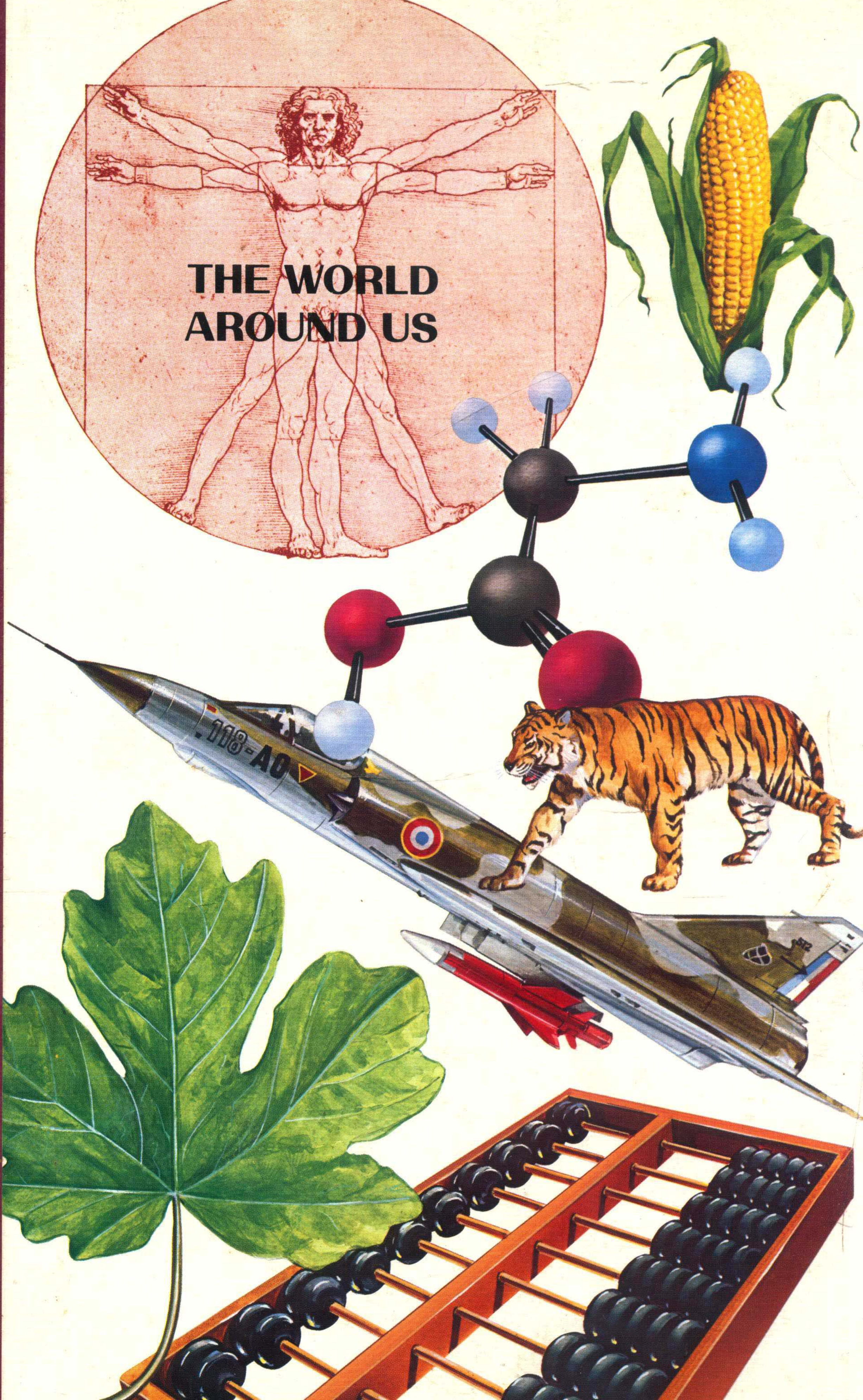
SCIENCE AND TECHNOLOGY ILLUSTRATED

THE WORLD AROUND US



Science Technology

The World Around Us

Library of Congress Catalog Card Number: 84-80129

International Standard Book Number: 0-852229-425-5

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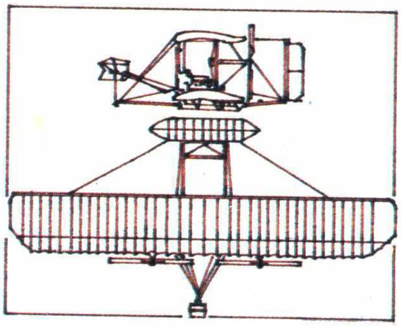

