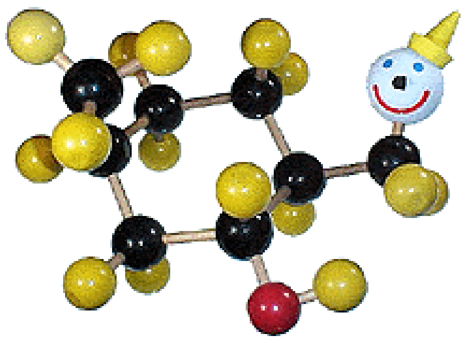

Major Types Of Chemical Compounds In Plants & Animals

Part I. Carbohydrates, Lipids, Proteins Nucleic Acids & Terpenes

Note: When the methyl group containing Jack's head is replaced by an isopropyl group, the model depicts a molecule of menthol.

Go To Part II

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Living systems can be organized into the following levels or categories, starting with the simplest units and proceeding to the largest and most complex levels of organization:

Subatomic particles (electrons, protons and neutrons) form atoms (hydrogen, helium, oxygen, iron, etc.) which form molecules (water, glucose, cellulose, etc.) which form complex macromolecules (glycoproteins, DNA, RNA, etc.) which form subcellular units called organelles (nucleus, mitochondrion, chloroplast, etc.) which form cells which form tissues (muscle, nerve, adipose, epithelial, etc.) which form organs (brain, heart, liver, root, leaf, etc.) which form an individual organism. All of the elements are listed in a periodic table by their atomic number or number of protons. In a neutral atom the number of protons is equal to the number of electrons. To calculate the number of neutrons for each element see the following link to a periodic table.

See A Periodic Table Of The Elements

Individual oganisms form species populations (ant, human, deer, ponderosa pine, duckweed, etc.) which are further organized into complex communities composed of many species populations (chaparral, coastal sage scrub, yellow pine forest, redwood forest, etc.). These communities interact with physical environmental factors (soil, terrain, water, atmosphere, climate, etc.) to form complex ecosystems (ocean, coral reef, prarie, tundra, tropical rain forest, etc.). These ecosystems are often named after the plant communities they are associated with (chaparral, coastal sage scrub, creosote bush scrub, Douglas fir forest, etc.).

There are many different kinds of atoms from the 103 elements. Ninety-two of these elements occur naturally on the planet Earth. Six of these elements (carbon, hydrogen, nitrogen, oxygen, phosphorus & sulfur) comprise about 98% of the body weight of most living organisms. Two or more atoms joined together by chemical bonds form molecules of chemical compounds such as water (H_2O), glucose ($C_6H_{12}O_6$) and sucrose ($C_{12}H_{22}O_{11}$).

The four major elements of living systems are carbon (C), hydrogen (H), oxygen (O) and nitrogen (N).

The four major compounds of living systems are carbohydrates, lipids, proteins and nucleic acids. Molecules of these compounds are composed mostly of atoms from the four major elements, plus some additional elements, such as phosphorus (P), sulfur (S), iron (Fe), magnesium (Mg), sodium (Na), chlorine (Cl), potassium (K), iodine (I) and calcium (Ca).

The following is a brief outline of the major chemical compounds of living systems; please refer to your recommended textbook for more information, illustrations and structural formulas.

Types Of Carbohydrates: Make A Selection

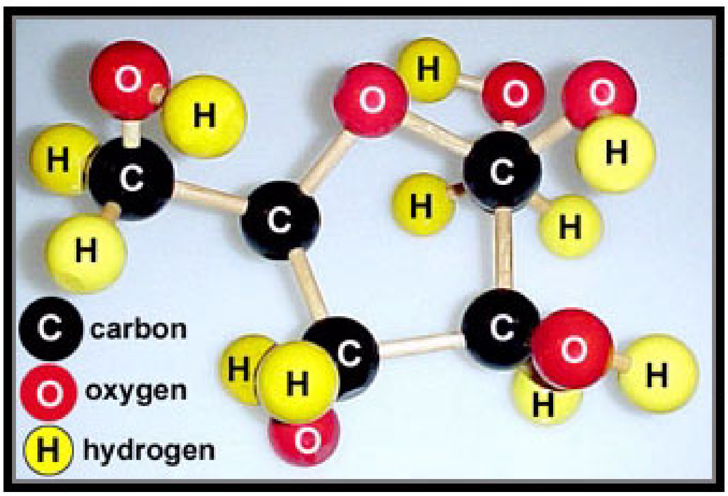
I. Carbohydrates: Compounds containing carbon (C), hydrogen (H) and oxygen (O); the H and O atoms typically occur in a 2:1 ratio.

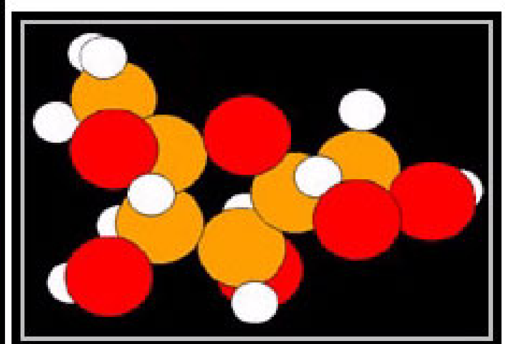
A. Sugars: Relatively small carbohydrate molecules composed of one or two sugar subunits (monomers).

1. Monosaccharides: Simple sugars composed of one sugar subunit. This includes 6-carbon (hexose) and 5-carbon (pentose) simple sugars. The pentose sugars deoxyribose and ribose are essential components of the genetic material DNA (deoxyribonucleic acid) and RNA (ribonucleic acid).

E.g. glucose & fructose: ($C_6H_{12}O_6$); arabinose & xylose: ($C_5H_{10}O_5$).

There are many other 6 carbon (and 5-carbon) sugar isomers with the same empirical formula, but with different structural formulas. In isomers of glucose, the six carbon, twelve hydrogen and six oxygen atoms are arranged in different positions within ring-shaped molecules. Some common isomers of glucose are mannose, galactose and fructose. Fructose is a common monosaccharide that is found in many fruits and vegetables, such as apples, oranges, grapes, carrots and sweet corn.





fructose: $C_6H_{12}O_6$

There are also optical (enantiomorphic) isomers in which the molecules occur in two mirror image forms, a right-handed or dextrorotatory (D) form and a left-handed or levorotatory (L) form. This is somewhat like right and left-handed gloves. The sugars of living systems are typically of the D form, such as D-glucose, while the amino acids of proteins are of the L form, such as L-alanine. The primary producers of glucose in the earth ecosystem are green plants, through the remarkable process of photosynthesis inside chlorophyll-bearing organelles called chloroplasts:

$$6\ CO_2 + 6\ H_2O = C_6H_{12}O_6 + 6\ O_2$$

See Photosynthesis & Cellular Respiration

Note: Complex organic molecules used in prescription drugs also occur as mirror image (enantiomorphic) isomers. It has been shown that the isomers of some drugs, such as SSRIs (selective serotonin reuptake inhibitors) have some undesirable side effects. In the antidepressant drug Lexapro®, the mirror image isomers have been removed to minimize side effects. Since this requires a smaller dosage, other medications may eventually be available with the undesirable or ineffective mirror image isomers removed.

2. Disaccharides: Two 6-carbon sugar subunits are joined together to form a 12-carbon sugar. E.g. the disaccharide sucrose ($C_{12}H_{22}O_{11}$) is made from two monosaccharide molecules (glucose and fructose) by dehydration synthesis in which one molecule of water is formed. The formation of water accounts for 22 hydrogen atoms (instead of 24) and 11 oxygen atoms (instead of 12) in the sucrose molecule. Maltose (called malt sugar) is a disaccharide composed of two glucose monomers. Lactose (called milk sugar) is a disaccharide composed of galactose and glucose.

$$C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O$$

Sugar cane and sugar beets are rich in sucrose. Malt sugar (maltose) is a disaccharide that is fermented to produce beer. It is obtained from germinated barley in which the starch polymers inside starch grains have been converted (hydrolyzed) into maltose. Lactose is a disaccharide composed of the two monosacharride sugars glucose and galactose. It is found in milk and other dairy products. Lactose intolerance is the inability to digest significant amounts of lactose, the predominant sugar in milk. This inability results from the shortage of the enzyme lactase, which is produced by cells that line the small intestine.

See Sugar Cane On The Island Of Kauai
See Sucrose-Rich Taproot Of Garden Beet
See The Hop Plant Used In The Beer Industry

B. Polysaccharides: Complex carbohydrates composed of many 6-carbon sugar subunits (monomers) joined together by dehydration synthesis. Depending on the polysaccharide, the sugar subunits may consist of complex chains of glucose molecules or other 6-carbon monosaccharides.

1. Starches (Amylum): Consisting of two polysaccharide polymers (amylose and amylopectin) composed of D-glucose subunits; stored in membrane-bound "starch grains" (amyloplasts) inside plant cells. [Animal starch or glycogen is stored in the liver.] Note: The carbohydrate inulin is different from starch. It is a polysaccharide composed of D-fructose subunits. Inulin occurs in the tubers of Jerusalem artichoke (**Helianthus tuberosus**), a member of the sunflower family (Asteraceae). See link to Jerusalem artichoke following the starch section.

a. Amylose (Soluble Starch): Soluble in hot water and used for starching clothing. A long molecule composed of 200-1000+ glucose subunits forming an unbranched helix.

b. Amylopectin (Insoluble Starch): Shorter molecules than amylose, with only 40-60 glucose subunits, forming highly branched chains that do not coil. Starch is deposited in concentric layers within the starch grains or amlyloplasts. Starch grains of different plant species have characteristic shapes, such as maize (corn), oats, bananas, potatoes and wheat. For example, banana starch grains are more elongate than potato starch grains. Starch is hydrolyzed (broken down) by amylase enzymes (including B-amylase and maltase). During hydrolysis a water molecule is inserted between each glucose subunit. Starch is stored in underground organs, including storage roots, rhizomes, tubers, corms and bulbs:

See Amyloplasts Of A Potato Tuber

1. Sweet Potatoes (**Ipomoea batatas**--Convolvulaceae): Fascicled storage roots.

2. Cassava (**Manihot esculenta**--Euphorbiaceae), the source of tapioca: Storage root.

3. Potato (**Solanum tuberosum**--Solanaceae): Tuber

4. Taro and Dasheen (**Colocasia esculenta**--Araceae), the source of poi: Corms

5. Achira (**Canna edulis**--Cannaceae): Tuberous Rhizomes.

6. True Yam (**Dioscorea alata** & other spp.--Dioscoreaceae): Large tubers.

Duckweed species, including **Lemna**, **Spirodela** and **Wolffia** produce starch-filled, overwintering bodies called turions. Because starch has a specific gravity of 1.5 it is heavier than water. Turions sink to the bottom during the winter months, as the surface of lakes and ponds freeze over. Since ice floats, the deeper water at the bottom remains liquid and slightly above freezing, hence, the turions remain unfrozen and alive in a dormant state. With the arrival of spring and warming temperatures, the surface ice melts and the turions rise to the surface where they give rise to another generation of duckweeds by budding.

Potatoes: Tubers From The Andes
Achira: An Amazing Species Of Canna
Sweet Potatoes: Roots From The Andes
See Turions Of Spirodela During The Fall
Cassava & Taro: Underground Vegetables
Dioscorea Yam: World's Largest Vegetable
Jerusalem Artichoke And Carbohydrate Inulin

2. Cellulose: Complex polysaccharide composed of long, unbranched chains of glucose subunits which are hydrogen bonded to adjacent glucose chains forming microfibril polymers. The microfibrils are in turn bonded together to form strong cellulose fibers. Cellulose is found in the cell walls of plants and provides rigidity and strength. It is one of the most abundant organic compounds on Earth. [Wood cells contain a different polymer called lignin which accounts for the strength, hardness and weight of lumber. Lignin is a phenolic compound, another class of chemicals to be discussed later in this outline.] Cotton fibers are almost pure cellulose, and are the world's most important textile fiber. Purified wood cellulose (from plant cell walls) is used in the manufacture of a number of synthetic products. Cellophane is made from a viscous solution of wood cellulose that is extruded through a narrow, slit-like opening. In rayon, the viscous solution of wood cellulose is extruded through minute openings called spinnerets to form strong, pliable fibers. Humans are not able to digest cellulose, and cellulose in the cell walls of plant tissues (vegetables, fruits and grains) mainly serves as insoluble fiber in a healthy diet. Herbivorous animals contain symbiotic bacteria that produce cellulose-digesting (cellulase) enzymes, such as in the rumen of cattle and in the caecum of rabbits. Termites are able to digest wood cellulose because of flagellate protozoans in their gut which in turn contain cellulase-producing bacteria.

Plant Fibers For Cordage & Textiles

3. Hemicellulose: A modified form of cellulose found in the endosperm tissue of seeds. The cell walls of the endosperm tissue become thickened with hemicellulose until they occlude most of the lumen (i.e. they cells become completely filled with hemicellulose). These thick-walled endosperm cells become very hard when dry, with hard, bony texture similar to ivory. The large seeds of several palm species are rich in hemicellulose, and this is the source of vegetable ivory. Even heavily lignified dead cells of the hardest ironwoods have a specific gravity less than 1.4, compared to more than 1.5 for vegetable ivory. Like wood, vegetable ivory is essentially composed of thick-walled dead cells; however, unlike grainy hardwoods it has a texture and hardness similar to ivory. In fact, vegetable ivory is remarkably dense, with a rating of roughly 2.5 on the scale of mineral hardness. [Compare this rating with 3.5 for a copper penny and 10 for diamond.] Ivory-nuts can be polished in a stone tumbler, as you would polish agates and quartz, or by using tin oxide and a buffing wheel.

Vegetable Ivory From Ivory-Nut Palms

4. Pectin: A large polysaccharide (molecular weight of 20,000 to 400,000) that is present in the middle lamella layer between plant cells. It functions as an intercellular cementing material that binds adjacent plant cells together. As fruit ripens, the pectin layer dissolves due to enzyme action, thus making the fruit soft and mushy. Some bacteria and fungi produce the enzyme pectinase which accelerates the break down of fruit tissues. Because pectin absorbs water

molecules forming a gel, most of the worlds pectin is used in the manufacture of jams and jellies. It is primarily extracted from apples and citrus peels, profitable by-products of the fruit juice industry. Because it is a very effective thickening agent and emulsifier, it is used in pharmaceuticals, cosmetics, adhesives, candy gumdrops and the popular medicine for diarrhea called Kaopectate®. It also prevents the formation of ice crystals in frozen deserts and adds viscosity to catsup.

