Blood Identification through the Ages

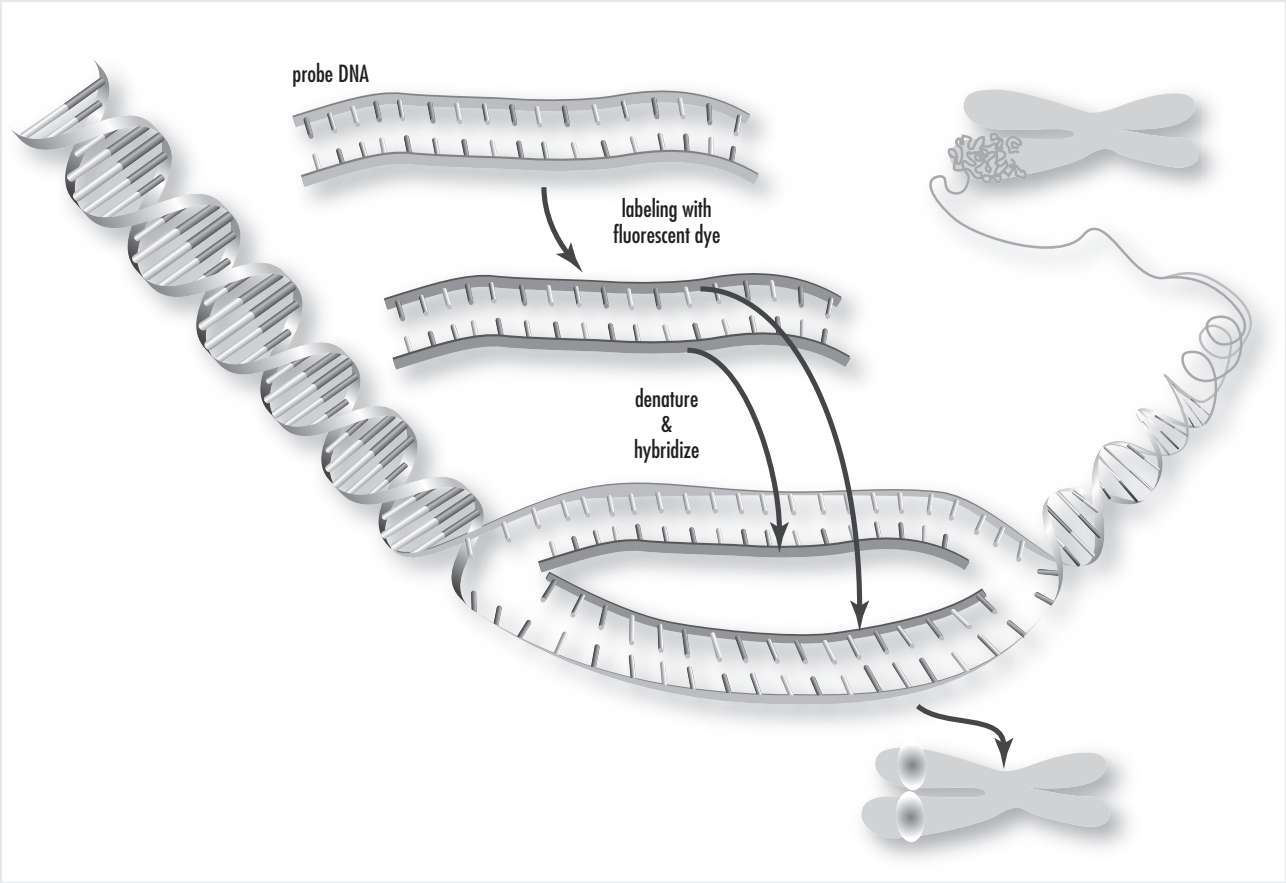
by John C. Brenner and Demetra Xythalis

Blood is a fluid that circulates throughout the body, transporting oxygen, nutrients and waste materials. Blood is composed of various formed elements such as red blood cells (erythrocytes), white blood cells (leukocytes), platelets (thrombocytes), and a liquid fraction called plasma, each containing a vast array of biochemical constituents. Red blood cells comprise the majority of the formed elements in the blood. Hemoglobin is a chemical that is found in red blood cells, consisting of an iron-containing pigment, heme, and a protein component, globin. The components of blood are controlled genetically and have the potential of being a highly distinctive feature for personal identification.

