetic material. As little as 2×10^{-12} g is active as a lure for the males in field tests. The three pheromones we have mentioned are available commercially for the specific trapping of these destructive insect pests.

Don't suppose that the females always do all the work; both male and female olive flies produce pheromones that attract the other sex. The remarkable thing is that one mirror image of the molecule attracts the males while the other attracts the females!

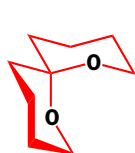


olean

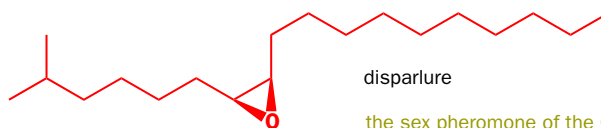
sex pheromone of the olive fly
Bacrocera oleae



this mirror image isomer
attracts the males



this mirror image isomer
attracts the females

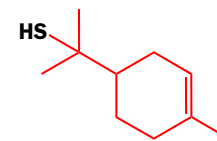


disparlure

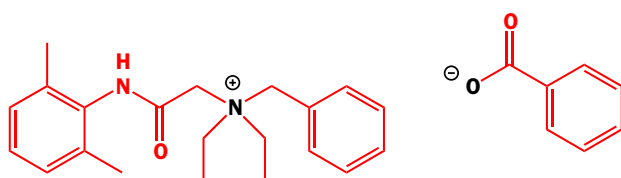
the sex pheromone of the Gypsy moth
Porthesia dispar

What about taste? Take the grapefruit. The main flavour comes from another sulfur compound and human beings can detect 2×10^{-5} parts per billion of this compound. This is an almost unimaginably small amount equal to 10^{-4} mg per tonne or a drop, not in a bucket, but in a good-sized lake. Why evolution should have left us abnormally sensitive to grapefruit, we leave you to imagine.

For a nasty taste, we should mention 'bittering agents', put into dangerous household substances like toilet cleaner to stop children eating them by accident. Notice that this complex organic compound is actually a salt—it has positively charged nitrogen and negatively charged oxygen atoms—and this makes it soluble in water.



flavouring principle of grapefruit



bitrex

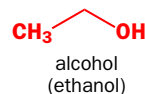
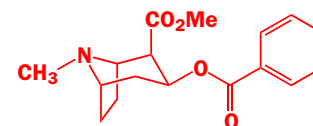
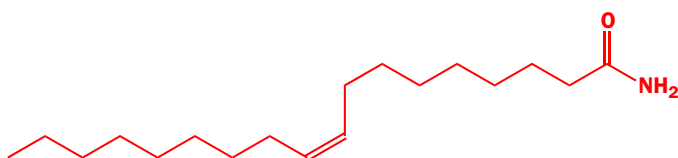
denatonium benzoate

benzyl-diethyl[(2,6-xylyl-carbamoyl)-methyl]ammonium benzoate

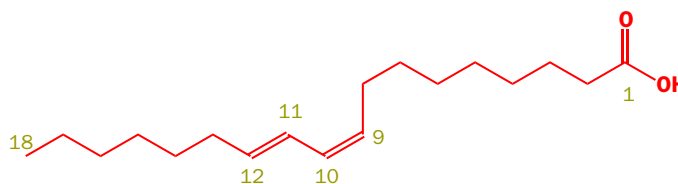


Other organic compounds have strange effects on humans. Various 'drugs' such as alcohol and cocaine are taken in various ways to make people temporarily happy. They have their dangers. Too much alcohol leads to a lot of misery and any cocaine at all may make you a slave for life.

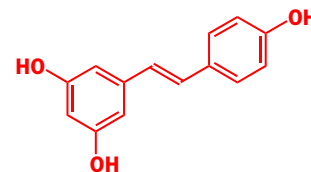
Again, let's not forget other creatures. Cats seem to be able to go to sleep at any time and recently a compound was isolated from the cerebrospinal fluid of cats that makes them, or rats, or humans go off to sleep quickly. It is a surprisingly simple compound.

alcohol
(ethanol)cocaine
- an addictive alkaloida sleep-inducing fatty acid derivative
cis-9,10-octadecenoamide

This compound and disparlure are both derivatives of fatty acids, molecules that feature in many of the food problems people are so interested in now (and rightly so). Fatty acids in the diet are a popular preoccupation and the good and bad qualities of saturates, monounsaturates, and polyunsaturates are continually in the news. This too is organic chemistry. One of the latest molecules to be recognized as an anticancer agent in our diet is CLA (conjugated linoleic acid) in dairy products.

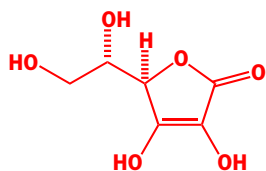
CLA (Conjugated Linoleic Acid)
cis-9-*trans*-11 conjugated linoleic acid
dietary anticancer agent

Another fashionable molecule is resveratrole, which may be responsible for the beneficial effects of red wine in preventing heart disease. It is a quite different organic compound with two benzene rings and you can read about it in Chapter 51.



resveratrole from the skins of grapes is this the compound in red wine which helps to prevent heart disease?

Vitamin C (ascorbic acid) is a vitamin for primates, guinea-pigs, and fruit bats, but other mammals can make it for themselves.



vitamin C (ascorbic acid)



For our third edible molecule we choose vitamin C. This is an essential factor in our diets—indeed, that is why it is called a vitamin. The disease scurvy, a degeneration of soft tissues, particularly in the mouth, from which sailors on long voyages like those of Columbus suffered, results if we don't have vitamin C. It also is a universal antioxidant, scavenging for rogue free radicals and so protecting us against cancer. Some people think an extra large intake protects us against the common cold, but this is not yet proved.