5. True Gums: Complex polysaccharides composed of sugars other than glucose (primarily arabinose, fucose, galactose, mannose, rhamnose and xylose). Many different species of plants in a variety of families produce sticky saps composed of gums. These chemicals presumably seal off wounds and help to protect the plant from bacterial and fungal infections. The resinous pitch of conifers, such as pines (**Pinus**), also retards the boring larvae of bark beetles, but this is a terpene compound and not a gum. True carbohydrate gums are an entirely different class of chemicals from pine pitch (raw turpentine), gum mastic, gum guaiac and the chicle gum used in chewing gums. The latter chemicals are terpene derivatives which will be discussed later in this outline. Eucalyptus gums (gum kino) are chemically related to yet another group of plant chemicals called phenolic compounds. True plant gums are polysaccharides composed of many sugar subunits linked together. Unlike chicle gum, true gums are soluble in water. In fact, water-soluble plant gums are commonly used as thickening agents and emulsifiers, such as guar gum and gum tragacanth. Guar gum comes from the powdered seeds of **Cyamopsis tetragonolubus**, a herbaceous perennial legume from Africa. It is used in ice creams to prevent the formation of ice crystals by absorbing water. Gum tragacanth is considered one of the world's best natural plant gums. It comes from the sap of several species of spiny, shrubby, Middle Eastern locoweeds of the genus **Astragalus**, including **A. gummifer**. It was largely imported from the Zagros Mountains of Iran, when the United States was on better diplomatic terms with that nation. Locust bean gum, a thickening agent in ice creams and salad dressings, comes from the ground seeds of the carob tree (**Ceratonia siliqua**). Another valuable plant gum is gum arabic, obtained from the spiny, shrubby **Acacia senegal** of northeastern Africa. In addition to its use in foods, hand lotions and soaps, it is used in fine water colors, inks and confections. It also produces the water-soluble adhesive on postage stamps and the "lace curtain" on the sides of your beer glass. Plant gums also provide the soluble fiber in a healthy diet by absorbing water and adding bulk to the large intestine. Several dietary supplements contain the powdered husks of psyllium seeds from **Plantago ovata** (Plantaginaceae). Insoluble fiber comes from the indigestible cellulose cell walls of fruits and vegetables. Both types of fiber are beneficial in maintaining a healthy colon, particularly in older adults with diverticulosis.

Glistening globs of gum oozing from the branch of an apricot tree (**Prunus armeniaca**). Although it superficially resembles a terpene resin it is chemically very different. True gums are polysaccharides that will dissolve in hot water. Like resins they probably benefit the plant by sealing off wounds.

Photos & Information About Gum Tragacanth
Photos & Information About Psyllium Seeds

Two additional gums come from the sap of two species of trees native to dry forests of India. Gum karyaya or sterculia gum (**Sterculia urens**) comes from a tree in the chocolate family (Sterculiaceae). This water-soluble gum forms a strong adhesive gel when mixed with a small amount of water. Because of its resistance to bacterial and enzymatic breakdown, it has been used for dental adhesives and as a binder in bologna and other lunch meats. It is also used in salad dressings, cheese spreads, whipped toppings and hair setting gels. Gum ghatti (**Anogeissus latifolia**) is a natural gum from a tree in the combretum family (Combretaceae). The name "ghatti" is derived from the word "ghat" or mountain pass, and this valuable gum was originally carried by people over mountain passes or "ghats" to ports in India. Gum ghatti has properties intermediate between gum arabic and karaya gum. Because it is a superior oil emulsifier with a higher viscosity, is commonly used in liquid and paste waxes and for fat soluble vitamins.

Another polysaccharide gum used as a water soluble thickening agent, binder, and emulsifier in foods and cosmetics is xanthan gum. This natural gum is produced by fermenting corn sugar with the bacteria **Xanthomonas campestris**. The bacteria produce xanthan as part of their cell walls. Like starch and cellulose, xanthan gum is a long chain polysaccharide composed of many sugar subunits. Xanthan gum has the consistency of corn starch but is undigestible like cellulose.

It is used in many food products, including salad dressings and low cholesterol egg substitutes made from egg whites and vegetable gums.

Necco®, an old-fashioned brand of candy wafers that contain three natural vegetable gums, including gum tragacanth, gum arabic and xanthan gum.

The swelling of polysaccharide gums and cellulose when they are hydrated is a good example of imbibition, the remarkable process by which water molecules move into a porous, colloidal material and cause it to swell. In fact, one of the main factors that initiates the rock-splitting process by roots is also imbibition. Water (H-O-H) is a polar molecule with a negatively-charged oxygen atom (O) flanked by two positively-charged hydrogen atoms (H). Minute colloidal particles and long-chain polymer molecules develop electrical charges when they are wet. This is particularly true when they contain exposed hydroxyl (OH) groups with negatively-charged oxygen atoms and positively-charged hydrogen atoms. Like tiny magnets, the water molecules permeate these polymers, adhering to the charged surfaces as well as cohering to the positive and negative ends of adjacent water molecules. This influx of water molecules and chemical bonding (called hydrogen bonding) causes the colloidal polymers to swell.

The ability of polar water molecules to form hydrogen bonds explains water's remarkable "magnetic" properties which are absolutely vital for life on earth. In addition to the swelling and bursting of seed coats prior to germination, cohesive water molecules form continuous chains from the roots to the leaves of trees hundreds of feet above the ground. Without this strong force of attraction between adjacent water molecules, water could never rise in tall stems, and plant life on earth would be limited to low-growing species like mosses and liverworts. Because of its polarity, water is a very stable substance and tends to remain a liquid rather than changing into steam as in other liquids. Frozen water is lighter and floats, thus insulating the deeper water of lakes and ponds from freezing solid. Without this important attribute, aquatic animals living in lakes and ponds in cold climates could never survive the severe winter months. And because of its polarity, water is a universal solvent essential for the myriad of biochemical reactions necessary for life.

Alginates, carrageenans and agars are hydrophilic (water-loving) polysaccharides closely related to gums. In fact, they are treated here under the category of carbohydrate gums. Like gums, they absorb water and are used as thickening agents, emulsifiers and to prevent the formation of ice crystals in frozen deserts. They are also referred to as phycocolloids because they all come from algae (phyco) and they form jelly-like, colloidal suspensions in water. Alginates (also called algin) are obtained from species of **Laminaria** and another macroscopic brown algae called giant bladder kelp (**Macrocystis pyrifera**) that grows along the coast of southern California. In some fast food restaurants, shakes without the word "milk" were thickened with algin. For this reason they were called shakes rather than milk shakes. Algin colored with various dyes is also the source of the "fruits" in some fruitcakes. [Artificial candied "fruits" are also made from gelatin.] Carrageenans are extracted from a red alga called Irish moss (**Chondrus crispus**). Agar is another phycocolloid obtained from several red algae genera, including **Gelidium** and **Gracilaria**. Chemically, agar is similar to carrageenan, except that it has the superior quality of forming stiff gels in smaller concentrations. Agar gels have a superior capacity for changing into a liquid when heated, and then readily cooling back into a gel. They are unsurpassed for nutrient media used for tissue culture and in bacteriology (microbiology).

Note: the animal counterpart to plant gums and phycocolloids is gelatin, a heterogeneous mixture of water-soluble proteins. Gelatin is a thickening agent or hydrogel derived from denatured collagen protein in fibrous animal connective tissue, and is the key ingredient in Jello® desserts. It is not found in nature but is derived chemically from collagen. Its thermoreversibility properties allow gelatin to change from a liquid state to a gel as it cools. Gelatin is obtained by boiling skin, tendons, ligaments and bones with water. Gelatin from cattle bones and hides is used primarily in photographic and pharmaceutical applications, while pork skin is the most significant raw material for edible food-grade gelatin. Some of the uses for gelatin include Gummi Bears, Gummi Worms, soft caramels and other chewy confections. Gelatin also provides the elasticity and chewy consistency of marshmallows. Prior to the use of gelatin in the early 1800s, the precursor of modern-day marshmallows was thickened with the mucilaginous sap from the root of the European marsh mallow (**Althaea officinalis**), a hollyhock relative in the mallow family (Malvaceae).

It should be noted here that Jello® is not recommended with the following fresh or frozen fruits and roots: pineapple (**Bromeliaceae: Ananas comosus**), papaya (Caricaceae: **Carica papaya**), figs (Moraceae: **Ficus carica**), guava (Myrtaceae: **Psidium guajava**), kiwi (Actinidiaceae:

Actinidia chinensis), and ginger root (Zingiberaceae: **Zingiber officinale**). All of these plants contain proteolytic enzymes which prevent the gelatin from setting (changing into a gel state) as it cools. Some of these protease enzymes have been used medicinally and as meat tenderizers, such as ficin from figs (**Ficus**), papain from papaya (**Carica**), and bromelain from pineapples (**Ananas**). Try adding some pineapple juice to milk. The milk protein begins to coagulate and degrade as it reacts with the bromelain. Pineapple juice will also remove the gelatin-emulsion surface on black & white photographic film. [The emulsion surface contains light sensitive silver halides in a gelatin that is rinsed away during processing. The silver that remains on the film emulsion reveals the negative image from which the photographic print is created.] In French Polynesia, the ficin-rich sap from a native banyan fig is used to kill parasitic worms and to treat worts and skin cancers. Ficin also breaks down the female pollinator wasp inside wasp-pollinated Calimyrna figs grown in California's Central Valley. When you eat one of these delicious figs, you won't find the wasp inside that was responsible for the seed formation and superior nutty flavor.

See Candies Made With Gelatin
See The Red Alga Called Gelidium
See The Red Alga Called Irish Moss
Giant Bladder Kelp: Source Of Algin
Read About The Forces Of Imbibition
Calimyrna Fig & Its Pollinator Wasp
See Photo Of Gum Tragacanth Locoweed
Read About Natural Gums From Acacia Sap

6. Chitin: A complex nitrogen-containing polysaccharide found in the cell walls of certain fungi, and in the hard, exoskeletons of crabs, lobsters and insects. It is also found in many minute crustaceans and the statoblasts of bryozoans. Unlike the calcareous (calcium carbonate) shells of mollusks, chitin is not dissolved by strong acids. Like cellulose, the cross linkages between glucose molecules make it undigestible to humans. Unlike all other polysaccharides discussed in this section, each glucose subunit has an amino group (NH_2) attached to it. The word chitin is not to be confused with the marine intertidal mollusk called a chiton.

Note: Finger nails, horn, hair, wool, claws, beaks, scales, and feathers are composed of hard keratin. Soft keratin or pseudokeratin includes dead skin epidermal tissue and whalebone. Keratin is a fibrous protein with a high percentage of the amino acid cystine. Unlike other proteins, including collagen of connective tissue, tendons and cartilage, keratin is resistant to hydrolysis by most solvents (including weak acids and bases), and by proteolytic enzymes of the gastrointestinal tract. The stability of keratin is due to numerous primary disulfide (-S-S-) cross-linkages within the molecule and secondary hydrogen bonding between neighboring polypeptide chains. Keratoses are horny, wartlike, keratinized growths on the skin often associated with the precusors of certain skin cancers, such as basal cell carcinomas.

Types Of Lipids: Make A Selection

II. Lipids: A large group of chemicals that are generally insoluble in polar solutions such as water, but soluble in nonpolar solvents such as alcohol. Note: Some of the chemical groups included in this outline, such as terpene steroids and carotenoids, are classified as lipids in general biology textbooks.

A. Fats & Oils: Plant oils are typically composed of triglyceride molecules (technically called esters) composed of a 3-carbon alcohol (glycerol) plus three 18-carbon (or 16-carbon) fatty acids. Fatty acids are long, linear hydrocarbon chains containing 12 to 24 carbon atoms. One end of the molecule contains a carboxylic acid group (COOH) from which chemists count the number of carbon atoms. The other end is the methyl or omega end from which nutritionists and biochemists count the position of the first bond. The location of the first double bond determines whether the fatty acid is an omega-6 or an omega-3 fatty acid.

Unlike the saturated fatty acids of animal fats which are solid at room temperature, plant fatty acids are typically unsaturated and liquid at room temperature, with one or more double bonds between the carbon atoms (mono-unsaturated and polyunsaturated). [Note: The palm fatty acid palmitin is saturated and contains 16 rather than 18 carbon atoms.] Examples of unsaturated plant oils include safflower, soybean, sunflower, corn, sesame, cottonseed and canola. The degree of unsaturation is measured by allowing iodine to combine with a standard amount of a particular oil. Iodine ions are incorporated into the oil's fatty acid chains at positions where there were double bonds. Of the examples of unsaturated plant oils listed earlier in this paragraph, safflower oil has the highest iodine value of 140-150. Linseed oil, a polyunsaturated drying oil used in the paint industry, has an iodine value of 165-204. In order for unsaturated oils (such as the corn and soybean oils in margarines) to be solid at room temperature, they must be hydrogenated under heat and pressure, a process that some natural food enthusiasts find deplorable. The following table shows the structure of a typical plant fat molecule (triglyceride) composed of glycerol plus 3 fatty acids. Since it contains unsaturated fatty acids, it is liquid at room temperature and is often referred to as an oil. The fatty acids may be saturated (with all single bonds), mono-unsaturated (with one double bond) or polyunsaturated (with 2 or more double bonds): There is evidence that a diet high in saturated animal and palm fats may be correlated with high levels of blood cholesterol and fatty deposition in the blood vessels, a serious condition known as atherosclerosis. [Omega-3 fatty acids prevalent in fish oils may actually help to reduce levels of LDLs in the blood and lower the risk of atherosclerosis.] Diets rich in polyunsaturated oils have be correlated with an increased risk of certain cancers because of highly reactive carbon fragments from the breakdown of fatty acids. These carbon fragments have unpaired electrons and are powerful oxidizing agents known as free radicals. In oil base paints, unsaturated oils, such as castor and linseed oils, allow the paint to oxidize readily in the air, forming a dry, elastic, waterproof coating. A typical fat molecule has an empirical formula of $C_{57}H_{110}O_6$. Notice that the ratio of H and O atoms is not 2:1 as in carbohydrates.

