BIOCHEMISTRY

New Light on Photosynthesis

When the mechanism of photosynthesis upon which life depends is unravelled, it may help answer some of the problems of expanding population and man's ventures into space.

By Harland Manchester

➤ WHENEVER SUNLIGHT strikes a green leaf, it starts the chemical wheels, conveyor belts and valves of the most gigantic and mysterious factory known to man. Whether the factory operates in a blade of grass, a bit of sea-tossed algae or a giant sequoia tree, its units are all built from a common blueprint. Through myriads of tiny gates called stomata, which dot the foliage of the world's vegetation, it pumps every year about 400 billion tons of carbon dioxide from the atmosphere.

Splitting this gas, the plant factory obtains about 100 billion tons of carbon, the basic building block of living things. It recombines the carbon with hydrogen, which it obtains by splitting ground water, and with oxygen, to make an amazing variety of raw materials.

These "feed stocks" ultimately reach the consumer in the form of apples, aspirin, beefsteaks, bread, camera film, chairs, cooking gas, cotton goods, fish, gasoline, newspapers, plastics, sugar, woolens, yogurt, zithers and thousands of other useful items in the shopper's alphabet. And we could not live to enjoy these goods without an equally important product of the great machine: oxygen, which it releases to the air, constantly replenishing the world's supply and thus enabling us to breathe, and to build fires, which would not burn without it.

Photosynthesis Defined

The task performed by this machine is called photosynthesis, or "putting things together by means of light." For centuries, many of the world's most able scientists have been probing the hidden mechanism by which the plant, using power from the sun, takes a few common atoms and fashions them into the many complex compounds upon which all living things depend. A complete explanation of the intricate process has become one of the Holy Grails of science. Within the last two decades, newly developed research tools have revealed new facts about the marvelous photosynthetic machine. Work in many laboratories has been accelerated, and leading research men predict that within a few years every step of the green leaf's closely guarded secret will be charted and described. Such a breakthrough may well revolutionize the production of food and power for the expanding population.

Before scientists even knew what to look for in their study of photosynthesis, much ignorance about plant nutrition had to be cleared away. Once everyone believed, as some people still do, that plants obtain their organic food from the soil. This notion was disproved more than 300 years ago when the Dutch physician Jan van Helmont planted a willow sprig in a jar of carefully weighed earth, watered it with rainwater for five years, then took it out and weighed both treee and earth. The tree was 164 pounds heavier, but the weight of the earth had diminished by only a few ounces. It was a crude test, but later experiments made it clear that plants, as well as the animals and people who eat them, are constructed mostly from the carbon in the air. If you dry out a plant and then burn it, all its organic (carbon-based) matter, representing about 90 to 95% of its weight, will return to the air from whence it came, leaving a small ash residue composed of minerals drawn from the soil. Plants will not grow without these minerals, but the great bulk of all living things comes from the air.

One of the first clues to the other great function of plants, production of the breath of life, came in 1772 when Joseph Priestley of England grew a sprig of mint in a glass container of foul air and found that the air was refreshed so that a mouse could live in it. The stuff exhaled by the plant that made the air breathable was a previously unknown gas, which was named oxygen.

Soon scientific sleuths pieced together the first crude concept of the grand design. It can be likened to a dual system of endlessly revolving conveyor belts, driven by the mighty sun engine. One belt constantly bears its cargo of carbon dioxide from the atmosphere to the portals of earth's green factories, where it is fashioned into the stuff of life, and after it is used, collects it from respiration, rotting plants, motor exhausts and flues, and returns it to its reservoir in the skies. The other conveyor collects the oxygen exhaled by living plants—a leftover from food-building—and routes it through the earth's air blanket to the lungs of men and beasts, and to carburetors and furnace drafts. These belts revolve at different speeds.

Carbon Not Plentiful

Carbon is not a plentiful element, and the atom used by a plant today will complete its journey through earth and sky and enter another plant some 200 years from now. The oxygen you just breathed—the world's most abundant element—will ride the conveyor belt an estimated 2,000 years before someone else breathes it.