Science and Technology Illustrated

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Volume 2

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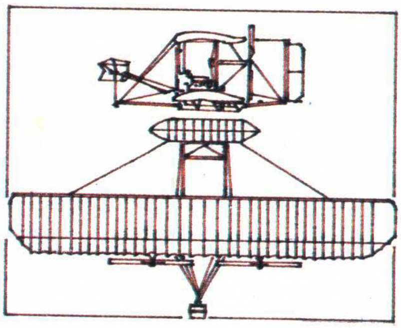
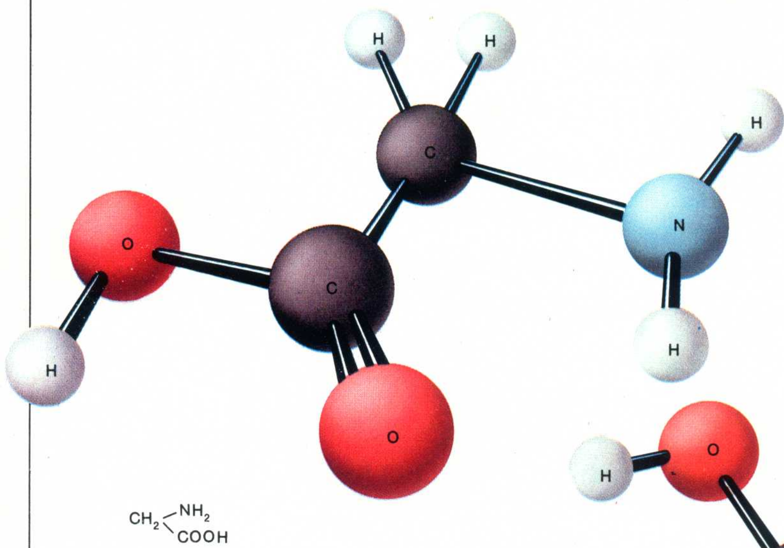
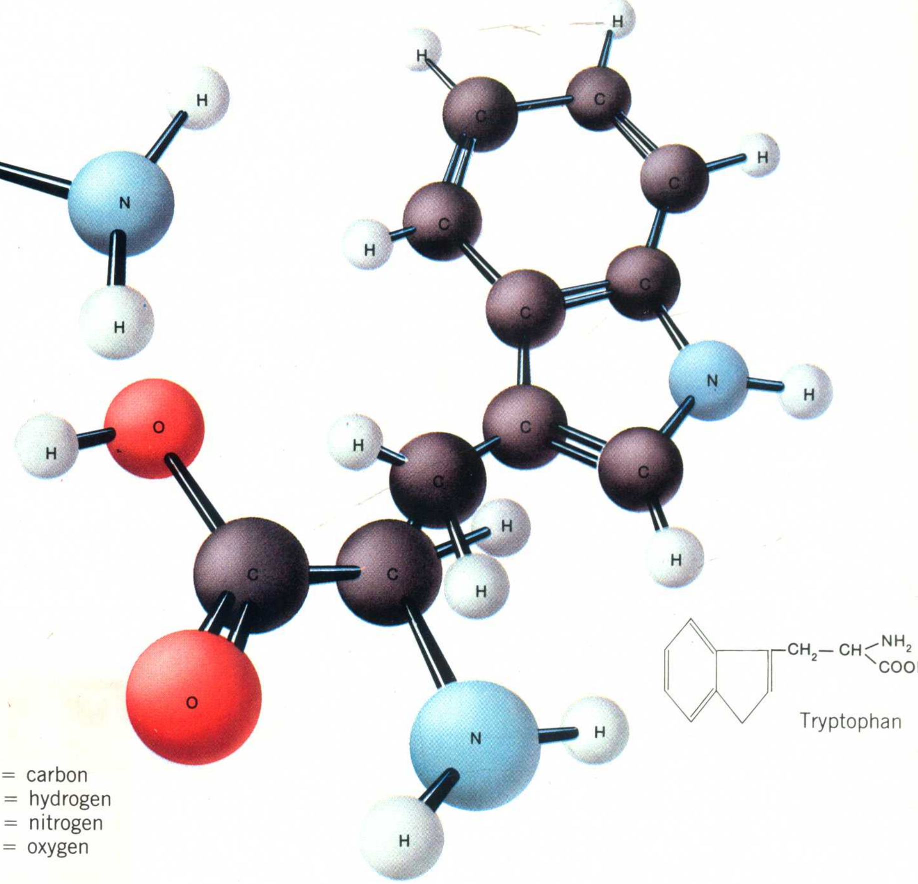




Glycine



Tryptophan

C = carbon
H = hydrogen
N = nitrogen
O = oxygen

If the human body is a house for the mind, then proteins—complicated substances that comprise about half the dry weight of the body—are the bricks out of which that house is built. Proteins are essential to the formation and repair of body tissues; they also play major roles in the formation of disease-resisting antibodies, the oxygen-carrying hemoglobin in red blood cells, and some hormones, and in the basic process of cell division and reproduction.