Organic chemistry and industry

Vitamin C is manufactured on a huge scale by Roche, a Swiss company. All over the world there are chemistry-based companies making organic molecules on scales varying from a few kilograms to thousands of tonnes per year. This is good news for students of organic chemistry; there are lots of jobs around and it is an international job market. The scale of some of these operations of organic chemistry is almost incredible. The petrochemicals industry processes (and we use the products!) over 10 million litres of crude oil every day. Much of this is just burnt in vehicles as petrol or diesel, but some of it is purified or converted into organic compounds for use in the rest of the chemical industry. Multinational companies with thousands of employees such as Esso (Exxon) and Shell dominate this sector.

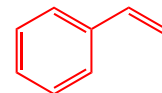
Some simple compounds are made both from oil and from plants. The ethanol used as a starting material to make other compounds in industry is largely made by the catalytic hydration of ethylene from oil. But ethanol is also used as a fuel, particularly in Brazil where it is made by fermentation of sugar cane wastes. This fuel uses a waste product, saves on oil imports, and has improved the quality of the air in the very large Brazilian cities, Rio de Janeiro and São Paulo.

Plastics and polymers take much of the production of the petrochemical industry in the form of monomers such as styrene, acrylates, and vinyl chloride. The products of this enormous industry are everything made of plastic including solid plastics for household goods and furniture, fibres for clothes (24 million tonnes per annum), elastic polymers for car tyres, light bubble-filled polymers for packing, and so on. Companies such as BASF, Dupont, Amoco, Monsanto, Laporte, Hoechst, and ICI are leaders here. Worldwide polymer production approaches 100 million tonnes per annum and PVC manufacture alone employs over 50 000 people to make over 20 million tonnes per annum.

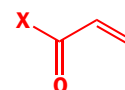
The washing-up bowl is plastic too but the detergent you put in it belongs to another branch of the chemical industry—companies like Unilever (Britain) or Procter and Gamble (USA) which produce soap, detergent, cleaners, bleaches, polishes, and all the many essentials for the modern home. These products may be lemon and lavender scented but they too mostly come from the oil industry. Nowadays, most products of this kind tell us, after a fashion, what is in them. Try this example—a well known brand of shaving gel along with the list of contents on the container:

Does any of this make any sense?

monomers for polymer manufacture



styrene



acrylates



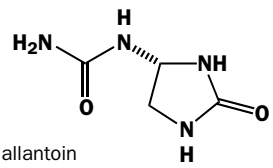
vinyl chloride



Ingredients

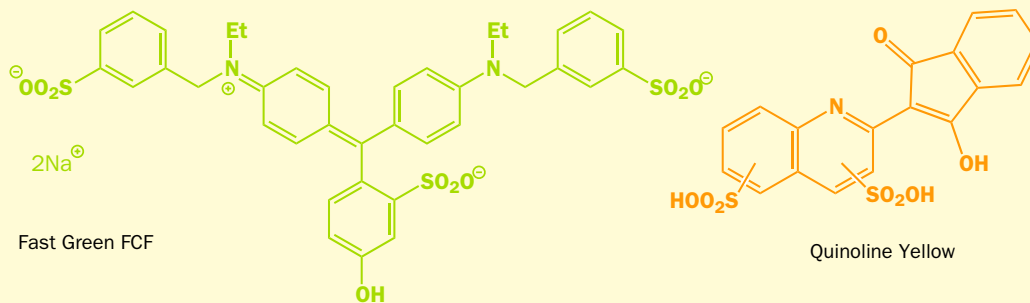
aqua, palmitic acid, triethanolamine, glycereth-26, isopentane, oleamide-DEA, oleth-2, stearic acid, isobutane, PEG-14M, parfum, allantoin, hydroxyethyl-cellulose, hydroxypropyl-cellulose, PEG-150 distearate, CI 42053, CI 47005

It doesn't all make sense to us, but here is a possible interpretation. We certainly hope the book will set you on the path of understanding the sense (and the nonsense!) of this sort of thing.

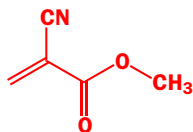
Ingredient	Chemical meaning	Purpose
aqua	water	solvent
palmitic acid	$\text{CH}_3(\text{CH}_2)_{14}\text{CO}_2\text{H}$	acid, emulsifier
triethanolamine	$\text{N}(\text{CH}_2\text{CH}_2\text{OH})_3$	base
glycereth-26	glyceryl $(\text{OCH}_2\text{CH}_2)_{26}\text{OH}$	surfactant
isopentane	$(\text{CH}_3)_2\text{CHCH}_2\text{CH}_3$	propellant
oleamide-DEA	$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{CONEt}_2$	
oleth-2	Oleyl $(\text{OCH}_2\text{CH}_2)_2\text{OH}$	surfactant
stearic acid	$\text{CH}_3(\text{CH}_2)_{16}\text{CO}_2\text{H}$	acid, emulsifier
isobutane	$(\text{CH}_3)_2\text{CHCH}_3$	propellant
PEG-14M	polyoxyethylene glycol ester	surfactant
parfum	perfume	
allantoin	 allantoin	promotes healing in case you cut yourself while shaving
hydroxyethyl-cellulose	cellulose fibre from wood pulp with $-\text{OCH}_2\text{CH}_2\text{OH}$ groups added	gives body
hydroxypropyl-cellulose	cellulose fibre from wood pulp with $-\text{OCH}_2\text{CH}(\text{OH})\text{CH}_3$ groups added	gives body
PEG-150 distearate	polyoxyethylene glycol diester	surfactant
CI 42053	Fast Green FCF (see box)	green dye
CI 47005	Quinoline Yellow (see box)	yellow dye

The structures of two dyes

Fast Green FCF and Quinoline Yellow are colours permitted to be used in foods and cosmetics and have the structures shown here. Quinoline Yellow is a mixture of isomeric sulfonic acids in the two rings shown.