At night, when the solar power is turned off, special guards close most of the gates and the food factories run slowly in reverse. In darkness, plants breathe oxygen and exhale carbon dioxide like animals, but in amounts too small to upset the grand

University of California

CONGOLESE ARTIFACTS—Jean-Pierre Hallet (right), Belgian explorer and ethnologist, shows a ceremonial dancer's mask from his 5,000-piece Central African collection to Dr. Clement Meighan, chairman of the department of anthropology at University of California at Los Angeles. The university has acquired the collection, the most complete of its kind in the world.

design. Because of this discovery, there was once a groundless fear that plants would poison sleeping people, and our grandmothers sometimes removed them from bedrooms.

Little by little, scientists put together a working theory of the great life-supporting merry-go-round, but a great gap of ignorance still remained. They learned that the basic unit of photosynthesis was the chloroplast, a multi-layered structure so small that thousands would fit on the head of a pin. This unit of the plant contains chlorophyll, the stuff that makes leaves green and is comparable to the red pigmentation in blood. Other pigments, bits of minerals and a group of enzymes—called "chemical traffic cops" because they direct all the activities of living things—play essential roles in the process. But no one knew how the mechanism worked.

If you know what raw materials go into a factory and what products come out, you may make shrewd guesses about its operation. You may tear the factory down, study the dismantled parts, and even make some of the machines do their special jobs, but your clumsy intrusion destroys precious evidence. Investigators looked for windows into the dark interior of the life factory, but none existed.

Radioactive Carbon

What the scientific sleuths finally did was, in effect, to send in spies, dressed as ordinary workers and equipped with pocket radios over which they made running reports to their masters. These spies were atoms of radioactive carbon-14, whose discovery and use have been one of the greatest triumphs of the nuclear age. These restless atoms behave in every way like ordinary stable carbon except that they emit particles at a known rate, revealing their presence to a Geiger counter or other detection devices. They were first created in an early atom-smasher at the University of California; after World War II, they were turned out in quantity in the big reactor at Oak Ridge, and quickly became a priceless tool in laboratories throughout the world.

In 1946, Dr. Melvin Calvin, a biochemist at the University of California, saw the great promise of this "talking carbon" in tracing the path of food production in plants, and organized a group which has been working on the problem ever since, winning world attention as it discloses new secrets of the mysterious photosynthesis production line.

Dr. Calvin first put a green leaf into a thin, upright flask of water containing the minerals needed for plant growth. Carbon dioxide containing the radioactive carbon was bubbled through the solution and when he turned on an electric bulb, which did the sun's work, the food assembly plant started moving. Timing it with a stopwatch, he doused the leaf in boiling alcohol after an interval of a few seconds, then planned to trace the progress of the telltale carbon atoms. But the leaves could not be killed fast enough for precise timing, so he tried single-celled algae, similar to green pond scum. These tiny organisms proved ideal for the purpose. The alcohol paralyzed the controlling enzymes and blocked all traffic in a split second. In this way Dr. Calvin found he could stop the machine at any time in the manufacturing process and examine the partly finished product.

Receiving and decoding the messages broadcast by the atomic spies posed a special problem. By great good fortune, an accurate new technique for separating and identifying elusive chemical compounds had just been devised by two British chemists, A. J. P. Martin and R. L. M. Synge. Now used in many laboratories, it won its inventors a Nobel Prize in 1952. This technique consisted of separating the compounds by the rate of their absorption in a sheet of damp filter paper, then photographing the sheet with X-ray film, so that every "hot" carbon atom wrote its signature on the film.

Chart Food Production

Thus the exact progress of food production as the seconds ticked by could be charted. This method is so sensitive that bits of material as small as a millionth of a drop of water can be found and labeled—a feat impossible by previous methods of chemical analysis.

By such experiments, repeated hundreds of times over several years, the California team has been able to trace most of the long series of actual steps by which the photosynthetic factory, infinitely more complicated than any man-made industrial plant, uses the energy of sunlight to construct from simple materials the wide range of products needed to sustain life.

