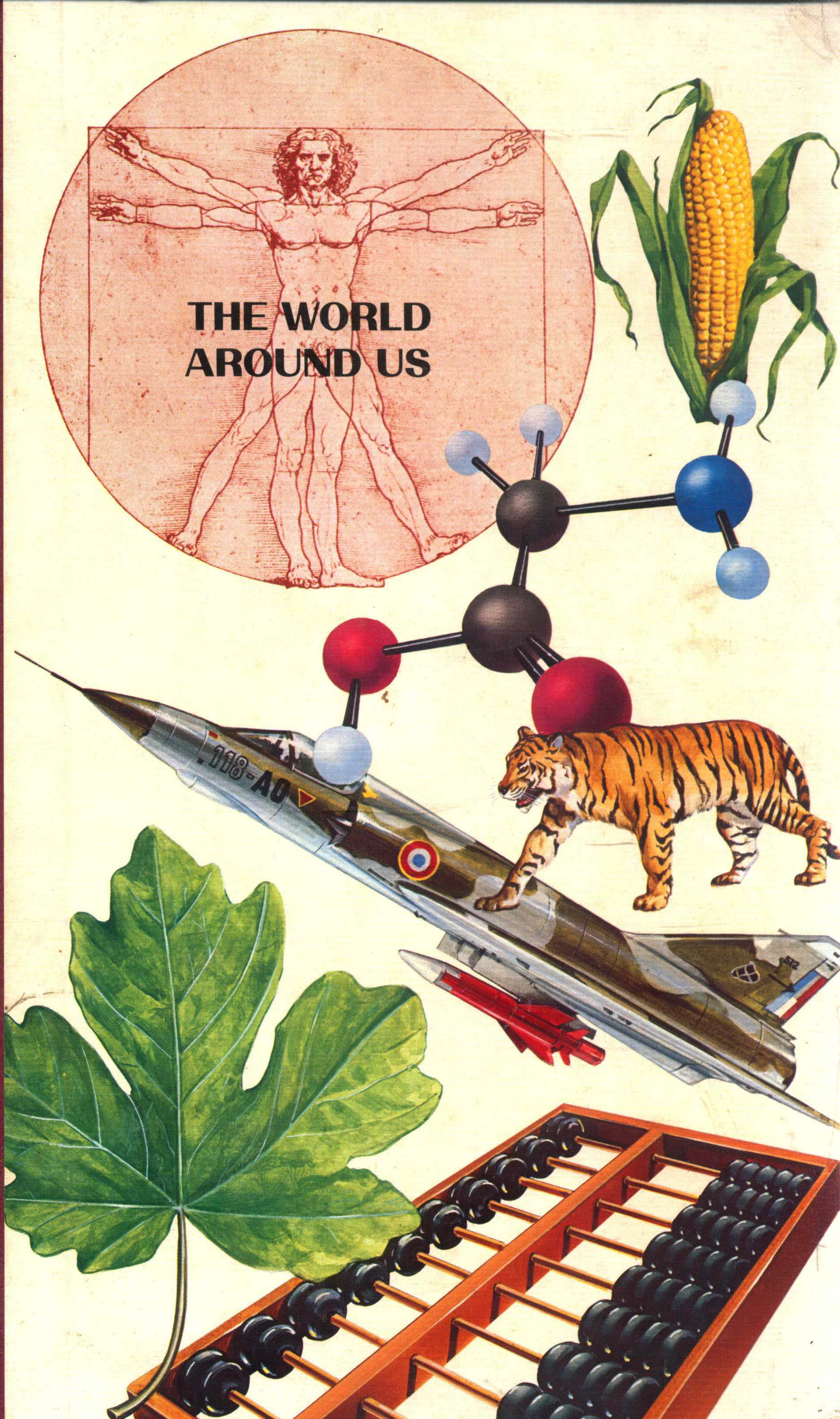
SCIENCE AND TECHNOLOGY ILLUSTRATED

THE WORLD AROUND US



Science and Technology Illustrated

The World Around Us

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Science Technology

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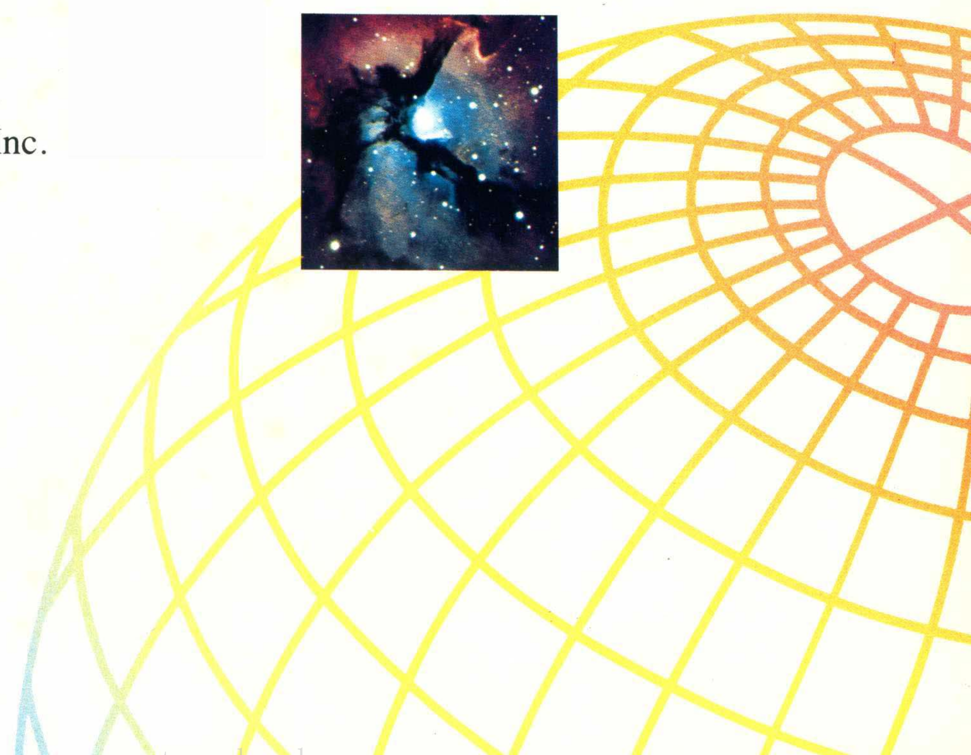