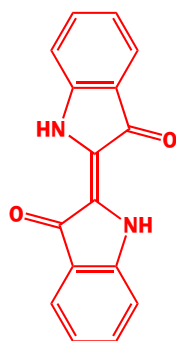


The particular acids, bases, surfactants, and so on are chosen to blend together in a smooth emulsion when propelled from the can. The result should feel, smell, and look attractive and a greenish colour is considered clean and antiseptic by the customer. What the can actually says is this: 'Superior lubricants within the gel prepare the skin for an exceptionally close, comfortable and effective shave. It contains added moisturisers to help protect the skin from razor burn. Lightly fragranced.'

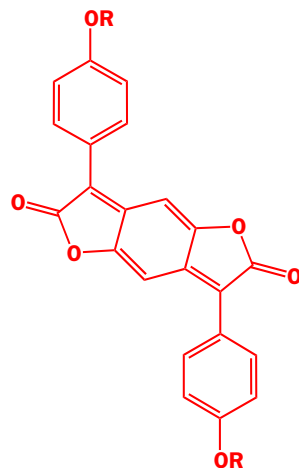


Superglue bonds things together when this small molecule joins up with hundreds of its fellows in a polymerization reaction

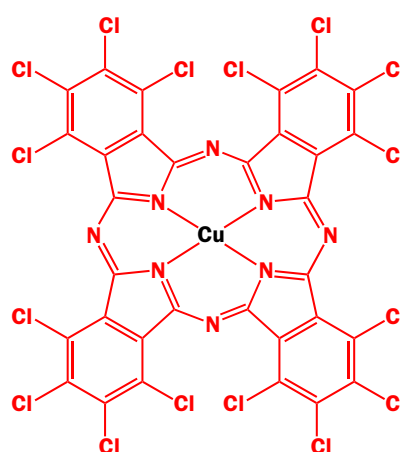
■ The formation of polymers is discussed in Chapter 52.



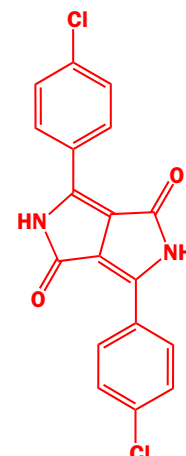
indigo
the colour of blue jeans



ICI's Dispersol
benzodifuranone
red dyes for polyester



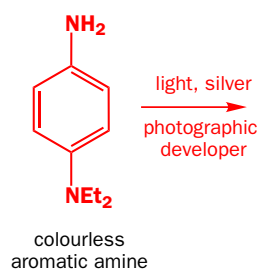
ICI's Monastral Green GNA
a good green for plastic objects



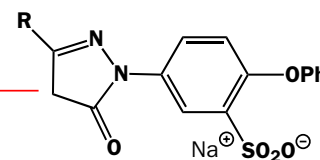
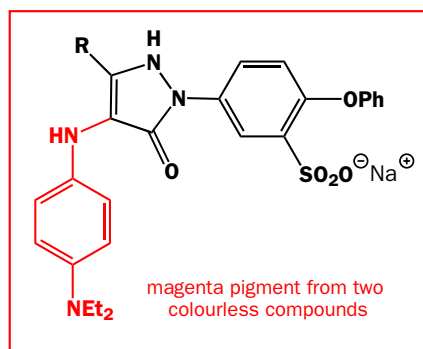
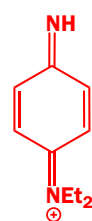
Ciba Geigy's Pigment Red 254
an intense DPP pigment

■ You can read in Chapter 7 why some compounds are coloured and others not.

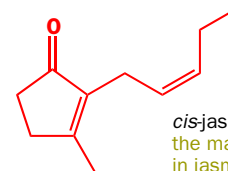
Colour photography starts with inorganic silver halides but they are carried on organic gelatin. Light acts on silver halides to give silver atoms that form the photographic image, but only in black and white. The colour in films like Kodachrome then comes from the coupling of two colourless organic compounds. One, usually an aromatic amine, is oxidized and couples with the other to give a coloured compound.



light, silver
photographic developer



That brings us to flavours and fragrances. Companies like International Flavours and Fragrances (USA) or Givaudan–Roure (Swiss) produce very big ranges of fine chemicals for the perfume, cosmetic, and food industries. Many of these will come from oil but others come from plant sources. A typical perfume will contain 5–10% fragrances in an ethanol/water (about 90:10) mixture. So the perfumery industry needs a very large amount of ethanol and, you might think, not much perfumery material. In fact, important fragrances like jasmine are produced on a >10 000 tonnes per annum scale. The cost of a pure perfume ingredient like *cis*-jasmone, the main ingredient of jasmine, may be several hundred pounds, dollars, or euros per gram.



cis-jasmone
the main compound
in jasmine perfume

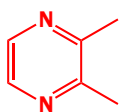


The world of perfumery

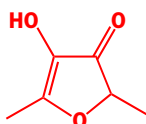
Perfume chemists use extraordinary language to describe their achievements: 'Paco Rabanne pour homme was created to reproduce the effect of a summer walk in the open air among the hills of Provence: the smell of herbs, rosemary and thyme, and sparkling freshness with cool sea breezes mingling with warm soft Alpine air. To

achieve the required effect, the perfumer blended herbaceous oils with woody accords and the synthetic aroma chemical dimethylheptanol which has a penetrating but indefinable freshness associated with open air or freshly washed linen'. (J. Ayres, *Chemistry and Industry*, 1988, 579)

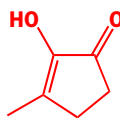
Chemists produce synthetic flavourings such as 'smoky bacon' and even 'chocolate'. Meaty flavours come from simple heterocycles such as alkyl pyrazines (present in coffee as well as roast meat) and furonol, originally found in pineapples. Compounds such as corylone and maltol give caramel and meaty flavours. Mixtures of these and other synthetic compounds can be 'tuned' to taste like many roasted foods from fresh bread to coffee and barbecued meat.



