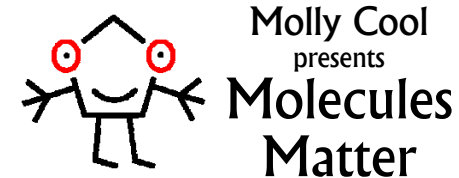
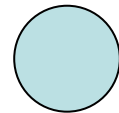


# Top Banana

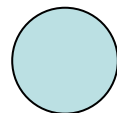


You may not think you look like a banana, but 90% of the human genome is the same as the banana genome! All plants contain DNA, but their genomes are all slightly different. A genome is the genetic code of the organism and is unique to a specific species.

Above your head is a 100 base pair model of DNA, part of the largest model of DNA in the world. Human DNA contains 3.4 billion base pairs! The genetic code is made up of four bases which pair up, Adenine with Thymine and Guanine with Cytosine. Together they combine with sugars and phosphates to make up the iconic double helix, probably the most beautiful and recognisable molecular structure.

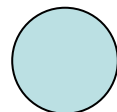


# Star Dust



It is said that we are all made of star dust, and some of that is Buckminster Fullerene. Life on this planet is based around one crucial element - carbon. With the exception of oxygen and water, the molecules around which life is based contain carbon as the central element and are called organic. A few features make carbon unique. Most importantly, it likes to make bonds with itself; even double and triple bonds; and it also makes stable bonds with other common elements such as oxygen, hydrogen, and nitrogen. Buckminster Fullerene (also known as Bucky Ball or C<sub>60</sub>) contains 60 carbon atoms. Its shape is made up of interconnecting hexagons and pentagons, exactly the same as for a leather football. It is the most recent form of elemental carbon to be discovered - the others being graphite and diamond. In 1996 Robert Curl, Harry Kroto and Richard Smalley won the Nobel Prize for discovering C<sub>60</sub>.

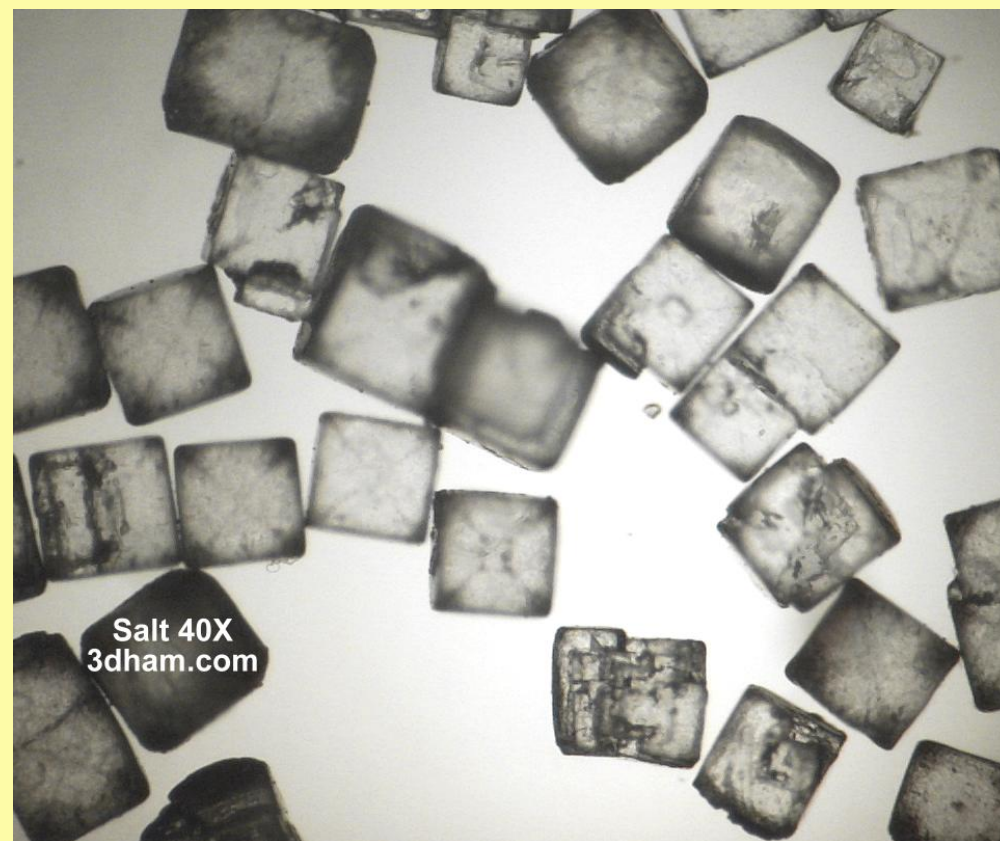
# Salt of the Earth



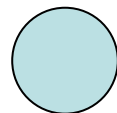
Molly Cool  
presents  
**Molecules  
Matter**

Table salt is made up of two atoms, sodium and chlorine. Chlorine is a micronutrient of plants whereas sodium is only a micronutrient for certain specialised species such as the *Chenopodiacea* which have adapted to love a high sodium environment. So why have a salt crystal at the start of an exhibition about plants?

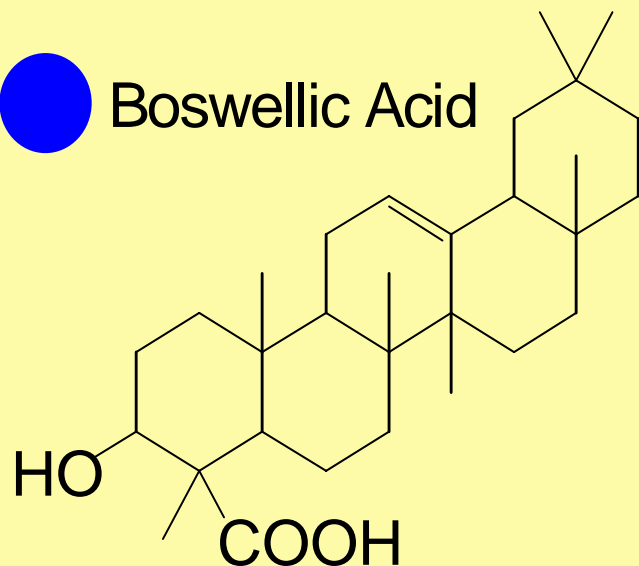
There are 109 elements and in the rest of this exhibition you will only see on display carbon, hydrogen and oxygen which make up about 90% of the elements in plants, along with a little nitrogen, phosphorous, magnesium and sulphur. So the sodium and chlorine are here to represent all the other elements that didn't make it to Edinburgh.