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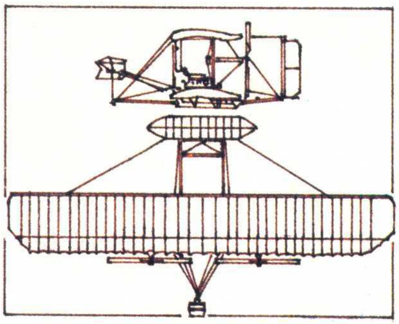
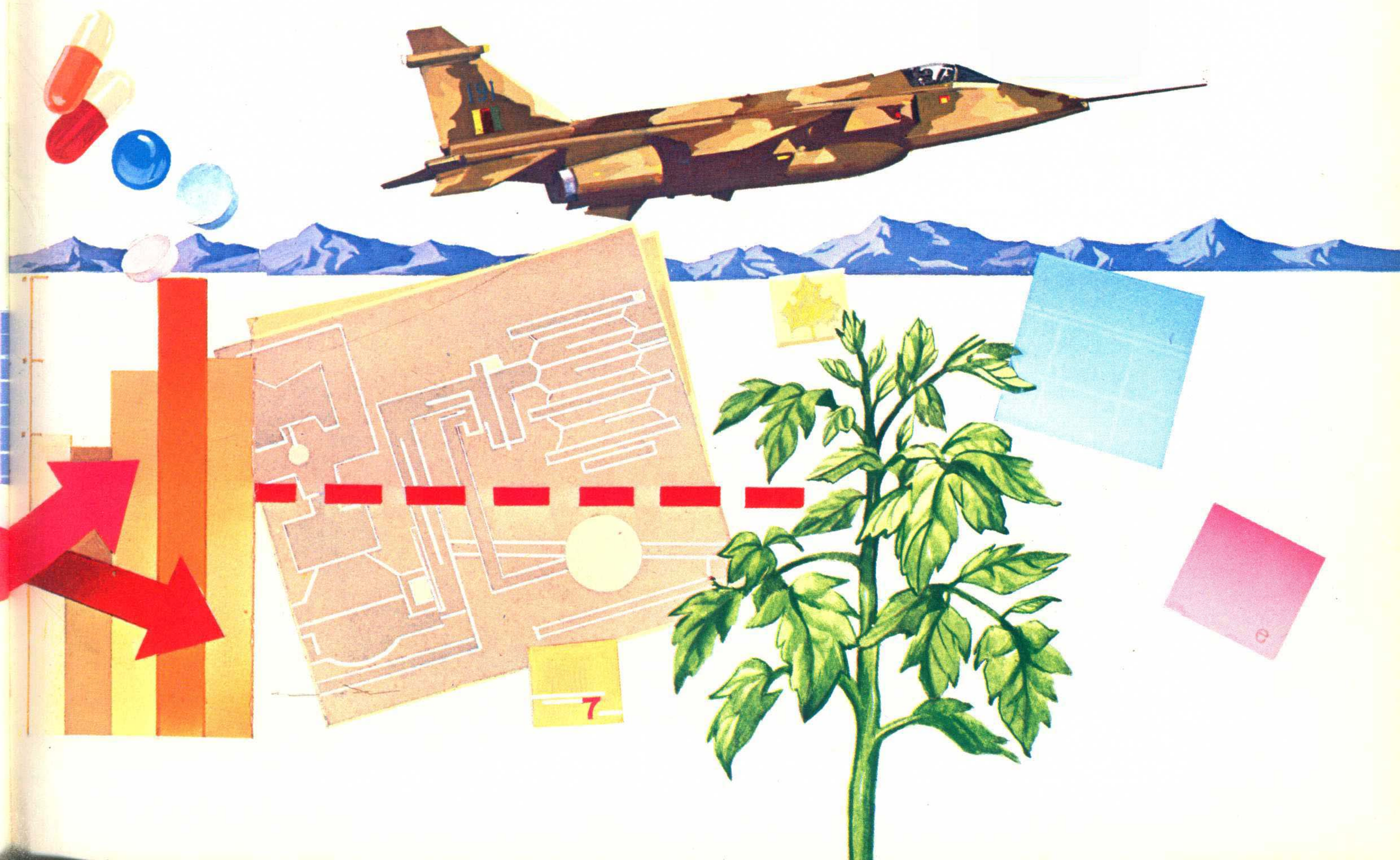
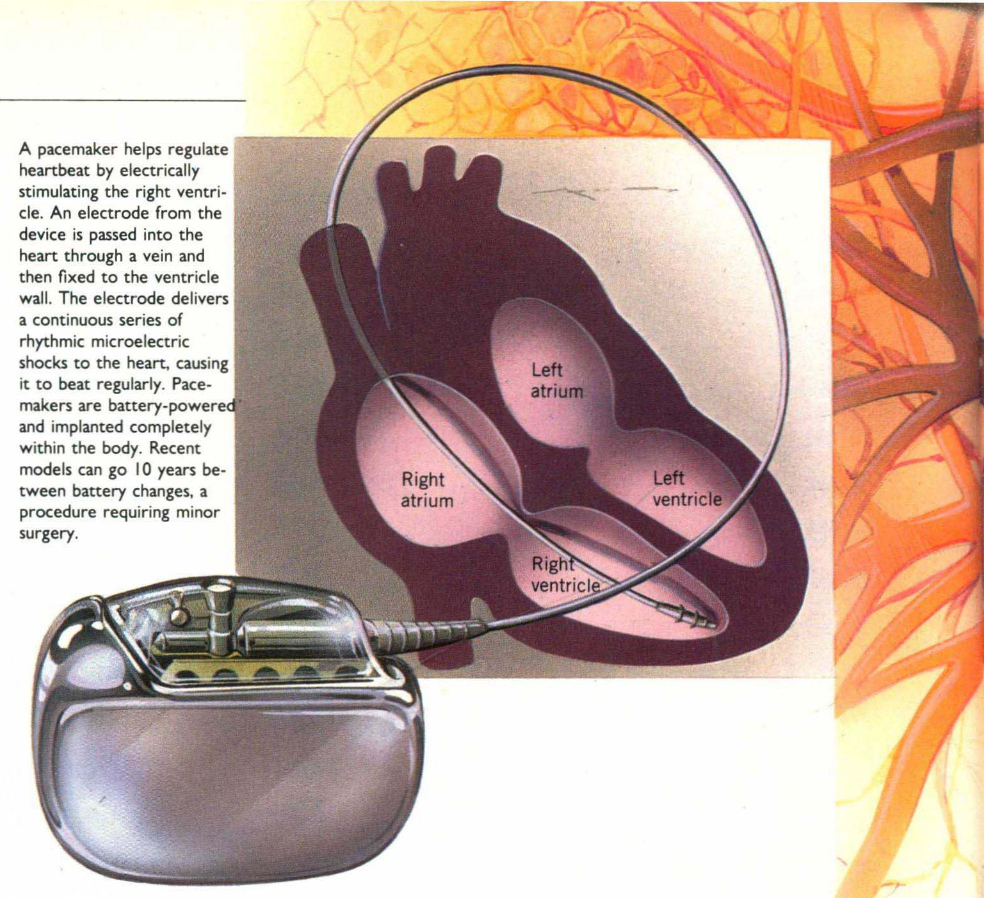




Bioengineering



A pacemaker helps regulate heartbeat by electrically stimulating the right ventricle. An electrode from the device is passed into the heart through a vein and then fixed to the ventricle wall. The electrode delivers a continuous series of rhythmic microelectric shocks to the heart, causing it to beat regularly. Pacemakers are battery-powered and implanted completely within the body. Recent models can go 10 years between battery changes, a procedure requiring minor surgery.

During the dogfighting days of World War I, pilots in open-air cockpits sometimes attained altitudes as high as 20,000 feet (6,100 m). This was in the day before oxygen masks, pressurized flying suits, or cabin pressure, so loss of consciousness was always a possibility. To prevent the onset of dizziness, these early aces took to the air with small tubes of flowing oxygen clenched in their teeth. As engineering goes, it wasn't beautiful or sophisticated, but it undoubtedly kept some pilots alive, and that makes it one of the earliest examples of bioengineering.

Bioengineering is the term used to describe man-made mechanisms that maintain life in hostile environments; it is useful in medical research, diagnosis, and therapy. The environment may be external, as in outer space, or internal, as in a malfunctioning kidney. There are two main areas of development in bioengineering. The first concerns artificial organs, machines that duplicate the function of biological organs (such as the heart or lungs) to prolong life.

The second area is more environmental in principle and concerns itself with sophisticated interconnected mechanisms—called life-support systems—that maintain basic necessities of life (oxygen and air pressure, for example) in places where they normally are not found. A good example of a life-support system is the space suit, which—together with special space capsules—allows astronauts to travel into outer space and walk on the Moon.

Biomedical Mechanisms

Biomedical devices are a relatively recent addition to health treatment, and they promise to have much greater significance for human life in the future. Medical engineers have already developed man-made valves and other parts for the human heart. In fact, a completely functional, long-lasting artificial heart may be a reality before long. For the time being, the three most common biomedical devices currently in use are the iron lung, the heart-lung machine, and the kidney dialysis machine.

The iron lung is a mechanical breathing device that derives its forbidding name from the heavy, airtight, metal chamber in which the patient lies. Just as muscles in the human diaphragm (which separates the chest from the stomach) force air in and out of the lungs, the iron lung uses a movable mechanical diaphragm (lying beneath the patient's body on a bellows-like bedspring) to force air in and out of the chamber.

When the bellows of the diaphragm contracts and the diaphragm pushes up, the air pressure within the metal chamber increases until it exceeds the pressure of the atmosphere surrounding the patient's head, which extends outside the chamber. This has the effect of squeezing air out of the patient's lungs. When the bellows expands and the diaphragm relaxes, pressure inside the iron lung drops below atmospheric pressure, and air—obeying basic laws of nature—rushes into the lungs to equalize the pressures. By mechanically repeating the action of the diaphragm rapidly, the iron lung accomplishes with pressure variations what is normally done with the body's muscle contractions.

Heart-Lung Machines

The heart-lung machine reduces the functions of the heart and lungs (pumping and oxygenation, respectively) to mechanical processes. First used in 1953, the machine allows surgeons to stop a person's heart and perform delicate cardiac surgery while the body tissues continue to receive nourishing supplies of blood.