Structure Of A Fat Molecule or Triglyceride:

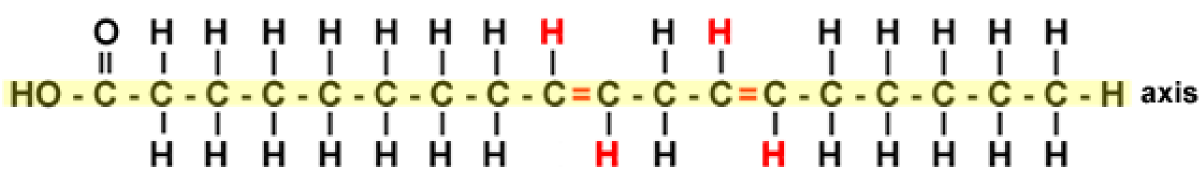
```
  H   C#    1  2  3   4   5   6   7   8  9  10  11  12  13  14  15  16  17 18
  |
H-C-OH HOO-C-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH3 Stearic
  |
H-C-OH HOO-C-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH=CH-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH3 Oleic
  |
H-C-OH HOO-C-CH2-CH2-CH2-CH2-CH2-CH2-CH2-CH=CH-CH2-CH=CH-CH2-CH2-CH2-CH2-CH3 Linoleic
  |
  H

Glycerol                           3 Fatty Acid Molecules
```

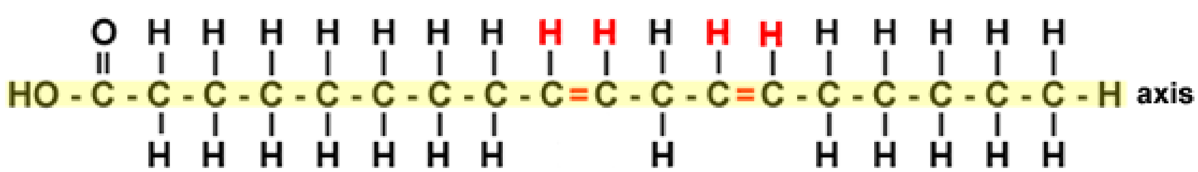
Glycerol + Three Fatty Acids = A Fat Molecule (Triglyceride).
Linoleic Acid Polyunsaturated: 2 Double Bonds In The Molecule.
Stearic Acid Saturated: All Single Bonds Between Atoms Of Carbon.
Oleic Acid Monounsaturated: 1 Double Bond Between Carbons 9 & 10.
H_2O (HOH) Formed When Fatty Acid Bonds To Each Carbon Of Glycerol.

Cis and Trans Fatty Acids

Fatty acid isomers containing double bonds may have the cis or trans configuration. In cis fatty acids, all the hygrogen atoms adjacent to the double bonds are on the same side of the longitudinal carbon axis. In trans fatty acids, the hygrogen atoms adjacent to the double bonds occur on alternate sides of the main axis. To illustrate the difference between cis and trans configurations, see the following illustration of the 18-carbon fatty acid called linoleic acid :



linoleic acid: *trans* configuration (*trans* isomer)



linoleic acid: *cis* configuration (*cis* isomer)

Polymers of linoleic acid: The **trans** and **cis** configurations of $\mathbf{C_{18}H_{32}O_2}$

> In the **trans** configuration, the four hydrogen atoms adjacent to the double bonds occur on alternate sides of the main carbon axis (two on one side and two on the opposite side). The **trans** configuration is chemically more stable. It is typically produced during partial hydrogenation of polyunsaturated vegetable oils. In the **cis** configuration, all four hydrogen atoms adjacent to the double bonds occur on the same side of the carbon axis.

When polyunsaturated vegetable oils are partially hydrogenated to improve their texture, **trans** fatty acids are produced. **Trans** fatty acids tend to raise the level of low density lipoproteins (bad LDLs) and lower the level of high density lipoproteins (good HDLs). These changes in blood lipids (cholesterol levels) may increase the risk of heart disease (atherosclerosis) in some people. Dieticians generally recommend the use of mono-unsaturated, unhydrogenated oils such as canola or olive oil whenever possible, and the avoidance of **trans** fatty acids found in french fries, donuts, chips, cookies and crackers.

Omega-3 and Omega-6 Fatty Acids

In the above illustration, the first double bond is located on carbon #6, counting backwards from right to left. [The first carbon is at the end opposite the carboxylic or COOH group.] Therefore, this is an omega-6 fatty acid. Unsaturated fatty acids found in plant oils and seeds are typically omega-6 fatty acids. In omega-3 fatty acids, the first double bond in on carbon #3, counting back from right to left on the above illustration. Omega-3 fatty acids are prevalent in fish oils and flax seeds (**Linum usitatissimum**).

Blood Triglycerides and Cholesterol

Cholesterol is a complex lipid and vital precursor of sex hormones, vitamin D and bile salts. It is produced by the body, although some dietary cholesterol comes from animal products. Cholesterol is carried to sites in the body by low-density lipoprotein molecules (LDLs). High-density lipoproteins (HDLs) remove cholesterol from these sites and deliver it to the liver for breakdown. Excessive levels of cholesterol in the blood can lead to fatty deposition in blood vessels (arteries) called plaque. For example, damage to a blood vessel wall (by injury or strain) causes cells underlying the internal wall to divide. White blood cells (macrophages) accumulate in the area to ingest particles of damaged cells. LDLs carrying cholesterol gather in the area to provide materials for repairing the wall. While waiting to be used, the cholesterol molecules can become oxidized, causing them to be engulfed by macrophages. After engulfing several oxidized molecules, the macrophages die and become deposited as fatty "foam cells" in the area of the wall being repaired. A buildup of these fatty deposits mixed with fibrous muscle cells is called plaque, which can narrow the diameter of an artery and seriously impede the blood flow. This can be life threatening if the blood vessel happens to be a coronary artery that supplies the heart muscle with oxygen-rich hemoglobin. Even without injury, plaque can form in arteries if cholesterol levels in the blood are high enough, particularly if they become oxidized and are engulfed by roving macrophages. The condition or disease in which blood vessels become clogged with plaque is called atherosclerosis.

Any substance that lowers the LDLs and increases the HDLs tends to reduce the probability of plaque formation and a heart attack. Lowering the intake of saturated animal fats can reduce the total cholesterol level but does not alter the ratio of lipoproteins. Saturated fatty oils in tropical palms and hydrogenated oils in margarines can increase the amount of LDLs in the blood. At this time, the best type of fatty acids for a healthy balance of LDLs and HDLs are the monounsaturated fatty acids found in olive oil (**Olea europea**) and canola oil (**Brassica napus**).

Some of the most important seed oils used for food are olive oil (**Olea europea**), mustard oil (**Brassica** spp., incl. **B. nigra**), canola oil (**B. napus**), corn oil (**Zea mays**), soybean oil (**Glycine max**), peanut oil (**Arachis hypogea**), cottonseed oil (**Gossypium** species), safflower oil (**Carthamus tinctorius**), sunflower oil (**Helianthus annuus**) and sesame oil (**Sesamum indicum**). With the exception of olives, all of these oils are extracted entirely from the seeds. Olive oil is expressed from the seed and the fruit wall or pericarp. Oils used for food and industrial purposes include coconut oil (**Cocos nucifera**), palm oil from the African oil palm (**Elaeis guineensis**), castor oil (**Ricinus communis**), tung oil (**Aleurites fordii**), candlenut or kukui-nut oil (**A. moluccana**) and linseed oil (**Linum usitatissimum**).

Although castor oil is rather malodorous and distasteful, it is the source of several synthetic flower scents and fruit flavors (esters), such as jasmine, apricot, peach, plum, rose, banana and lemon. The chemicals (esters) responsible for these flavors and aromas are obtained from ricinoleic acid, one of the important ingredients of natural castor oil. In fact, ricinoleic acid comprises about 90% of the total triglyceride fatty acids of castor oil. Castor oil is also the primary raw material for the production of sebacic acid, which is the basic ingredient in the production of nylon and other synthetic resins and fibers. Approximately three tons of castor oil are necessary to produce one ton of nylon. Sebacic acid is a 10-carbon dicarboxylic acid with a carboxylic group (C-OOH) at each end of the molecule. It is reacted with 1,6-hexanediamine, a 6-carbon molecule with an amino group ($C\text{-}NH_2$) at each end. The free carboxylic and amino ends of these molecules begin bonding together in a chain reaction called condensation polymerization, in which a water molecule is produced at each link. The resulting nylon polymer is called Nylon 6,10 to denote the 6-carbon diamine and 10-carbon sebacic acid.

Linoleum, discovered in 1863 by Frederick Walton, is named after the flax plant (**Linum**) and oil (**oleum**). Oxidized linseed oil was mixed with ground cork and pigments, pressed onto a burlap or felt backing, and then baked. The tough, elastic, waterproof qualities of oxidized linseed oil gave linoleum its fine quality features.

See Article About Castor Oil
See Kukui Nuts & Tung Oil Tree
Article About Olives & Stone Fruits
Palm Fruits: Coconut & African Oil Palm

B. Waxes: Complex lipids composed of a long-chain alcohol (longer than glycerol) plus many fatty acids (more than 3 as in fats & oils). Waxes tend to be solid at room temperature and provide a durable, protective covering for plants and animals. Examples of waxes include the cuticle of leaves (waxy covering over leaf surface); waxy coating on fruits (e.g. apples); beeswax (hexagonal cells of honeycomb); lanolin (waxy layer secreted onto wool of sheep); and, of course, ear wax.

1. Carnauba Wax: From exudate on leaves of Brazilian wax palm (**Copernicia prunifera**). Wax is removed from dried leaves by beating them to dislodge the exudate. The wax is melted and molded into blocks for export. A very hard wax used for car polishes, floor waxes and shoe polish.

2. Jojoba "Oil": From the seeds of jojoba (**Simmondsia chinensis**), a member of the Simmondsiaceae. This shrubby species was once placed in the boxwood family (Buxaceae), but rabbit serology tests (comparing the reactions of antibodies in rabbit serum with plant proteins) have shown that it is more closely related to the euphorbia family (Euphorbiaceae), and actually should be placed in its own monotypic family. Although it is native to the American southwest, the first specimen was named **Buxus chinensis** because it was thought to be a boxwood (**Buxus**) from China. Since it is composed of unsaturated fatty acids, it is liquid at room temperature. It has outstanding lubricating qualities and can be hydrogenated to produce a solid wax for candles and cosmetics. A high quality liquid wax with properties similar to whale oil.

3. Candelilla Wax: A high quality wax obtained from the succulent stems of candelilla **Euphorbia antisyphilitica**, a member of the diverse euphorbia family (Euphorbiaceae). Candelilla is native to the Chihuahuan Desert along the United States-Mexico border.

4. Meadow Foam: Another high quality wax obtained from the seeds of meadow foam (**Limnanthes** species) in the false-mermaid family (Limnanthaceae). Several species of meadow foam are native to the rare and endangered vernal pool habitat in California's Central Valley, and in coastal valleys of southern California. Although too rare of a plant to be harvested commercially, modern techniques in recombinant DNA technology using bacterial plasmids could make this a potentially valuable wax product.

See Photo Of Jojoba "Oil"
See Honeycomb Of Honey Bee
Waxes From Stems And Leaves

C. Phospholipids: Important lipids found in the cell membranes of plants and animals. Their structure is similar to that of a fat molecule, except that a polar (hydrophilic) phosphate group (PO_4) replaces the third fatty acid. Because of their unique bipolar structure, phospholipids form a double lipid layer (bilayer) in cell membranes (sandwiched between two layers of protein) that is permeable to water molecules. This "sandwich structure" provides the vital interface between the interior and exterior of cells that is permeable to water molecules.

Cell Membrane: Sandwich Model Of Lipid Bilayer

D. Steroids: A complex group of compounds with the same backbone structure of four fused carbon rings (see hyperlink at end of this paragraph). In botany textbooks they are referred to as terpene derivatives, and perhaps are better treated under the terpene category. [In fact, use the terpene category for plant steroids on Botany 115 Exam #2.] Steroids include vital animal compounds, including cholesterol, cortisone, and the sex hormones estrogen, progesterone and testosterone. Vitamin D and bile salts used for fat digestion are synthesized from cholesterol. Steroids are also common in plants, including diosgenin in the tubers of certain yams of the genus **Dioscorea**. In fact, diosgenin is used as the steroid precursor for synthetic sex hormones used in birth control pills. Steroidal glycosides (molecules containing a steroid plus sugar) are toxic to some vertebrates, including people. They are synthesized by many flowering plants, including milkweeds of the genus **Asclepias**. They are taken up by the larvae of monarch butterflies who feed extensively on milkweeds. When the caterpillars metamorphose into butterflies, the stored glycosides make them toxic to birds who learn to avoid these brightly colored insects.

See Steroids From Dioscorea Yams

Types Of Proteins: Make A Selection

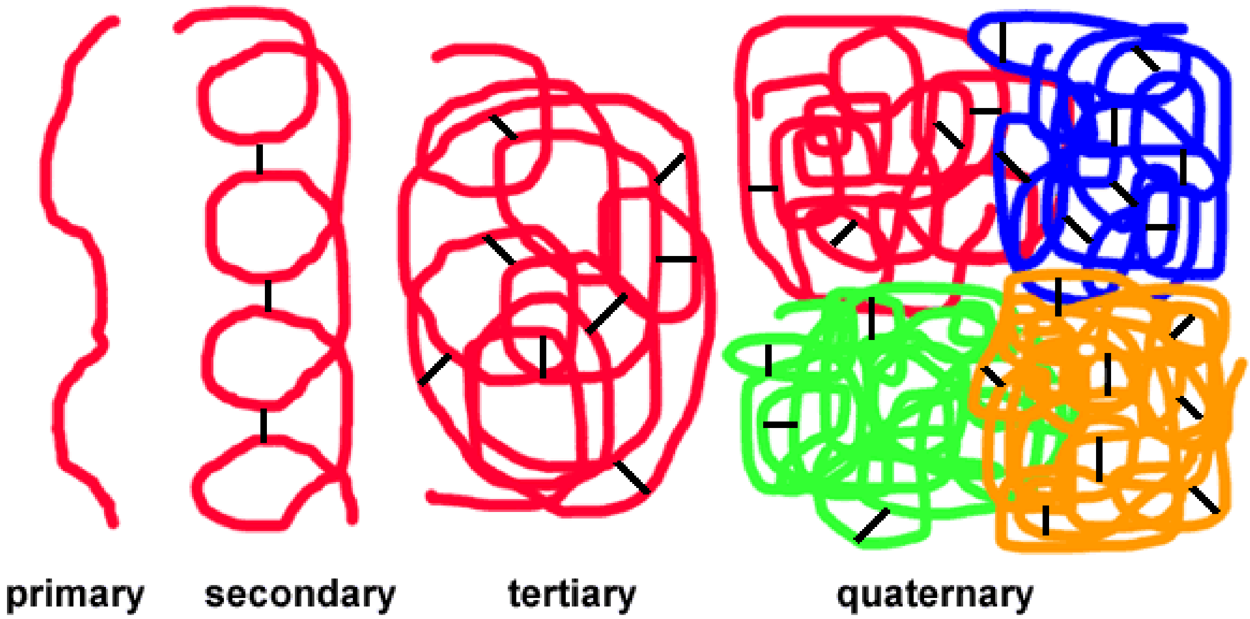
III. Proteins: This is a huge group of macromolecules produced by plants and animals. Structural protein include collagen of fibrous connective tissue and skin, which constitutes about one third of the total protein of mammals, and keratin of nails, horn, hair, wool, claws, beaks, scales and feathers. Proteins are composed of long chains (polypeptides) of subunits called amino acids, with an average of about 400 or 500 amino acid molecules per protein. For example, the human red blood pigment hemoglobin contains 584 amino acids. Amino acids of living systems are the L-form optical isomer, in contrast to the D-form for sugars. There are 20 different amino acids in human protein, although many additional amino acids occur in nature. Eight of the 20 amino acids are called "essential" because they must come from a protein diet. The remaining 12 are called "nonessential" because they can be synthesized by cells. All the amino acids must be present to synthesize protein, if one or more are missing, the organism will eventually die from protein deficiency. Essential amino acids are to proteins as vowels are to words. If one or more vowels are missing, then words canot be spelled correctly and sentences become meaningless. For example, the short sentence "the man and boy are sad" is meaningless without vowels. If you take away the vowels, the sentence becomes "th mn nd b re sd" Although plants can synthesize all of their amino acids, the herbicide Roundup® blocks the synthesis of certain aromatic amino acids, thus gradually killing the plant.