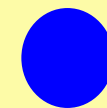
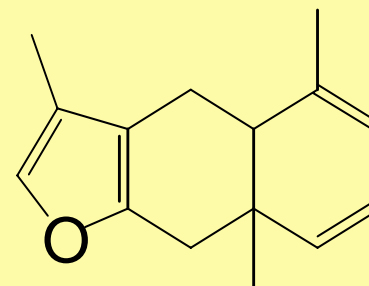
# Biblical Molecules



Boswellic Acid



The Bible records that the three wisemen bore gifts of Gold, Frankincense and Myrrh, giving us an interesting insight into the products of the chemical industry of ancient Persia and Arabia. Sadly gold doesn't grow on trees but the others do.

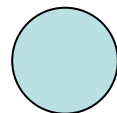


Curzarene

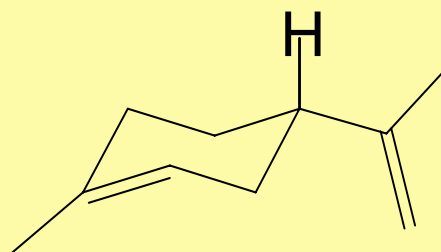
Frankincense was extensively used by the ancients in religious rituals and was extremely expensive. It comes from trees in the genus *Boswellic*. The major constituent of the resin is boswellic acid.

Myrrh is a complex mixture of oil, resin and gum from the tree *Commiphora myrrha* and has an aromatic odour and bitter and acid taste. An interesting compound found in the oil is Cuzarene which has a morphine-like effect.

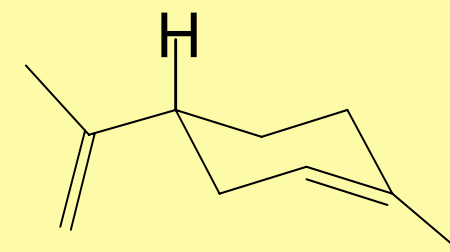
# Left and Right



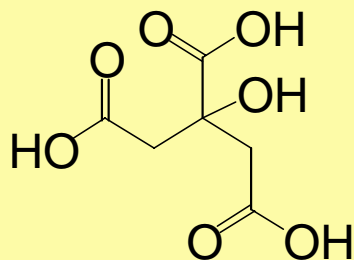
Some molecules can be found in either a right-handed or left-handed form and are the mirror image of each other - just like your hands. Limonene is an interesting example. Right-handed limonene is found in oranges and gives them their distinctive taste whereas left-handed limonene is found in lemons and gives them their taste. Look at the models - can you spot the difference?



● Left - Limonene  
Lemons



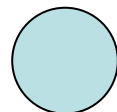
Right - Limonene ●  
Oranges



● Citric Acid

Citric acid is the other molecule that is important to the taste of oranges and lemons – lemons have more and hence have a sharper taste.

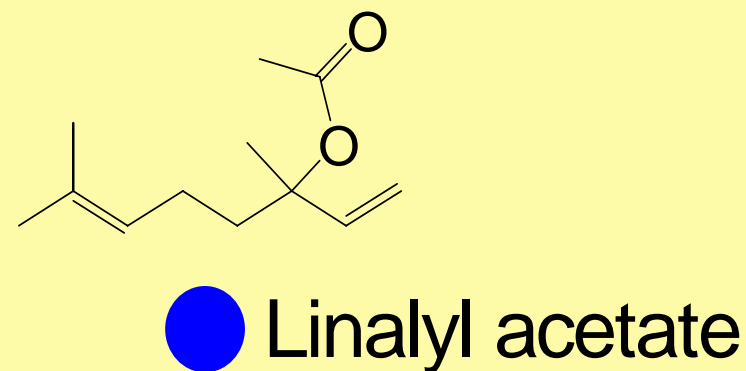
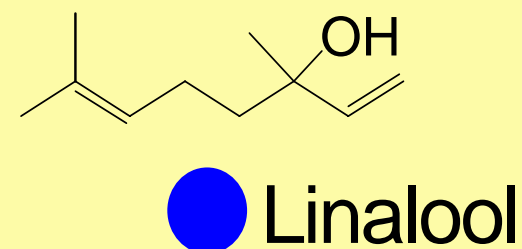
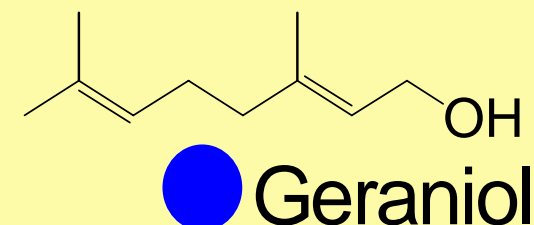
# Relieving Stress



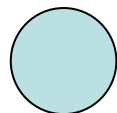
Relaxing in a bath containing essential oils or drinking a cup of herbal tea is a popular way of relieving the stress of modern lives. Essential oils are produced either by crushing the plant material or by steam distillation. In the latter the plant material is boiled with water and the steam generated condensed and collected. The oil separates out of the condensed steam, floating on top of the water. Here are two examples;

Geraniol is responsible for the wonderful aroma of geraniums, *Pelargonium graveolens*, which is said to help menstrual and hormonal problems.

Bergamot, *Citrus bergamia*, found in Earl Grey tea is used as an anti-depressant when drunk. Apply it topically, and it can relieve skin irritation from cold sores and chicken pox: however, be careful as the linalool and linalyl acetate in bergamot are both phototoxic and react in sunlight.

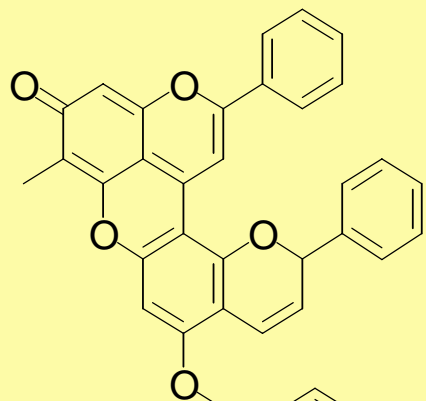


# Dragons Blood

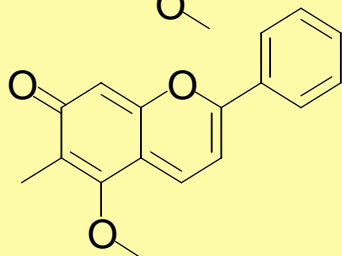


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presents  
Molecules  
Matter

*Dracaena Cinnabari*, the dragons blood tree of Socotra, produces a red resin that was used in ancient times as a medicine and pigment. Dracorubin and dracorhodin are the two molecules that gives the resin its distinctive red colour.



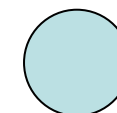
Dracorubin



Dracorhodin

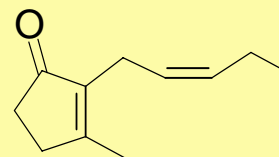


# A Sweet Perfume

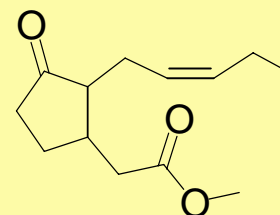


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presents  
Molecules  
Matter

Jasmone and methyl jasmonate are the odour molecules of the sweet smelling *Jasmine*. When plants are attacked they produce methyl jasmonate to warn neighbouring plants of the danger, stimulating them to produce defensive molecules.