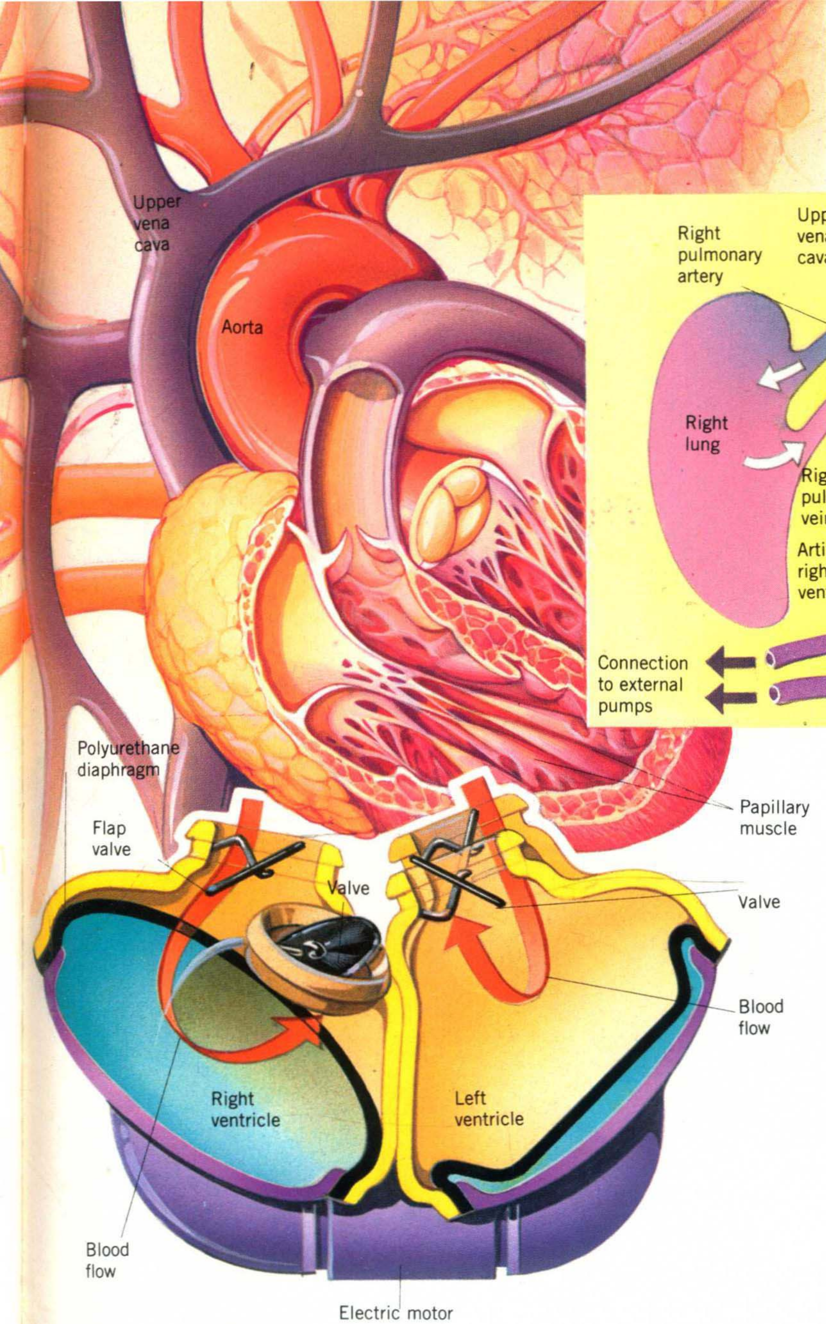
It works like this. Tubes are attached to the heart itself and to the vena cava, the major vein for carrying deoxygenated (or oxygen-poor) blood to the heart. This "used" blood is siphoned out of the body and carried by silicon-coated tubes to glass cylinders known as oxygenators. Steel disks inside the cylinders constantly rotate, in effect flicking the blood into a flow of oxygen in the cylinder and thus mimicking the oxygen-blood transfer of the lungs.

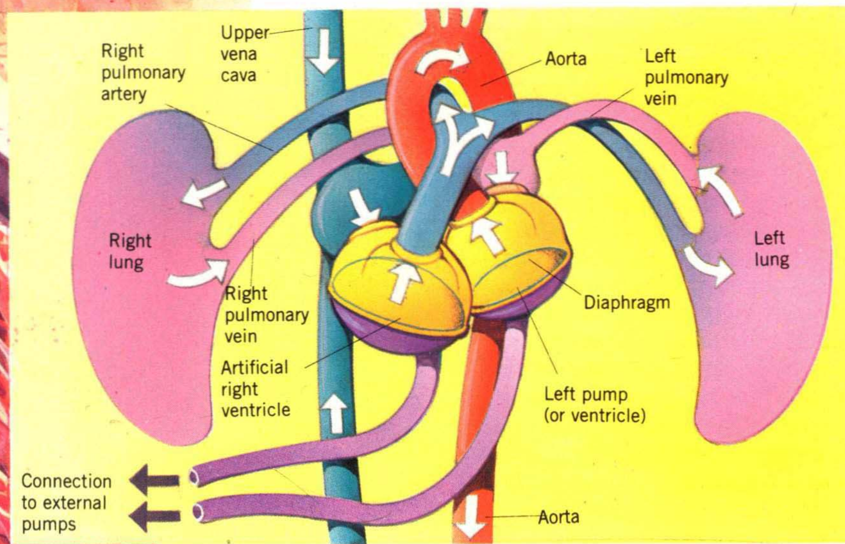
Once the red blood cells have picked up enough oxygen, the blood is pumped through a heat regulator and a filter back into the body's arterial system, just outside the heart. An extra supply of blood can be introduced to the system, since some blood loss is inevitable.

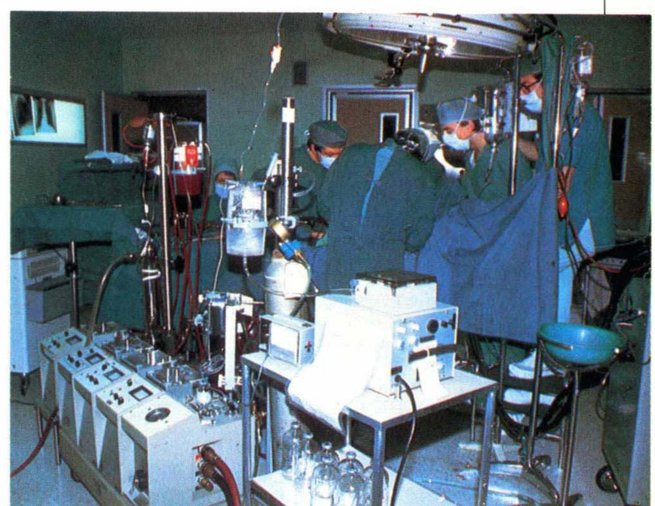
The Artificial Kidney

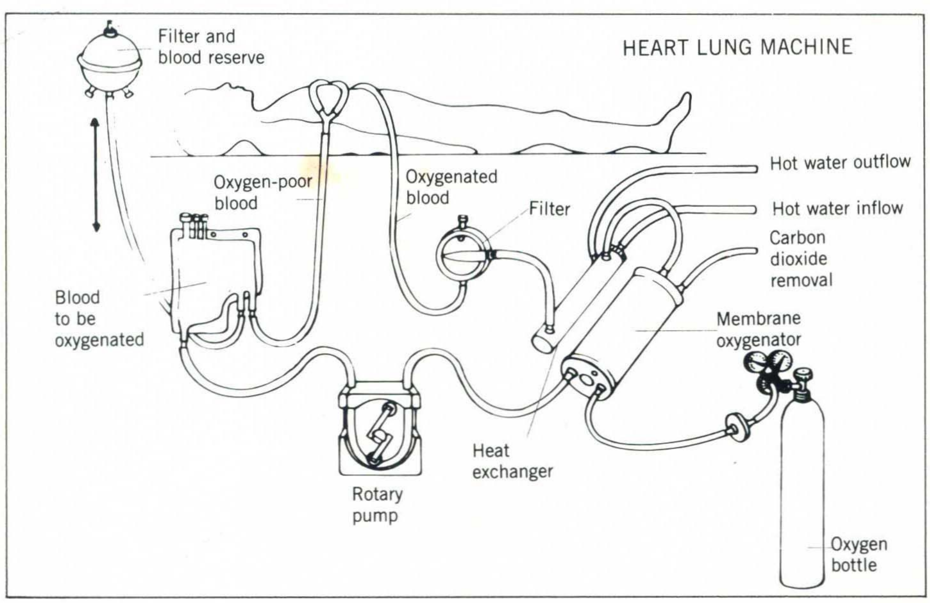
The artificial kidney, or hemodialyzer, is a complicated machine that takes in blood, removes its impurities, maintains its acid-base balance, and adds any needed components. This machine is necessary to a person who suffers from kidney malfunction or has had kidneys surgically removed.

Dialysis is essentially a chemical exchange process that takes place in two chambers separated by a porous membrane (usually of cellulose or a related substance). One chamber is filled with blood, the other with a sterile solution. Urea, inorganic salts, and other wastes in the blood are small enough to pass through the pores of the membrane and thus flow into the sterile solution; proteins and hemoglobin molecules are too big, however, and remain on their side of the membrane. The blood is kept at a higher pressure than the accompanying solution, so that water molecules in the solution do not flow into the blood and dilute it. The treatment is time-consuming and painful, but life for many would be impossible without it.









Above: Cutaway diagram compares the artificial heart (bottom) with the human heart. Two polyurethane diaphragms within the artificial heart actually move the blood. These diaphragms are powered by a compressor surgically implanted in the thorax. The compressor itself is driven by a miniaturized electric motor. Other designs for artificial hearts make use of external compressors.