In turn, proteins are composed of chains of amino acids. If proteins are the bricks from which the body is made, then amino acids are, perhaps, the grains of sand and clay that make up those bricks. There are over 200 known amino acids, more than 80 of which are commonly found in living creatures. And 20 of those 80 are the basic constituents of proteins, which means that they are some of the substances most important to life itself.

An amino acid contains a central carbon atom that is bonded to a hydrogen atom, an amino group (NH_2), an organic acid group (COOH), and R, a radical whose structure varies in different amino acid chains.

Composition

All amino acids are built around carbon atoms. Any carbon-containing material is known to scientists as an organic chemical, and so all amino acids fall within the province of organic chemistry. Carbon atoms can bond with as many as four other atoms, which means that they often serve as a kind of glue, holding together groups of other, more selective atoms.

The carbon atom in an amino acid is always tied to four other components: an amino group, a single hydrogen atom, a carboxyl group, and something else. If the carbon atom were put in the middle of a tetrahedron (a four-cornered pyramid with identical triangular faces), the amino group, the hydrogen atom, the carboxyl group, and the other molecule would each be at one of the four "corners" (apices) of the pyramid. An amino group consists of one nitrogen atom and two hydrogen atoms, for which the formula is NH_2. These groups are made by taking one hydrogen atom away from a molecule of ammonia (NH_3). The carboxyl group is composed of a carbon atom bonded to two oxygen atoms and a hydrogen atom bonded to one of the oxygen atoms. The "something else" can be any of over 200 compounds; replacing one with another gives you a different kind of amino acid. Chemists show this general structure as in the following diagram, where R stands for the "something else."

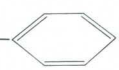
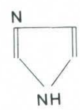
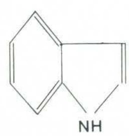
Any molecule with this structure is an amino acid. The simplest is glycine, where R is a single hydrogen atom. Other amino acids, however, have much more complicated additions.

Peptide Bonds

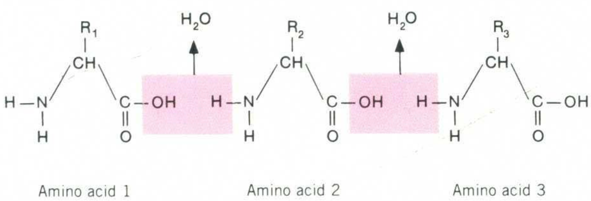
Amino acids can be hooked together into long chains, forming proteins. Generally, there are more than 50 but fewer than 8,000 units—amino acids— in each chain. Hemoglobin, for instance, consists of four chains, two with 141 amino acids and two with 146. Different proteins have different numbers and types of amino acids; as an example, the substitution in hemoglobin of just one amino acid on the two chains with 146 produces hemoglobin S, which causes the condition called sickle-cell anemia, a "molecular disease" that can be fatal. There are an astonishing number of possible configurations for

Amino acids are present in all living cells. They unite to form proteins, enzymes, and hormones. The two spatial diagrams on the facing page show the amino acids glycine and trytophan; glycine is found in most animal tissue, and tryptophan is necessary for proper nitrogen balance.

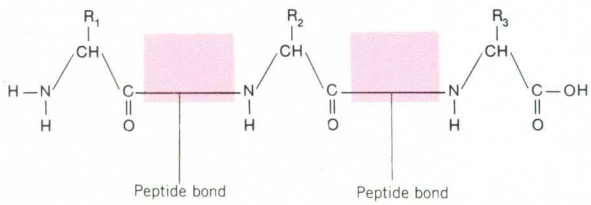
Right: Table shows the amino acid composition of five major proteins. Keratin is the principal component of hair; myosin is a major component of muscle tissue; egg albumin is present in eggs; milk albumin and casein are the major proteins in milk. *Below:* the diagram shows the formation of a peptide bond between two amino acids.