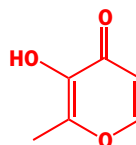
an alkyl pyrazine
from coffee and
roast meat



furonol
roast meat



corylone
caramel
roasted taste

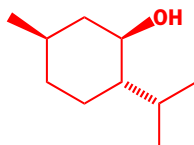
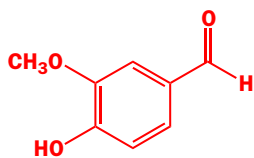


maltol
E-636 for cakes
and biscuits



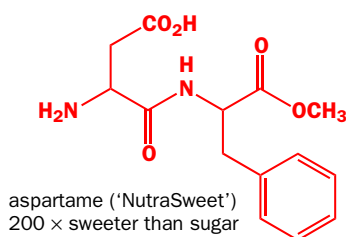
Some flavouring compounds are also perfumes and may also be used as an intermediate in making other compounds. Two such large-scale flavouring compounds are vanillin (vanilla flavour as in ice cream) and menthol (mint flavour) both manufactured on a large scale and with many uses.

vanillin
found in vanilla pods;
manufactured
on a large scale



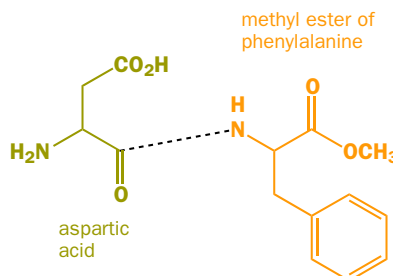
menthol
extracted from mint;
25% of the world's supply
manufactured

Food chemistry includes much larger-scale items than flavours. Sweeteners such as sugar itself are isolated from plants on an enormous scale. Sugar's structure appeared a few pages back. Other sweeteners such as saccharin (discovered in 1879!) and aspartame (1965) are made on a sizeable scale. Aspartame is a compound of two of the natural amino acids present in all living things and is made by Monsanto on a large scale (over 10 000 tonnes per annum).



aspartame ('NutraSweet')
200 × sweeter than sugar

is made from
two amino acids –



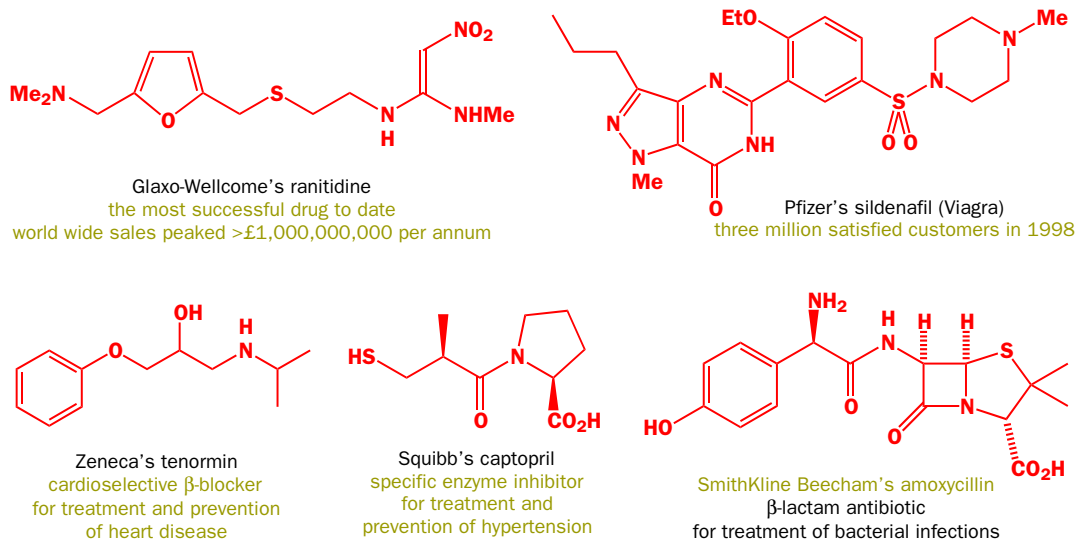
aspartic
acid

methyl ester of
phenylalanine

The pharmaceutical businesses produce drugs and medicinal products of many kinds. One of the great revolutions of modern life has been the expectation that humans will survive diseases because of a treatment designed to deal specifically with that disease. The most successful drug ever is ranitidine (Zantac), the Glaxo–Wellcome ulcer treatment, and one of the fastest-growing is Pfizer's sildenafil (Viagra). 'Success' refers both to human health and to profit!