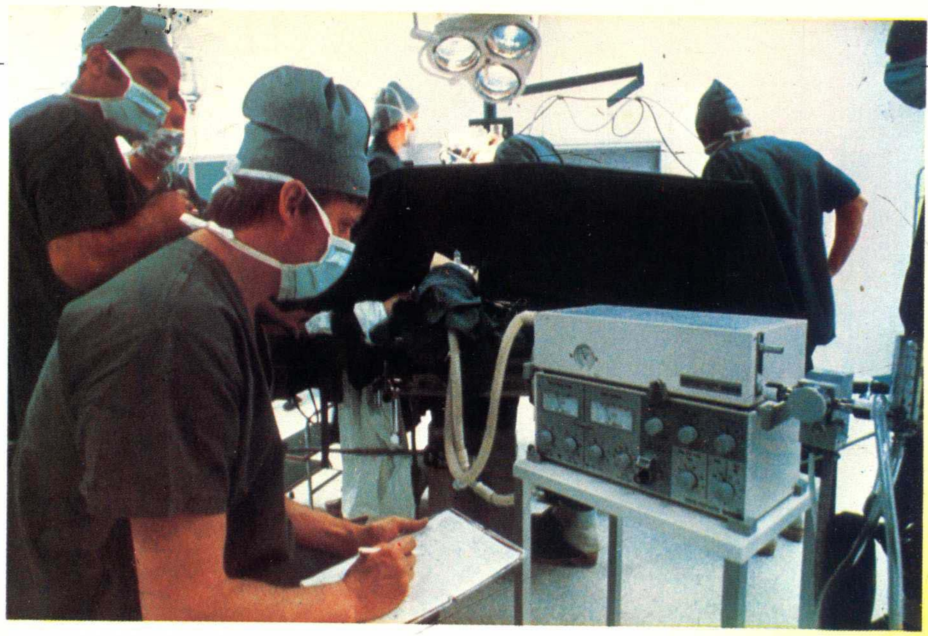
Above, right: Overall view of blood circulation driven by an artificial heart. The two dark arrows show the connection to an external compressor.

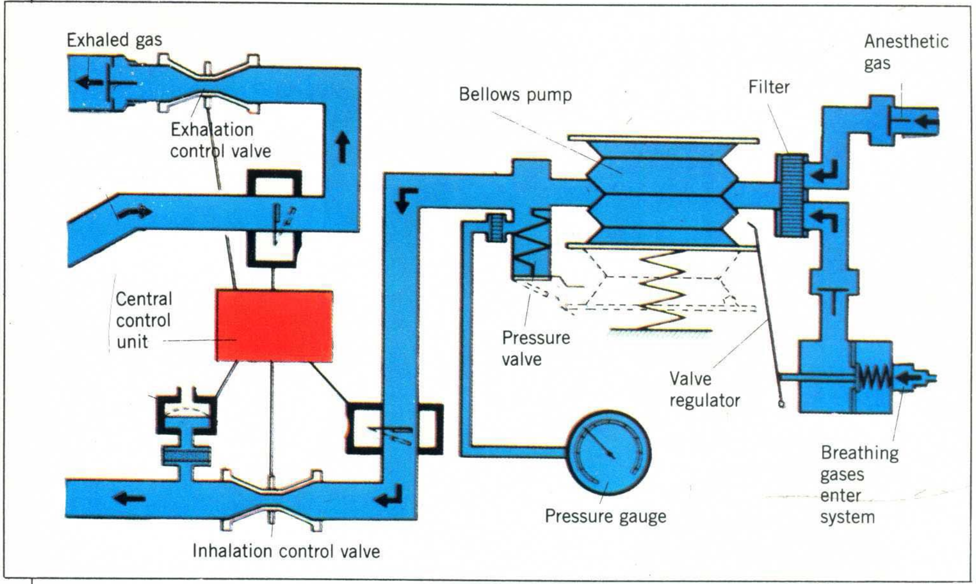
The photograph shows a heart-lung machine in use in an operating theater. These machines allow surgeons to stop a patient's heart temporarily during cardiac surgery. The essential parts of such a machine are shown in the diagram. Since blood cools outside the body, a heat exchanger warmed by hot water is used to keep it at body temperature.

Re-creating Environments

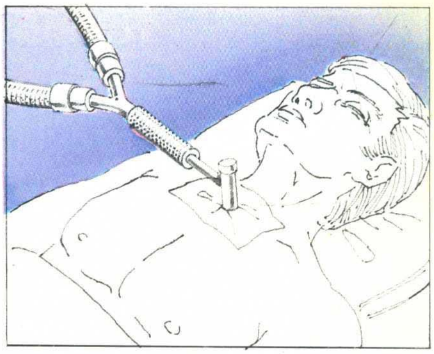
Life would also be impossible in outer space, underwater, and even in jet airplanes without engineering solutions to the problem of hostile environments. In these cases, bioengineering has the job of "re-creating" life-sustaining environments for humans. These life-support systems maintain constant pressure and temperature, supply oxygen and water, and remove carbon dioxide, odors, and wastes. In short, bioengineers package the complex environment of Earth at sea-level and put it in an artificial setting—a submarine or space capsule or aircraft cabin.

Although we take it for granted, the pressure of the atmosphere is essential to normal life. Since a pressurized environment is considered the easiest to re-create, it is usually the key feature in a life-





The servo-ventilator, like the iron lung, is an artificial breathing device. In this case, though, it is designed only for temporary use in the emergency room or during surgery. Breathing gases, which can be mixed with anesthetics, bypass the patient's mouth and nose, entering directly in the windpipe by way of a tracheotomy. The entire system is controlled by computer.



support system. Any time man moves up or down from sea level, the effects of pressure change and become increasingly problematic. As one ascends in altitude above the Earth, pressure decreases—with the effect that oxygen is not so effectively "pushed" into human lungs, and ordinary breathing may not bring enough oxygen to the body. As one descends into the sea, water pressure increases tremendously. Bioengineering neutralizes these hostile conditions with pressure-resistant structures, such as the oceangoing bathysphere and other pressurized environments.

Flying Under Pressure

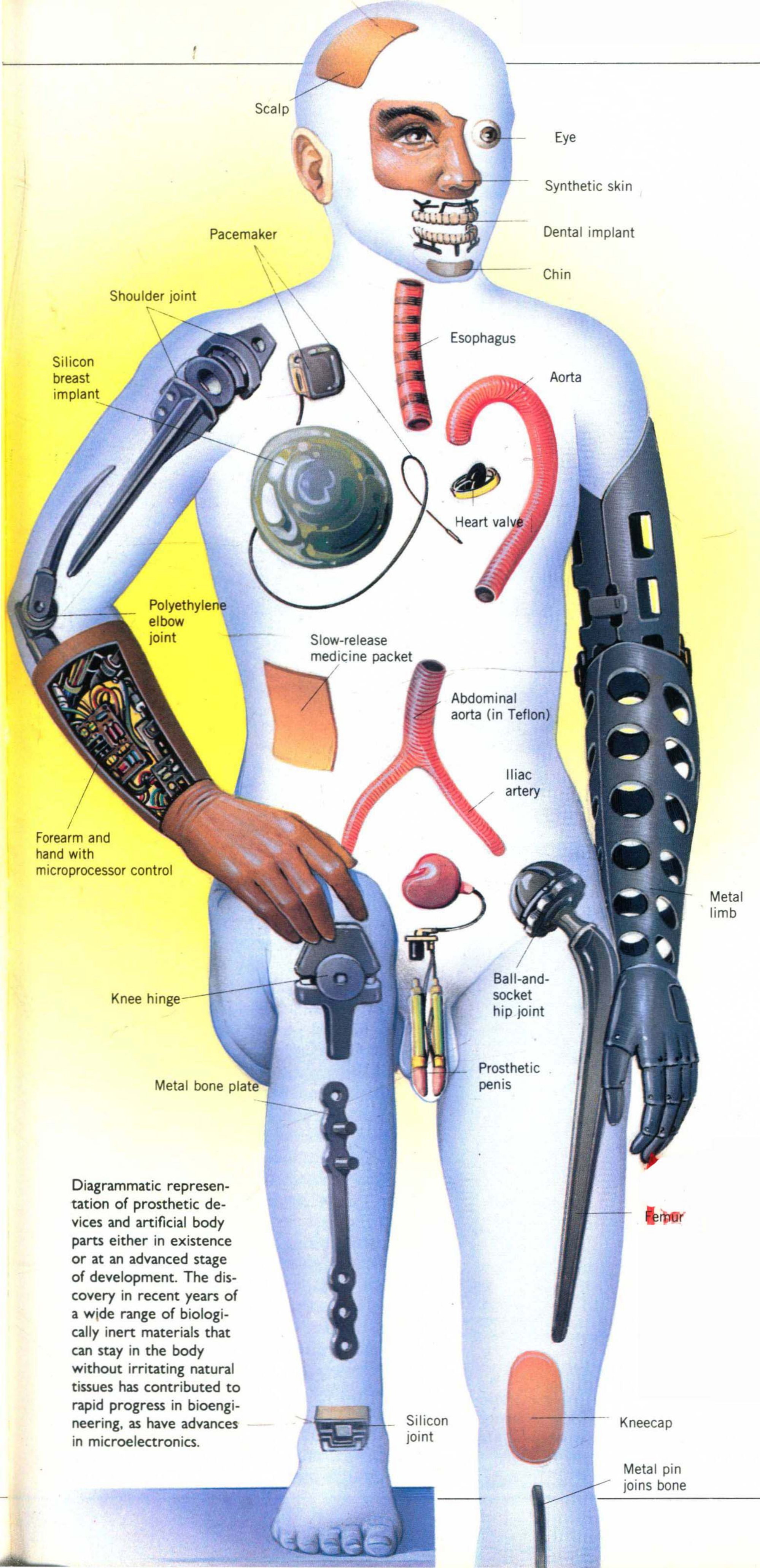
A common example of a pressurized environment is the cabin of a jetliner at cruising altitude. At 34,000 feet (10,400 m) the reduced atmospheric pressure means that a human would have to breathe pure oxygen (as opposed to the 20-percent oxygen content of air at sea level) for normal function. Without cabin pressure, human lungs could not draw in enough oxygen from the air, and the traveler would become ill and quite possibly unconscious.