Jasmone

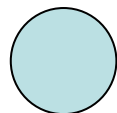


Methyl Jasmonate



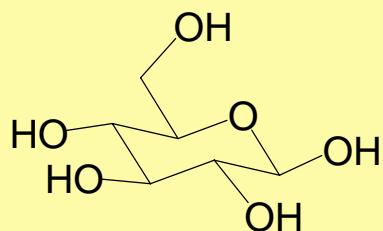
It takes 15000 blossoms just to give 1.5 g of jasmine oil!

# Smooth as Silk

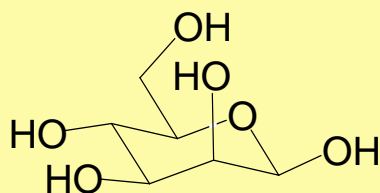


Molly Cool  
presents  
Molecules  
Matter

*Aloe Vera* is a very popular additive in cosmetics to help give skin a silky smooth feel. A gel is extracted from the leaf which contains a very complex mixture of molecules which include, polysaccharides, glycoproteins, terpenes and plant steroids.



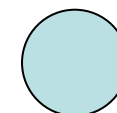
Glucose



Mannose

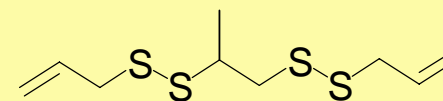
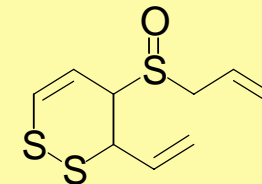
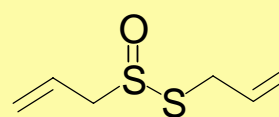
The most important compounds are glucomannans – polymers made from two sugars glucose and mannose, very subtly different.

# Smells that Repel



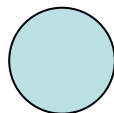
Molly Cool  
presents  
Molecules  
Matter

Zulus plant African wild garlic *Tulbaghia violacea* around their homes to repel snakes. All garlic plants contain very smelly molecules which contain sulphur atoms – here are just three of them:



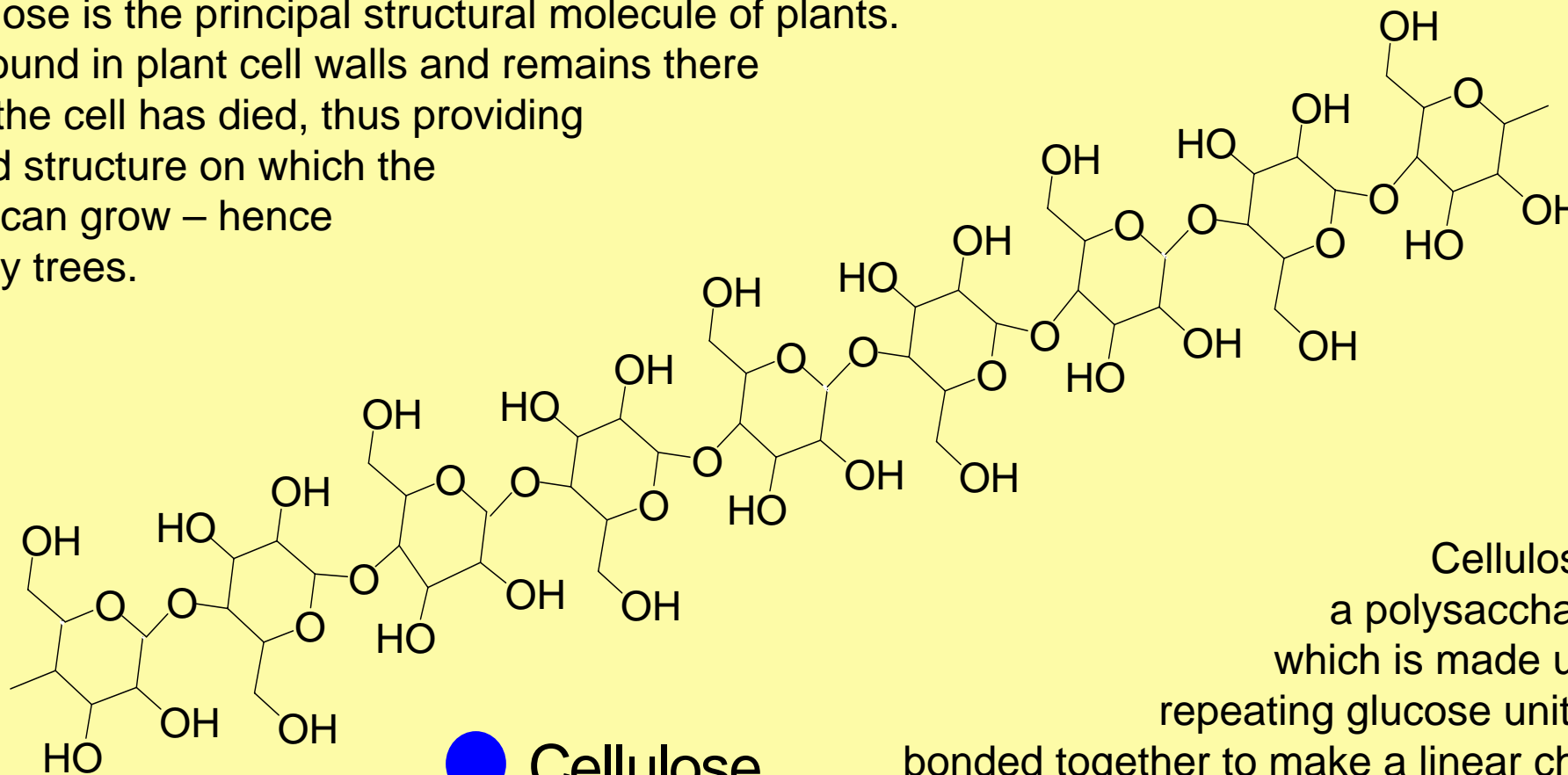
Zulus also use the root bulb in cooking and as an aphrodisiac which I guess is OK so long as you both eat it!

# The Mighty Cellulose



Molly Cool  
presents  
**Molecules  
Matter**

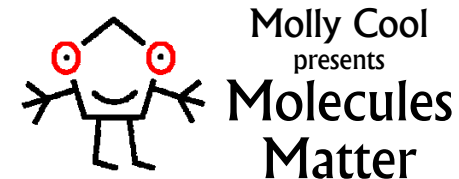
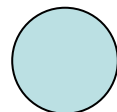
Cellulose is the principal structural molecule of plants. It is found in plant cell walls and remains there after the cell has died, thus providing a rigid structure on which the plant can grow – hence mighty trees.