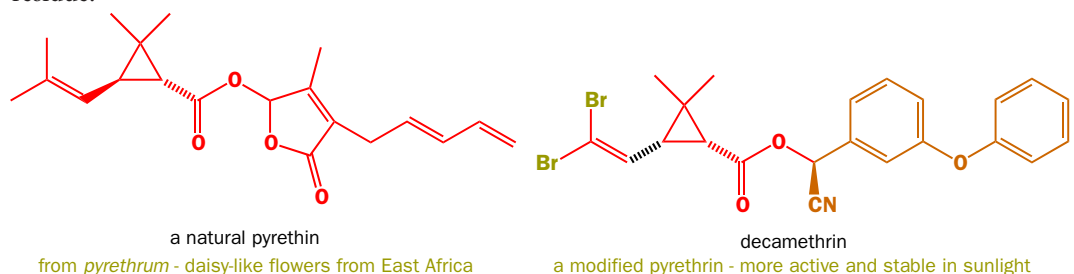
You will know people (probably older men) who are 'on β -blockers'. These are compounds designed to block the effects of adrenaline (epinephrine) on the heart and hence to prevent heart disease. One of the best is Zeneca's tenormin. Preventing high blood pressure also prevents heart disease and certain specific enzyme inhibitors (called 'ACE-inhibitors') such as Squibb's captopril work in this way. These are drugs that imitate substances naturally present in the body.

The treatment of infectious diseases relies on antibiotics such as the penicillins to prevent bacteria from multiplying. One of the most successful of these is Smith Kline Beecham's amoxicillin. The four-membered ring at the heart of the molecule is the ' β -lactam'.



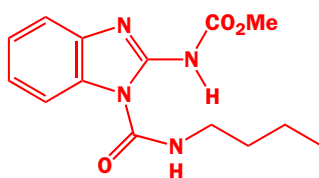
We cannot maintain our present high density of population in the developed world, nor deal with malnutrition in the developing world unless we preserve our food supply from attacks by insects and fungi and from competition by weeds. The world market for agrochemicals is over £10 000 000 000 per annum divided roughly equally between herbicides, fungicides, and insecticides.

At the moment we hold our own by the use of agrochemicals: companies such as Rhône-Poulenc, Zeneca, BASF, Schering–Plough, and Dow produce compounds of remarkable and specific activity. The most famous modern insecticides are modelled on the natural pyrethrins, stabilized against degradation by sunlight by chemical modification (see coloured portions of decamethrin) and targeted to specific insects on specific crops in cooperation with biologists. Decamethrin has a safety factor of >10#000 for mustard beetles over mammals, can be applied at only 10 grams per hectare (about one level tablespoon per football pitch), and leaves no significant environmental residue.

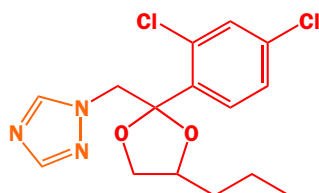


As you learn more chemistry, you will appreciate how remarkable it is that Nature should produce three-membered rings and that chemists should use them in bulk compounds to be sprayed on crops in fields. Even more remarkable in some ways is the new generation of fungicides based on a five-membered ring containing three nitrogen atoms—the triazole ring. These compounds inhibit an enzyme present in fungi but not in plants or animals.

One fungus (potato blight) caused the Irish potato famine of the nineteenth century and the various blights, blotches, rots, rusts, smuts, and mildews can overwhelm any crop in a short time. Especially now that so much is grown in Western Europe in winter, fungal diseases are a real threat.



benomyl
a fungicide which controls
many plant diseases



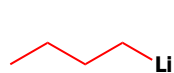
propiconazole
a triazole fungicide

You will have noticed that some of these companies have fingers in many pies. These companies, or groups as they should be called, are the real giants of organic chemistry. Rhône-Poulenc, the French group which includes pharmaceuticals (Rhône-Poulenc-Rorer), animal health, agrochemicals, chemicals, fibres, and polymers, had sales of about 90 billion French Francs in 1996. Dow, the US group which includes chemicals, plastics, hydrocarbons, and other bulk chemicals, had sales of about 20 billion US dollars in 1996.

Organic chemistry and the periodic table

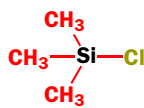
All the compounds we have shown you are built up on hydrocarbon (carbon and hydrogen) skeletons. Most have oxygen and/or nitrogen as well; some have sulfur and some phosphorus. These are the main elements of organic chemistry but another way the science has developed is an exploration of (some would say take-over bid for) the rest of the periodic table. Some of our compounds also had fluorine, sodium, copper, chlorine, and bromine. The organic chemistry of silicon, boron, lithium, the halogens (F, Cl, Br, and I), tin, copper, and palladium has been particularly well studied and these elements commonly form part of organic reagents used in the laboratory. They will crop up throughout this book. These 'lesser' elements appear in many important reagents, which are used in organic chemical laboratories all over the world. Butyllithium, trimethylsilyl chloride, tributyltin hydride, and dimethylcopper lithium are good examples.

The halogens also appear in many life-saving drugs. The recently discovered antiviral compounds, such as fialuridine (which contains both F and I, as well as N and O), are essential for the fight against HIV and AIDS. They are modelled on natural compounds from nucleic acids. The naturally occurring cytotoxic (antitumour) agent halomon, extracted from red algae, contains Br and Cl.