The field of forensic science is the study and practice of the application of natural sciences for the purpose of the law. One of the disciplines in forensic science is forensic serology, which involves the identification and characterization of blood and body fluids, either in a liquid or dried state, in association with a criminal or civil investigation. Blood and dried bloodstains are two of the most important and most frequently encountered types of evidence in criminal investigation of crimes such as homicides, assaults, and rapes.

Since the 1900s, forensic serologists have attempted to identify blood and/or bloodstains found at crime scenes. When serology was in its early stages, stains at crime scenes were identified just as blood. Now that forensic serologists can individualize human blood by identifying all of its known factors, the result could be evidence of the strongest kind for linking a suspect to the crime scene or finding a lost victim.

When examining dried bloodstains, the forensic serologists are trying to determine the following: (1) Is the stain blood? (2) If the stain is blood, is it human or animal? (3) If



Fluorescence in situ hybridization is a process that vividly paints chromosomes or portions of chromosomes with fluorescent molecules. This technique is useful for identifying chromosomal abnormalities and gene mapping. ***(Courtesy of Darryl Leja, NHGRI, National Institutes of Health)***

the stain is human blood, can it be associated with a particular individual? The forensic serologist, in an attempt to do blood identification, uses two categories of tests: the presumptive test, which is nonspecific for blood, and the confirmatory, which is specific for blood species.

The first step in determining whether a crime scene stain is blood involves the use of a chemical screening test or presumptive test. Some presumptive tests used by forensic serologists include benzidine (introduced in 1904), phenolphthalein (1901), leucomalachite green (1904), and luminol (1928).

The identification of benzidine as a carcinogen led to its discontinuance as a screening test for blood. Another chemical used for screening stains for blood is phenolphthalein. Both tests consist of a two-step procedure. The first step is to moisten a white filter paper with distilled water. Apply the filter paper to the suspected bloodstain. A portion of the stain will transfer onto the moistened paper. Add the leucomalachite green reagent to the paper. The second step is to add hydrogen peroxide to the filter paper and look for a color change on the paper. A positive result will yeild a bluish-green color. When phenolphthalein is mixed with a dried bloodstain, with the addition of hydrogen peroxide, the hemoglobin in the blood causes the formation of a deep pink color. The leucomalachite green test is a presumptive test for blood that is used by many laboratories today. The heme group in hemoglobin catalyzes the oxidation by peroxide of the malachite green to produce a bluish-green reaction when the suspected stain is blood.

Luminol is a chemical reagent that is very useful in locating small traces of blood at a crime scene. Unlike the above-mentioned chemical screening test, the reaction of luminol with blood results in the production of light rather than color. The one requirement for the use of luminol is that the scene be completely dark. Luminol is a chemical that can be used as a spray at crime scenes and will react with any blood present, causing a luminescence.

The second step in blood identification is the use of confirmatory tests. Confirmatory blood identification tests are specific for the heme component of hemoglobin. A positive confirmatory test result is taken as positive proof of the presence of blood in a questioned stain. Some of the confirmatory tests include: microcrystalline tests, Teichmann and Takayama tests, ring precipitin test, gel diffusion method, and electrophoresis (1907). The Teichmann (1853) and the Takayama (1905) confirmatory tests are based on the observation that heme, in the presence of certain chemicals, will form characteristic crystals that can be seen using a microscope.

The precipitin test is based on antibody molecules interacting with antigens to form a precipitate that can be visualized under the proper light conditions or with a stain. Serologists use this test to determine whether the origin of the bloodstain is human or animal. The ring precipitin test involves layering a dilute saline extract of the bloodstain on top of the antihuman serum in a capillary tube. Because of the density of the antihuman serum, the bloodstain extract will layer on top, and the two solutions will not mix, thus forming a cloudy ring or band at the interface between the two solutions.

The gel diffusion method is based on the fact that antigens and antibodies will diffuse, or move toward each other, on an agar-gel-coated plate, such as the Ouchterlony plate. The extracted bloodstain and the human antiserum are placed in separate holes opposite each other on the gel. A white precipitate line will form where the antigens and antibodies meet if the bloodstain is of human origin.