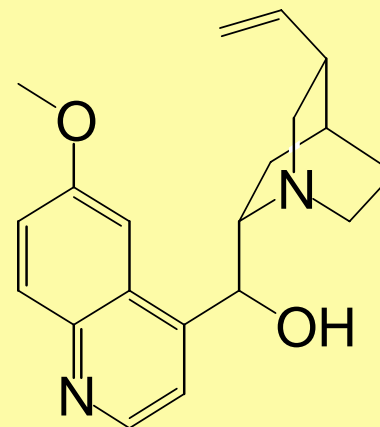
 **Cellulose**

Cellulose is a polysaccharide which is made up of repeating glucose units all bonded together to make a linear chain, usually several thousand glucose units long.

# A Real Tonic



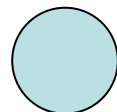
Native Americans were the first to use the bark of the cinchona tree to calm fevers. Jesuit priests realised its potential and brought it back to Europe where it was used as a cure for Malaria and was known as 'Jesuit bark'. Quinine was one of the earliest medicinal compounds to be isolated: its structure being determined in 1820.



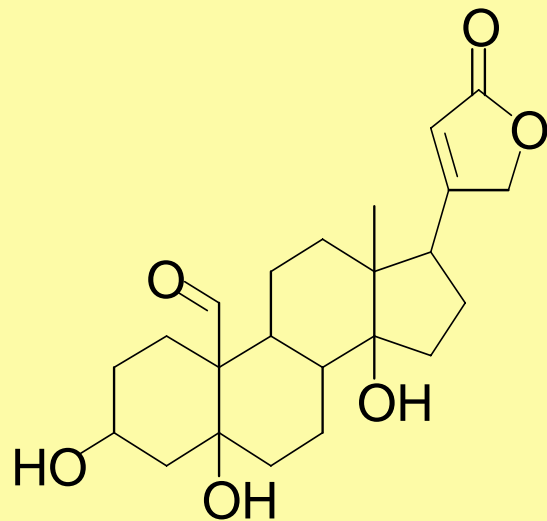
 Quinine

To taste pure quinine is extremely bitter, in fact humans find solutions of quinine at low concentration even more distasteful than solutions of salt water! Fortunately around 1870 Schweppes invented tonic water to make the taking of quinine more palatable.

# Heart Stopping



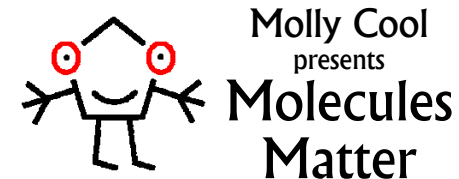
Extracts of *Strophanthus* leaves are used by African hunters as a poison on their arrow-tips. We now know that the effect of the extract was to stop the heart of the animal. Strophanthin is the active ingredient in *Strophanthus* and is now used as a cardiac drug to slow the heart. It is part of a class of heart slowing molecules from plants, the most common of which is digitoxin found the foxglove *Digitalis*. All of these molecules are very similar in structure and have a sugar attached to one of their oxygens increasing the rate at which the body absorbs the molecule.



 Strophanthin

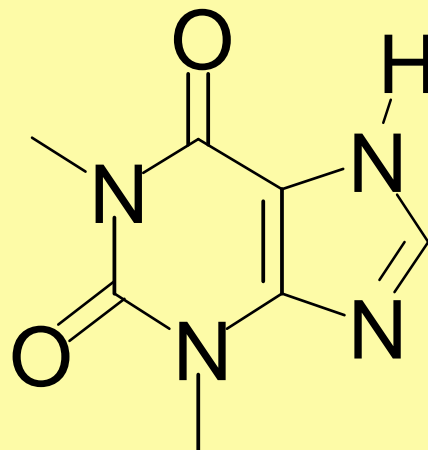


# Wake-up & Feel Good

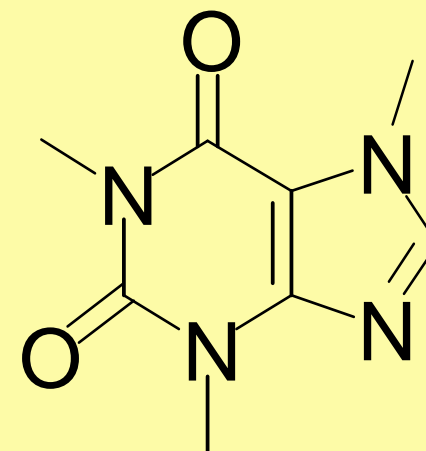


The caffeine in coffee, *Coffea arabica*, and the theobromine in cocoa, *Theobroma cacao*, are both stimulants that pick you up and make you feel good.

Look at the molecular drawings and models and see if you can spot the difference. You will find that the molecules are almost identical, so it is not surprising that their effect is so similar.

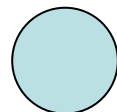


 Theobromine



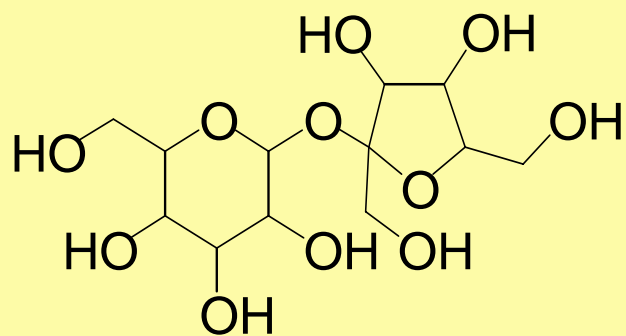
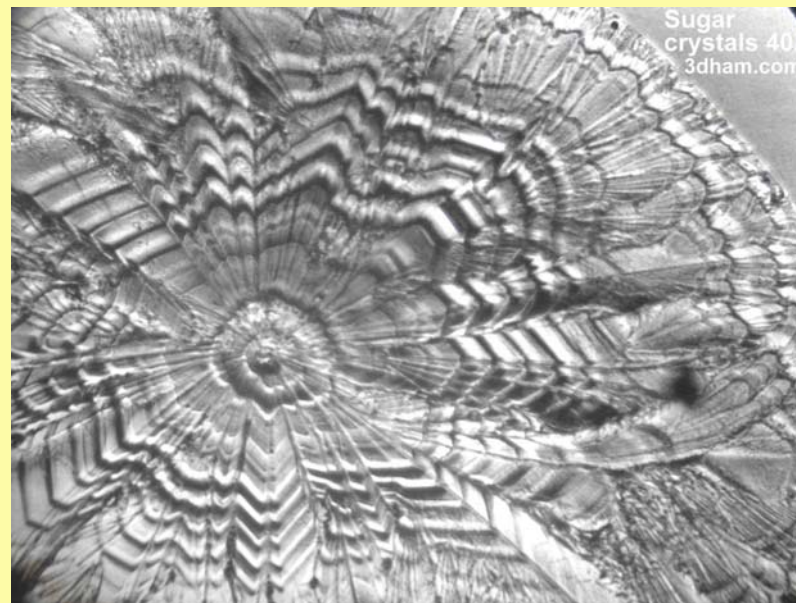
 Caffeine

# Sweet as Sugar



Molly Cool  
presents  
**Molecules  
Matter**

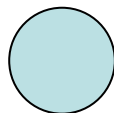
Sugar Cane *Saccharum officinarum*, was originally described as “the reed which gives honey without bees”. The plant originates from India and then moved west into Persia and Arabia and was brought to Europe by the Crusaders. In the C15 it was transported to the Americas.