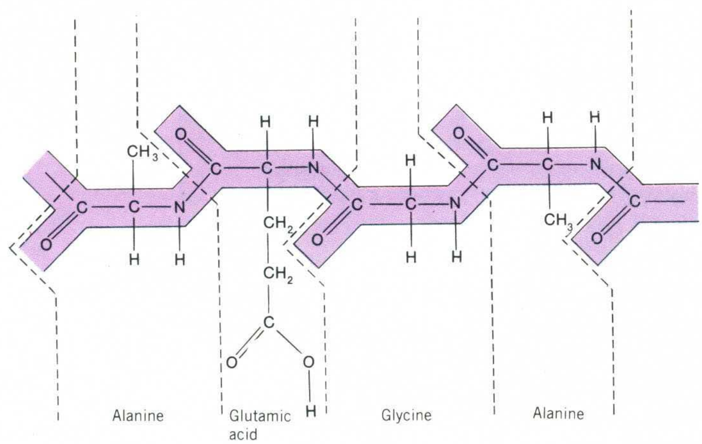
ABBREVIATION	AMINO ACIDS		KERATIN	MYOSIN	EGG ALBUMIN	CASEIN	MILK ALBUMIN
ARG	Arginine	$NH=C(NH_2)-NH-(CH_2)_3-CH(NH_2)COOH$	10.4	7.4	5.7	3.8	4.0
GLU	Glutamic acid	$HOOC-(CH_2)_2-CH(NH_2)COOH$	14.1	22.1	16.5	21.8	18.0
ASP	Aspartic acid	$HOOC-CH_2-CH(NH_2)COOH$	6.5	8.9	9.3	6.0	11.0
GLY	Glycine	$H_2C(NH_2)COOH$	6.5	1.9	0	0.5	0.37
ALA	Alanine	$CH_3-CH(NH_2)COOH$	4.1	6.5	6.7	1.9	6.6
VAL	Valine	$(CH_3)_2CH-CH(NH_2)COOH$	4.6	2.5	7.0	7.9	6.6
LEU	Leucine	$(CH_3)_2>CH-CH_2-CH(NH_2)COOH$	11.3	15.6	16.2	9.7	19.6
PHE	Phenylaline	 $-CH_2-CH(NH_2)COOH$	3.6	4.3	7.7	3.9	5.0
SER	Serine	$HO-CH_2-CH(NH_2)COOH$	10.0	4.3	8.1	5.8	4.9
THR	Threonine	$CH_3-CH(HO)-CH(NH_2)COOH$	6.4	5.1	4.0	4.0	6.0.
CYS—CYS	Cystine	$S-CH_2-CH(NH_2)COOH$ $\vert$ $S-CH_2-CH(NH_2)COOH$	11.9	1.5	1.8	0.4	4.0
TYR	Tyrosine	HO—  $-CH_2-CH(NH_2)COOH$	4.6	3.5	3.7	6.6	5.3
LYS	Lysine	$NH_2-(CH_2)_4-CH(NH_2)COOH$	2.7	11.9	6.3	6.3	10.5
MET	Methionine	$CH_3S-CH_2-CH_2-CH(NH_2)COOH$	0.7	3.4	5.2	3.3	2.6
HIS	Histidine	 $-CH_2-CH(NH_2)COOH$	1.0	2.4	2.3	2.5	2.3
TRY	Tryptophan	 $-CH_2-CH(NH_2)COOH$	1.8	0.8	1.2	1.2	2.5