Cabin pressure, in effect, makes sure there is enough pressure to push oxygen into human lungs. In jets, it does this by tapping compressed air from either the engine or an accompanying blower. The compressed air, after cooling, is circulated through the cockpit and cabin. Excess air is vented from the cabin, together with carbon dioxide, so the system doesn't require recycling or purification.

Technology's ultimate answer to a hostile environment is the lunar space suit. This bulky garment (actually about 10 separate layers of synthetic fabrics with varying functions) and its attached 190-pound (85 kg) life-support backpack answered every question raised by the Moon's strange environment.

The lunar space suit incorporated such diverse substances as nylon, which stands up against high temperatures; neoprene, a synthetic rubber that protects against meteoroids; aluminized plastic, for insulation; and a fancy pair of space-age long johns webbed with tubes of liquid coolants running over the surface of the skin. The backpack—which weighs only about 30 pounds (13.5 kg) in the Moon's reduced gravity—provided supplies of oxygen and water as well as constant pressure, power, communications hookups, and "containment units" for waste. Like a technological update of Atlas, the astronaut carried the world, and its essential biochemical qualities, on his back.

Two key elements of a life-support system—whether under water or in outer space—are the supply of oxygen and the removal of carbon dioxide. Oxygen can



Diagrammatic representation of prosthetic devices and artificial body parts either in existence or at an advanced stage of development. The discovery in recent years of a wide range of biologically inert materials that can stay in the body without irritating natural tissues has contributed to rapid progress in bioengineering, as have advances in microelectronics.

be supplied by bottles of compressed gas, which has found use in such varying enterprises as scuba diving, nuclear submarines, and Mercury space shots. If large volumes are needed, oxygen can be drastically cooled until it liquefies; liquid oxygen takes up less space and has a good shelf life.

When space and weight are prime considerations, solid forms of oxygen are an alternative. Chlorate candles, for example, are blocks of iron powder and sodium chlorate that, when burned, produce oxygen. Sodium dioxide and potassium dioxide, known as alkaline superoxides, react chemically with either carbon dioxide or water to produce oxygen. Modern submarines employ new electrochemical technologies that involve the separation of ordinary water into oxygen and hydrogen by the process of electrolysis.

Carbon Dioxide Removal

While oxygen must constantly be supplied, carbon dioxide (a by-product of breathing) must constantly be removed from the artificial atmosphere. This is usually accomplished with powdery compounds known as chemical scrubbers. The scrubbers simply snatch carbon dioxide molecules out of the air that is circulated through them. Lithium hydroxide, probably the most common scrubber, has been a fixture in both submarines and all U.S. space capsules.

Some submarines use an amine scrubber, in which water and amines react with carbon dioxide in the air and remove it. Unlike other scrubbers, the amine scrubber is reusable; the collected carbon dioxide can be separated by heat, concentrated, and then expelled from the system.

In order to remove odor-causing molecules and other organic contaminants from the air, most circulation systems include a filter of activated charcoal. With its large surface area, activated charcoal is an extremely effective cleaner.

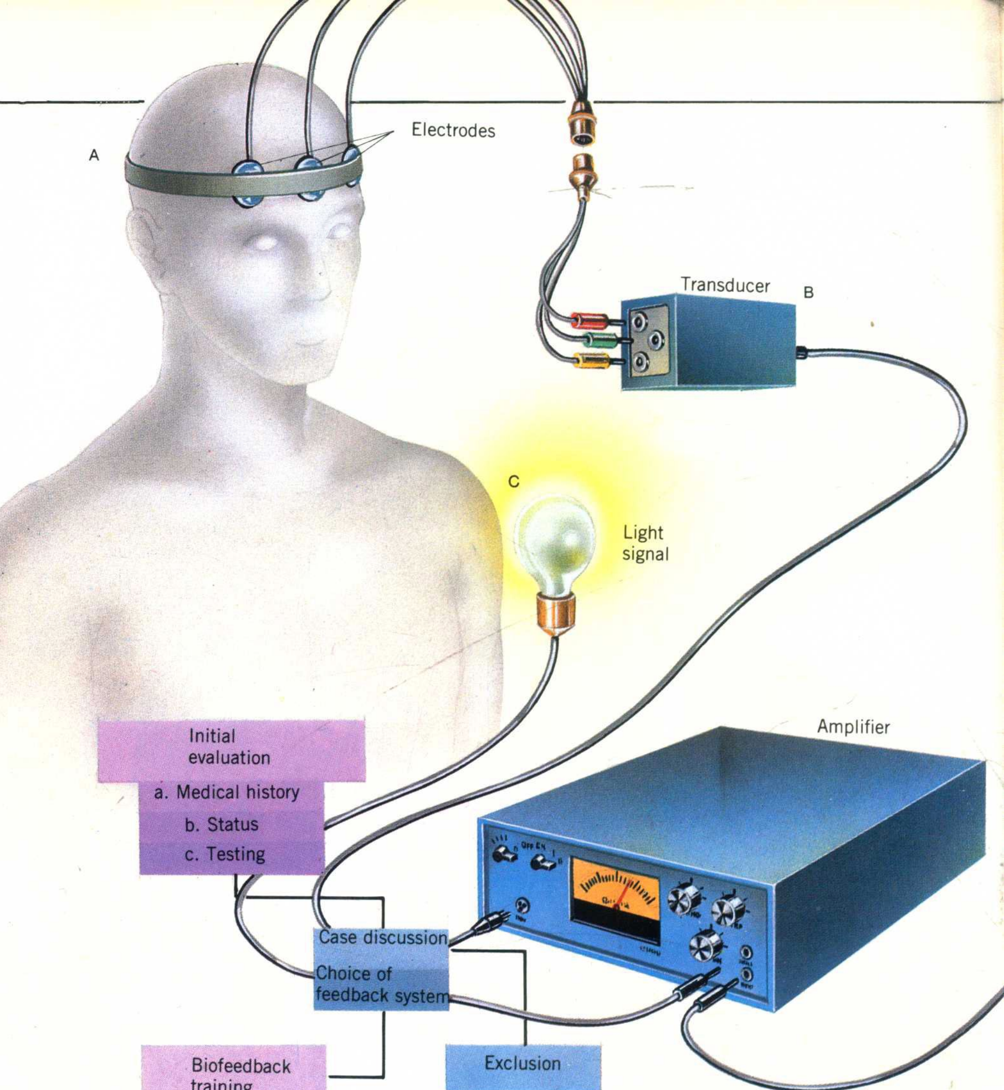
The ultimate aim of bioengineers is the creation of a closed system that would permit interplanetary space travel. The essence of a closed system is the reuse, or recycling, of materials, with energy as the only input required. Such a system must be designed for self-sufficiency, since supplies of oxygen, food, water, and other necessities obviously couldn't be obtained along the way. Developments such as fuel cells in spacecraft, which produce water as a by-product of generating electricity, are steps toward achieving a closed system. The closed system is a distant technological prospect. Yet so, too, looking back in history, is that image of the World War I flying ace with his oxygen tube in his teeth.

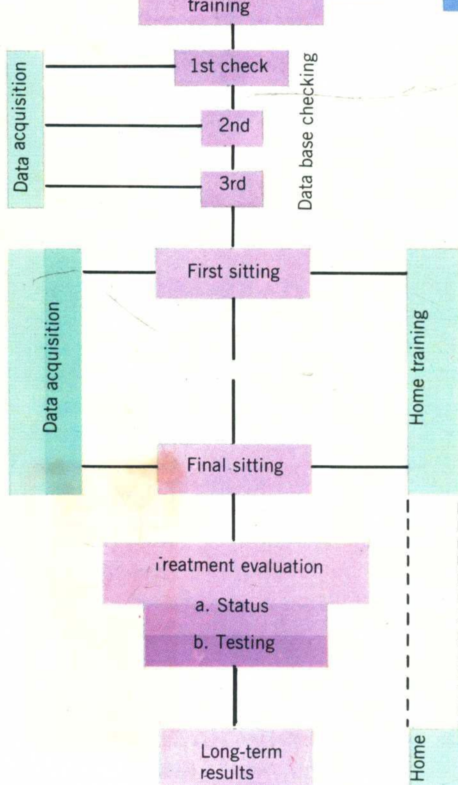
Biofeedback

The patient lies in his hospital bed watching the flashing lights of the computer display at the foot of the bed. Nearby is the cardiotachometer, which converts the patient's heartbeat into electrical signals to be analyzed by a computer. The signals emitted by the computer are synchronized with the patient's heartbeat and converted into a kind of code that can easily be understood. Generally, a red light indicates that the patient's heart rate is too fast, the green light suggests that it is too slow, and the yellow light indicates that the rate is normal. Watching for the occurrence of the yellow light carefully, the patient can "tune into" his body and slow his heart rate so that it falls into an even, steady, healthy rhythm.