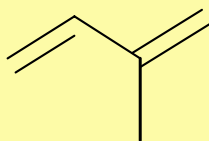
 Sucrose

In chemistry the term sugar is used to describe a whole class of molecules with a similar structure, containing lots of alcohol groups – oxygens attached to hydrogens. Chemists call the sugar we eat Sucrose.

# A Smooth Ride



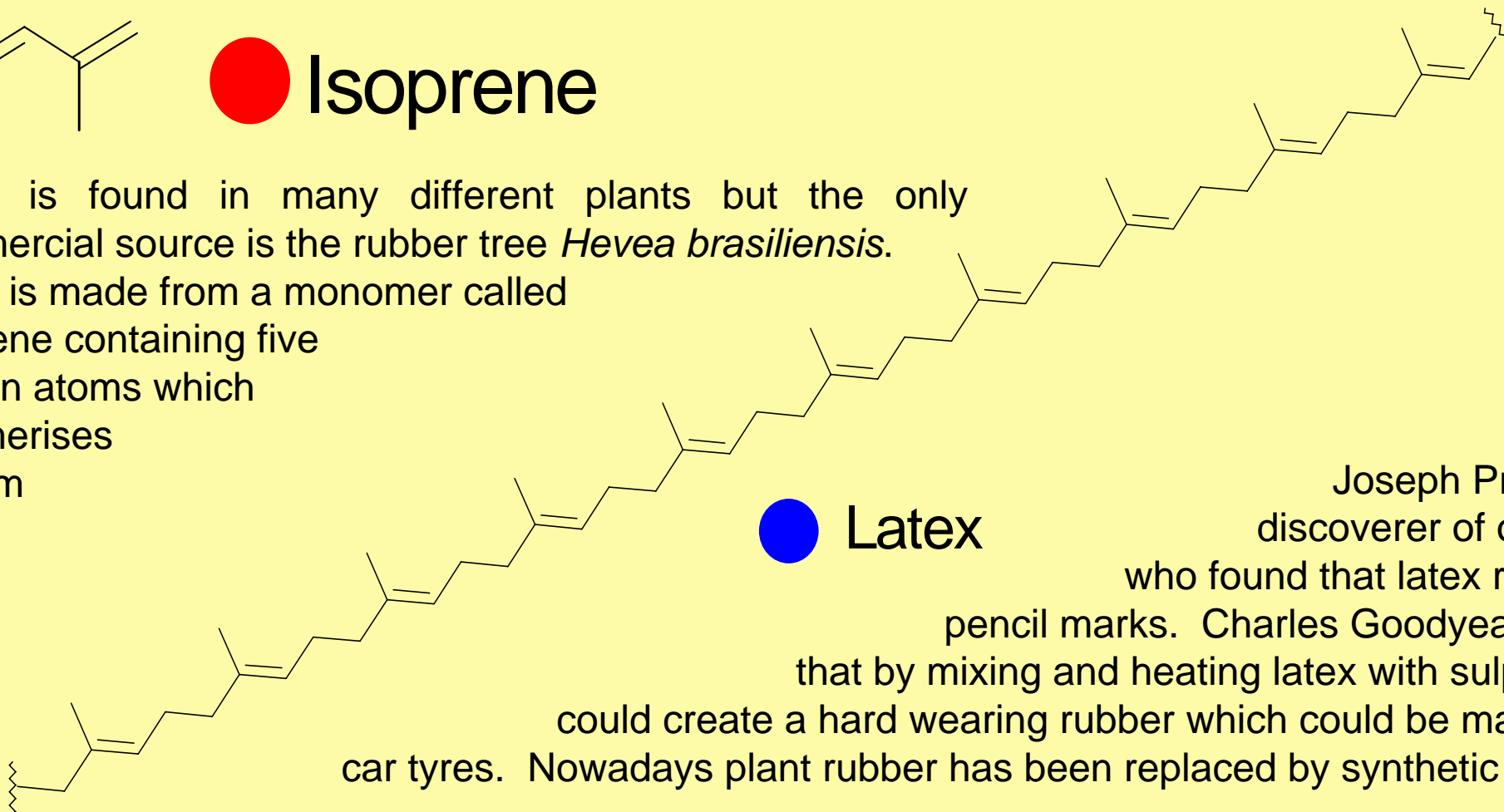
Molly Cool  
presents  
**Molecules  
Matter**



## ● Isoprene

Latex is found in many different plants but the only commercial source is the rubber tree *Hevea brasiliensis*.

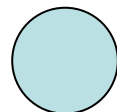
Latex is made from a monomer called isoprene containing five carbon atoms which polymerises to form latex.



## ● Latex

It was Joseph Priestley, discoverer of oxygen, who found that latex rubs out pencil marks. Charles Goodyear found that by mixing and heating latex with sulphur he could create a hard wearing rubber which could be made into car tyres. Nowadays plant rubber has been replaced by synthetic rubber.

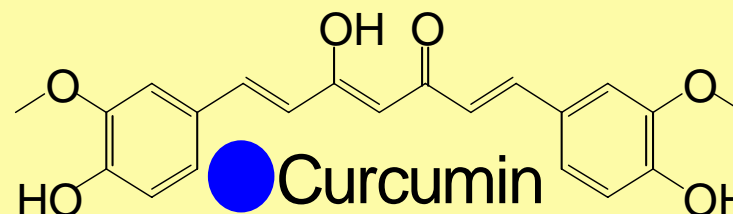
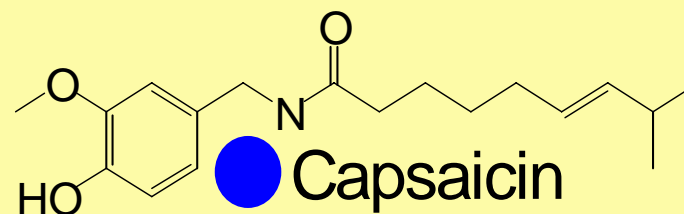
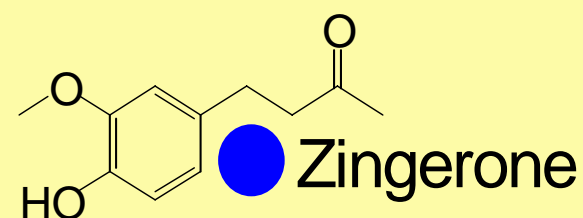
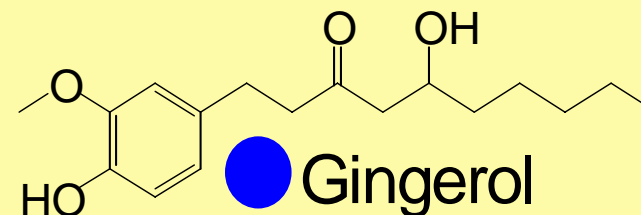
# Hot and High