PROTEIN SYNTHESIS

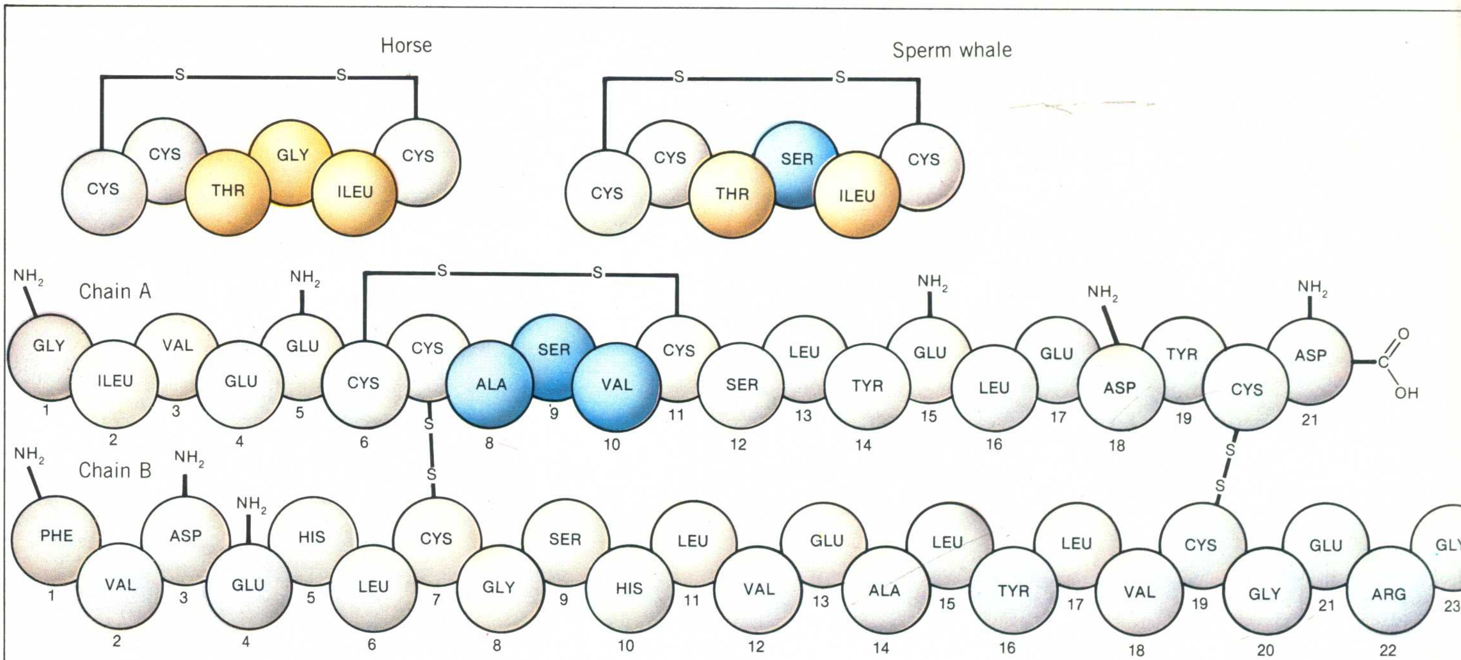


A peptide bond forms between amino acids, releasing a molecule of water.





PROTEIN FRAGMENT



proteins; 20 amino acids can be arranged in a chain 100 units long in more than 10^{100} ways—more, that is, than can be represented by the number 1 followed by 100 zeroes. The huge variety of possible proteins is one factor in the great diversity of life.

The connections between amino acids in a protein are called peptide bonds, the result of a specific kind of chemical interaction between the carboxyl group on the right side of one amino acid and the amino group on the left side of a second. When one H of the amino group and the OH of the carboxyl groups are brought together, they form a molecule of HOH, which is also known as H_2O, or water. The water molecule splits off, and the carbon in the carboxyl and the nitrogen in the amino group then link up. This carbon-nitrogen link is a peptide bond.

Peptide bonds are not easy to create. It takes a considerable amount of energy to drive the H and OH together, then split them off from the joined amino acids. In the body, this reaction occurs only because of the presence of enzymes. Enzymes are a type of protein that serve to catalyze chemical reactions. (Catalysts cause a change in the rate of a chemical reaction without themselves being altered by the reaction, by providing alternate ways for the original reaction to occur.)

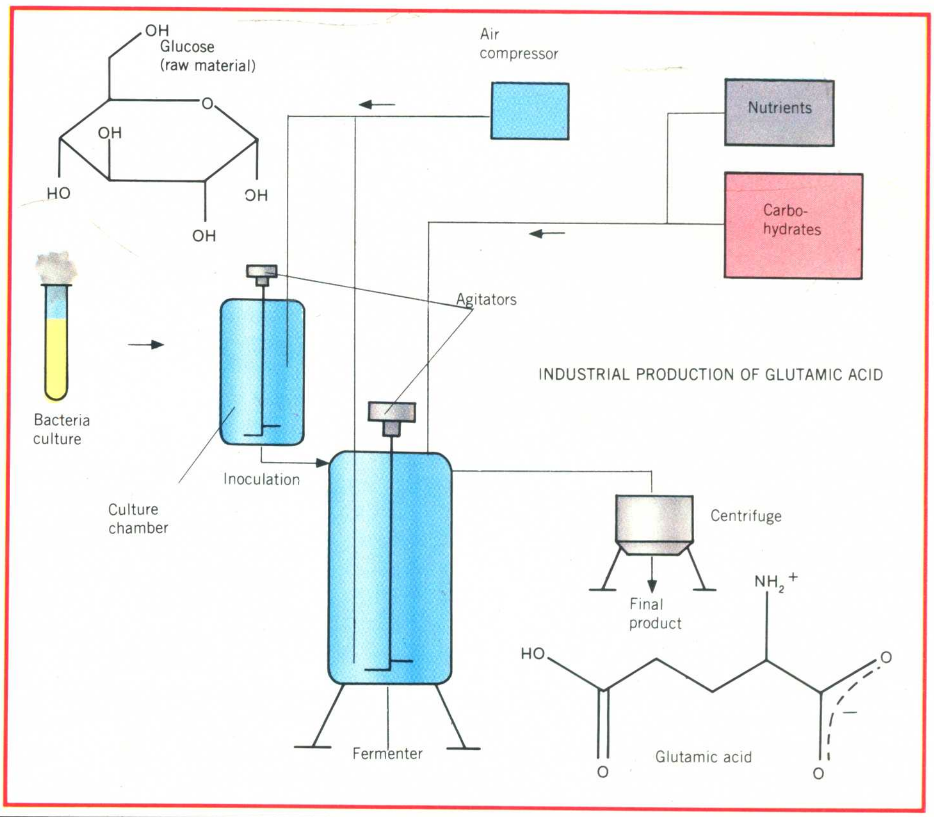
There are hundreds of known enzymes, and each is the key to a small number of reactions that take place under very particular circumstances. Most of the time they are inert, but when the right conditions occur, they work with amazing speed and efficiency.