First of all, much of this energy is used to split water. This process is not yet completely understood, but the chloroplast may be compared to an electronic photocell which converts light directly into power. Sub-units of the chloroplast, called grana, are arranged in layers which resemble the plates of a wet-cell battery, and this supports the accepted theory that the first steps of photosynthesis are electrochemical in nature. By exciting electrons to a higher state of energy, the light breaks up the water, releasing its oxygen to the atmosphere, and adding hydrogen ions and electrons to a chemical feedstock which furnishes both materials and power for food-building combinations. This may be compared to a cross-country gas line which uses a part of its cargo to run its pumps. Only the first few machines in the assembly line are driven directly by light. After that, photosynthesis can work in the dark, so long as the conveyor belts are full.

The plant's simplest job is to make the several kinds of sugar which are found in all vegetation. This is done by combining carbon, hydrogen and oxygen. The Calvin cycle, as it is called, is visualized as a series of chemical wheels which pick up bits of raw material or semi-finished parts with each revolution. As charted by the carbon-14 "spies," the chemical merry-go-round goes around six times, picking up a carbon dioxide molecule on each trip, to make glucose, a simple sugar which contains six carbon atoms. To make sucrose, which is ordinary table sugar, containing 12 carbon atoms, the machine goes around 12 times. Timed by a stopwatch, this job takes about 20 seconds from the time the light hits the plant.

Many other facts about the operation of the great factory have been revealed by the carbon-14 tracers. Once it was thought that only the simpler molecules were made directly by photosynthesis, and that the more complex structures of amino acids (the building blocks of protein), fats, etc., were produced independently in allied factories. The concept was that of a long line of production units turning out materials of increasing complexity, shunting various products into storage bins along the way. Now the tracers have revealed a diagram of many production lines fanning off from a common center—the little chloroplast. From uncountable trillions of these tiny units come the basic materials from which the 250,000 or so known organic compounds are ultimately fashioned by nature and by man.

Before these new methods were used to probe the chloroplast's interior, scientists were somewhat in the position of men on Mars trying to draw a blueprint of an earth factory with only telescopic photographs to guide them. Now much of the food-factory mechanism has been accurately charted, and scientists believe that in a few years the whole process will be finally explained. The ramifications of these flow charts tax the understanding of the non-scientist, but to the biochemist they are an exciting trail through a once unknown cavern.

Dr. Calvin Wins Nobel Prize

For his work in photosynthesis Dr. Calvin was awarded a Nobel Prize in 1961. He and his colleagues are pressing on to finish the job, and work on the plant's function is proceeding with new impetus in many other research centers.

Other curious things have been discovered about plant food production. By industrial standards, plants are very inefficient. It is calculated that no more than 1% of the solar energy that falls on a green leaf is used in plant-building. After a few hours of sunlight, plants stop photosynthesizing and take a siesta. Their assembly lines seem badly organized. One carrier will pile up partially completed goods faster than the next machine can process them. Word flashes back along the line; a part of the factory shuts down, and the leaves close their tiny mouths. What are the limiting factors in their use of sunlight to make food from air and water? Once we possess complete knowledge of the operation, can scientists alter the machinery to increase production, or to change the product of an individual plant? The Berkeley team has been experimenting with various chemicals which might, by inactivating certain enzymes, divert more sugar into the sugar bin, or convert more of the raw material into fats or proteins. Will farmers some day spray crops to enrich them for special markets?

Other investigators point out that the air contains only three-hundredths of 1% of

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Photosynthesis

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carbon dioxide, the plant's chief food, while our factories throw away great amounts of the gas daily. In Germany and the United States, factory fumes have been piped into greenhouses to speed plant growth. It has been found, however, that there is a limit to the amount of the gas a plant can use. Complete knowledge of the plant's mechanism may show what limits its use, and whether the limitation can be overcome to cause faster growth. There are speculations about tank farms of fast-growing algae located near factories to use their fumes. The algae could be processed into vitamin-rich foods, or the crop might be fermented to make fuel gas.