The eight essential amino acids in human protein are: tryptophan, phenylalanine, lysine, threonine, valine, methionine, leucine, and isoleucine. The twelve nonessential amino acids in human protein are glycine, alanine, serine, cystine (cysteine), aspartic acid (aspartate), asparagine, glutamic acid (glutamate), glutamine, arginine, histidine, tyrosine, and proline. The essential amino acid lysine is deficient in grains, but is present in adequate levels in legumes. Likewise, the essential amino acid methionine is deficient in legumes, but is present in adequate levels in grains. If either of these two essential amino acids is missing from your diet, you may suffer from protein deficiency. Some general biology textbooks state that a vegetarian diet should include legumes, such as beans and peas from the legume family (Fabaceae), and grains, such as wheat and rice from the grass family (Poaceae). The problem with this statement is that the diet of preagricultural humans, evolving as it did from primate ancestors, consisted primarily of fruits, nuts, wild legumes, edible roots and tubers, and some meat. Not until about 10,000 years ago did cereal grains and legume crops become an important component of the human diet. This subject is summarized by G. Wadley & A. Martin (1993) in an article entiltled "The Origins of Agriculture--A Biological Perspective and a New Hypothesis," **Australian Biologist** 6: 96-105.

The Origins Of Agriculture by Wadley & Martin

In the book **Jurassic Park** by Michael Crichton (1990), the dinosaurs on Isla Nublar (off the coast of Costa Rica) were genetically engineered to be "lysine dependent." All the dinosaurs received a mutant gene that produced a faulty enzyme in protein metabolism. As a result, they could not manufacture the amino acid lysine. Unless they received a rich dietary supplement of lysine they would die within days. This was a protective measure to prevent the dinosaurs from surviving in the real world. In the last chapter, some unknown animals were eating certain crops on the Costa Rica mainland. It turned out that the crops were agama beans and soy beans, two species of legumes rich in lysine. The book ended on this note, making you wonder if certain dinosaurs (perhaps velociraptors) had escaped and reached the mainland.

Amino acids are to proteins as letters are to words. An unabridged dictionary reveals the astonishing number of words that can be created with a 26 letter English alphabet, with most words less than 20 letters. Although human protein is constructed from a "20 letter" alphabet, the average protein "word" is made from hundreds of amino acid "letters," resulting in astronomical possibilities for different proteins. Some of the vital proteins in human systems are **(1) Structural Proteins** which comprise the body and its organs and tissues; **(2) Enzymes** which serve as vital catalysts in biochemical reactions; **(3) Hormones** such as the vital compound insulin that regulates the blood sugar level; and **(4) Antibodies** which serve to protect the body from renegade viruses and bacterial invasions. Proteins come in four main structural forms: **(1) Primary:** A straight chain of amino acids; **(2) Secondary:** A helical coil of amino acids stabilized by hydrogen bonds; **(3) Tertiary:** Folding and looping of a coiled polypeptide stabilized by hydrogen bonds; and **(4) Quaternary:** Four tertiary proteins joined together (e.g. hemoglobin). A molecule of hemoglobin is composed of four polypeptides, each with 146 amino acids, a grand total of 584. Heat or weak acid solutions can destroy the hydrogen bonding causing the tertiary proteins to uncoil, a condition termed denaturation. This is why vinegar (acetic acid) can actually "cook" an egg white (albumen) without heat. Proteins in raw fish called seviche (ceviche) are denatured by citric acid when the fish are marinated in lime or lemon juice. Hemotoxic proteins at the site of a rattlesnake bite can also be denatured by an electrical discharge from a device similar to a stun gun.



Oversimplified diagram of the four main structural forms of protein: **(1) Primary:** A straight chain of amino acids; **(2) Secondary:** A helical coil of amino acids stabilized by hydrogen bonds; **(3) Tertiary:** Folding and looping of a coiled polypeptide stabilized by various types of bonds, including hydrogen bonds and disulfide bridges; and **(4) Quaternary:** Four tertiary proteins joined together. The various types of chemical bonds between loops and folds in the molecules are shown as short black lines. In the helical protein of hair, hydrogen bonds within individual helices of keratin, and disulfide bridges between adjacent helices, impart strength and elasticity to individual hairs. Water can disrupt the hydrogen bonds, making the hair limp. When the hair dries, new hydrogen bonding allows it to take on the shape of a curler. Permanent wave solutions induce new disulfide bridges between the helices. Genetically determined, natural curly hair also has a different arrangement of disulfide bridges compared with straight hair.

Enzymes: Enzymes are large protein molecules that catalyze specific biochemical reactions. A phenomenon known as bioluminescence, where living organisms glow in the dark, requires a specific enzyme catalyst. The emission of light by an organism or population of organisms involves the oxidation of luciferin in the presence of ATP and the enzyme luciferase. If luciferase or ATP is lacking, the reaction will not occur. Examples of bioluminesence include dinoflagellates causing "red tide," lightning "bugs" (beetles), glow worms (beetle larvae), comb jellies (phylum Ctenophora), the deep sea angler fish, and a remarkable fungus called the jack-o-lantern mushroom.

The Mysterious Deep-Sea Angler Fish
The Beautiful Marine Comb Jellies
Bioluminescenct Comb Jellies
The Jack-O-Lantern Fungus

The complex folding of tertiary proteins produces their characteristic three-dimensional structure with unique shapes and grooves analogous to a key that fits into a lock. In fact, the "Lock & Key Theory of Enzyme Specificity" is a plausible model that explains how a specific enzyme only fits into a certain substrate molecule because of the unique shape of its active site. This temporary joining of the enzyme molecule affects the chemical structure of the substrate, weakening certain bonds within the molecule so that it breaks down (hydrolyzes). It is devastating to a living system if vital proteins, such as enzymes and antibodies, are not synthesized or are blocked by a genetic disease, invasive virus or poison. For example the AIDS (HIV) virus attacks the immune system that produces T-cells and antibodies, thus rendering the body helpless against infections by other viruses, bacteria and cancer cells. Some poison molecules, such as certain plant alkaloids, can attach to the active site of vital enzymes, thus blocking the action of these enzymes.

Illustration Of The Lock & Key Model Of Enzymes
Diagram Of Enzyme Block By A Poison Molecule
See Locoweed Alkaloids That Poison Livestock

The order and position of amino acids in a protein molecule is critical for the vital function of the molecule. The red bood pigment hemoglobin is a quaternary protein composed of two alpha polypeptides and two beta polypeptides. The substitution of valine for glutamic acid (glutamate) in the beta polypeptide changes the oxygen-carrying potential of this vital blood cell pigment, and is the biochemical explanation for the genetic disease called sickle-cell anemia. At position number six on the beta polypeptides, the amino acid glutamic acid is replaced by valine. This structural change in the protein results in a distortion of the blood cell from a normal biconcave disk to a sickle shape. The exact number and order of amino acids in protein molecules are determined by the DNA base sequence in genes, and genetic mutations are essentially "misspelled " genes.

For the sake of simplicity, let B stand for the gene that produces the normal beta polypeptide and B' stand for the mutant allele that produces the abnormal (mutant) form of the beta polypeptide. Normal homozygous people inherit two normal genes (BB) and have normal beta polypeptides in their hemoglobin molecule. Homozygous people suffering from sickle-cell anemia inherit two mutant genes (B'B') and have abnormal (mutant) beta polypeptides. Some people have the intermediate sickle-cell trait and are heterozygous BB'. These people have normal and abnormal beta polypeptides. Although their blood cells appear normal, they may become distorted under lower oxygen conditions, such as high elevation roads or in airplanes; therefore gene B is not completely dominant over gene B'. Some references (including your recommended text) refer to this condition as incomplete dominance.

Prions: Renegade Proteins That Cause Mad Cow Disease. Prions (pronounced PREE-ons) are disease-causing protein particles. They may be a mutated form of a brain protein with an abnormal (improper) tertiary structure. Prion diseases are referred to as spongiform encephalopathies because of the post mortem appearance of the brain with large vacuoles in the cortex and cerebellum. A number of diseases of animals may be caused by prions, including Scrapie (sheep), TME (Transmissible Mink Encephalopathy), CWN (Chronic Wasting Disease in muledeer and elk), and BSE (Bovine Spongiform Encephalopathy in cows). The latter condition is better known as Mad Cow Disease. There are also several human diseases attributed to prions including CJD (Creutzfeldt-Jacob Disease), FFI (Fatal Familial Insomnia), Kuru, and Alpers Syndrome.

Prions are thought by some researchers to be proteins with an abnormal tertiary structure. Exactly what causes this 3-dimensional protein to be folded improperly has been a topic of great speculation. Some earlier hypotheses stated that it was due to an incorrect amino acid sequence, but this may not be the case. The prion protein may interact with normal protein molecules, forcing them to fold abnormally. Over time, the improperly folded proteins increase in concentration and may destroy brain tissue. Prions reproduce without DNA or RNA. They replicate by interacting with other proteins in a chain reaction, thereby causing subsequent proteins to also fold improperly. The precise mechanism by which they multiply is unknown at this time, but they appear to work like a enzyme that catalyzes its own multiplication. Prions may be inherited, possibly by a recessive gene that shows up in homozygous recessive individuals. Or, they may be transmitted by eating infected brain tissue that has been ground up in animal feed or in hamburger and sausage. Muscle tissue contains nerve tissue and blood vessels; however, preliminary tests indicate that prions are confined to the brain and spinal cord of livestock. The bottom line here is that prions are renegade proteins that multiply and destroy the brains of livestock and people. They are not a bacterium or virus, and they are practically impossible to kill by conventional methods. In a sense they are "immortal molecules" that truly represent a serious threat to mammalian life forms.

Glycoproteins (protein plus carbohydrate) are complex polypeptides (amino acid chains) plus polysaccharide chains. They include a number of large molecules in living systems, including membrane proteins that provide cell recognition. Patrolling white blood cells called T-cells can recognize "self" versus "alien" cells by these special membrane proteins. Glycoproteins also include blood cell antigens and antibodies. They are also involved in pollen grain recognition on the receptive stigmas of the same or different species.

Immunotoxins are conjugated proteins consisting of monoclonal antibodies (made from another animal) with an attached protein toxin called a lectin. For example, the deadly lectin from the castor bean (called ricin) is joined to special antibodies against a specific type of cancer. Like armed, molecular missiles, the antibodies carry the deadly ricin directly to the tumor, thus killing the tumor cells without affecting other mitotic cells in the patient. See the following references for more information about lectins and the anti-tumor uses of castor beans.

Anti-Tumor Uses Of Castor Bean
The Deadliest Seeds On Earth

One of the deadliest seeds on Earth is the castor bean (**Ricinus communis**). The seeds contain ricin, a very toxic protein compound known as a lectin. According to the **Merck Index: An Encyclopedia of Chemicals, Drugs, and Biologicals** (1997), a dose of ricin weighing only 70 micrograms or two millionths of an ounce (roughly equivalent to the weight of a single grain of table salt from a salt shaker) is sufficient to kill a 150 pound (68 kg) person. In striking contrast with its use in medicine to prolong human life, there are also reports of ricin being used in covert assassination attempts and as a potential toxin for biological warfare.

In 1978, a Bulgarian dissident, Georgi Markov, was assasinated in London after being pricked by a ricin-tipped umbrella. Ricin causes a slow and painful death through blood poisoning and a breakdown of the circulatory system. There is no known antidote for ricin poisoning. Even before the tragic terrorist plane crashes into the Trade Center Twin Towers in New York, some airports hand-inspected umbrellas packed in carry-on luggage. Following the Gulf War, UN investigator teams (UNSCOM) discovered that Iraq was purifying ricin for possible use in biological warfare, along with anthrax (**Bacillus anthracis**), botulism toxin (**Clostridium botulinum**), gas gangrene (**C. perfringens**), and aflatoxin (**Aspergillus parasiticus**). From: **Facts on File News Services** (23 January and 13 February 1998).

According to **The Washington Post** Online (16 November 2001), Osama bin Ladens's al-Qaida network also had working plans for making ricin. Instructions for preparing the poison were found in the cellar of an abandoned house once used as a terrorist training center. According to the article, the ricin may be ingested, injected and inhaled. The article also states that the laxative effect of castor oil is due to ricin, but this is doubtful. Castor oil is derived from the seeds of the castor bean. It contains 87 percent ricinoleic acid, a fatty acid with many industrial uses, along with small amounts of several other fatty acids including oleic (7%), linoleic (3%), palmitic (2%) and stearic (1%). The deadly protein ricin is not a component of purified castor oil.

Although they are not proteins, some respiratory pigments called porphyrins, such as the heme component of the red blood cell pigment hemoglobin, are associated with polypeptides. Porphyrins contain a complex nitrogenous ring with a metallic atom (iron, magnesium or copper) in the center.