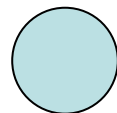
Molly Cool  
presents  
**Molecules  
Matter**

Why is fresh ginger hotter than cooked ginger? Fresh ginger (*Zingiberaceae*) contains gingerol which is fiery hot but which degrades to Zingerone on cooking. Both of these compounds are closely related to Capsaicin (look at the rings), the main hot constituent of chilli peppers (*Capsicum*). Capsaicin also produces a burning sensation on the skin and is the active ingredient in pepper spray used in riot control. Some people can get 'high' on capsaicin, the hot sensation leads to the release of Endorphins - feel good molecules produced by the body.

A related species, *Curcuma* (Turmeric) contains a similar hot tasting compound, curcumin which is a known diuretic (makes you wee). In Indian medicine Turmeric is used to aid digestion - hence its presence in large quantities in curry.

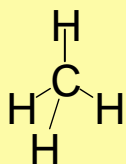


# In the Beginning..

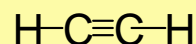


Molly Cool  
presents  
**Molecules  
Matter**

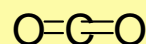
In the beginning there were simple molecules like the ones that are shown here.



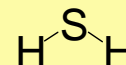
● Methane



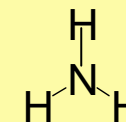
Acetylene



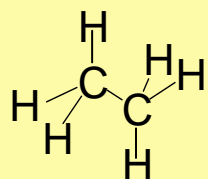
Carbon Dioxide



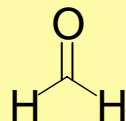
Hydrogen Sulphide



Ammonia ●



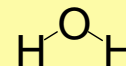
● Ethane



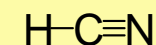
Formaldehyde



Carbon Monoxide



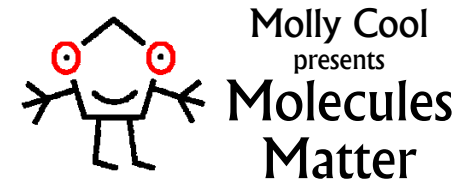
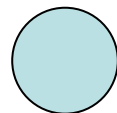
Water



Hydrogen Cyanide ●

Sparked by lightening, these simple molecules began to react and make larger more sophisticated molecules, like sugars, bases and amino acids, which in turn created large macromolecules such as RNA and DNA and proteins. These molecules began to replicate, recognise each other and organise themselves and from this single cell organisms arose, which eventually evolved into us and all the flora and fauna we see around us.

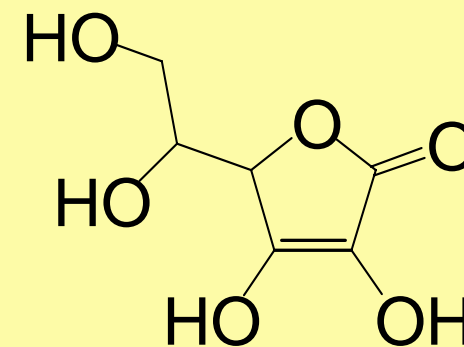
# Essential for Life



Vitamin C is an essential nutrient for life. Most other organisms on this planet have the capacity to make Vitamin C for themselves, but unfortunately humans and a few other animals such as the guinea pig are unable to make it and have to rely on a dietary source – Five a day!

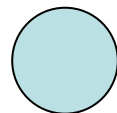
Vitamin C was first isolated in 1928 and in 1932 Albert Szent-Gyorgyi proved that it was the agent that prevented scurvy. It has the action of an antioxidant, reacting with free radicals that would otherwise damage our cells. Some people advocate taking high doses of Vitamin C, though the effectiveness of this has yet to be proven.

Vitamin C is found in high amounts in many common fruits such as oranges and lemons, but also in more exotic fruits such as guava (*Psidium guineense*) and the tomato tree (*Chyphomandra betacea*).



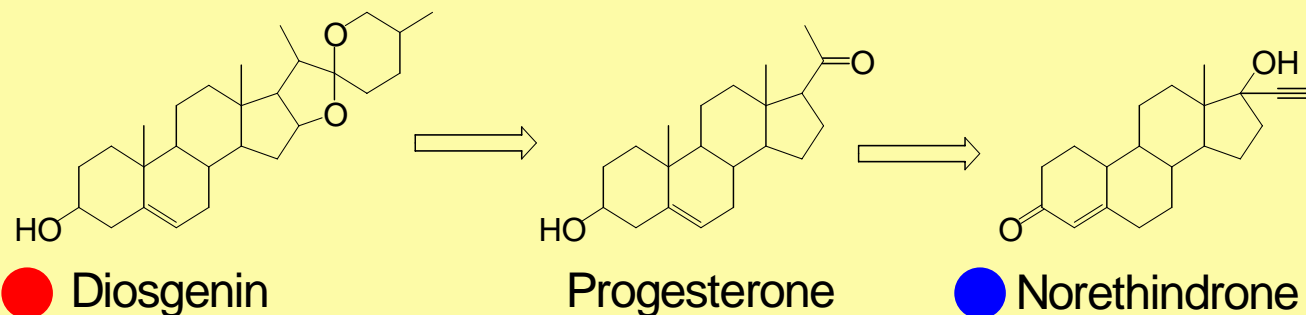
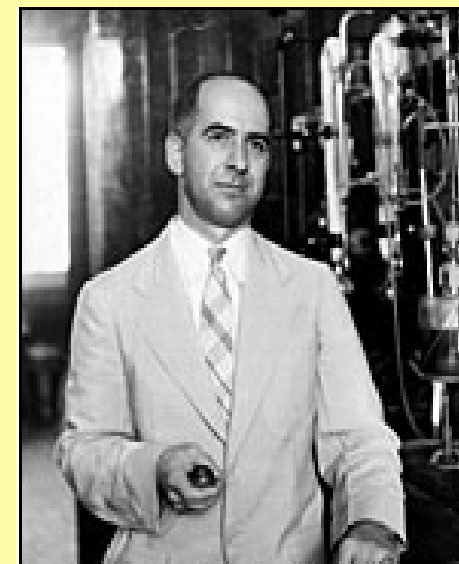
 Vitamin C

# The Story of the Pill



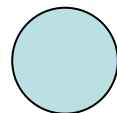
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**Molecules  
Matter**

The Mexican Yam, *cabeza de negro* (*Dioscorea*) is the source of the steroid diosgenin used to make the contraceptive pill. It took Russell Marker (right) 3 years and over 400 plants before he found the Mexican Yam to be an economical source of diosgenin.