In the cell, one group of previously created chains of amino acids (enzymes) assists in the formation of new chains of amino acids (proteins), some of which are antibodies, which attack the proteins in harmful bacteria and viruses. Known as protein synthesis, this interplay goes on within the body 24 hours a day; the laborious discovery of this perpetual chemical symphony is one of the great intellectual triumphs of the 20th century.

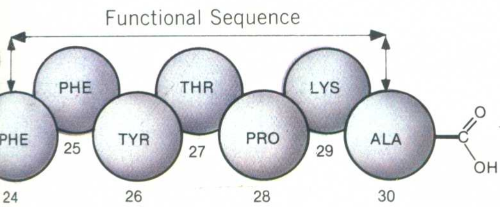
Essential Amino Acids

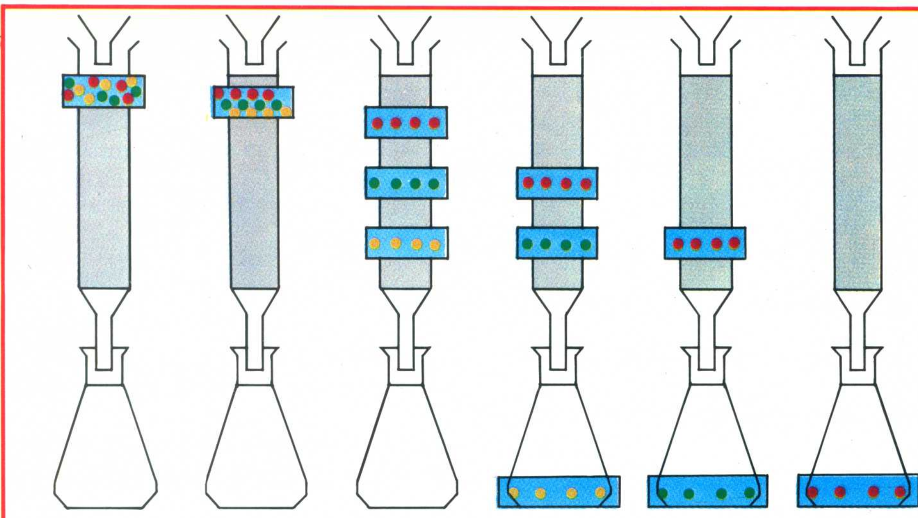
A similar, enzyme-controlled process governs the production of amino acids within the body as well. If the right amino acids are already present in the food, there is no need to create them anew in the cell; if they are not there, enzymes within the

Glutamic acid is used in the preparation of monosodium glutamate, a flavor enhancer in prepared foods. Glutamic acid is manufactured by the industrial fermentation of glucose by bacteria. The procedure is shown at right. Advances in biotechnology are likely to make possible the synthetic preparation of other amino acids.



A polypeptide chain is a chain of amino acids organized in a particular sequence. Each polypeptide has its own sequence. The pancreatic hormone insulin forms when two polypeptides, A and B, are joined by two disulfur bonds. A third disulfur bond joins amino acids 6 and 11 in chain A. Horse insulin differs from cow insulin at amino acids 8, 9, and 10. Whale insulin differs only at 8 and 10.





Chromatography is used to separate amino acids. In the diagram, three amino acids are represented by three different colors. The group of amino acids is placed in a buret with a solvent (water and butanol). The three acids have different affinities for the solvent and therefore separate into three layers.

organisms—the pepsin in gastric juice, for example—tear apart molecules, turning them into small groups of atoms that can be used to make amino acids.

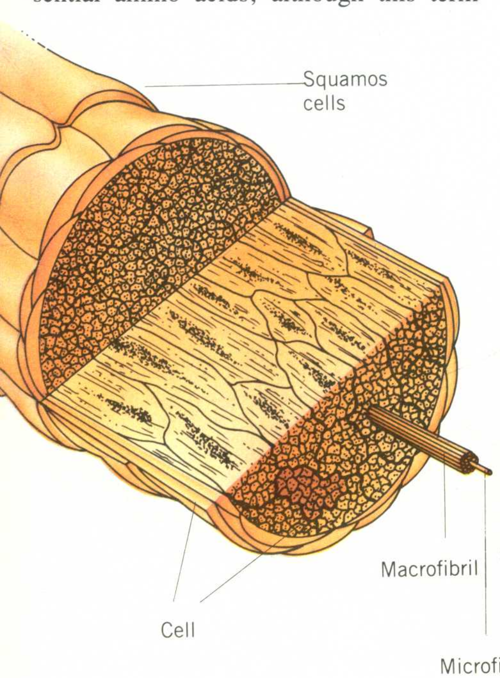
There are, however, exceptions to this process. Eight of the 20 amino acids in proteins—leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophane, and valine—cannot be produced by the human body and must be taken in from food. These eight are called the essential amino acids, although this term does not mean that the other 14 are any less vital to life.

