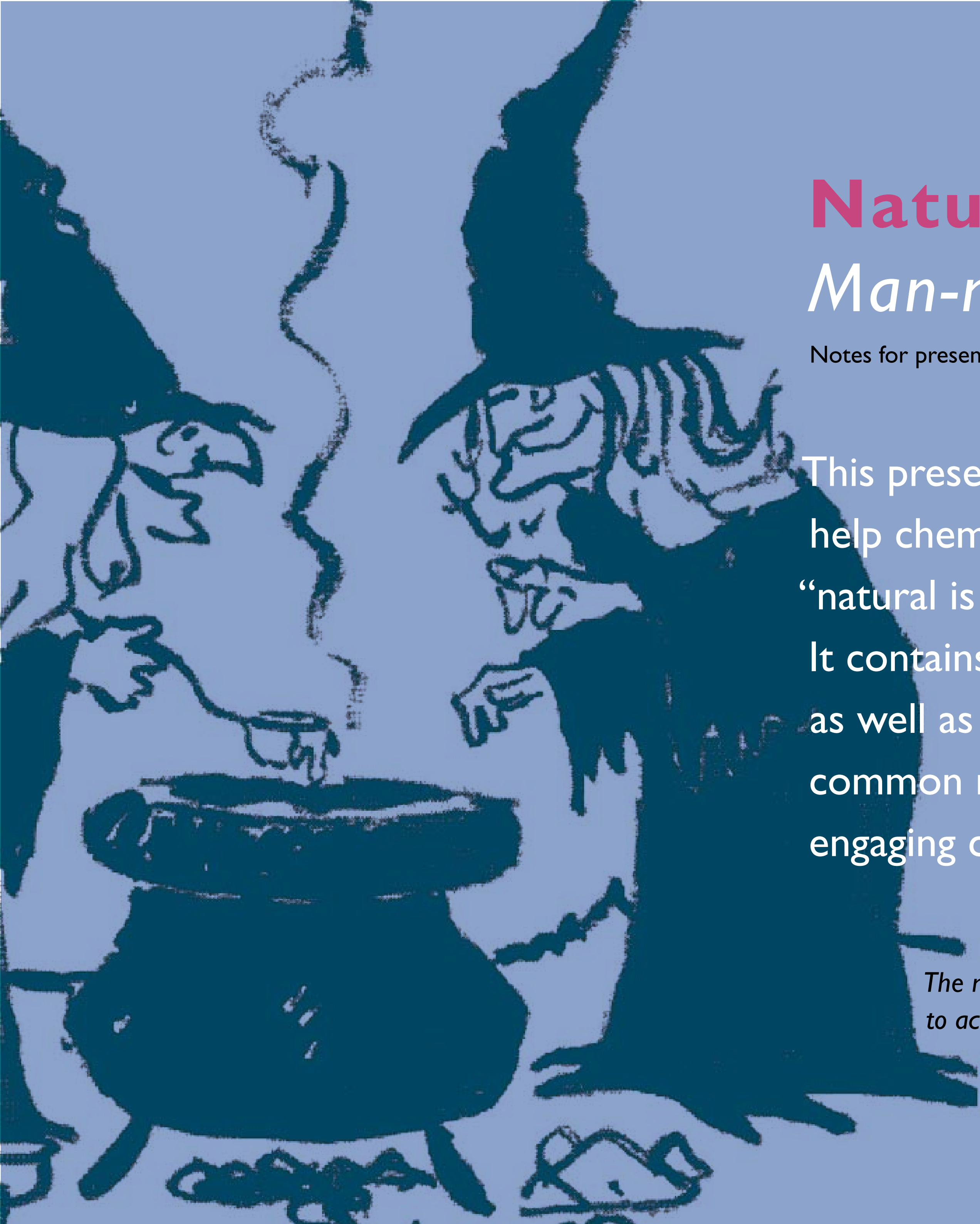