The electrophoretic method, or crossover electrophoresis, is a sensitive method using an electric current that is passed through a gel plate. A line of precipitation formed between the hole containing the bloodstain extract and the hole containing the human antiserum denotes a specific antigen antibody reaction.

The next generation of confirmatory test, which in some forensic laboratories has replaced the electrophoretic or crossover electrophoresis is called the One Step ABAcard HemaTrace. This test utilizes a combination of monoclonal and polyclonal antibody reagents to selectively detect human hemoglobin. Adding a portion of the prepared elution from the bloodstain to the sample well and observing the development of indicative colored lines conduct the test. The species specificity of the reaction is based on the recognition by antibodies of antigens displayed on human hemoglobin. A positive result is visualized because gold-conjugated, monoclonal antibody-Hb immune complexes are captured and condensed on the test mambrane by stationary phase polyclonal anti-human hemoglobin antibodies, causing the gold particles to condense. This produces a pink-colored line at the test area. Absence of this colored line indicates a negative result.

There are many different substances in human blood that can be grouped to individualize the blood. Blood contains many inherited factors referred to as genetic markers. Determination of factors in a person's blood is called blood grouping or blood typing. True individualization of a specimen of blood would mean that a sufficiently large number of genetic markers could be typed so that nobody else in the

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world would have that particular combination of genetic markers.

In 1900, Dr. Karl Landsteiner announced one of the most significant discoveries of the 20th century—the typing of human blood. Out of Landsteiner's work came the classification system that is called the ABO system. Blood group systems are the most well known and widely recognized class of genetic markers.

Bloodstains can be typed for ABO using two different procedures: (1) by detecting the antibodies of the serum or (2) by detecting the antigens of the red cells. Detection of the antibodies is the older method. This procedure was first extensively employed by Lattes in Italy in 1913. The procedure has been modified and improved with the development of new antisera. In this test, which detects antibodies in dried bloodstains, two portions of the stains are placed onto microscope slides. Type A red cells are added to one glass slide, and Type B red cells to the other slide. If the bloodstain on the slide contains anti-A antibodies, the A red cells that were added will agglutinate, which looks like crosslinked cells under the microscope. Agglutination of the A cells indicates that anti-A is present, and therefore, that the bloodstain is of blood group B.

The other approach to typing dried bloodstains is the detection of the antigens that are on the surface of the red blood cells. When blood dries, the red cells break apart, but the red blood cell antigens are still present in the dried stains. The two major methods that have been used are absorption-inhibition and absorption-elution. The absorption-inhibition method depends on the ability to estimate the amount of antibody present in an antiserum before and after exposure to a stain extract containing a possible antigen.

The absorption-elution method is based on the theory that blood-group antibodies can bind to their specific red-cell surface antigens in bloodstains. The antigen-antibody complex can then be dissociated and the antibodies recovered. The breaking of the antigen-antibody bond can be done by increasing the temperature. Removing specific antibodies from complexes with their antigens in this way is called elution.

Another main class of blood constituents used as genetic markers is the polymorphic enzymes. The enzymes of interest to the forensic serologists are primarily located within the red blood cell and are commonly referred to as isoenzymes. These enzyme forms can be grouped from a bloodstain to further individualize the blood. Red-cell isoenzymes are frequently typed by a procedure called electrophoresis. This procedure brings about the separation of different proteins based primarily upon differences in net charge, and it is usually done with some kind of starch-gel or on a cellulose acetate support. The most important enzyme systems used in forensic serology are phosphoglucomutase (PGM), erythrocyte acid phosphatase (EAP), esterase D (ESD), adenylate kinase (AK), adenosine deaminase (ADA), and glyoxalase I (GLO).

The main features of the molecular architecture of deoxyribonucleic acid (DNA) were first formulated by Watson and Crick in 1953, who at the same time pointed out how the proposed structure would account for the three basic attributes of genetic material: gene specificity, gene replication, and gene mutation. It was not until 1985 that forensic scientists discovered that portions of the DNA structure of certain genes are as unique to an individual as their fingerprints. Alec Jeffreys and his colleagues at Leicester University, England, who were responsible for these revelations, named the process for isolating and reading these DNA markers "DNA fingerprinting." The DNA typing of biological fluid and stains finally gives the forensic scientist the ability to link crime scene evidence such as bloodstains to a single individual.