Porphyrins are included here because of their similarity to the heme component of the protein hemoglobin. Chlorophylls a & b are certainly the most common and conspicuous pigments in our visible world. They are magnesium porphyrins with the following empirical formulas:

Chlorophyll a: $\mathbf{C_{55}H_{72}O_5N_4Mg}$ Chorophyll b: $\mathbf{C_{55}H_{70}O_6N_4Mg}$

Hemoglobin ($C_{3032}H_{4816}O_{872}N_{780}S_8Fe_4$), the vital red blood cell pigment, contains four iron porphyrins. Some invertebrates with green blood have copper porphyrins. Porphyrins also include the iron-containing cytochrome pigments located on the inner membranes (cristae) of mitochondria in plants and animals. Cytochrome pigments also occur on the inner membranes of bacteria. They are involved in oxidative phosphorylation (electron transport system) and ATP production. Leghemoglobin is a porphyrin within the cells of symbiotic nitrogen-fixing bacteria living in the root nodules of legumes. Nitrogen fixation, the conversion of atmospheric nitrogen into ammonia, requires the enzyme nitrogenase which is inhibited by free oxygen. To maintain a low level of free oxygen in these bacterial cells, the oxygen is bound to leghemoglobin where it is readily available for cellular respiration, but not at a level that is damaging to the nitrogenase. In N-fixing cyanobacteria such as **Anabaena azollae** living symbiotically within leaf cavities of the water fern **Azolla**, the site of N-fixation occurs in non-photosynthetic cells called heterocysts. Heterocysts have a much lower level of oxygen compared to photosynthetic, oxygen-producing cells with thylakoid membranes.

Nitrogen-Fixing Cyanobacteria In A Water Fern
Nitrogen-Fixing Bacteria In Root Nodules Of Legumes
Nitrogen-Fixing Cyanobacteria In Coralloid Roots Of Cycads

Phycobiliproteins are complex photoreceptor pigments found in cyanobacteria (Division Cyanobacteria) and red algae (Division Rhodophyta). They are composed of water-soluble phycobilin pigments and protein. The phycobilin component is similar to porphyrins but without the metallic atom. Phycobilins include the blue-green pigment phycocyanin and the red pigment phycoerythrin. The latter phycobilin is a photoreceptor pigment associated with chlorophyll, enabling red algae to be photosynthetically efficient in deep water where blue light predominates. The red light waves that activate green chlorophyll pigments do not penetrate the deeper water of the photic zone; hence, green algae cannot survive at this depth. Phytochromes are phycobilin-protein pigments involved in floral induction. They are activated by the length of day (hours of darkness). The cocklebur is a classic example of a short-day plant (i.e. it only flowers when the nights are long). At least one leaf of a cocklebur plant needs 15 hours of darkness to undergo various complex biochemical reactions leading to the release of a hypothetical flower stimulant called "florigen." The protein leaf pigment called "phytochrome" controls the release of florigen from the leaves. One form of this pigment (P-660) is formed during the hours of darkness and is essential for the release of florigen. The phytochrome P-660 pigment is very sensitive to specific wavelengths of light, and a flash of light during the 15 hours of darkness can instantaneously convert it into another form called P-730 which inhibits the release of florigen, thus blocking the flowering process. Cocklebur plants can bloom in the tropics where the days are short and the nights are long, thus greatly increasing its range and potential for seed production. In North America, cocklebures typically bloom during the fall months when the days are shorter and the nights longer. They will not bloom during the long days of summer or near a street light.

Read About The Short-Day Cocklebur
Read About Day Length In Duckweeds

DNA Structure # Function: Make A Selection

IV. Nucleic Acids: This class of compounds includes the genetic material DNA (deoxyribonucleic acid), largest of the biomolecules, and RNA (ribonucleic acid), a smaller nucleic acid made from a section of DNA called a gene. Two main types of RNA are made in the nucleus of a cell, including messenger RNA (M-RNA) and transfer RNA (T-RNA). A third type called ribosomal RNA is made in the nucleolus of the nucleus. All three types of RNA are involved in protein synthesis. M-RNA molecules are made from sections of DNA in the nucleus, a process called transcription. The M-RNA strands are essentially complementary copies from one side of the DNA ladder after it has separated or "unzipped."

Completed M-RNA molecules then leave the nucleus and travel to organelles in the cytoplasm called ribosomes (made of ribosomal RNA). Smaller T-RNA molecules attach to specific amino acids in the cytoplasm and bring them to the ribosomes where they join with precise base triplets called codons along the M-RNA strand, a process called translation. A complementary base triplet on each T-RNA called the anticodon joins with the codon of M-RNA (e.g. the anticodon AUG joins with the codon UAC). Different T-RNA molecules carry different amino acids, depending on their anticodons. Since there are 64 different codons (4X4X4) and only 20 different amino acids (in human protein), some codons of M-RNA stand for the same amino acid. [E.g. the codons UUA, UUG, CUU, CUC, CUA and CUG all stand for the amino acid leucine.] As each amino acid is linked to the growing polypeptide, a molecule of water is released, a chemical reaction called dehydration synthesis. The completed polypeptides become vital proteins, such as enzymes, antibodies or structural proteins of muscles, blood vessels and other tissues. This remarkable process is essentially the same in all animals as well as in plants.

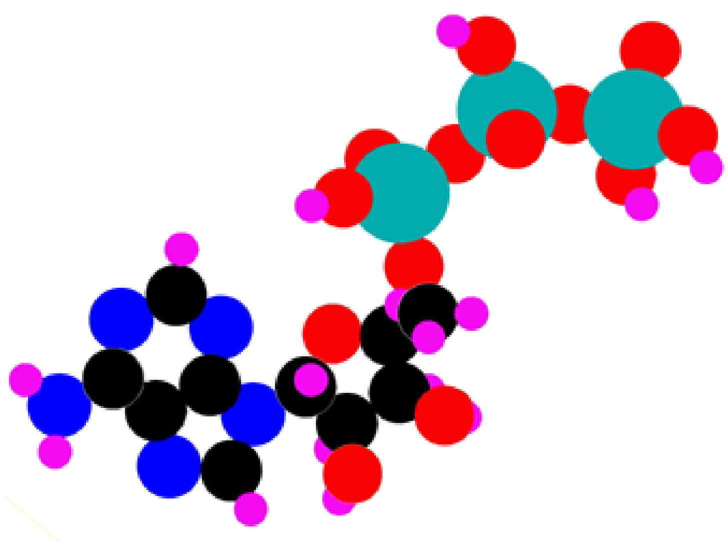
See Generalized DNA Model Used In Biology 100
Read About DNA In Biology 100 Exercise #3
PCR, Sequencing Of DNA & Cladograms
See Cloverleaf Model Of Transfer RNA

DNA is the master molecule that carries all of the inherited characteristics (genes) of an individual in the form of chromosomes. Each individual (such as a human) receives one haploid set of 23 chromosomes from their father's sperm and one haploid set of 23 chromosomes from their mother's egg. The two sets come together at conception when the diploid zygote (fertilized egg) is formed. Each eukaryotic chromosome (the chromosomes of algae, fungi, plants and animals) carries thousands of genes, about 100,000 functional genes per cell. A chromosome is analogous to a high capacity storage disk (DVD disk), while genes are analogous to files on this storage disk. If a chromosome could be completely unraveled it would reveal a long, ladder-shaped DNA molecule that is coiled into helical spirals. At intervals along this double helix, the DNA ladder is wrapped around small beads of protein called nucleosomes. There are also extrachromosomal genes in the form of bacteria-like (prokaryotic) plasmids within cytoplasmic organelles called mitochondria and chloroplasts. Photosynthetic chloroplasts are found only in plant cells, while mitochondria are present in both plant and animal cells. Indeed, some biologists believe these intracellular organelles evolved from bacteria-like ancestors. It has been generally thought that all mitochondrial and chloroplast DNA was passed on solely through the egg cells of animals and plants, although this theory has been challenged in a recent article in **Science** Vol. 286 (24 Dec. 1999).

See Chromosomes, Nucleosomes & Cell Division

The spiral, ladder-like (double helix) structure of DNA was discovered by James Watson and Francis Crick in 1953. Using data from x-ray diffraction, Rosalind Franklin was also close to this discovery, but Watson and Crick got their research published first. For their discovery that truly revolutionized the science of biology, Watson and Crick received the Nobel Prize in 1962. Basically, the uprights or rails of the ladder are composed of alternating 5-carbon sugars (deoxyribose) and phosphates, while the rungs of the ladder are composed of nitrogenous base pairs. Four bases occur in DNA, larger purine bases (adenine and quanine), and smaller pyrimidine bases (cytosine and thymine). DNA (and RNA) are composed of subunits called nucleotides, each nucleotide consisting of a phosphate, a sugar and a base. DNA is recycled into nucleotides which are used to synthesize more DNA in the nucleus of the cell. In the DNA ladder, adenine always pairs with thymine, and guanine always pairs with cytosine. Depending on their sequence and left vs. right configurations in the DNA ladder, every base pair has four different arrangements: A-T, T-A, C-G and G-C. The total number of different possible arrangements in a DNA molecule with a million base pairs is equal to 4 raised to the one millionth power, or a number with more than 600,000 digits. This astronomical number far exceeds the number of electrons in some models of the visible universe. Herein lies the tremendous variability factor of DNA, and the computer-like chemical coding of all the genetic characteristics of a complete plant or animal. The amount of genetic information stored in the DNA within one human nucleus is enormous. In terms of printed information (using a 26 letter English alphabet), this represents about 500 volumes of **Encyclopedia Britannica**. All this is stored in a microscopic nucleus 5 micrometers in diameter (smaller than a human red blood cell). Imagine a computer using the storage potential of DNA. RNA is similar to DNA except it is single-stranded in M-RNA , has the 5-carbon sugar ribose instead of deoxyribose, and the pyrimidine base uracil instead of thymine.

ATP: Energy Currency Of The Cell



ATP $C_{10}H_{16}N_5O_{13}P_3$

Can you locate all the atoms of carbon, hydrogen, nitrogen, oxygen and phosphorus?

The structure of adenosine monophosphate, an RNA nucleotide containing the purine base adenine, is very similar to ATP (adenosine triphosphate), except that ATP has three phosphates (PO_4) instead of one. ATP is synthesized in all living cells by the addition of a phosphate to ADP (adenosine diphosphate). ATP is the vital energy molecule of all living systems which is absolutely necessary for key biochemical reactions within the cells. The terminal (3rd) phosphate of ATP is transferred to other molecules in the cell, thereby making them more reactive. For example, the monosaccharide glucose is very stable at ordinary body temperatures and would require a great amount of heat (such as from a flame) to break it down into carbon dioxide and water. After receiving a phosphate from ATP (a process called phosphorylation), glucose becomes glucose-phosphate and can be enzymatically broken down within seconds.

See Diagram Of An ATP Molecule

Most of the ATP in eukaryotic cells of animals is made inside cellular organelles called mitochondria from the oxidation of glucose, a process called cellular respiration. Glucose combines with oxygen (oxidation), forming carbon dioxide, water and 38 molecules of ATP. During the oxidation process, electrons from glucose are shuttled through an iron-containing cytochrome enzyme system on the inner mitochondrial membranes (called cristae). The actual synthesis of ATP from the coupling of ADP (adenosine diphosphate) with phosphate is very complicated and involves a mechanism called chemiosmosis. The electron flow generates a higher concentration (charge) of positively-charged hydrogen (H+) ions (or protons) on one side of the membrane. When one side of the membrane is sufficiently "charged," these protons recross the membrane through special channels (pores) containing the enzyme ATP synthetase, as molecules of ATP are produced.

Light Reactions Of Photosynthesis

In addition to mitochondrial ATP synthesis, plants can also make ATP by a similar process during the light reactions of photosynthesis within their chloroplasts. Electrons flow through a cytochrome transport system on thylakoid membranes in a region of the chloroplast called the grana; except that the electrons come from excited (light activated) chlorophyll molecules rather than the break down of glucose. This is an especially vital source of ATP for plants because ATP is also needed for them to synthesize glucose in the first place. Without a photosynthetic source of ATP, plants would be using up their ATP to make glucose, and then using up glucose to make ATP, a "catch-22" situation.

A transparent-green solution of chlorophyll is made by grinding up spinach or grass leaves in acetone (in a mortar and pestle), and then filtering it through cheesecloth and course filter paper. If a bright beam of light is directed at this chlorophyll solution, a deep red glow is emitted from the test tube. The chlorophyll electrons become excited by the light energy, but have no cytochrome transport system to flow along because the chloroplast thylakoid membranes have been dissolved away. Therefore, the chlorophyll electrons give up their excited energy state by releasing energy in the form of a reddish glow. This phenomenon is known as fluorescence, and is essentially the same principle as a neon light. In a neon light, the electrons of neon gas become excited and then release their energy of activation as a white glow inside the glass tube. In an intact chloroplast with thylakoid membranes, ATP is generated by an electron flow along the cytochrome transport system. Since the electrons are being transported to other "carrier" molecules, their energy is used to generate ATP and no reddish glow is emitted. Leaves generally appear green because wavelengths of light from the red and blue regions of the visible spectrum are necessary to excite the chloroplast electrons, and unused green light is reflected. Thus, we perceive trees, shrubs and grasses as green. During the fall months when chlorophyll production ceases in deciduous trees and shrubs, the leaves turn golden yellow or red due to the presence of other pigments, such as yellow and orange carotenoids and bright red anthocyanins.

Another important ingredient for photosynthesis is also produced during the light reactions. During these light-dependent reactions of photosynthesis, a chemical called NADP picks up two hydrogen atoms from water molecules forming $NADPH_2$, a powerful reducing agent that is used to convert carbon dioxide into glucose during the dark reactions of photosynthesis (also called the Calvin Cycle). When the two atoms of hydrogen join with NADP, oxygen is liberated, and this is the source of oxygen gas in our atmosphere. ATP and $NADPH_2$from the light reactions are used in the dark reactions of photosynthesis that take place in the stroma region of the chloroplast.