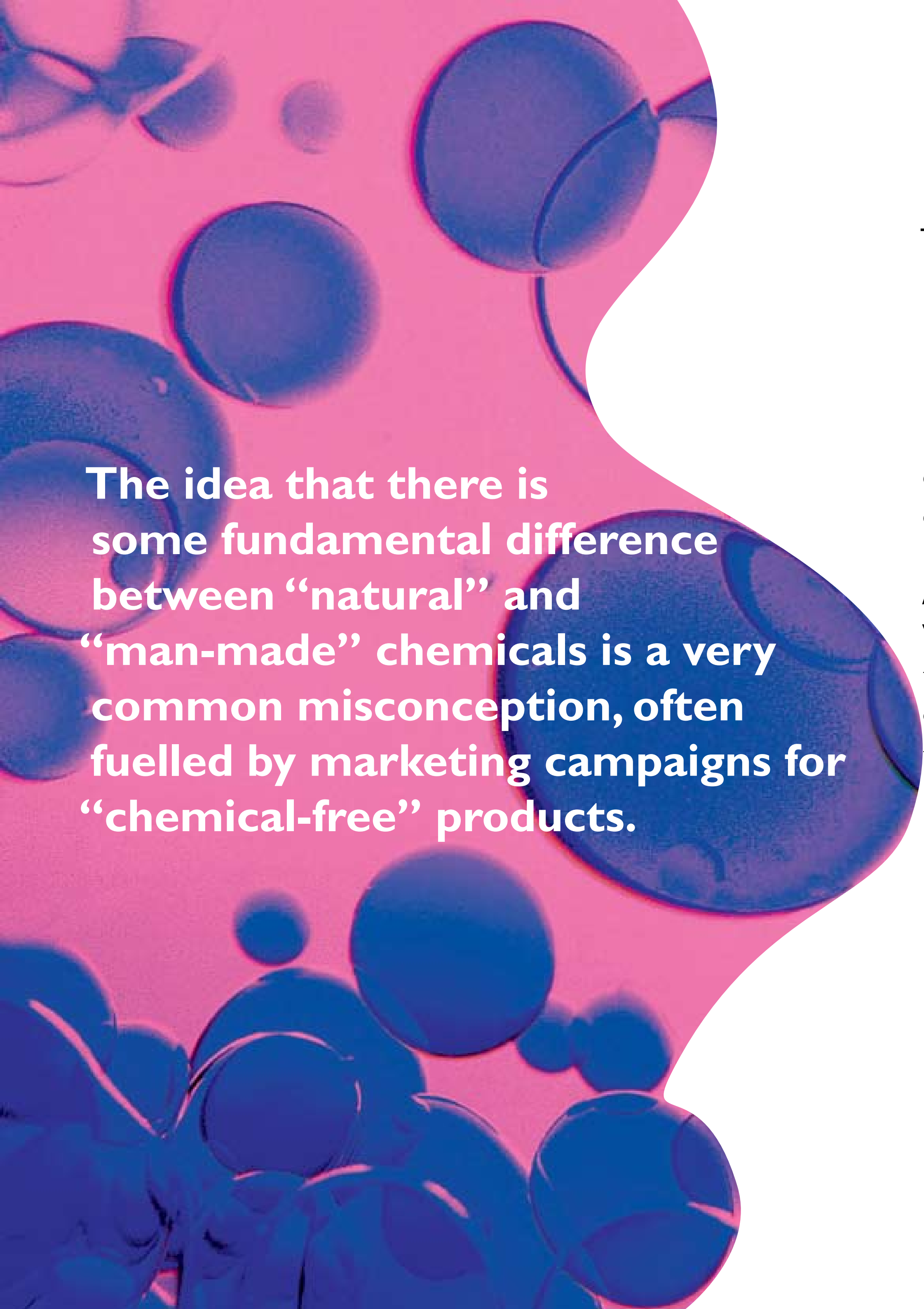