The separation of DNA fragments of different sizes usually can be efficiently accomplished by agarose gel electrophoresis. The agarose gels are thick, which makes them difficult to process in terms of hybridization, washing, and autoradiography. To overcome these problems, a transfer technique was developed that transferred the DNA fragments from the agarose gel onto a nylon membrane. This technique was first described by E. Southern in 1975, and it is called Southern blotting. If a specific recognition base sequence is present, the restriction enzyme recognizing that site will cleave the DNA molecule, resulting in fragments of specific base-pair lengths. Restriction fragment length polymorphism (RFLPs) generates different DNA fragment lengths by the action of specific endonucleases. To visualize the separate RFLPs, a nylon sheet is treated with radioactively labeled probes containing a base sequence complementary to the RFLPs being identified, a process called hybridization. Once the radioactive sequences are on the nylon membrane, the membrane is exposed to a piece of X-ray film. The developed X-ray film shows DNA fragments that combined with radioactive probe. The size of the bloodstain (i.e., the amount of blood required) on forensic evidence and the time required to obtain the DNA information from the evidence were two drawbacks to this procedure.

As the push to individualize forensic bloodstain proceeded, the next advancement came in 1983, with molecular

biologist Kary Mullis's development of a process called polymerase chain reaction (PCR). PCR has revolutionized the approach to the recovery of DNA from a variety of sources. Availability of oligonucleotide primers is the key to the amplification process. PCR consists of three steps, beginning with the denaturing of the double-strand DNA, separated by heating to 90–96°C. The second step involves hybridization or annealing, in which one primer is annealed to the flanking end of each DNA target sequence complementary strand. The third step uses a thermally stable Taq polymerase to mediate the extension of the primers. The result is two new helices in place of the first, each one composed of the original strands plus its newly assembled complementary strand.

All eukaryotic genomes contain regions of simple repetitive DNA, called short tandem repeats (STR) or microsatellites, which consist of variable numbers of tandem repeats (VNTRs). The number of repeats at an STR locus can be highly variable among individuals, resulting in different-length polymorphisms that can be detected by relatively simple use of the PCR-based assays. STR loci are useful to forensic science because of their small range of alleles, their high sensitivity, and suitability even if the DNA is degraded. Today the forensic laboratory using the PCR/STR analysis can individualize bloodstains obtained from forensic evidence with a very high probability of identifying a single individual.

In the past, forensic scientists who handled biological forensic evidence were only able to tell the investigating official whether the dried stain at the crime scene was blood. Today the forensic laboratory reports contain information about dried stains at crime scenes that can be related to one individual. This information has been tremendously helpful in the investigation of crimes. With the establishment of a DNA database, physical evidence collected from the crime scene that contains biological stains can be analyzed even if there is no suspect. The DNA profile developed from forensic bloodstain evidence can be compared with various DNA databases to develop a match, which could lead to identification of an individual.

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blood pressure The hydrostatic force that blood exerts against the wall of a blood vessel. This pressure is greatest during the contraction of the ventricles of the heart (systolic pressure), which forces blood into the arterial system. Pressure falls to its lowest level when the heart is filling with blood while at rest (diastolic pressure). Blood pressure varies depending on the energy of the heart action, the elasticity of the walls of the arteries, and the volume and viscosity (resistance) of the blood. Blood pressure rises and falls throughout the day.

When the blood flows through the vessels at a greater than normal force, reading consistently above 140/90 mm Hg (millimeters of mercury), it is called hypertension or high blood pressure. High blood pressure strains the heart; harms the arteries; and increases the risk of heart attack, stroke, and kidney problems. About one in every five adults in the United States has high blood pressure. Elevated blood pressure occurs more often in men than in women, and in African Americans it occurs almost twice as often as in Caucasians. Essential hypertension (hypertension with no known cause) is not fully understood, but it accounts for about 90 percent of all hypertension cases in people over 45 years of age.

Low blood pressure is called hypotension and is an abnormal condition in which the blood pressure is lower than 90/60 mm Hg. When the blood pressure is too low, there is inadequate blood flow to the heart, brain, and other vital organs.