Dark Reactions Of Photosynthesis (Calvin Cycle)

Similar electron transport systems occur in the membranes of prokaryotic bacteria. Methanogenic bacteria live in marshes, swamps and your gastrointestinal tract. In fact, they are responsible for some intestinal gas, particularly the combustible component of flatulence. They produce methane gas anaerobically (without oxygen) by removing the electrons from hydrogen gas. The electrons and H+ ions from hydrogen gas are used to reduce carbon dioxide to methane. In the reaction, the H+ ions combine with the oxygen from carbon dioxide to form water. During this process, the electrons are shuttled through an anaerobic electron transport system within the bacterial membrane which results in the phosphorylation of ADP (adenosine diphosphate) to form ATP (adenosine triphosphate). This process is much less efficient than aerobic respiration, so only two molecules of ATP (rather than 38) are formed. Desert varnish bacteria make their ATP in a similar fashion, only the electrons are coming from the aerobic oxidation of iron and manganese. A thin coating of iron or manganese oxide is deposited on the surfaces of desert boulders and rocky slopes. During the oxidation process, the electrons are shuttled through an iron-containing cytochrome enzyme system on the inner bacterial membrane. One has only to gaze at the spectacular panoramas of varnish-coated, granitic boulders throughout desert areas of the American southwest to appreciate the magnitude of this bacterial ATP production. The mechanism of ATP synthesis in prokaryotic bacteria is remarkably similar to eukaryotic cells. In addition, the circular DNA molecules of these bacteria are similar to the DNA molecules within some organelles of eukaryotic cells. In fact, some biologists believe that mitochondria (and chloroplasts) within eukaryotic animal and plant cells may have originated from ancient symbiotic bacteria that were once captured by other cells in the distant geologic past. This fascinating idea is called the "Endosymbiont Theory" (or "Endosymbiont Hypothesis" for those who are more skeptical).

Desert Varnish & Lichen Crust On Rocks
Archaebacteria: Possible Life Form On Mars?

Trace amounts of DNA can be amplified (cloned) into millions of copies using the PCR technique (Polymerase Chain Reaction) discovered by Kary Mullis of UCSD. This technique provides investigators with sufficient DNA to use in sequencing gels in which the banding patterns represent different base pair sequences. DNA sequencing is widely used in modern research, including crime scene investigations to determine genetic "fingerprints" (e.g. the O.J. Simpson Trial). [And remember the DNA evidence on Monica Lewinski's dress that almost led to the removal of President Clinton from office!] DNA is also used in phylogenetic studies (cladistics) to show evolutionary trends and relationships among plant and animal species. Depending on the level of study, certain types of genes are preferred. For larger taxonomic groups at the plant family level, chloroplast DNA is particularly useful. For phylogenetic studies at the species level, mitochondrial DNA and small subunit ribosomal DNA is commonly used. Researchers can compare their results with others and download gene sequences from the GenBank Data Base at the National Center For Biotechnology Information. Please consult your textbook for more information and illustrations of this remarkable class of compounds which truly are the chemicals of life.

See Generalized DNA Model Used In Biology 100
Read About DNA In Biology 100 Exercise #3
Read About Polymerase Chain Reaction

Types Of Terpenes: Make A Selection

V. Terpenes: An enormous group of plant hydrocarbons formed by the polymerization of 5-carbon isoprene (C_5H_8) subunits. Terpenes are one of the largest and most varied group of plant chemicals. They may contain carbon chains and rings in different structural forms called isomers. They may also be reduced and oxidized into a vast array of compounds, including alcohols, ketones, acids and fragrant aldehydes. There are five main types of terpenes, including 10-carbon monoterpenes (2 isoprenes), 15-carbon sesquiterpenes (3 isoprenes), 20-carbon diterpenes (4 isoprenes), 30-carbon triterpenes (6 isoprenes) and 40 carbon tetraterpenes (8 isoprenes). Terpene chemicals present in the resinous foliage and fallen leaves of chaparral shrubs inhibit germination of nearby wildflower seeds, a phenomenon known as allelopathy. This explains the abundance of wildflowers in recently cleared chaparral that has not burned. It has also been shown that the burned remains of shrubs greatly stimulate the germination of certain seeds. The developing wildflowers thrive in the ash and often grow much more vigorously than in soil without ash. There are also allelopathic phenolic compounds.

Catechin: A Potent Phenolic Allelopathic Compound

Some terpenes are poisonous and can cause painful rashes. Excellent examples of these terpenes can be found in the milky sap of some members of the euphorbia family (Euphorbiaceae). The infamous manchineel tree (**Hippomane mancinella**) of the Caribbean region and coastal Central America contains two potent diterpene compounds with carbon atoms arranged in rings, including the tetracyclic (4-ring) mancinellin and the tricyclic (3-ring) huratoxin. Contact with these terpenes can cause inflammation and a painful, blistering rash. The caustic terpenes are structurally similar to phorbol, a potent carcinogen listed among organic compounds in the **Merck Index**. One of the earliest written accounts of the manchineel tree appeared in memoirs of Columbus' second voyage to the West Indies in 1493. On November 3 a landing party went ashore on the island of Marie Galante. The fleet physician, Dr. Chanca, writes: "There were wild fruits of various kinds, some of which our men, not very prudently, tasted; and upon only touching them with their tongues, their countenances became inflamed, and such great heat and pain followed, that they seemed to be mad, and were obliged to resort to refrigerants to cure themselves."

See Article About Ashes To Wildflowers
Read About The Infamous Manchineel Tree

One of the most poisonous terpenes is cicutoxin, the toxic component in the sap of water hemlock (**Cicuta douglasii**). Water hemlock is a member of the carrot family (Apiacaeae). Like some members of this family, such as carrots and parsnip, this widespread perennial has large taproots and umbrellalike clusters of small white flowers. Cicutoxin is an unsaturated aliphatic alcohol that acts directly on the central nervous system. [Aliphatic compounds have carbon atoms in straight chains rather than the benzene rings of aromatic compounds.] In sufficient doses cicutoxin causes paralysis and death from respiratory failure. Water hemlock is not to be confused with the true hemlocks, coniferous trees of the pine family (Pinaceae) belonging to the genus **Tsuga**. The "hemlock" given to Socrates in 399 B.C. was undoubtedly an alkaloid mixture from the roots of poison hemlock (**Conium maculatum**), another member of the carrot family.

One of the most famous poisonous terpenes may have affected the creativity of Vincent van Gogh. The terpenoid compound thujone is composed of several volatile monoterpenes found in the resins of several species of cone-bearing species in the cypress family (Cupressaceae). The resins of conifers (especially the monoterpenes) are the primary defensive mechanism against the ravaging effects of bark beetles. Thujone is also found in the sap of wormwood (**Artemisia absinthium**), a European shrub related to our North American sagebrushes. Wormwood oil derived from **A. absinthium** was the principal flavoring of absinthe liqueur, an alcoholic beverage that was taken regularly by van Gogh. Ingested repeatedly, absinthe can cause dramatic personality changes and may have affected van Gogh's creativity and fondness for the color yellow. See the link below for more information

Dripping pitch from the trunk of a Douglas fir (**Pseudotsuga menzeisii**) in northern Montana. Conifers such as this ignite like a torch during a fire storm due to the combustible terpene oleoresins.

Abundant resin ducts throughout the trunk and branches of healthy trees is vital to survive freezing winters and to retard the invasion of bark beetle larvae. During prolonged summer drought conditions, stressed trees produce less resin and are more vulnerable to bark beetles. In fall of 2003, this drought stress was especially evident throughout mountainous areas of San Diego County where thousands of pines were dying.

See Photos Of Poison Hemlock & Water Hemlock
A Terpene That May Have Poisoned Vicent van Gogh

A. Essential Oils Smaller, monoterpenes and sesquiterpenes that are volatile at room temperature. They occur in leaves, flowers and fruits, often imparting a distinctive odor and flavor. Note: Some essential oils include phenolic compounds and terpene-phenolic derivatives. Phenolic compounds typically contain one or more benzene rings with one or more hydroxyl groups (C-OH) attached to the rings. Essential oils serve several functions in plants, such as repelling fungi and harmful insects, and the sweet fragrances of flowers that attract insect pollinators.

1. Herbs: Herbaceous plants mostly from temperate regions, particularly in the mint, carrot and sunflower families. Some representative herbs of the mint family (Lamiaceae) include basil (**Ocimum basilicum**), rosemary (**Rosmarinus officinalis**), thyme (**Thymus vulgaris**), sage (**Salvia officinalis**), peppermint (**Mentha piperita**), spearmint (**M. spicata**), oregano (**Origanum vulgare**), horehound (**Marrubium vulgare**) and catnip (**Nepeta cataria**). The terpene in catnip (nepetalactone) is a methylcyclopentane monoterpene that for some reason is very attractive to members of the cat family (Felidae). Herbs of the carrot family (Apiaceae) include parsley (**Petroselinium crispum**), coriander seeds & cilantro leaves (**Coriandrum sativum**), caraway (**Carum carvi**), dill (**Anethum graveolens**), anise (**Pimpinella anisum**), fennel (**Foeniculum vulgare**) and cumin (**Cuminum cyminum**). Some herbs of the sunflower family (Asteraceae) include tarragon (**Artemisia dracunculus**), chamomile (**Anthemis nobilis**) and German chamomile (**Matricaria chamomilla**). There are many other plant families with species containing essential oils. For example, the myrtle family (Myrtaceae) includes eucalyptol from (**Eucalytus globulus**), citronellal from (**E. citriodora**) and eugenol from species of **Eugenia** (**Syzygium**). Remember that some of these aromatic essential oils are phenolic compounds rather than terpenes. For more information refer to Wayne's Word Economic Plant Families.

Catnip: An Herb That Drives Cats Crazy
California Sages (Salvia) In The Mint Family

2. Spices: Like herbs, spices are used to enhance the flavors of foods, but unlike most herbs, spices are generally tropical in origin and are usually more expensive. In fact, the famous voyages of explorers such as Marco Polo, Vasco de Gama, Christopher Columbus and Sir Francis Drake were (at least in part) in search of valuable spices. The aroma and tantalizing flavor of some spices is due to volatile phenolic compounds and alkaloids, in addition to terpenes. Some of the world's most important spice plants include ginger (**Zingiber officinale**), cardamom (**Elettaria cardamomum**) and turmeric (**Curcuma domestica**, all members of the ginger family (Zingiberaceae); black pepper (**Piper nigrum**, Piperaceae), nutmeg and mace (**Myristica fragrans**, Myristicaceae), cloves from unopened flower buds of **Syzygium aromaticum** (Myrtaceae), and cinnamon from the bark of **Cinnamomum zeylanicum** (Lauraceae). [The Mediterranean herb called capers (**Capparis spinosa**, Capparaceae) is also from flower buds.] Allspice comes from the dried, green berries of **Pimenta dioica**, a central American tree of the myrtle family (Myrtaceae). It is also known as pimento; however, the red

pimentos that are stuffed into green olives are actually a variety of sweet chile pepper (**Capsicum annuum**) that belongs to the nightshade family (Solanaceae). The name "allspice" refers to the flavor of the berries, which resemble a combination of cinnamon, nutmeg and cloves. Red chile peppers and bell peppers are from species of **Capsicum**, New World plants in the nightshade family (Solanaceae). Red peppers were discovered by Columbus in the West Indies while en route to the East Indies. The name pepper was used by the Spanish, who were hoping to find the true spice pepper of the East Indies. Chile peppers will be discussed in more detail under alkaloids. Vanilla comes from the seed capsule of the vanilla orchid (**Vanilla fragrans**), the only commercially important product in the Orchidaceae, the second largest plant family. Most vanilla flavorings sold in markets are synthetic vanillin containing artificial food coloring & preservatives. Vanillin is a phenolic compound derived from the breakdown of lignin, a complex phenolic polymer that gives seasoned wood its color, hardness and mass. For more information about spices refer to Wayne's Word Economic Plant Families.

Allspice, Witch Hazel & Bay Leaves
Black Peppers & Kava Kava Root
Colorful Fruits Of Clove Relative

3. Perfumes: A large group of sweet, aromatic terpenes produced by many species in diverse plant families. Some of these compounds contain aldehyde groups, and some are phenolic essential oils. One of the most obvious adaptive advantages of perfumes is to provide flowers with fragrant scents that attract insect pollinators. The distillation of these fragrant compounds by people, and the ancient art of perfumery dates back to the beginning of recorded history. Plants grown for their unique essential oils include **Rosa damascena** (Rosaceae), **Jasminum grandiflorum** (Oleaceae), **Pelargonium** spp. (Geraniaceae), **Gardenia** spp. (Rubiaceae), and **Viola odorata** (Violaceae). Lavender comes from the species of **Lavandula** in the mint family (Lamiaceae). Orange blossom perfume comes from **Citrus aurantium** and bergamot is from the fruit rinds of **C. bergamia** (**C. aurantium** ssp. **bergamia**), two members of the citrus family (Rutaceae). Saffron is a yellowish-orange dye that is used in medicinals, as a flavoring, and in perfumes. It is obtained from the stigmas of **Crocus sativus** of the iris family (Iridaceae). The coloring principle is crocin, a tetraterpene carotenoid pigment related to vitamin A. It takes about 4,000 stigmas to yield one ounce of the dye, and one part of commercial saffron is sufficient to color 10,000 parts of water. Because of their volatile, strongly-scented terpene component, balsam oleoresins from several species of trees are also used in perfumes, incenses and medicines. Resins are discussed in the next section.

Saffron: A Dye Used A Perfume
Cananga Oil (Ylang-Ylang)

B. Resins: Plant exudates containing nonvolatile 20-carbon diterpenes and 30-carbon triterpenes that are insoluble in water but soluble in organic solvents. [Have you ever tried to wash pine pitch off your hands in water?] Oleoresins (oleo referring to the essential oil component) contain nonvolatile terpenes plus volatile 10-carbon monoterpenes and 15-carbon sesquiterpenes. Resins are generally produced by cells lining resin ducts or canals in stems and leaves. Resins repel insects (such as bark beetles), deter vertebrate herbivores, and inhibit the growth of fungi and bacteria. Exuded resins aid in the healing of wounds and prevent desiccation. The resin glob at left came from the trunk of the Australian bunya-bunya (**Araucaria bidwillii**).

The leaves of some desert shrubs, such as creosote bush (**Larrea tridentata**) have a glistening resinous coating that reduces water loss through transpiration. Although it has a similar odor, this resin is not the commercial source of creosote. The commercial source of creosote is derived from the distillation of coal tar. It is produced by high temperature carbonization of bituminous coal. Wood creosote is obtained from the distillation of wood tar from several woods of the eastern United States. Wood creosote is a mixture of phenolic compounds that are used medicinally as an antiseptic and expectorant. Under no circumstances should coal tar creosote be taken internally. Although creosote bush does not grow in the chaparral plant community, the dried leaves of this shrub are the source of "chaparral tea," a controversial herbal remedy with antitumor properties. The leaves contain a powerful antioxidant that apparently destroys tumor cells; however, there are reported cases of liver toxicity, including toxic hepatitis and jaundice.