Knowledge of what happens in a blade of grass may some day help man to reach distant planets. When the manned Apollo plunges toward the moon, much of its thrust will come from the explosive combination of hydrogen and oxygen, one of the most powerful energy sources known. Every hour the world's plants produce vast quantities of these gases by splitting water. Full knowledge of their mechanism may lead to a cheaper hydrogen fuel, not only for space, but for surface industries.

The crews of these spacecraft may some day breathe air and eat food made possible by today's explorers of photosynthesis. The government is deeply involved in programs for growing algae in small tanks, utilizing exhaled carbon dioxide and other wastes from the crew to provide oxygen and edible proteins. The green plant's recipe may make this possible.

There are many other informed speculations, but the results of a quest of such magnitude can never be fully foreseen. Biochemists are confident that just as decades of obscure research by nuclear physicists led to atom bombs and power plants, new knowledge of the life-supporting green factory will yield incalculable and unexpected dividends.

Writes Nobel Laureate Albert Szent-Gyorgyi: "All agriculture seems to me a primitive, medieval, if not archaic process. To wait until plants grow and develop their chlorophyll and accumulate the energy seems ridiculously primitive and slow at our present rate of scientific potential. Why cannot we construct a 'chlorophyll bomb' to blow up need and poverty?"

This article was prepared for SCIENCE NEWS LETTER in cooperation with the READER'S DIGEST. It will appear shortly in that magazine.

• Science News Letter, 83:202 March 30, 1963

GENERAL SCIENCE

News From Science Clubs

➤ THESE SCIENCE CLUB activities have recently been reported to Science Clubs of America's National Headquarters, 1719 N Street, N.W., Washington 6, D. C.

THE REGIS HIGH SCHOOL SCIENCE CLUB, Cedar Rapids, Iowa, holds weekly science seminars giving the members an opportunity to share experiments and articles read on current science problems.

The goals of THE SCIENCE AND MATHEMATICS CLUB of the Roger Junior-Senior High School, Canton, Miss., are to increase oral and written expression, improve scholarship and stimulate science interest within the school.

Of 600 applicants, 180 students were selected as delegates for the General Seminars and 60 for Seminars in Depth on the basis of tests conducted by the admissions committee for the third annual Baltimore City-County Science Seminars, Feb. 9 to April 30.

Science club members from Craig High School, Craig, Alaska, assisted by U.S. Forest Service personnel, have established the Craig Arboretum for study of botanical features of native trees and shrubs. The arboretum is located behind the school and the whole area is in the Tongass National Forest.

Science Clinic Night, sponsored by the BLADENSBURG SCIENCE CLUB of Bladensburg High School, Bladensburg, Md., presented an opportunity for students working on science projects to talk to specialists about any problems they might have encountered. The fields of interest represented were agriculture, biology, botany, chemistry, earth and astronomical sciences, electronics, mathematics, medical sciences, physics and zoology.

BSA TROOP 106 SCIENCE CLUB of St. Philip Neri Church, New York, N. Y., prepares a science show each year for the Exposition of the Greater New York Council of Boy Scouts of America. A science demonstration display window is prepared by the Troop for Boy Scout Week.

THE BIO-CHEM CLUB, Jackson High School, Jonesboro, La., has entries in the Research Paper Writing Contest and their State Science Fair.

• Science News Letter, 83:206 March 30, 1963

Do You Know?

More than 2600 organic compounds in *trees* have been identified.

Plutonium refined by an electro-refining process has been declared the nation's standard for pure plutonium.

A new technique for measuring neutron absorption in gold has provided scientists with an accurate *"radiation yardstick."*

A seven-pound ring of pure *plutonium* is worth more than $95,000.

Research on the electrical and magnetic properties of *riboflavin,* vitamin B-2, has given information on how the body derives energy from foodstuffs.

• Science News Letter, 83:206 March 30, 1963