This patient is using "biofeedback" to control his heartbeat—a therapy that may save his life, since he has been diagnosed as having a dangerous irregularity in his heartbeat.

Until recently, the idea that one could voluntarily regulate one's heart in this manner went against traditional medical belief. For a long time, it was believed that the central autonomic system, which includes the digestive tract, heart, and circulatory system, was beyond the conscious control of the individual. But that belief has been changed in the light of biofeedback research.





Powers of the Mind

In an explosion of research during the 1960s, scientists throughout the world found that, through biofeedback techniques, the individual can learn to control certain physiological responses once felt to be completely involuntary. This means that blood pressure, heart rate, kidney functions, blood flow, digestion, and other functions may all be controllable through biofeedback. Scientists have discovered that some people can affect more than one neurological or biological function at a time through biofeedback training, so that one might, for example, be able simultaneously to lower such related functions as heartbeat and blood pressure. What researchers found is that we have great, and as yet untapped mental powers to use in regulating our own internal organs—and therefore, our health.

Central to biofeedback is the principle of feedback—the process through which a system, machine or animal, regulates itself by continually analyzing its performance or environment, then incorporates that knowledge into its operation. A good example of feedback is the thermostat, a device that automatically adjusts room temperature to a preset reading by a process of constant comparison.

In biofeedback, one monitors internal organs through the use of an electronic feedback device that registers and amplifies basic physiological activities, translating them into readily observable signals—like the flashing lights studied by the heart patient. Once people recognize those signals, they can use a variety of techniques to condition their bodies and control the biological functions being monitored. As an example, to aid in the control of migraine headaches, researchers set up instruments that measure the temperature of the hand as a gauge of blood flow. This information can be translated into a series of signals, such as clicking sounds, so that the patient can monitor fluctuations in blood flow. Guided by these signals, the patient can then learn to gradually redirect the blood away from this throbbing head and toward other parts of the body, helping to relieve the pressure of migraine attacks. With practice, this conscious redirection becomes second nature.

According to biofeedback researchers and many doctors, some of the body's response systems work improperly because of the debilitating effects of prolonged stress, which create physiologically ingrained, unhealthy behavioral responses. Through biofeedback, its supporters be-

Left: Biofeedback device used for brain-wave training. The electrodes placed around the head detect electrical activity in the brain. These signals are then amplified and made readily observable to the patient by way of lights or an acoustic signal. *Below:* Schematic diagram shows the steps involved in adapting a program of biofeedback training to individual patients and then studying the results.

Right: Summation of research data regarding the use of biofeedback systems to treat torticollis, the medical name for chronic involuntary muscle spasms in the neck. Results indicate that such training may help ease this painful condition.

BIOFEEDBACK TRAINING OF INVOLUNTARY MUSCLE SPASMS

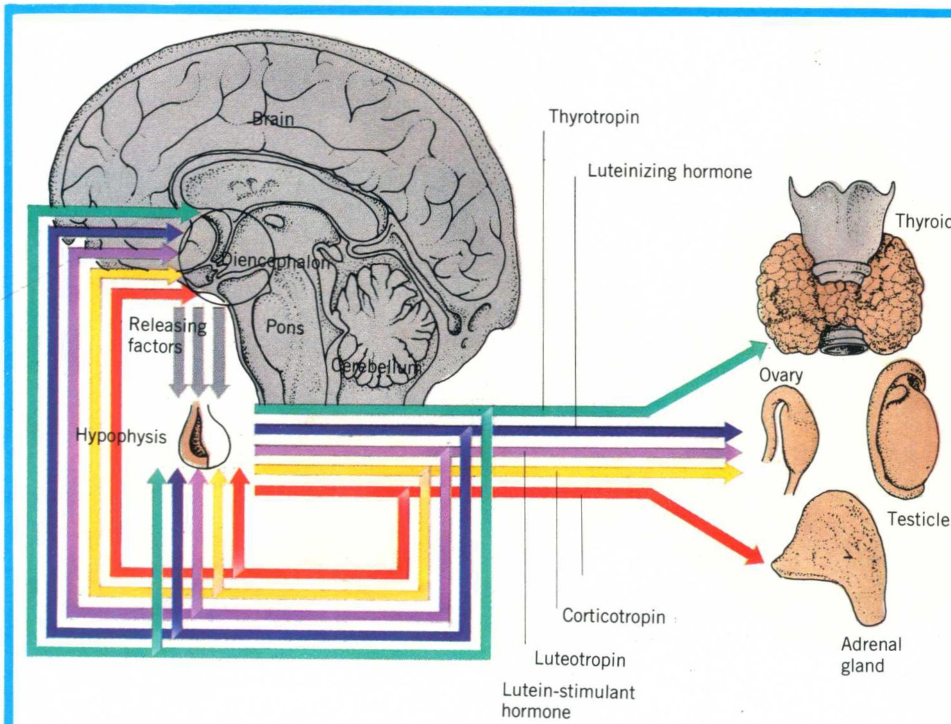
Author	Clinical problem	Sittings	Technique	Results
Brundy *et al.*	Spasmodic torticollis, or 'wryneck'	3 to 5 a week for 8 to 12 weeks	Muscle EMG, audiovisual feedback	Improvement in 2/3 of patient sample
Cleeland		6-23	Muscle EMG, acoustic feedback, mild shocks	Marked improvement in 4 patients, moderate in 4
Jankel		20	Muscle EMG, acoustic feedback, mild shocks	Improvement
Russ		16 (3 + 13)	Frontal and muscular EMG, acoustic feedback, mild shocks	Improvement
Williams		5	Cardiac rhythm, acoustic feedback	Improvement

Acoustic signal

lieve, we can deprogram those stress-related bad habits and program healthy ones in their place.

Biofeedback has already proved a valuable therapy in a wide range of disorders. Even in its comparatively recent history, biofeedback training has helped patients control high blood pressure and irregular heartbeat, suppress migraine headaches, control digestive disturbances, suppress asthmatic attacks; it has even helped in the rehabilitation of damaged muscles.

The leading edge of biofeedback is brain-wave training. By using an electroencephalograph (EEG) machine, which measures brain-wave activity, some biofeedback subjects have been able to control electrochemical activity within the brain to the point where they can will themselves into certain states of mind. Some subjects have apparently trained themselves after a period of time to slip easily into alpha brain-wave activity, the state of passive but receptive awareness that is usually associated with meditation, hypnosis, and heightened creative sensitivity.



The hypothalamus produces compounds called releasing factors, which then cause the hypophysis to secrete substances that control hormone production within the body. The circulation of these hormones is self-regulating, since the hypothalamus and hypophysis can also act to block production if hormone concentrations in the blood exceed required levels. This is a natural form of biofeedback.

"Biogas" is a relatively modern term for a product that has been around as long as bogs, logs, and even hogs. It is odorless and colorless, yet has taken the blame for all sorts of spectacular phenomena, from eerie nocturnal lights to UFOs. When it is pumped out of the ground as natural gas, it is called methane. When it rises like an invisible mist above warm marshlands, it is called "swamp gas." And when it is produced by plant or animal wastes, it is called biogas. By any name, it is a cheap, safe, and highly useful fuel.

As the principal component of natural gas, methane occurs in plentiful—if increasingly expensive—amounts in nature. Methane from biological decomposition, however, is a cheap and readily available fuel that is particularly well suited to rural and agricultural locations, where the raw materials are easily obtained. Unlike natural gas, a fuel developed after eons of geochemical transformations, biogas is essentially a recycled fuel. Though it is produced in modest amounts, the oil crises of the 1970s made biogas an attractive alternative to costlier fuels.

In simple home production units, organic residues such as animal manure or plant wastes decompose in an anaerobic (or oxygen-free) environment. Tiny micoorganisms usually accomplish this conversion by digesting the organic wastes and liberating a mixture of gases, including methane and carbon dioxide as well as smaller amounts of hydrogen, hydrogen sulfide, and nitrogen.

The Methane Component

Natural gas contains anywhere from 50 to 98 percent methane. Biogas, by contrast, usually contains only 55 to 65 percent methane, but it is relatively inexpensive to produce and generates about 12,900 Btu per pound (a Btu, or British thermal unit, equals 252 calories of heat), which makes it one of the richest biomass fuels.