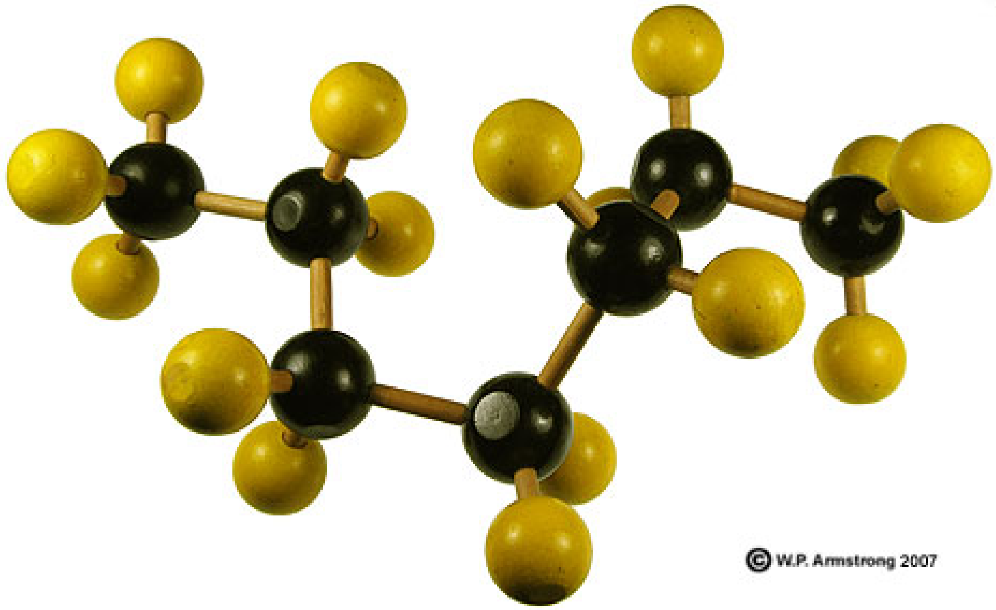
Some resins are referred to as gums, but they are chemically very different. True gums are complex polysaccharides composed of many sugar subunits. Although the sap of the mastic tree (**P. lentiscus**) is called a gum, it is really an oleoresin used in perfumes, chewing gums, pharmaceuticals, dental adhesives, and in high grade varnishes for protecting pictures. Gum mastic is one of the oldest known high grade resins utilized by people, and it is extensively cultivated on the Greek island of Chios. Gum guaiac is another famous resin from a Caribbean tree called lignum vitae (**Guaiacum officinale**), one of the world's hardest and heaviest woods. A similar species (**G. sanctum**) is native to the Florida Keys. Both species are members of the caltrop family (Zygophyllaceae) along with North and South American creosote bush and the ubiquitous puncture vine (**Tribulus terrestris**). The name lignum vitae means "wood of life," owing to the medicinal properties of the heavy, resinous wood. During the days of masted sailing ships, the wood and sweet-smelling resin globs were sought after for treatments and cures for a variety of human ailments, including gout, syphilis and rheumatism. Today the resin is still used for expectorants and as a dye to detect the presence of occult (hidden) blood. Peroxidase enzymes in the blood cells oxidize chemicals in the resin resulting in a characteristic blue-green color change. The raw resin contains about 15 percent vanillin (artificial vanilla), resulting in the sweet aroma. The density and high resin content of the wood make it extremely resistant to friction and abrasion and account for its remarkable self-lubrication properties. In fact, under certain conditions the wood wears better than iron. Because of this, the wood has been highly valued for pulley sheaves, bearings, casters, food-handling machinery, and especially for end grain thrust blocks which once lined the propeller shafts of steamships. During World War I, attempts were made to use other ironwoods such as **Tabebuia guayacan** from Central America for propeller shaft bearings, but the wood lacked the oily resin of lignum vitae.

See Resin Ducts In A Pine Stem
Resin Ducts In Poison Oak Stem
Gum Mastic From Island Of Chios
Gum Guaiac From Lignum Vitae Tree
Photos Of Natural Resins From Plants

1. Turpentines: A large group of oleoresins from gymnospermous trees. Raw or crude turpentine is essentially the sticky sap or pitch from coniferous trees. In the U.S., raw turpentine is largely derived from southeastern pines, including longleaf pine (**Pinus palustris**) and slash pine (**P. elliotti**) grown in large plantations. Crude turpentine is distilled in order to separate the volatile essential oils called "spirits" from the nonvolatile diterpene residue called rosin. Spirits of turpentine are used in thinners and other organic solvents, while rosin is used in the manufacture of varnishes and oil base paints (and for violin bows and baseball pitchers). Oil base paints also contain unsaturated drying oils, such as castor, tung and linseed oils. The settlement of North America was partially due to England's desire to rid herself of dependence on Scandinavian sources of resin, since the pitch was used to caulk ships and waterproof the rigging.

See Slash Pines & Saw Palmetto

According to N.T. Mirov (The Genus Pinus, Ronald Press, 1967), all species of pines, except two California species, contain terpenes in their turpentines. The exceptional species are **P. jeffreyi** and **P. sabiniana**. The turpentines of these latter two species consists almost entirely of an alkane, n-heptane, with a small mixture of fragrant aliphatic aldehydes. The aldehydes produce distinctive odors in bark fissures of jeffrey pine variously described as resembling vanilla extract, butterscotch or pineapple. Pure heptane, distilled from the resin of **P. jeffreyi**, was used to develop the octane scale for rating petroleum as a motor vehicle fuel. The following account comes from Conifers of California by Ronald M. Lanner (1999): During the Civil War, Union manufacturers of turpentine used pitch from ponderosa pine (**P. pondersosa**) because southern pine resins (incl. longleaf and slash pines) were not available in the Confederate States. Sometimes pitch from Jeffrey pine containing volatile n-heptane would get into the heated vats and cause an explosion.



C_7H_{16} (**n-heptane**)

Seed Cones Of 20 Pine Species In California

2. Copals & Balsams A group of resins that form particularly hard varnishes and fragrant perfumes. They are derived from tropical trees in the legume family (Fabaceae), including West Indian locust (**Hymenaea courbaril** (the source of Central American copal varnish & incense), and the closely related East African copal (**H. verrucosum**. Copal resins also come from the Kauri pine **Agathis australis**, an important New Zealand source of varnishes, and the closely related amboyna pine (**A. alba**), another source of copal resins from the East Indies and Malaysia. In Chiapas, Mexico, Dominican Republic, and parts of Colombia and Brazil, the subterranean resin globs of ancient **Hymenaea** trees (related to the present day West Indian locust) have transformed into amber through a remarkable chemical process requiring millions of years. During the polymerization process, the volatile terpenes escape and the nonvolatile terpenes bond together forming a hard plastic-like polymer that is resistant to natural decay processes and the ravages of time. Unlike copal resins and balsams, the amber is unaltered by organic solvents such as alcohol, acetone and ether. Although some copals will take a high polish, they contain volatile terpenes that gradually evaporate, causing the surface to become deeply crazed like the cracked mud of a dry lake bed

Balsams are oleoresins containing volatile essential oils and nonvolatile resins. Because of the volatile, strongly-scented terpene component, balsams are used in perfumes, incenses and medicines. The well-known "Canada balsam" is a natural turpentine collected from resin blisters on the bark of **Abies balsamea**, a cone-bearing tree of the northern United States and Canada. Central and South American copaiba balsams (balsamos de copaiba) come from rain forest trees in the legume family, including **Prioria copaifera**, **Copaifera reticulata** and **C. officinalis**. The fragrant balsum-of-peru (**Myroxylon balsamum**) is gathered in Central America (El Salvador) by "balsameros," and used in medicines, soaps and perfumes.

[Drift Fruit From A Balsam Tree](#)
[Photos Of The West Indian Locust](#)
[See Article About New World Amber](#)

3. Dammar Resins: East Indian and southeast Asian resins similar to copals. Like copals they are shiny and transparent when dry and are used extensively in the paint and varnish industry. They are primarily obtained from large rain forest trees of the dipterocarpus family (Dipterocarpaceae). Some of the sources for dammar resins in this family are **Dipterocarpus turbinatus** (also called gurjun balsam), and several species of **Shorea**, including **S. aptera**, **S. hypochra**, **S. robusta** and **S. wiesneri**.

4. Incenses: Fragrant, strong-scented oleoresins mostly from the torchwood family (Burseraceae) and the legume family (Fabaceae), including some of the copals and balsams discussed in the previous section. But probably the most famous incense resins come from the Burseraceae, including frankincense (**Boswellia carteri**) and myrrh (**Commiphora abyssinica**), native trees (or large shrubs) of the Middle East deserts. Some of the New World counterparts of this fascinating resinous family include Guatemalan incense (**Protium copal**) and gumbo limbo (**Bursera simaruba**), two incense species widely used by the Maya. Several closely related Mexican incense trees of the Sonoran Desert are called elephant trees because of their thick trunks resembling the legs of elephants, including **B. odorata** and **B. microphylla**. In fact, the latter species is native to remote, rocky canyons in the Anza-Borrego Desert of San Diego County. Another very resinous elephant tree in Baja California (**Pachycormus discolor**) belongs to the sumac family (Anacardiaceae).

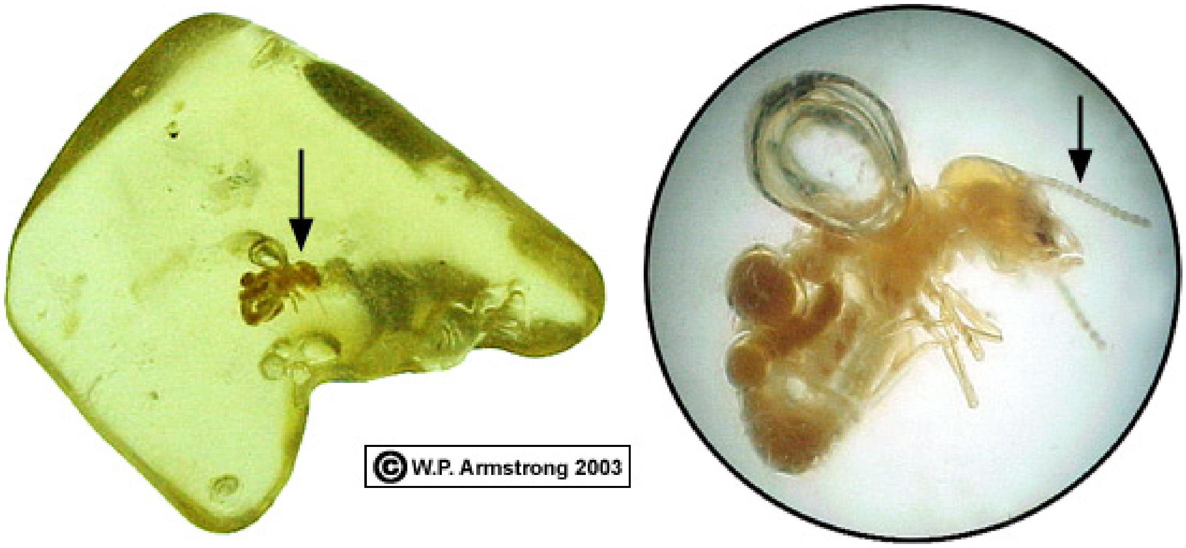
[Photos Of Natural Resins From Plants](#)

5. Natural Lacquer: An oleoresin produced in resin canals of the Japanese lacquer tree **Toxicodendron vernicifluum**, a member the sumac family (Anacardiaceae). Related species, including poison oak (**T. diversilobum**), poison ivy (**T. radicans**) and poison sumac (**T. vernix**) also have a resinous sap that oxidizes and polymerizes into a dark, shiny lacquer. The resin canals also contain urushiol, the insidious allergen that gives these species their bad reputation. The name is derived from "urushi", Japanese name for lacquer made from the sap of the Japanese lacquer tree ("kiurushi" or "urushi ki"). Urushiol is a phenolic compound that causes serious dermatitis in hypersensitive people. It is discussed in the Wayne's Word poison oak article (see link at end of this paragraph). Shellac is prepared from a resinous excretion on the twigs of several species of Asian and southeast Asian trees by the lac insect. The lac insect belongs to the Order Homoptera (along with aphids, scale insects and mealy bugs), and depending on the reference, it is listed as **Tachardia lacca** or **Laccifer lacca**.

Resin Ducts In Poison Oak Stem
Wayne's Word Poison Oak Article
Bowl With Japanese Lacquer Finish
See Resinous Secretion Of Lac Insect

6. Amber: A hard, terpene material that develops from subterranean globs of resin. During the polymerization process (which may take millions of years), the volatile terpenes escape and the nonvolatile terpenes bond together forming a hard plastic-like polymer that is resistant to natural decay processes and the ravages of time. Unlike copal resins and balsams, the amber is unaltered by organic solvents such as alcohol, acetone and ether. Since the first records of neolithic man in Europe, approximately 5,000 years ago, amber has been cherished for its natural beauty and mysterious properties. Amber trade routes of the Phoenicians, Greeks and Romans crossed Europe from the Baltic Sea region, where it was found in great abundance. For decades Baltic amber has been arbitrarily assigned to an extinct pine (**Pinus succinifera**); however, infrared spectroscopy (IR) studies show that Baltic amber is more closely related to resins of broad-leafed conifers of the araucaria family (Araucariaceae). Today the only evidence of araucariads in the northern hemisphere comes from amber deposits and petrified wood, such as occurs at Petrified Forest National Park in Arizona. In New Zealand a living araucariad forest of "kauri pine" **Agathis australis** produces copious amounts of resin that once formed a thriving industry for hard, durable varnishes and linoleum. Large lumps of hardened resin (up to 100 pounds in size) were dug out of the ground in extensive forested areas of North Island. Forests such as this may have once flourished in the Baltic region 60 million years ago.