Marker developed a way of converting diosgenin into the human pregnancy hormone progesterone and in 1943 he co-founded the pharmaceutical company Syntex in Mexico to make progesterone. Progesterone is not a good contraceptive because has to be injected, so in 1951 Carl Djerassi converted progesterone into norethindrone which can be taken orally and thus the contraceptive pill was born, just in time for the swinging 60's.

# Saving the Whale

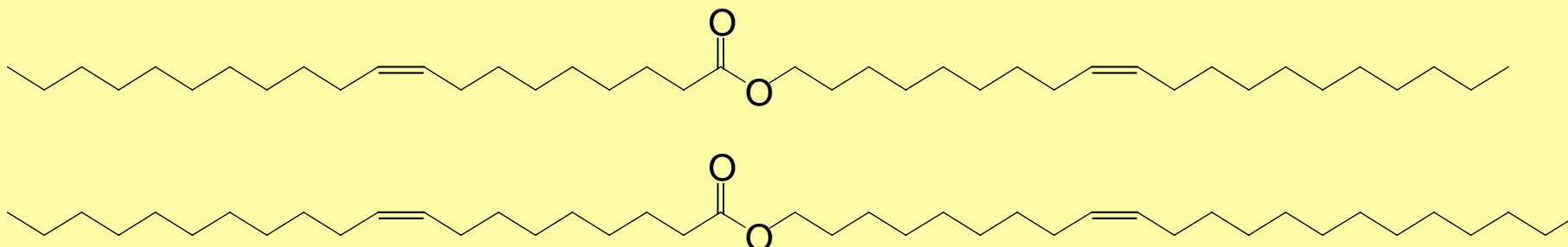


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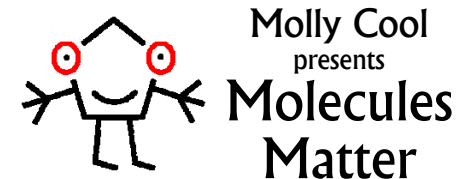
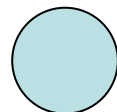
In 1970 the Endangered Species Act banned the hunting of sperm whale for their oil. Sperm whale oil has the unique property of being stable at high temperatures (up to 300 °C) and was widely used as a lubricant in engines – an alternative needed to be found! The replacement, Jojoba oil, had been found in the 1930's and was used during WWII, but then use stopped because it was easier to hunt whales than to grow the jojoba bush, *Simmondsia chinensis*. The plant is native to the deserts of America, but is now grown commercially across the world. Jojoba is unique amongst plants because the nuts contains a mixture of wax esters (below) and not the usual triglyceride fats. The oil was first used by native Americans as a hair dressing and is still widely used in cosmetics.



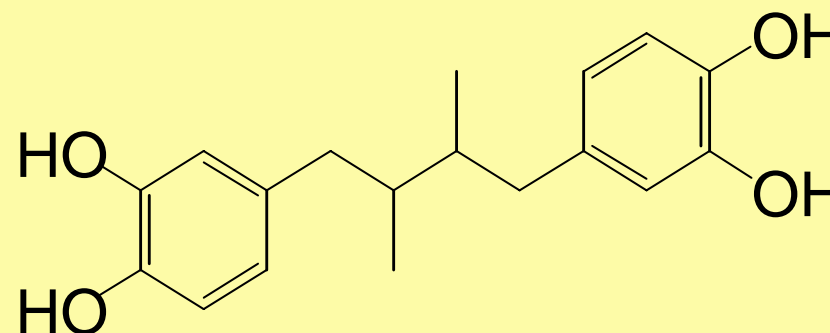
A Sperm whale breaching  
with permission of The Center for Whale Research




# A Word of Warning



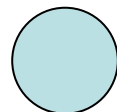
American Indian folklore uses chapparral tea made from *Larrea tridentata* as a remedy for many ailments. In 1995 scientists found that NDGA, the active component in chapparral tea, inhibited the growth of breast cancer cells in a laboratory. However, it is not effective against cancer inside a living organism. NDGA is termed a lead compound - it leads scientists towards better anti-cancer drugs.



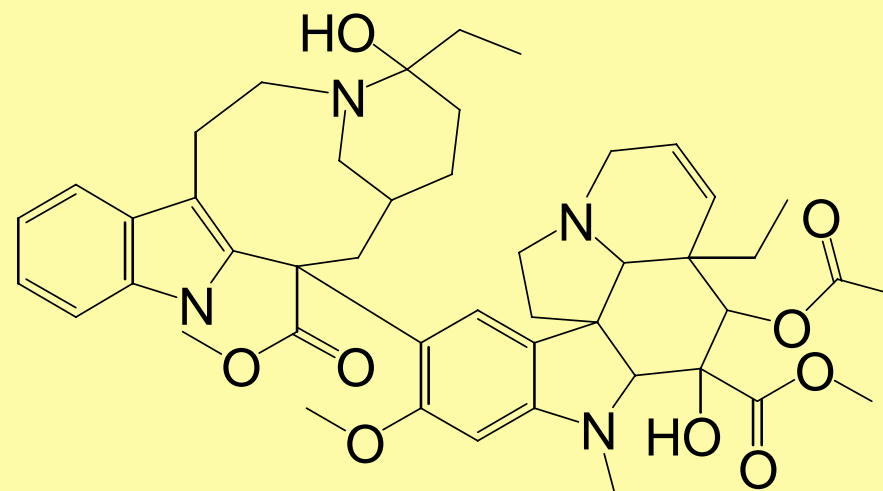
 Nordihydroguaiaretic Acid (NDGA)

Unfortunately, some people latched onto the first bit of good news, and drank chapparral tea as an alternative therapy against cancer, and even as a preventative medicine. However it appears that prolonged exposure to NDGA leads to cysts on the kidneys and liver poisoning. Please be careful: some molecules in plants can harm you.

# Just by Chance



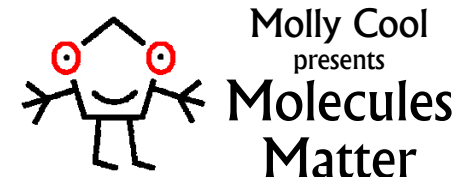
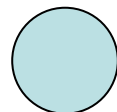
The drug company Eli Lilly originally tested extracts of the Madagascan periwinkle *Vinca rosea* for a treatment of diabetes but they were not effective. It wasn't until years later, during a random screening, that it was discovered that the extracts inhibited the growth of certain cancer cells. Eventually Vinblastine was isolated and it is now used in the chemotherapy against Hodgkin's disease and for advanced testicular and breast cancers.