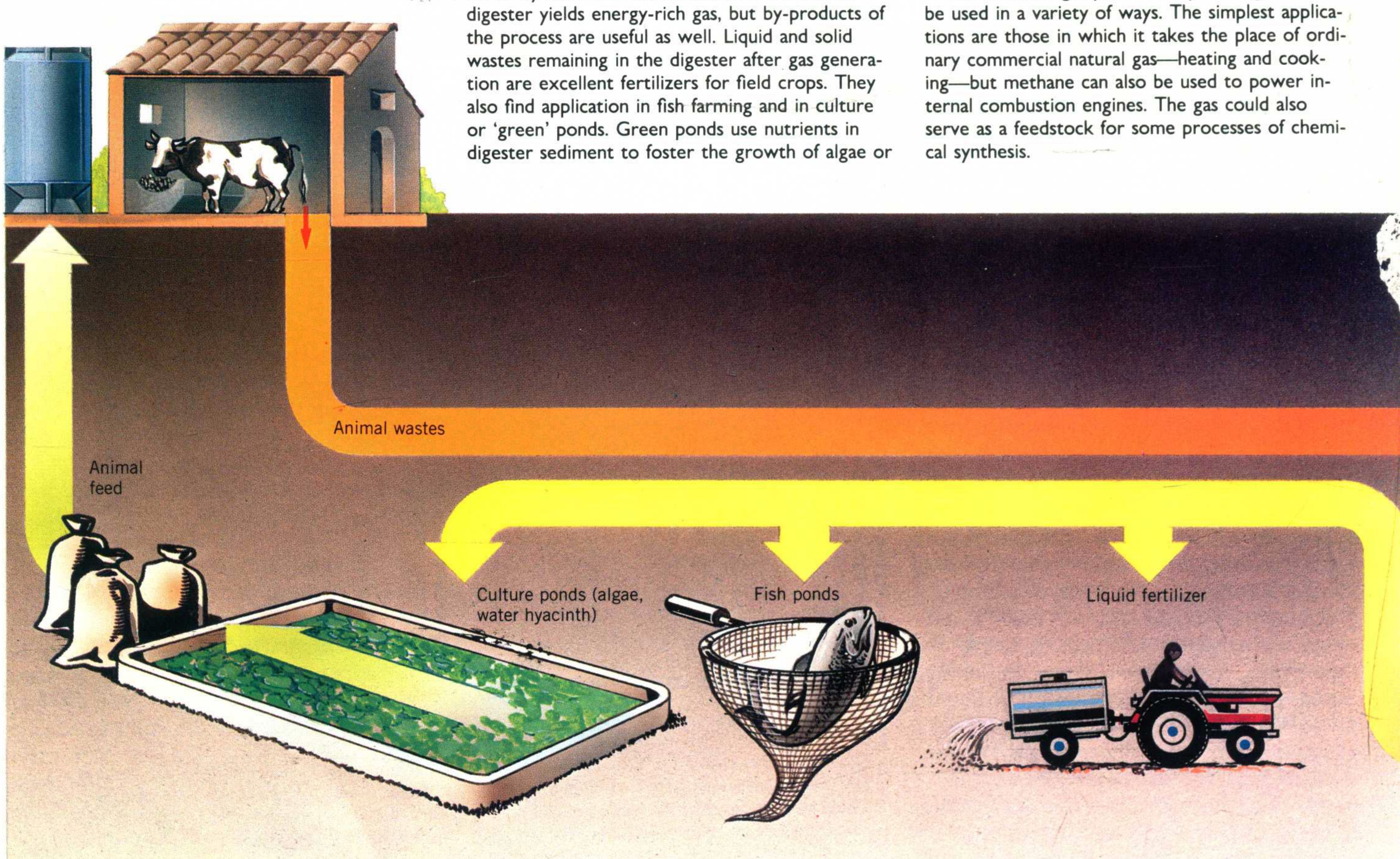
A practical small-scale biogas plant can be constructed near any agricultural enterprise, and such units are finding increasing use in India, China, Korea, Taiwan, the Philippines, and—to a lesser extent—the United States and Europe. A typical plant will feature a mixing unit, a digester, a gasholder, and auxiliary parts. They work in the following manner.

Animal manure, usually from cows or pigs, is stored in the mixing unit, a sort of refuse bin that is most often located near a barn or animal pen. The manure is usually ground up until it reaches a creamy liquid consistency and then is introduced, by cement pipe, into the digester. A typical digester is a tank set in the ground; it measures about 3 by 6 feet (1 × 2 m) and reaches a depth of about 5½ feet (1⅔ m). Here the manure is stirred, usually with a hand-crank mechanism, to facilitate the spread of bacteria through the decomposing mix.

Methane Production

When the mixture is warm (between 85-105°F., or 40°C.), the bacteria operate most efficiently. In a complex series of steps, they break down the raw material into soluble compounds and then into organic acids. The organic acids are then digested, producing as bacterial by-products methane and carbon dioxide. Since methane is lighter than air, it rises to the surface of the digester, where it is collected by the gasholder and stored until actual use.

Manure can be processed in large single batches, or it can be fed into the digester in small daily allotments. One of the added advantages of biogas plants is that the resulting sludge, or fermented waste



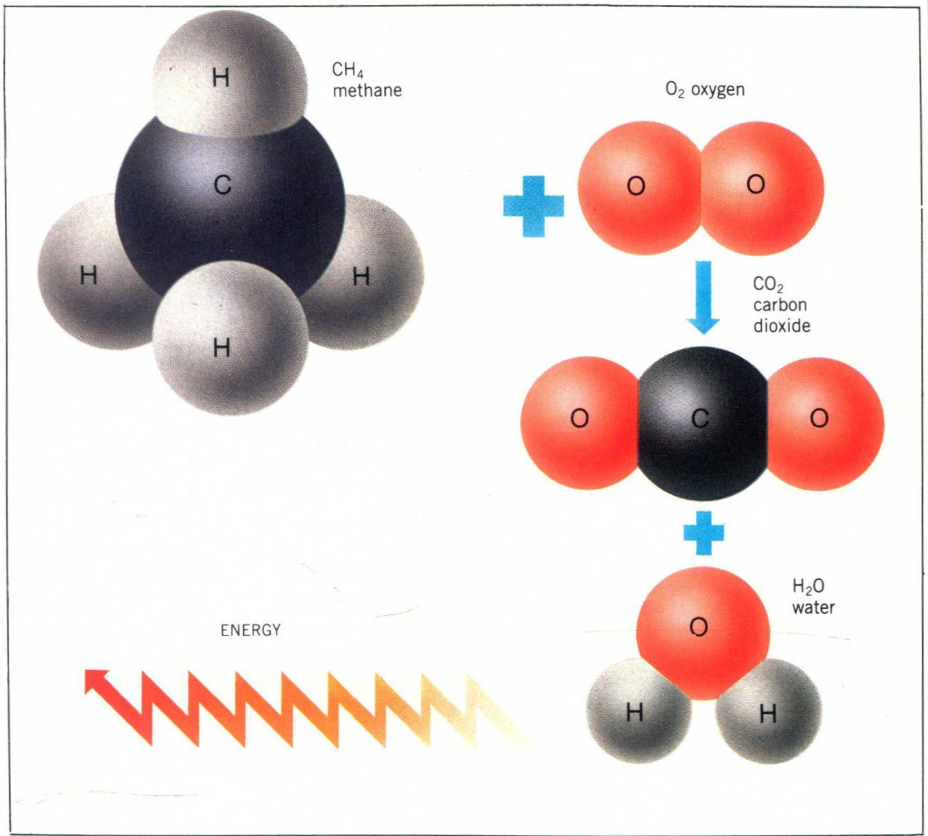
Conversion of animal manure and other organic waste by anaerobic fermentation in a methane digester yields energy-rich gas, but by-products of the process are useful as well. Liquid and solid wastes remaining in the digester after gas generation are excellent fertilizers for field crops. They also find application in fish farming and in culture or 'green' ponds. Green ponds use nutrients in digester sediment to foster the growth of algae or water hyacinths, potential sources of cattle fodder.