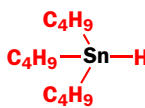
BuLi

butyllithium



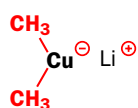
Me₃SiCl

trimethylsilyl chloride



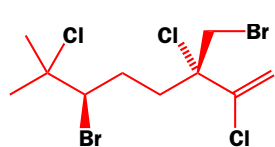
Bu₃SnH

tributyltin hydride



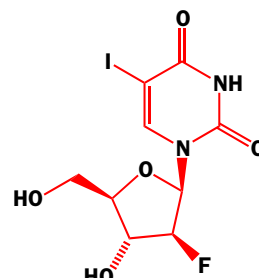
Me₂CuLi

dimethylcopper lithium



halomon

naturally occurring
antitumour agent



fialuridine

antiviral compound

Another definition of organic chemistry would use the periodic table. The key elements in organic chemistry are of course C, H, N, and O, but also important are the halogens (F, Cl, Br, I),

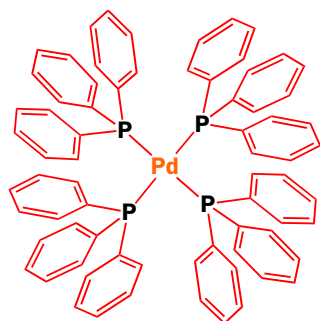
p-block elements such as Si, S, and P, metals such as Li, Pd, Cu, and Hg, and many more. We can construct an organic chemist's periodic table with the most important elements emphasized:

▶ You will certainly know something about the periodic table from your previous studies of inorganic chemistry. A basic knowledge of the groups, which elements are metals, and roughly where the elements in our table appear will be helpful to you.

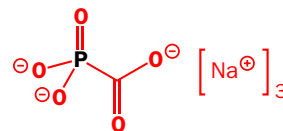
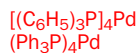
the organic chemist's periodic table

1												13	14	15	16	17	
H												B	C	N	O	F	
Li													Al	Si	P	S	Cl
Na	Mg	3	4	5	6	7	8	9	10	11	12				Se	Br	
K			Ti		Cr					Cu	Zn						
										Pd			Sn			I	
										Os			Hg				

So where does inorganic chemistry end and organic chemistry begin? Would you say that the antiviral compound foscarnet was organic? It is a compound of carbon with the formula CPO_5Na_3 but it has no C–H bonds. And what about the important reagent tetrakis triphenyl phosphine palladium? It has lots of hydrocarbon—twelve benzene rings in fact—but the benzene rings are all joined to phosphorus atoms that are arranged in a square around the central palladium atom, so the molecule is held together by C–P and P–Pd bonds, not by a hydrocarbon skeleton. Although it has the very organic-looking formula $\text{C}_{72}\text{H}_{60}\text{P}_4\text{Pd}$, many people would say it is inorganic. But is it?



tetrakis
triphenylphosphine
palladium



foscarnet – antiviral agent

The answer is that we don't know and we don't care. It is important these days to realize that strict boundaries between traditional disciplines are undesirable and meaningless. Chemistry continues across the old boundaries between organic chemistry and inorganic chemistry on the one side and organic chemistry and biochemistry on the other. Be glad that the boundaries are indistinct as that means the chemistry is all the richer. This lovely molecule $(\text{Ph}_3\text{P})_4\text{Pd}$ belongs to *chemistry*.

Organic chemistry and this book

We have told you about organic chemistry's history, the types of compounds it concerns itself with, the things it makes, and the elements it uses. Organic chemistry today is the study of the structure and reactions of compounds in nature of compounds, in the fossil reserves such as coal and oil, and of those compounds that can be made from them. These compounds will usually be constructed with a hydrocarbon framework but will also often have atoms such as O, N, S, P, Si, B, halogens, and metals attached to them. Organic chemistry is used in the making of plastics, paints, dyestuffs, clothes, foodstuffs, human and veterinary medicines, agrochemicals, and many other things. Now we can summarize all of these in a different way.

- The main components of organic chemistry as a discipline are these
 - **Structure determination**—how to find out the structures of new compounds even if they are available only in invisibly small amounts
 - **Theoretical organic chemistry**—how to understand those structures in terms of atoms and the electrons that bind them together
 - **Reaction mechanisms**—how to find out how these molecules react with each other and how to predict their reactions
 - **Synthesis**—how to design new molecules—and then make them
 - **Biological chemistry**—how to find out what Nature does and how the structures of biologically active molecules are related to what they do

This book is about all these things. It tells you about the structures of organic molecules and the reasons behind them. It tells you about the shapes of those molecules and how the shape relates to their function, especially in the context of biology. It tells you how those structures and shapes are discovered. It tells you about the reactions the molecules undergo and, more importantly, how and why they behave in the way they do. It tells you about nature and about industry. It tells you how molecules are made and how you too can think about making molecules.

We said 'it tells' in that last paragraph. Maybe we should have said 'we tell' because we want to speak to you through our words so that you can see how we think about organic chemistry and to encourage you to develop your own ideas. We expect you to notice that four people have written this book and that they don't all think or write in the same way. That is as it should be. Organic chemistry is too big and important a subject to be restricted by dogmatic rules. Different chemists think in different ways about many aspects of organic chemistry and in many cases it is not yet possible to be sure who is right.

We may refer to the history of chemistry from time to time but we are usually going to tell you about organic chemistry as it is now. We will develop the ideas slowly, from simple and fundamental ones using small molecules to complex ideas and large molecules. We promise one thing. We are not going to pull the wool over your eyes by making things artificially simple and avoiding the awkward questions. We aim to be honest and share both our delight in good complete explanations and our puzzlement at inadequate ones. So how are we going to do this? The book starts with a series of chapters on the structures and reactions of simple molecules. You will meet the way structures are determined and the theory that explains those structures. It is vital that you realize that theory is used to explain what is known by experiment and only then to predict what is unknown. You will meet mechanisms—the dynamic language used by chemists to talk about reactions—and of course some reactions.