An optimal blood pressure is less than 120/80 mm Hg.

blotting A technique used for transferring DNA, RNA, or protein from gels to a suitable binding matrix, such as nitrocellulose or nylon paper, while maintaining the same physical separation.

blue copper protein An ELECTRON TRANSFER PROTEIN containing a TYPE 1 COPPER site. Characterized by a strong absorption in the visible region and an EPR (ELECTRON PARAMAGNETIC RESONANCE SPECTROSCOPY)

signal with an unusually small HYPERFINE coupling to the copper nucleus. Both characteristics are attributed to COORDINATION of the copper by a cysteine sulfur.

bond energy (**bond dissociation energy**) Atoms in a molecule are held together by covalent bonds, and to break these bonds atoms need bond energy. The source of energy to break the bonds can be in the form of heat, electricity, or mechanical means. Bond energy is the quantity of energy that must be absorbed to break a particular kind of chemical bond. It is equal to the quantity of energy the bond releases when it forms. It can also be defined as the amount of energy necessary to break one mole of bonds of a given kind (in gas phase).

bone imaging The construction of bone tissue images from the radiation emitted by RADIONUCLIDES that have been absorbed by the bone. Radionuclides such as ^{18}F, ^{85}Sr, and ^{99}mTc are introduced as complexes with specific LIGANDS (very often phosphonate ligands) and are absorbed in the bones by metabolic activity.

See also IMAGING.

book lungs The respiratory pouches or organs of gas exchange in spiders (arachnids), consisting of closely packed blood-filled plates, sheets, or folds for maximum surface aeration and contained in an internal chamber on the underside of the abdomen. They look like the pages of a book.

Bordet, Jules (1870–1961) Belgian *Bacteriologist, Immunologist* Jules Bordet was born in Soignies, Belgium, on June 13, 1870. He was educated in Brussels and graduated with a doctor of medicine in 1892. Two years later he went to Paris and began work at the Pasteur Institute, where he worked on the destruction of bacteria and explored red blood cells in blood serum, contributing to the founding of serology, the study of immune reactions in bodily fluids. In 1901 he returned to Belgium to found the Pasteur Institute of Brabant, Brussels, where he served until 1940. He was director of the Belgian Institute and professor of bacteriology at the University of Brussels (1907–35).

His work in immunology included finding two components of blood serum responsible for bacteriolysis (rupturing of bacterial cell walls) and the process of hemolysis (rupturing of foreign red blood cells in blood serum). Working with his colleague Octave Gengou, Bordet developed several serological tests for diseases such as typhoid fever, tuberculosis, and syphilis. The bacteria responsible for whooping cough, *Bordetella pertussis,* was named for him after he and Gengou discovered it in 1906. In 1919, he received the Nobel Prize in physiology and medicine for his immunological discoveries.

He was the author of *Traité de l'immunité dans les maladies infectieuses* (Treatise on immunity in infectious diseases) and numerous medical publications.

Bordet was a permanent member of the administrative council of Brussels University, president of the First International Congress of Microbiology (Paris, 1930), and member of numerous scientific societies. He died on April 6, 1961.

bottleneck effect A dramatic reduction in genetic diversity of a population or species when the population number is severely depleted by natural disaster, by disease, or by changed environmental conditions. This limits genetic diversity, since the few survivors are the resulting genetic pool from which all future generations are based.

Bovet, Daniels (1907–1992) Swiss *Physiologist* Daniel Bovet was born in Neuchâtel, Switzerland, on March 23, 1907, to Pierre Bovet, professor of pedagogy at the University of Geneva, and Amy Babut. He graduated from the University of Geneva in 1927 and then worked on a doctorate in zoology and comparative anatomy, which he received in 1929.

During the years 1929 until 1947 he worked at the Pasteur Institute in Paris, starting as an assistant and later as chief of the institute's Laboratory of Therapeutic Chemistry. Here he discovered the first synthetic antihistamine, pyrilamine (meplyramine). In 1947 he went to Rome to organize a laboratory of therapeutic chemistry and became an Italian citizen. He became the laboratory's chief at the Istituto Superiore di Sanità, Rome. Seeking a substitute for curare, a muscle relaxant, for anesthesia, he discovered gallamine (trade

name Flaxedil), a neuromuscular blocking agent used today as a muscle relaxant in the administration of anesthesia.