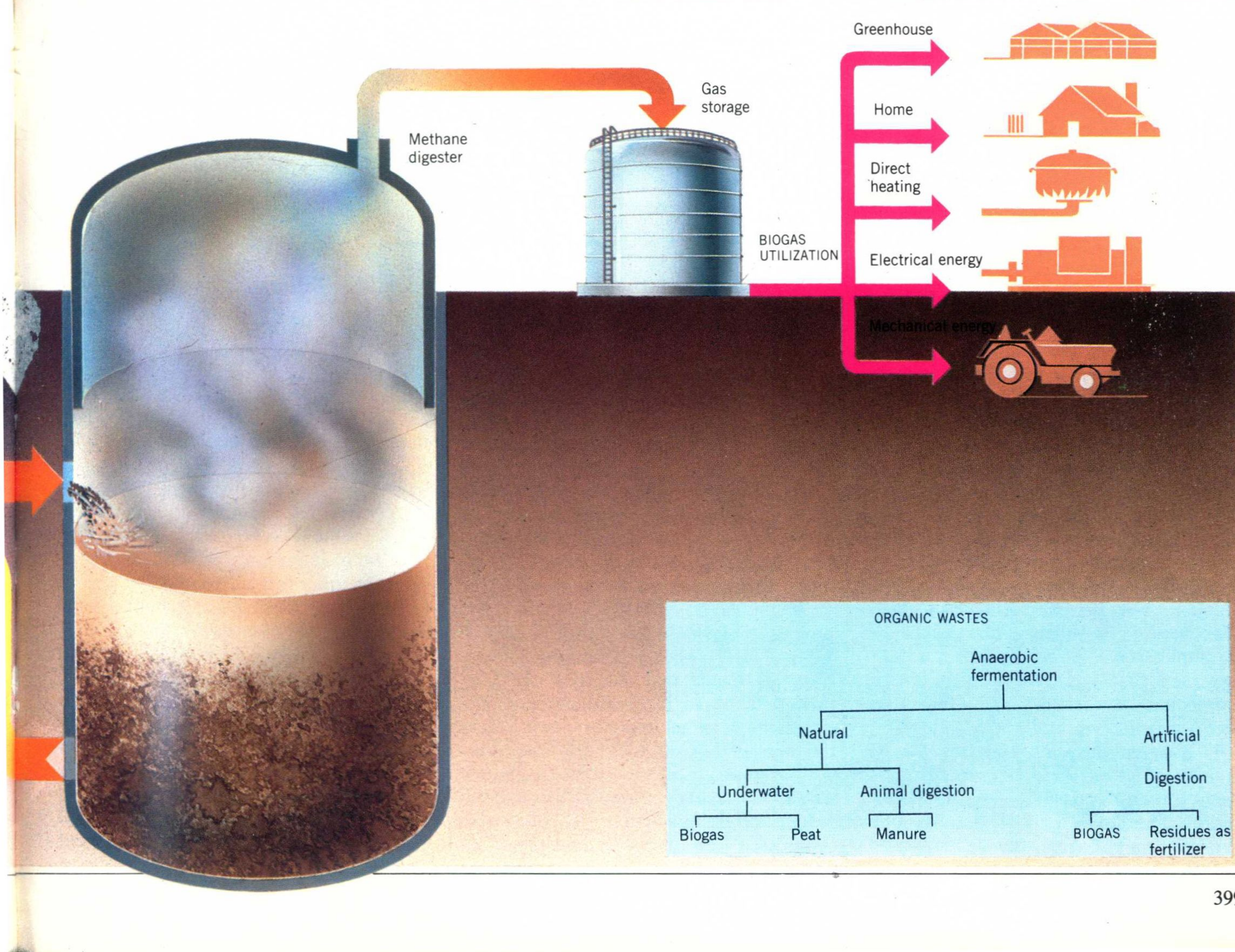
The methane gas produced by the digester can be used in a variety of ways. The simplest applications are those in which it takes the place of ordinary commercial natural gas—heating and cooking—but methane can also be used to power internal combustion engines. The gas could also serve as a feedstock for some processes of chemical synthesis.

left over after methane is produced, makes excellent fertilizer. When vegetal wastes are used instead of animal wastes, the decomposed material can be used for animal feed as well.

Biogas is particularly useful as a cheap cooking fuel in developing countries. Thousands of biogas generators have been constructed in India and China within the past 20 years. Highly industrialized countries are also beginning to consider biogas production as a means of reducing dependence on foreign oil. There are several biogas plants in Italy, for example, that process the dung of 10,000 pigs each day into about 2,100 cubic yards (1,600 cu m) of methane. In the field of alternate energy, that is about as close as technology can come to making a silk purse out of a sow's ear.

See also BIOMASS.





Biology

Roughly 2,300 years ago, a Greek scientist named Polybus wrote *On the Nature of Man*. In it Polybus, a son-in-law and disciple of Hippocrates, sought to understand the relationship between the basic constituents of life and temperament. He called these constituents humors and identified four of them: blood (corresponding to a cheerful spirit), black bile (a melancholy temperament), yellow bile (a fiery nature), and phlegm (an impassive nature). The theory of the four humors, of course, has been discredited, but that should not diminish the significance of Polybus' achievement. His was one of the earliest attempts to explain the nature of life, an inquiry that we now label biology.

Before the word "biology" entered the vocabulary, there were many biologists like Polybus who attempted to explain living phenomena. By the time the term gained currency in the early 19th century, many seminal discoveries in the field had already been made. As a science, biology can be described as the study of living things, which can be loosely defined as matter that is capable of metabolism (an ongoing process of chemical exchange with the environment, for the purpose of producing life-sustaining energy) and reproduction (the ability to perpetuate life by producing subsequent generations of the same organisms through division or fractionation).

Living things derive only from other living things. Those we are most familiar with fall into two broad categories: plants and animals. The more than a million species of animals belong to the study of zoology. Plants, which number more than 300,000 species, are studied under the discipline of botany.

But divisions within the science of biology are hardly so cut and dried. A more useful division of living things separates complex organisms (both plant and animal) from simpler organisms. Animals, plants, protozoans, and fungi all belong to the more advanced group known as eukaryotes—organisms whose cells have true nuclei (that is, separate "command centers"). Bacteria and blue-green algae, probably the oldest living things on Earth, are prokaryotes—organisms lacking true nuclei. There are other divisions as well. The way that animals affect plants, for example, is a legitimate concern of biology, as is the way in which tiny molecular compounds such as enzymes affect an entire organism.

In a larger sense, biology can also be thought of as an accumulation of truths about life on the basis of rigorous observation. The Greek philosopher Aristotle qualifed as a biologist when he first posed questions about the nature of life—questions that are still pertinent. Thus, biology is often a matter of asking the right questions and having the right tools—both physical (a well-equipped laboratory) and mental (insight and intellect)—to "see" things in the living world. The history of biology, or the increasingly sophisticated ways in which man has viewed living things, is biology itself.

Biology in Ancient Greece

The general outlines of biology were sketched, however crudely, during the height of ancient Greek civilization, about 500 years before the birth of Christ. The philosopher Empedocles, for example, was among the first to theorize that the human heart is the chief organ of the circulatory system. Two other early biologists, Alcmaeon of Crotona and Diocles of Carystus, investigated the development of fetuses (an anticipation of embryology, the study of animal development from fertilization to birth).

Because the first Greek biologists were limited to visual observation, their conclusions suffered obvious lapses. Empedocles, who tailored his biological observations to philosophical ideas, proclaimed that blood possessed "innate heat"—an obviously incorrect assertion. Yet, even these first attempts to define the living world encouraged further research and opened up avenues of inquiry that are still pursued.

The comparison of human and goat brains by Hippocratic investigators, for example, represents one of the earliest instances of comparative morphology. Morphology is the study of form—from the shape of a whale to the shape of a cell—and is a cornerstone of biology. Development, the study of form over a period of time, is a biological approach that has been well known since ancient times.

Aristotle, born in 384 B.C., is traditionally recognized as a great philosopher, but his achievements as a biologist were prodigious, laying much of the groundwork for modern biology. His work contains the seeds of such fundamentally important areas of biology as morphology, ethology (the study of animal behavior), taxonomy (the classification of living things according to related form and function), and even evolution (the study of life's continuity and progression toward more complex forms).

As a naturalist (someone who directly observes plants and animals), Aristotle proved to be an insightful observer and generally accurate reporter—two essential attributes of any biologist. One of his most significant contributions was his notion of the *scala naturae*—the scale, or ladder, of living things. He believed it progressed from inorganic matter to simple organisms to the complex. In a more philosophic vein, he characterized the "soul" of living matter as vegetable (with the capacity for growth and reproduction), or animal (which added the capacity of willful movement, or locomotion), or rational (which added the capacity to think and reason). The combination of these Aristotelian modes of organization points toward two crucial divisions of biology: classification and evolution.

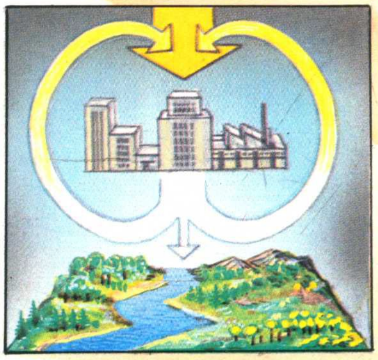
Biology in Eclipse

With few exceptions, biological knowledge did not significantly expand between the time of Aristotle's death (in 322 B.C.) and the Renaissance in Europe. Nonetheless, several important advances did occur.

The Greek physician Galen, for example, had a lasting influence on the biological approach known as physiology, which studies the function of living things and their component parts. Galen developed an imaginative (though erroneous) theory of "pneuma," or spirits within the body, which persisted well past his death in A.D. 200. More important, he devised experiments in order to gain greater knowledge of physiological processes, such as the function of the heart and the spinal cord.

Human embryo

Environmental alterations caused by humans



Experimentation goes hand in hand with the Aristotelian model of observation. If naturalism is a kind of "passive" observation, we can think of experimentation as a kind of "controlled" observation. The biologist—or any scientist—starts out with a hypothesis—an assertion or assumption—for example, about the way an organism functions. The hypothesis is based