Natural *or* *Man-made chemicals?*

Notes for presenters

This presentation is intended as a tool to help chemistry teachers dispel the myth, “natural is good; man-made is bad”. It contains examples of useful chemicals as well as dangerous ones, highlights some common misconceptions and provides an engaging context for discussion.

The notes that follow are intended as background information to accompany the PowerPoint® presentation, not as a script.



The idea that there is some fundamental difference between "natural" and "man-made" chemicals is a very common misconception, often fuelled by marketing campaigns for "chemical-free" products.

It is important that students understand that this is a fallacy. There is no difference whatsoever between a "natural" chemical, such as Vitamin C (ascorbic acid) from a fruit, and a synthetic sample of the same material.

It is also not the case that "natural" chemicals, *ie* those produced by plants and animals, are always "good" whilst "man-made" chemicals are always "bad". The presentation offers several examples to support this argument.

Many natural organisms can kill you.
What is a poison? Paracelsus made the point in the 16th Century that the dose is the important factor. Some years ago a death occurred due to the overconsumption of carrots. The victim turned orange and died.

The seven most deadly chemical compounds

The LD_{50} values shown in the table refer to the lethal dose for 50% of animals exposed to the chemical concerned. This value is established by carrying out tests on cats or rats/mice.

The seven most deadly chemical compounds

	LD_{50}/mg/kg
Botulinum toxin A	3×10^{-8}
Tetanus toxin A	5×10^{-6}
Diphtheria toxin	3×10^{-4}
Dioxin*	3×10^{-2}
Muscarine	2×10^{-1}
Bufotoxin	4×10^{-1}
Sarin*	4×10^{-1}

**Synthetic*

Dioxin is the most toxic man-made compound but it is still a million times less toxic than botulinum. The name botulinum comes from the Latin word for sausage. The compound was given this name because it was first identified in sausage meat.

One teaspoon of botulinum could kill a quarter of the world's population, yet some people choose to inject it in the form of Botox®. This is a popular non-surgical method of temporarily reducing or eliminating frown lines, forehead creases, crows' feet near the eyes and thick bands in the neck. The toxin blocks nerve impulses and temporarily paralyzes the muscles that cause wrinkles. This gives the skin a smoother appearance.

Nature is the world's best chemist: five of the seven most deadly known compounds occur in nature. Many naturally occurring compounds have very complicated structures that present great challenges to chemists wishing to determine their structures or replicate them.

Dioxin

Compared to many natural compounds, dioxin has a fairly simple structure. It gained notoriety in 1976, when an explosion occurred in a TCP (2,4,5-trichlorophenol) reactor at a chemical plant about 20km north of Milan, Italy. A mixture of chemicals, including dioxin, was released into the atmosphere and contaminated a densely populated area near the plant. This event is known as the Seveso disaster, named after the Seveso municipality, which was the most affected area. Chloracne, a severe skin disorder usually associated with dioxin, broke out amongst the people exposed to the cloud of chemicals released by the explosion and animals such as rabbits began to die *en masse*. Studies on the human population since the event have linked dioxin exposure to cancer and birth defects.

Agent Orange, the chemical weapon used by the USA in the Vietnam War, contained dioxin.

Viktor Yushschenko

Victor Yushschenko was elected President of the Ukraine in December 2004. He was the main opposition candidate in the 2004 election, supported by the "Syla Narodu" ("Power to the People") electoral coalition.

The initial vote was held on 31st October 2004 but Yushchenko and his main rival, the Prime Minister Viktor Yanukovyc, got such similar proportions of the vote that no clear winner could be named. On 21st November 2004, a second round of voting took place. Yanukovych was announced the winner by a margin of 3%. However, this was so inconsistent with the results of exit polls, and observers reported so many irregularities in the voting procedure, that Yushchenko refused to accept the result. Thirteen days of popular protests led to another run-off election, which Yushchenko won.

The campaign leading up to the election in October was hard-fought and bitter. Yushchenko became seriously ill in early September 2004 and accused the government of poisoning him when Austrian doctors announced his illness to be due to a viral infection and "chemical substances which are not normally found in food products."

Tests carried out by several doctors outside the Ukraine showed that Yushchenko was a victim of dioxin poisoning.

The high levels of dioxin in his blood produced disfiguring cysts on his face that have left him looking far older than he is. He also suffered from ulcers in his stomach and intestines, as well as problems with his liver and spleen.

Muscarine

Muscarine is the lethal ingredient in deadly mushrooms such as *fly agaric* or *fly fungus*.

Muscarine poisoning results in sweating and brings tears to the eyes within half an hour of ingestion. Large doses can lead to nausea and diarrhoea, blurred vision and breathing difficulty but these symptoms do not generally last longer than two hours.

Muscarine can kill but deaths are rare.

Bufotoxin

Bufatoxin is the active component of the venom of the common European toad, *bufo vulgaris*. It causes the heart to pump harder and the blood vessels to constrict.

Toads secrete venom in their skin when they feel threatened. Each species of toad has a different sort of venom containing a different mixture of active compounds.

The giant toad (*bufo marinus*) belongs to the same genus as the common European toad and its venom has some similar properties. *Bufo marinus* was introduced to Australia in the 1930s by sugar cane farmers who hoped it would rid their crops of an infestation of grayback beetles. The toads did not solve the beetle problem and the farmers eventually used the pesticide lindane instead, but the toad population continued to grow. Local people discovered that licking the toads had a hallucinogenic effect and some people began to dry toad skins and smoke them. Unfortunately, there were also some unpleasant side effects: delirium, high blood pressure, increased heart rate and even seizures. These effects were caused by several components of the toad venom, including:

- **bufagin**, a heart stimulant
- **bufotenine**, a hallucinogen with a structure similar to that of serotonin (a human neurotransmitter).