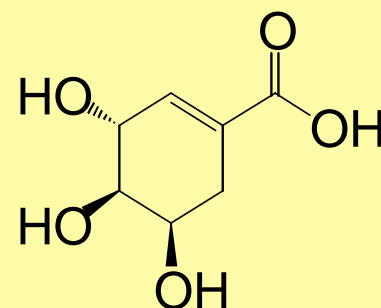
 Vinblastine

Vinblastine occurs in exceptionally low amounts, around 0.0002% of the mass of the plant, making it incredibly expensive, about £15,000 per gram, double the price of gold. It is an incredibly complex molecule and amazingly chemists have made it in the laboratory, but the synthetic vinblastine is even more expensive! – Better leave it to the periwinkle.

# Surviving Flu

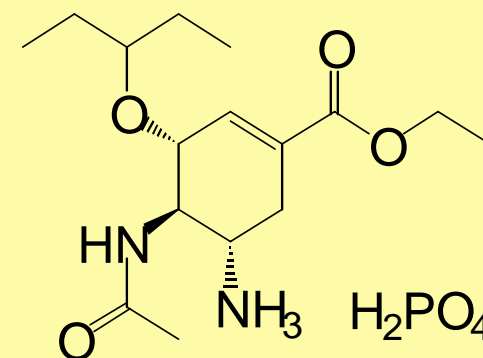


Tamiflu is our first line of defence against an influenza (flu) epidemic. For its size it is relatively complex and it takes over 10 steps to make the structure – one reason why it is not cheap. It is made from shikimic acid which is extracted from the seeds of the star anise *Illicium vernum* which is grown in China. From plant to Tamiflu takes one year!



 Shikimic acid

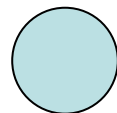
10 Steps  
→



 Tamiflu

It is an anti-influenza drug that has a unique action. When you catch flu the virus enters a cell and begins to make replicas of itself which then go on to infect more cells. Tamiflu prevents the virus from moving between cells by sticking to the surface of the virus. Overall the effect of Tamiflu (if taken early enough) is to shorten an attack of flu and reduce the symptoms: so less bad flu for half the time.

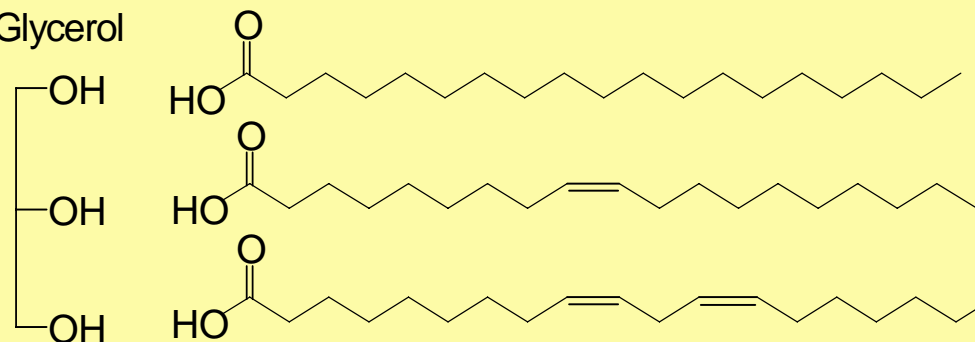
# Healthy Eating



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The fats we eat are made of triglycerides in which glycerol is attached to 3 fatty acids. Fatty acids are long chains of carbon atoms with an acid group at the top. Sometimes they contain a carbon carbon double bond and are called unsaturated (can you see it in the model?) whereas saturated fatty acids have only carbon-carbon single bonds.

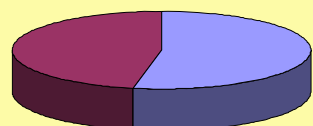
Glycerol



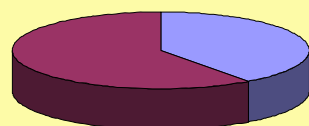
Stearic Acid

Oleic Acid

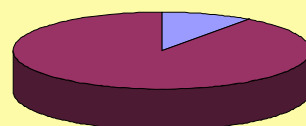
Linoleic Acid



Cocoa Butter



Animal Fat

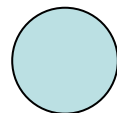


Olive Oil

Unsaturated fatty acids vs Saturated fatty acids

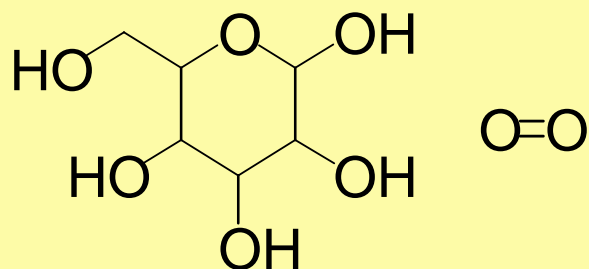
Saturated fatty acids are converted into cholesterol by your liver which can lead to heart disease, so it is better to eat unsaturated fatty acids. Olive oil contains 90% unsaturated fatty acids and is healthy, but sadly the cocoa butter found in chocolate is very high in saturated fatty acids.

# What Plants do for Us



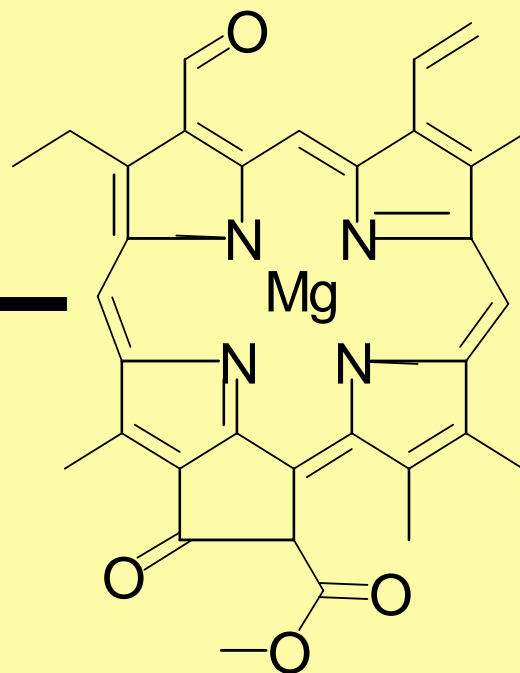
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Photosynthesis is a remarkable process, which takes water and carbon dioxide and converts it to oxygen and glucose. The



Glucose Oxygen

energy required to drive this reaction comes from sunlight. Sunlight is captured by chlorophyll the green pigment that is found in all plants.



 Chlorophyll

Reducing global emissions of carbon dioxide is key to slowing down the rate of climate change. Part of this strategy is



Carbon dioxide Water

to prevent the destruction of the rainforests so that their high density of plants can continue to convert carbon dioxide into oxygen for us to breath. Let's all say a big thanks to the plants.