The book starts with an introductory section of four chapters:

- 1 What is organic chemistry?
- 2 Organic structures
- 3 Determining organic structures
- 4 Structure of molecules

In Chapter 2 you will look at the way in which we are going to present diagrams of molecules on the printed page. Organic chemistry is a visual, three-dimensional subject and the way you draw molecules shows how you think about them. We want you too to draw molecules in the best way available now. It is just as easy to draw them well as to draw them in an old-fashioned inaccurate way.

Then in Chapter 3, before we come to the theory of molecular structure, we shall introduce you to the experimental techniques of finding out about molecular structure. This means studying the interactions between molecules and radiation by **spectroscopy**—using the whole electromagnetic spectrum from X-rays to radio waves. Only then, in Chapter 4, will we go behind the scenes and look at the theories of why atoms combine in the ways they do. Experiment comes before theory. The spectroscopic methods of Chapter 3 will still be telling the truth in a hundred years time, but the theories of Chapter 4 will look quite dated by then.

We could have titled those three chapters:

- 2 What shapes do organic molecules have?
- 3 How do we know they have those shapes?
- 4 Why do they have those shapes?

You need to have a grasp of the answers to these three questions before you start the study of organic reactions. That is exactly what happens next. We introduce organic reaction mechanisms in Chapter 5. Any kind of chemistry studies **reactions**—the transformations of molecules into other molecules. The dynamic process by which this happens is called **mechanism** and is the language of organic chemistry. We want you to start learning and using this language straight away so in Chapter 6 we apply it to one important class of reaction. This section is:

- 5 Organic reactions
- 6 Nucleophilic addition to the carbonyl group

Chapter 6 reveals how we are going to subdivide organic chemistry. We shall use a mechanistic classification rather than a structural classification and explain one type of reaction rather than one type of compound in each chapter. In the rest of the book most of the chapters describe types of reaction in a mechanistic way. Here is a selection.

- 9 Using organometallic reagents to make C–C bonds
- 17 Nucleophilic substitution at saturated carbon
- 20 Electrophilic addition to alkenes
- 22 Electrophilic aromatic substitution
- 29 Conjugate Michael addition of enolates
- 39 Radicals

Interspersed with these chapters are others on physical aspects, organic synthesis, stereochemistry, structural determination, and biological chemistry as all these topics are important parts of organic chemistry.

‘Connections’ section

Chemistry is not a linear subject! It is impossible simply to start at the beginning and work through to the end, introducing one new topic at a time, because chemistry is a network of interconnecting ideas. But, unfortunately, a book is, by nature, a beginning-to-end sort of thing. We have arranged the chapters in a progression of difficulty as far as is possible, but to help you find your way around

we have included at the beginning of each chapter a ‘Connections’ section. This tells you three things divided among three columns:

- what you should be familiar with before reading the chapter—in other words, which previous chapters relate directly to the material within the chapter (‘Building on’ column)
- a guide to what you will find within the chapter (‘Arriving at’ column)
- which chapters later in the book fill out and expand the material in the chapter (‘Looking forward to’ column)

The first time you read a chapter, you should really make sure you have read any chapter mentioned under (a). When you become more familiar with the book you will find that the links highlighted in (a) and (c) will help you see how chemistry interconnects with itself.

Boxes and margin notes

The other things you should look out for are the margin notes and boxes. There are four sorts, and they have all appeared at least once in this chapter.

● Heading

The most important looks like this. Anything in this sort of box is very important—a key concept or a summary. It’s the sort of thing you would do well to hold in your mind as you read or to note down as you learn.

Heading

Boxes like this will contain additional examples, amusing background information, and similar interesting, but inessential, material. The first time you read a chapter,

you might want to miss out this sort of box, and only read them later on to flesh out some of the main themes of the chapter.



Sometimes the main text of the book needs clarification or expansion, and this sort of margin note will contain such little extras to help you understand difficult points. It will also remind you of things from elsewhere in the book that illuminate what is being discussed. You would do well to read these notes the first time you read the chapter, though later, as the ideas become more familiar, you might choose to skip them.

End-of-chapter problems

You can’t learn organic chemistry—there’s just too much of it. You can learn trivial things like the names of compounds but that doesn’t help you understand the principles behind the subject. You have to understand the principles because the only way to tackle organic chemistry is to learn to work it out. That is why we have provided end-of-chapter problems. They are to help you discover if you have understood the material presented in each chapter. In general, the 10–15 problems at the end of each chapter start easy and get more difficult. They come in two sorts. The first, generally shorter and easier, allow you to revise the material in that chapter. The second asks you to extend your understanding of the material into areas not covered by the chapter. In the later chapters this second sort will probably revise material from previous chapters.

If a chapter is about a certain type of organic reaction, say elimination reactions (Chapter 19), the chapter itself will describe the various ways (‘mechanisms’) by which the reaction can occur and it will give definitive examples of each mechanism. In Chapter 19 there are three mechanisms and about 65 examples altogether. You might think that this is rather a lot but there are in fact millions of examples known of these three mechanisms and Chapter 19 only scrapes the surface. Even if you totally comprehended the chapter at a first reading, you could not be confident of your understanding about elimination reactions. There are 13 end-of-chapter problems for Chapter 19. The first three ask you to interpret reactions given but not explained in the chapter. This checks that you can use the ideas in familiar situations. The next few problems develop specific ideas from the chapter concerned with why one compound does one reaction while a similar one behaves quite differently.



This sort of margin note will mainly contain cross-references to other parts of the book as a further aid to navigation. You will find an example on p. 000.

Finally there are some more challenging problems asking you to extend the ideas to unfamiliar molecules.