Nature's poisons outrank those synthesized by chemists, both in number and in toxicity.

The next ten… (most deadly)

	LD_{50}/mg/kg
Strychnine	5×10^{-1}
Soman*	6×10^{-1}
Tabun*	6×10^{-1}
Tubocurarine chloride	7×10^{-1}
Rotenone	3
Isoflurophate*	4
Parathion*	4
Aflatoxin B1	10
Sodium cyanide*	15
Solanine	42

**Synthetic*

The next ten most deadly compounds

Strychnine can be extracted from the seeds of the plant *Strychnos nux veronica*, which is native to Southern Asia and Australia. It has been used as rat poison for centuries and can be deadly to humans.

Soman and Tabun are both potential chemical warfare agents classified as nerve agents. They were initially developed as an insecticide and a pesticide, respectively. Neither occurs in nature.

Tubocurarine chloride can be extracted from *Chondodendron tomentosum*, a South American plant. It has been used as an arrow poison but is also a valuable component of some anaesthetics.

Rotenone is an insecticide. It can be extracted from the stems and roots of tropical plants such as the jewel vine or flame tree and is often used to control the pests that attack celery.

Isoflurophate has a structure similar to those of many nerve gases. It is used in the treatment of a range of eye diseases.

Parathion is an agricultural insecticide. Its LD_{50} value is 4 in female rats, but 13 in male rats. This suggests its effect on women may be different from that on men.

Aflatoxin B1 is found in mold on grains and legumes and belongs to a family of chemicals known as the aflatoxins. These chemicals were first isolated in 1960 when an outbreak of "Turkey X Disease" (a liver disease) in the UK killed over 100,000 turkeys. Aflatoxins were identified as the cause.

Sodium cyanide has several important industrial applications; for example, it is used in the extraction of gold and silver from ores and in electroplating.

Solanine is found in the deadly nightshade (*atropa belladonna*) plant. It has been used in many ways throughout history, often as a poison. Today it has many uses, for example in purple dyes or to treat gout, rheumatism, angina and Parkinson's disease.

Vitamin C

Vitamin C, or ascorbic acid, is one of the most commonly used preservatives and is an essential nutrient for humans. It occurs naturally in many fruits and vegetables but is not very stable and is often destroyed upon cooking.

Vitamin C can be synthesized from glucose in the laboratory and the product is EXACTLY the same as the naturally occurring substance.

Other variations of "natural is good, man-made is bad"

"We haven't had time to become resistant to synthetic chemicals"

There are several possible responses to this statement:

a) Botulism has been around for millennia and we have not developed resistance to it.

b) There are probably millions of naturally occurring compounds that we have not yet discovered and it may be that compounds considered "man-made" in fact occur in nature.

c) Plants are constantly evolving and making new natural chemical compounds that we have not been exposed to before.

d) The enzymes of our metabolic pathways are often not specific to a particular molecule but to a part (functional group) of the molecule that appears in many members of a family of substances. A new synthetic compound consisting of a different arrangement of groups that are "known" by an enzyme may still be broken down by the same pathways as the related naturally occurring substance(s). The body does not make a molecular distinction between natural and synthetic.

"Synthetic chemicals bioaccumulate in our bodies"

Naturally occurring compounds can accumulate in our bodies too. For example, vitamins A and D are fat-soluble vitamins and can accumulate in fatty tissues. Large excesses of these vitamins can cause death just as an accumulation of some synthetic chemicals can. There is no reason why synthetic compounds should accumulate to a greater extent than naturally occurring ones.

Chemicals in food

Advertisements and labels on food packaging can be very misleading and often play on the consumer's concerns about mysterious "nasty chemicals". Campaigns of this sort overlook the fact that our food is **made of** chemicals, be they naturally occurring or synthetic.

We benefit greatly from the addition of some synthetic chemicals to our food. For example, without the preservatives developed by food scientists and chemists, our supermarket shelves could not be filled with such a wide range of foods brought from far-flung corners of the globe – the food would not stay safe to eat long enough to make it to the shelves.

Chemicals used to preserve food

EDTA (ethylenediaminetetraacetic acid) is a common preservative and is especially useful in oils and fats. It sequesters stray metal ions that can catalyze oxidation and spoilage – in effect, EDTA chemically removes these impurities. Several other examples of antioxidants are given in the PowerPoint® presentation.

Sodium nitrite ($NaNO_2$) is used as a preservative in processed and smoked meats like bacon, salami and pastrami. It reacts with hydrogen chloride in a test tube to form nitrous acid, which can react with some amines to form nitrosamines. Some researchers have suggested that a similar process could take place in the stomach when foods preserved with sodium nitrite are consumed. Hydrochloric acid is naturally present in the stomach and amines are produced when food proteins are broken down.