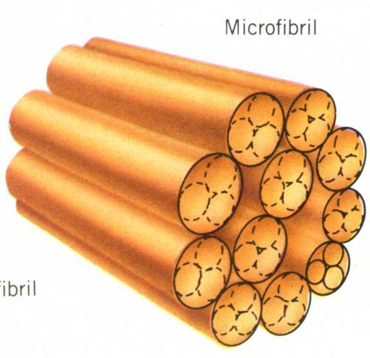
Most proteins from animal sources contain all eight of the essential amino acids. Plants, however, generally do not have all of the essential amino acids. This means that considerable care must be taken by vegetarians to ensure that they have some source for all eight. A good balance of grains and legumes (peas and beans) can in princple provide the necessary amino acids, but maintaining the right mix is a complicated process.

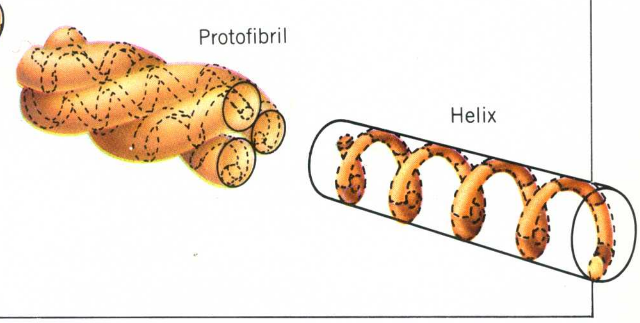
Not getting the right amino acids is disastrous. The body is put in the position of trying to build a house without any bricks—or, more accurately, without the clay to construct those bricks. In extreme cases, sustained amino acid deprivation can lead to the disease known as kwashiorkor, a form of malignant (or untreatable) malnutrition that strikes children. According to United Nations estimates, from 100 to 300 million children under the age of 8 are now afflicted with kwashiorkor, largely because their principally vegetarian diet lacks the essential amino acids. Poverty, not ignorance, is the cause of most cases of kwashiorkor; the children (chiefly in Africa) who suffer from it are from families that simply cannot afford a balanced diet.

As this example shows, amino acids play a vital role in keeping our lives together. Without them, the proteins essential to living creatures could not be made, and even the enzymes necessry to build amino acids could not exist.

See CATALYST AND CATALYSIS.





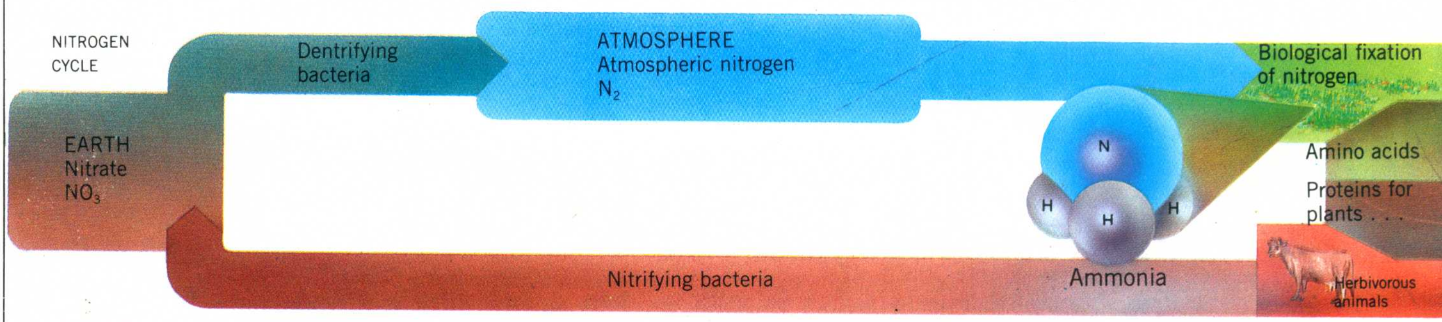


Keratin is a major protein in wool. A single wool fiber is diagramed here. It consists of cortical cells having a fibrous protein structure. Each filament is a group of macrofibrils, which in turn consist of microfibrils. Each microfibril consists of a group of spiraled proteins. One functional length of this spiral is a helix, which consists of the specific chain of amino acids that form wool.

Ammonia

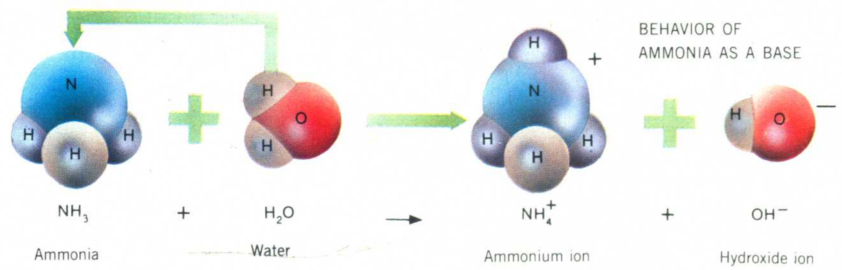
Because of its sharp odor, ammonia has been used in smelling salts to relieve faintness for more than a century.