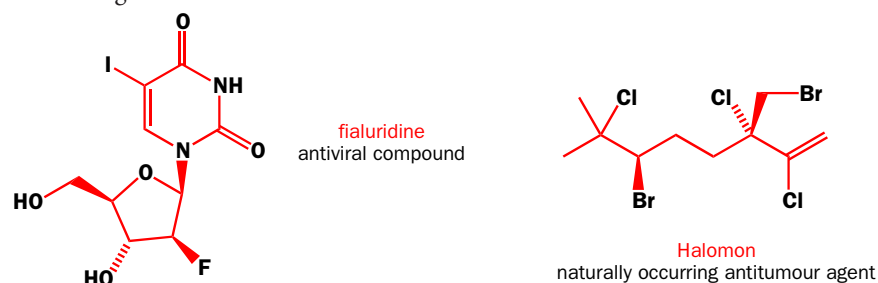
The end-of-chapter problems should set you on your way but they are not the end of the journey to understanding. You are probably reading this text as part of a university course and you should find out what kind of examination problems your university uses and practise them too. Your tutor will be able to advise you on suitable problems for each stage of your development.

The solutions manual

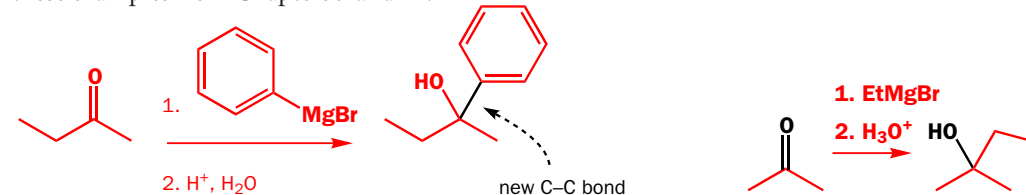
The problems would be of little use to you if you could not check your answers. For the maximum benefit, you need to tackle some or all of the problems as soon as you have finished each chapter without looking at the answers. Then you need to compare your suggestions with ours. You can do this with the solutions manual (*Organic Chemistry: Solutions Manual*, Oxford University Press, 2000). Each problem is discussed in some detail. The purpose of the problem is first stated or explained. Then, if the problem is a simple one, the answer is given. If the problem is more complex, a discussion of possible answers follows with some comments on the value of each. There may be a reference to the source of the problem so that you can read further if you wish.

Colour

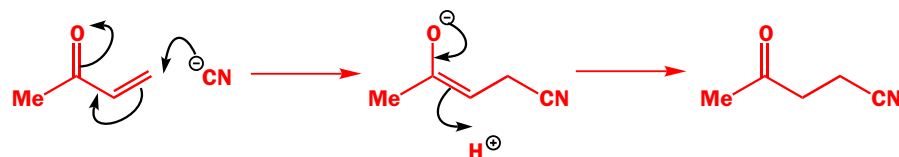
You will already have noticed something unusual about this book: almost all of the chemical structures are shown in red. This is quite intentional: emphatic red underlines the message that structures are more important than words in organic chemistry. But sometimes small parts of structures are in other colours: here are two examples from p. 000, where we were talking about organic compounds containing elements other than C and H.



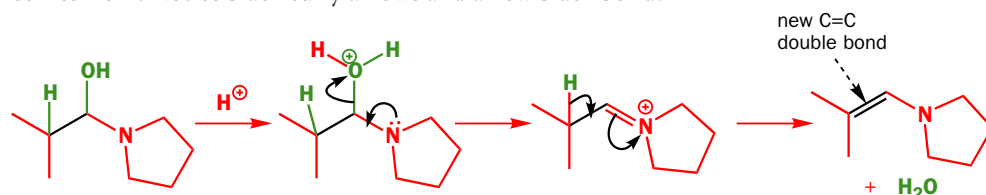
Why are the atom labels black? Because we wanted them to stand out from the rest of the molecule. In general you will see black used to highlight important details of a molecule—they may be the groups taking part in a reaction, or something that has changed as a result of the reaction, as in these examples from Chapters 9 and 12.



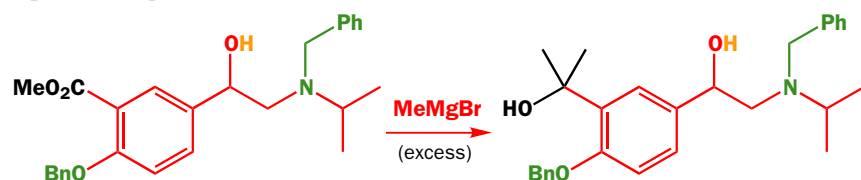
We shall often use black to emphasize ‘curly arrows’, devices that show the movement of electrons, and whose use you will learn about in Chapter 5. Here is an example from Chapter 10: notice black also helps the ‘+’ and ‘−’ charges to stand out.



Occasionally, we shall use other colours such as green, or even orange, yellow, or brown, to highlight points of secondary importance. This example is part of a reaction taken from Chapter 19: we want to show that a molecule of water (H_2O) is formed. The green atoms show where the water comes from. Notice black curly arrows and a new black bond.



Other colours come in when things get more complicated—in this Chapter 24 example, we want to show a reaction happening at the black group in the presence of the yellow H (which, as you will see in Chapter 9, also reacts) and also in the presence of the green ‘protecting’ groups, one of the topics of Chapter 24.



And, in Chapter 16, colour helps us highlight the difference between carbon atoms carrying four different groups and those with only three different groups. The message is: if you see something in a colour other than red, take special note—the colour is there for a reason.



That is all we shall say in the way of introduction. On the next page the real chemistry starts, and our intention is to help you to learn real chemistry, and to enjoy it.