Nitrosamines are powerful carcinogens and there has, therefore, been great media concern about the use of sodium nitrite as a preservative. However, it is not known whether nitrosamines are really produced in the stomach as described above. It **is** clear that the use of sodium nitrite to preserve meats helps prevent the spread of botulism.

Even if we totally removed all nitrite additives from our food we would still have nitrites in our bodies that could react to form nitrosamines. At least two thirds of the nitrite in our bodies comes from fresh vegetables. Nitrate salts in vegetables are converted into nitrites by essential bacteria that live in our mouths and guts.

Sodium nitrite is just one example of a chemical that could have both negative and positive affects on humans. Decisions about the use of food additives and preservatives have to be based on a balanced view of the risks and benefits involved. This is called the precautionary principle.

Loss of chemical preservatives would be as great a disaster for our food supply as loss of all forms of refrigeration!

Natural toxins in food

Natural toxins in food can be just as dangerous as synthetic ones. For example, garlic, mustard and horseradish all contain allyl isothiocyanate, which can cause cancer. Should we all stop enjoying a summer barbecue because meat cooked in this way contains the carcinogen benzopyrene?

Examples of this kind illustrate that there is no difference between the negative effects of some synthetic chemicals and those of many of the chemicals that occur naturally in the things we eat. The quantity consumed is a vital factor in the effect produced.

Natural toxins in food – Part 2

Milk products can be toxic for those who lack the enzyme needed to digest it.

Parsley, carrots and celery are good for you! Nevertheless, they contain myristicin, which in large quantities can cause hallucinations, liver damage and even death.

Some people used nutmeg as a hallucinogen in the 1960s and 70s but the dose required to obtain a hallucinogenic effect caused other health problems.

We all consume a wide variety of natural toxins in an average week. The secret of our survival lies in the variety of foods we eat. Since we only consume very small amounts of each of the different toxic compounds at any one time, our livers can process the toxins and they are broken down by a range of metabolic pathways.

We are exquisitely designed to cope with a whole variety of substances in small quantities that would be poisonous in larger amounts. It is possible to overdo it and suffer the negative effects of these toxins, but in most cases this is rather difficult.

For example, you would have to drink 85 cups of coffee at one sitting to die from caffeine poisoning.

Organic food is better for you

This is a common misconception not borne out by the research evidence. In properly controlled investigations on the same dry weight of organic and non-organic fruit and vegetables, analysis showed the same amounts of vitamins, minerals etc. If all the food in the world was organic so much manure would be needed that there would need to be three times as many cows.

John Emsley quotes

John Emsley is a chemist who has published several popular science books. The publication from which the quotations in the presentation were taken is listed in the *References* section of these notes.

Cosmetics

The marketing campaigns associated with cosmetics often make much of the rejuvenating properties of their "natural" ingredients. However, compounds developed by chemists working in laboratories are often the essential ingredients of these products.

Although people have used all sorts of substances to alter their appearance in the past, the ingredients that may be used in today's cosmetics are very carefully regulated, as is the use of animal testing in cosmetics research. This might be an interesting topic for a group discussion.

More background information on the chemistry of cosmetics can be found on the RSC's *Chemsoc* website at http://www.chemsoc.org/chembytes/ezine/1998/houlton.htm.

Should DDT be banned everywhere?

DDT (dichlorodiphenyltrichloroethane) was the first chlorinated organic insecticide to be developed. It is cheap, has a relatively low toxicity for mammals and is very effective against the mosquito that spreads malaria and the lice that carry typhus. Its use has saved millions of lives.

Unfortunately, extensive use of DDT after World War II caused several problems. Many species of insect developed resistance to DDT and it was discovered to be highly toxic to fish. In addition, it is not metabolised very rapidly in animals but builds up in their fatty tissues over time and can then be passed along the food chain. Research has suggested that DDT may cause cancer and that it can harm bird reproduction by causing birds to lay eggs with very thin shells. In particular, its use as a pesticide has been connected with the severe decline of peregrine falcon populations after World War II.

The negative effects of DDT have resulted in a ban on its use in many countries. However, this is still a controversial issue. The World Health Organisation supports the continued used of DDT under controlled circumstances until viable, affordable alternatives for combating the spread of malaria have been developed.







Handout material

Some material you may wish to use as a handout is included in a Microsoft Word® document on the CD-ROM.

Acknowledgement

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