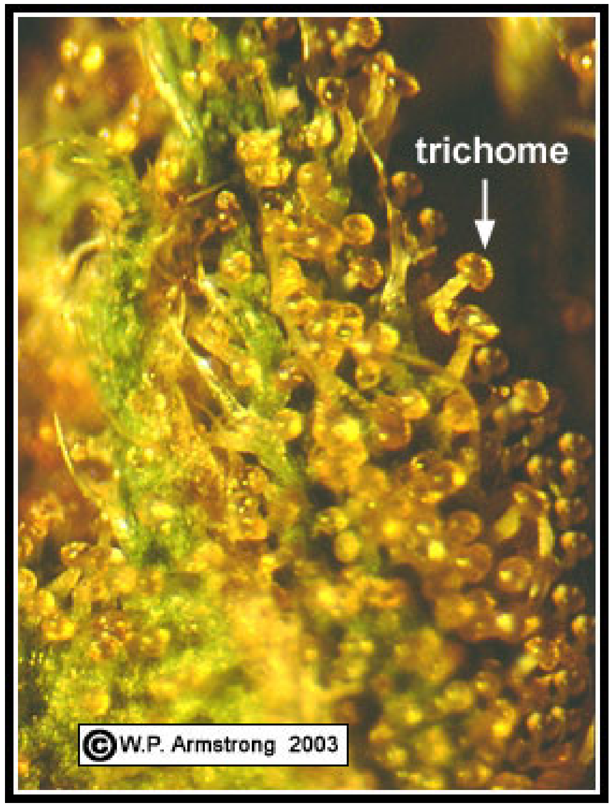
Throughout the world, the most copious resin-producing trees occur in tropical regions. These complex mixtures of terpene resins may serve as a chemical defense against the high diversity of plant-eating insects and parasitic fungi found in the tropics. Many tree species are known to produce amber, but most neotropical (New World) amber comes from the fossilized resin of extinct **Hymenaea protera**, an ancient leguminous tree that once grew throughout the Caribbean region, Mexico, Central and South America more than 30 million years ago (see: D.A. Grimaldi, **Amber: Window to the Past**, 1996). The tropical distribution and chemistry of this beautiful honey-colored amber correlates remarkably well with the present-day West Indian locust (**Hymenaea courbaril**). Unlike the extinct progenitors of Baltic amber, the West Indian locust is the living descendent of most neotropical amber. And unlike most trees of the New World tropics, the genus **Hymenaea** allows one to peer into the geologic past--to actually see some of the creatures it was associated with millions of years ago, perfectly preserved in a transparent tomb of fossilized resin.



A termite embedded in a transparent tomb of fossilized resin known as amber. The piece was sold as Baltic amber, but it probably has a tropical New World origin. The slender, beadlike (moniliform) antennae are quite different from those of ants. Ant antennae are elbowed with a distinct right angle bend. Both insect orders are common in New World amber dating back 25 million years.

See Article About New World Amber
See The Elbowed Antennae Of An Ant
See Plants That Lived With Dinosaurs

7. Phenolic Resins Of Cannabis: The pure resin of marijuana (**Cannabis sativa**) is called hashish. It contains a mixture of volatile mono and sesquiterpenes, along with about 30 phenolic cannabinoids. The most potent cannabinoid is delta-tetrahydrocannabinol (THC), the psychoactive ingredient of marijuana. Globs of resin are produced at the tips of glandular hairs (trichomes) on the inflorescences and floral bracts of female plants. The male plants generally lack the dense glandular hairs and are used for their strong and very durable stem fibers called Indian hemp.



Left: Close-up view of the inflorescence of a female marijuana plant (**Cannabis sativa**). The threadlike structures are styles of pistillate (female) flowers. The granular appearance is due to numerous glandular hairs (trichomes), each with a blob of resin. Male plants generally lack the dense, glandular hairs. Right: Microscopic view of the inflorescence showing numerous gland-tipped hairs called trichomes, each with a tiny blob of resin at the tip. The resin contains a mixture of volatile mono and sesquiterpenes, along with several phenolic cannabinoids. The most potent psychoactive cannabinoid is delta-tetrahydrocannabinol (THC).

An Excellent Reference About Plant Resins

- Langenheim, J.H. 2003. **Plant Resins (Chemistry, Evolution, Ecology and Ethnobotany).** Timber Press, Portland Oregon.

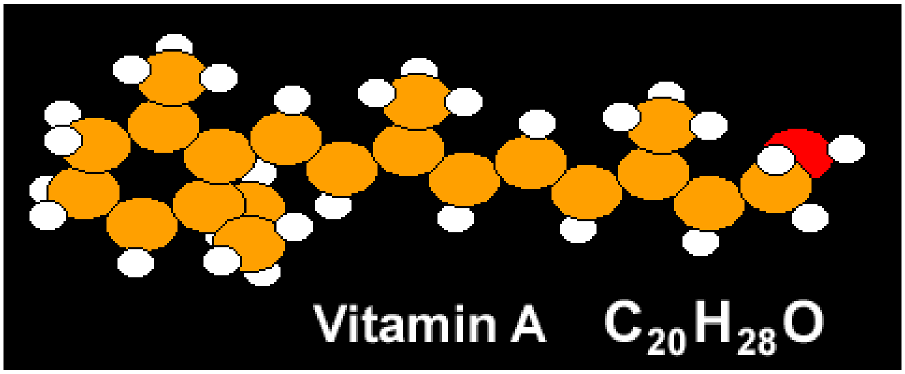
More Information About THC of Marijuana
See Marijuana & Closely Related Hops
See Stem Fibers Including Marijuana

C. Polyterpenes: Elastic terpenes composed of thousands of C_5H_8 isoprene subunits. They are found in the milky latex sap produced inside special cells called laticifers or laticiferous tubules in the secondary phloem. Laticifers are single cells or strings of cells that form tubes, canals or networks in various plant organs. Plant families which produce copious amounts of milky latex include the euphorbia family (Euphorbiaceae), milkweed family (Asclepiadaceae), mulberry family (Moraceae), and the dogbane family (Apocynaceae). The main source of natural rubber comes from **Hevea brasiliensis** (Euphorbiaceae), a rain forest tree native to the Amazon Basin. Ninety percent of all natural rubber comes from the latex sap of this species. A process called vulcanization (discovered by Charles Goodyear) produces cross-linkages between the thousands of isoprene subunits in the rubber latex, improving the elasticity and durability of the rubber. Although synthetic butadiene and styrene polymers are commonly used in the manufacture of tires, natural rubber is still incorporated into radial and high impact airplane tires to provide more resilience. Other rubber-producing plants include **Ficus elastica** (Moraceae) and gutta-percha (**Palaquium gutta**, Sapotaceae). Because the latex of gutta percha contains fewer branched polyterpene chains than **Hevea** rubber, it is not as elastic. A native shrub of Mexico and the southwestern United States called guayule (**Parthenium argentatum**, Asteraceae) contains a latex sap with polyterpenes similar to those found in **Hevea** rubber. It is a potentially good source of natural rubber, possibly grown on large plantations in arid desert regions.

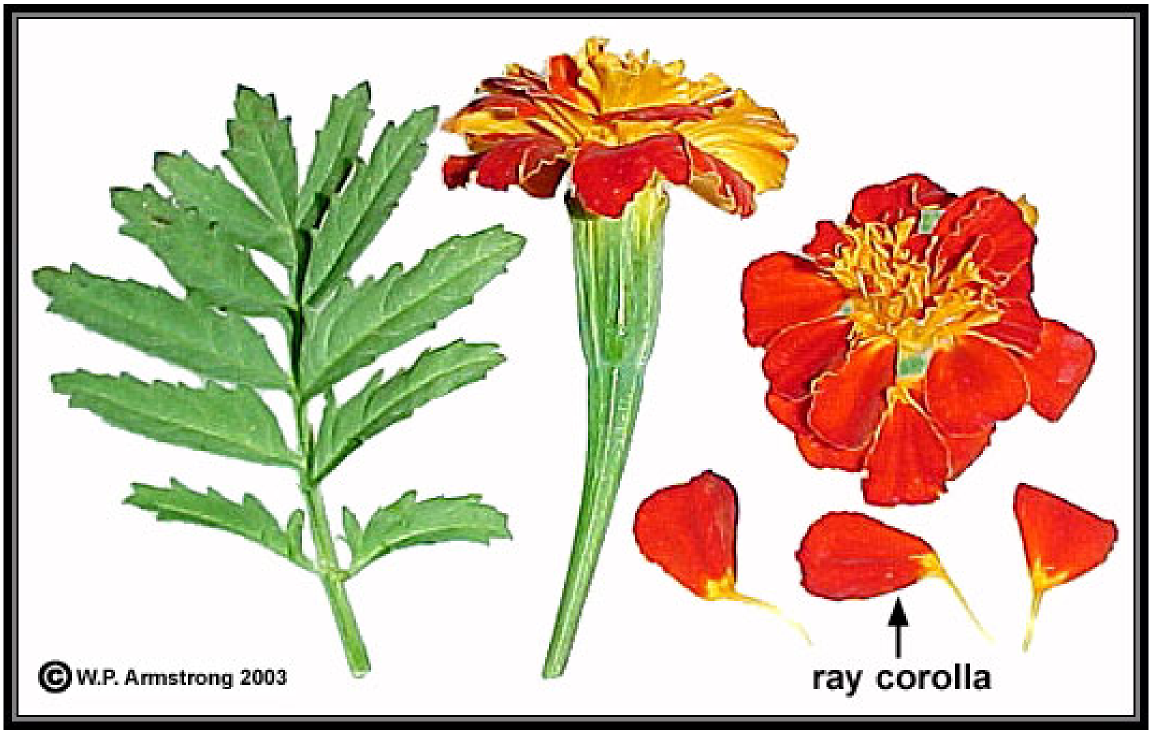
Chicle is a polyterpene from the naseberry or sapodilla tree (**Manilkara zapota**), a native tree of Central America and the West Indies. Chicle is extracted from the sap of the trunk and is used in some chewing gums. Large trees were originally tapped by tree-climbing workers called chicleros. Although the rubbery latex is a polyterpene, it does not vulcanize into durable rubber. Although natural chicle is still used, most of today's chewing gums are made from a synthetic vinyl gum base. The fruit of the chicle tree is also known as the sapodilla. The fleshy pulp is used to make sapodilla custard and ice cream.

Rubber-Producing Plants And Chicle

D. Other Terpenes: This group includes many additional terpene derivatives produced in a variety of diverse plant families. Since some of these are soluble in nonpolar solvents such as alcohol, they are often placed in the lipid category. Many of these terpenes occur naturally as glycosides with attached sugar molecules. Diterpenes include gibberellins, plant hormones controlling stem (internode) elongation, fruit development and seed germination. Triterpenes include saponins that foam in water and sterols (steroids) from which animal sex hormones are derived. [See steroids under the lipid category above, but use the terpene category for steroids on Botany 115 Exam #2.] Carotenoids are tetraterpenes composed of 8 isoprene subunits. Beta-carotene ($C_{40}H_{56}$) is the precursor of the anti-oxidant vitamin A ($C_{20}H_{28}O$), also called retinol.



Carotenoids are water insoluble plastid pigments associated with chlorophylls in chloroplasts and in colored plastids called chromoplasts. They are found in tomatoes, red peppers, carrots, sweet potatoes, and in many colorful flowers and autumn leaves. [Note: Some of the brilliant red pigments in autumn leaves are actually anthocyanins, a different class of chemicals called phenolic compounds.] The bright red pigments in snow algae, and in halophilic algae and bacteria, are carotenoids. In these unicellular organisms the pigments help to protect the delicate cells from intense UV light from the sun. The bright red pigment in the exoskeletons of lobsters, crayfish and crabs is carotenalbumin, including fat-soluble carotenoid pigment called astaxanthin conjugated with protein. The bright red color shows up when the lobster in boiled in water because the pigment separates from the protein. Other carotenoids are found in insect wings, brightly-colored corals, and in the skins of fish, amphibians and marine invertebrates. Egg yolks contain astaxanthin which produces the characteristic yellow color. In fact, chickens throughout the world are fed astaxanthin in their diets to intensify the yolk color. One important source of astaxanthin for chicken feed are the petals of red marigolds (**Tagetes**). In fact, fields of bright red marigolds are grown for this purpose in coastal valleys of central California. The petals are so rich in xanthophylls that the reddish pigment readily rubs off on your fingers. Since flamingos cannot synthesize carotenoid pigments, their pink plumage in the wild results from a diet rich in shrimp and other crustaceans. In captivity, they also fed supplemental astaxanthin in their diet to intensify their pink color.



Petals (ray corollas) from bright red hybrid marigolds (**Tagetes**) are an important source of xanthophyll pigments, such as astaxanthin. They are grown for seed in the coastal valleys of Central California.

Other carotenoids include zeaxanthin, a xanthophyll pigment responsible for the yellow color of corn kernels (**Zea mays**). Another carotenoid pigment comes from achiote or annatto (**Bixa orellana**), a large shrub native to tropical America. The outer covering of achiote seeds contains bixin, a bright red dye that was used to dye clothing during ancient times. Today it is sold as a paste for food coloring in Latin American countries. It is also used as body paint by native South American people.

Ripe tomatoes are particularly rich in the carotenoid lycopene ($C_{40}H_{56}$). In addition to imparting the bright red color to tomatoes, 40 milligrams of lycopene ingested daily may reduce the risk of atherosclerosis (clogged arteries) and heart disease. Lycopene may also reduce the risk of certain cancers, including cancers of the prostate, lung, bladder, cervix, skin and digestive tract. According to Dr. A.V. Rao (**Experimental Biology and Medicine** 227 (10): 908-913, 2002), lycopene is an antioxidant that prevents the oxidation of low density lipoproteins (LDLs). High LDL oxidation is associated with increased risk of atherosclerosis and coronary heart disease. According to the **Merck Index** (1983), one kilogram (2.2 pounds) of fresh tomatoes yields 20 milligrams of lycopene. To obtain 40 milligrams of lycopene, you would need to eat about eight medium-sized tomatoes (or four large tomatoes) every day. Apparently lycopene is absorbed more readily in the processed form, such as tomato paste and juices. Several on-line references recommended drinking two glasses of tomato juice every day. Perhaps it is also wise to eat plenty of tomato soup, stewed tomatoes and tomato sauce on pasta and pizzas.

Intact pollen grains have been extracted from sedimentary strata that is millions of years old, and from animal exrement that has passed through a digestive system. The perfectly preserved pollen grains still retain the distinctive grooves and ornamentation in the outer exine layer. The chemical composition of exine is different from the siliceous shells of microscopic diatoms and grass phytoliths found in fossilized dinosaur dung. It also different from the chitinous exoskeletons of arthropods and the calcareous shells of mollusks. The exine layer is composed of a tough biopolymer called sporopollenin. Although it contains only carbon, hydrogen and oxygen, it is different from carbohydrate polymers such as starch and cellulose. In fact, it is one of the most stable organic compounds known. It has been extracted from plant spores using strong acid and alkali solutions that would disintegrate other substances. Although its structure is not completely understood, some scientists describe sporopollenin as "polycarotenoid in character."

Seedless Grapes & Gibberellins
See Achiote Dye From Costa Rica
Plant Steroids From Dioscorea Yams
See The Yoke Of A Fresh Chicken Egg
Pink Snow Caused By Unicellular Algae
Pink Salt Lakes Caused By Halobacteria
Soap Lilies And Other Saponaceous Plants
Phytoliths From Grasses In Dinosaur Dung

Part II: Phenolic Compounds, Glycosides & Alkaloids

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