Its most familiar use is as a strong-smelling and highly effective household cleaner. A clear, lighter-than-air alkaline gas, ammonia is the best-known compound of nitrogen and hydrogen—NH_3. During the Middle Ages, aqueous (mixed with water) ammonia was made from the horns and hoofs of oxen, thus earning the alchemical name "spirits of hartshorn." Ammonium chloride was made in ancient times by heating camel dung or a blend of urine and salt. In 1774, Joseph Priestley obtained ammonia gas, or alkaline air, by heating sal ammoniac with lime. Three years later, Karl Wilhelm Scheele proved that ammonia contained nitrogen, but it was C. L. Berthollet who finally determined the exact chemical formula of ammonia in 1785.



PHYSICAL PROPERTIES OF AMMONIA

Melting point	−107.93°F. (−77.74°C.)
Boiling point	−28.03°F. (−33.35°C.)
Critical Temperature	271.4°F. (133.0°C.)
Density (liquid: −22°F.; −30°C.)	0.5963%
Solubility in water at 1 atm 32°F. (0°C.)	47% by weight
Solubility in water at 1 atm 68°F. (20°C.)	33.1% by weight
Solubility in water at 1 atm 86°F. (30°C.)	28% by weight



How Ammonia is Formed

Ammonia occurs naturally in only a few places, such as the volcanic steam vents near Larderello, Italy, and in lava. Because ammonia forms when animal and vegetable material decompose, ammonia salts are found in soil, sea water, and plant and animal liquids, including urine.

At least 85 percent of all ammonia used is produced industrially, and has many commercial and agricultural uses. The chief method of production is the Haber process, which combines nitrogen with hydrogen at high temperatures and pressure using a catalyst (an agent to stimulate a chemical reaction). Ammonia is also prepared by combining nitrogen gas with calcium carbide and then water; it is a by-product of distilling coal. For laboratory use, an ammonium salt is heated with a strong base (a water-soluble compound that reacts with an acid to form a salt) to form ammonia. It can also be prepared by adding water to a metal nitride.

Uses of Ammonia

Ammonia and its salts are used in a wide range of commercial products and processes:

1. As fertilizer. This is the major use of ammonia and its compounds. Mixed ammonium nitrate fertilizers produced commercially contain various additives, including calcium phosphate, limestone, dolomite, and potassium. Fertilizers contain nitrogen as an essential nutrient and are often produced in pellet form designed for use with farm machinery.

2. In the manufacture of explosives. Ammonium nitrate is used to make various explosives, including dynamite and blasting devices. As it is quite flammable, especially when confined, special shipment and storage regulations are enforced by many governments.

3. With chemicals and dyes. Ammonium chloride, or sal ammoniac, is used in galvanizing, tinning, and soldering and in the manufacture of certain pharmaceuticals and dyes. It is a key ingredient in cough medicine and in dry cell batteries.

4. In refrigeration and air conditioning equipment. Water-free ammonia gas is easily liquefied under pressure and is used in refrigeration and air conditioning because the liquid absorbs a large amount of heat when it evaporates, speeding the cooling process.

5. As fuel. Ammonia is a potential fuel for both internal-combustion engines and jet propulsion. Ammonium nitrate in liquid ammonia forms a volatile fuel combination.

6. Ammonia is also used in the Ostwald process, named after the Nobel Prize-winning German chemist who specialized in catalyst research. Ostwald patented a means of using a catalyst to convert ammonia to nitric acid, which is used to make nitrates, an important food additive and component of fertilizer.

7. The Solvay Process, developed by the Belgian chemist Ernest Solvay, also utilizes ammonia. This procedure, which synthesizes sodium bicarbonate, is considered one of the most important 19th-century advances in industrial chemistry.

Ammonia is also used to synthesize sulfa drugs and to purify water supplies. As a household product, it is used in weak solutions to clean, bleach, and deodorize. The first atomic timekeeping device, the ammonia clock, was invented in 1948. Its design was based on the oscillation of the nitrogen atom in a molecule of ammonia, and it proved to be the most accurate clock in the world until it was replaced by another device, the cesium clock.

Chemical Properties of Ammonia

Ammonia is very soluble in water and is easily liquefied, either by cooling to the normal boiling point −92°F (−33.35°C.) or by compression. Most of the chemical reactions of ammonia may be classified under three chief heads:

1. Addition reactions (ammonation). In this process, a new compound is formed