He and his wife Filomena Nitti published two important books, *Structure chimique et activité pharmacodynamique des médicaments du système nerveux végétatif* (The chemical structure and pharmacodynamic activity of drugs of the vegetative nervous system) in 1948 and, with G. B. Marini-Bettòlo, *Curare and Curare-like Agents* (1959). In 1957 he was awarded the Nobel Prize for physiology or medicine for his discovery relating to synthetic compounds for the blocking of the effects of certain substances occurring in the body, especially in its blood vessels and skeletal muscles.

Bovet published more than 300 papers and received numerous awards. He served as the head of the psychobiology and psychopharmacology laboratory of the National Research Council (Rome) from 1969 until 1971, when he became professor of psychobiology at the University of Rome (1971–82). He died on April 8, 1992, in Rome.

Bowman's capsule A cup-shaped receptacle in the kidney that contains the glomerulus, a semipermeable twisted mass of tiny tubes through which the blood passes and is the primary filtering device of the nephron, a tiny structure that produces urine during the process of removing wastes. Each kidney is made up of about 1 million nephrons. Blood is transported into the Bowman's capsule from the afferent arteriole that branches off of the interlobular artery. The blood is filtered out within the capsule, through the glomerulus, and then passes out by way of the efferent arteriole. The filtered water and aqueous wastes are passed out of the Bowman's capsule into the proximal convoluted tubule, where it passes through the loop of Heinle and into the distal convoluted tubule. Eventually the urine passes and filters through the tiny ducts of the calyces, the smallest part of the kidney collecting system, where it begins to be collected and passes down into the pelvis of the kidney before it makes its way to the ureter and to the bladder for elimination.

brachyptery A condition where wings are disproportionately small in relation to the body.

brain imaging In addition to MAGNETIC RESONANCE IMAGING, which is based on the absorption by the brain of electromagnetic radiation, brain images can be acquired by scintillation counting (scintigraphy) of radiation emitted from radioactive nuclei that have crossed the blood-brain barrier. The introduction of radionuclides into brain tissue is accomplished with the use of specific ^{99}mTc(V) complexes with lipophilic ligands.

See also IMAGING.

brain stem (**brainstem**) The oldest and inferior portion of the brain that consists of the midbrain, pons, reticular formation, thalamus, and medulla oblongata,

Artwork combining profiles of brain and head anatomy. The brain is seen sliced in half to show internal anatomy. The brain's major area, the cerebrum, includes the folded outer layer (cerebral cortex) that produces memory, language, and conscious movement. The central space is a brain ventricle. The brain stem, at the base of the brain, controls subconscious functions like breathing. It extends downwards and connects to the spinal cord in the neck. The cerebellum (round area, at left of the brainstem) controls balance as well as muscle coordination. The head and neck blood vessels branch from the major chest vessels at bottom. ***(Courtesy © Mehau Kulyk/Photo Researchers, Inc.)***

and forms a cap on the anterior end of the spinal cord. The brain stem is the base of the brain and connects the brain's cerebrum to the spinal cord. It shares several features in common with the brain of reptiles and controls automatic and motor basic functions such as heart rate and respiration and also is the main channel for sensory and motor signals.

bridging ligand A bridging ligand binds to two or more CENTRAL ATOMs, usually metals, thereby linking them together to produce polynuclear coordination entities. Bridging is indicated by the Greek letter μ appearing before the ligand name and separated by a hyphen. For an example, see FEMO-COFACTOR.

bronchiole A series of small tubes or airway passages that branch from the larger tertiary bronchi within each lung. At the end of the bronchiole are the alveoli, thousands of small saclike structures that make up the bulk of the lung and where used blood gets reoxygenated before routing back through the heart.

See also LUNG.

Brønsted acid A molecular entity capable of donating a hydron to a base (i.e., a "hydron donor") or the corresponding chemical species.

See also ACID.

Brønsted base A molecular entity capable of accepting a hydron from an acid (i.e., a "hydron acceptor") or the corresponding chemical species.

See also BASE.

Brownian movement The rapid but random motion of particles colliding with molecules of a gas or liquid in which they are suspended.

bryophytes The mosses (Bryophyta), liverworts (Hepatophyta), and hornworts (Anthocerophyta); a group of small, rootless, thalloid (single cell, colony, filament of cells, or a large branching multicellular structure) or leafy nonvascular plants with life cycles dominated by the gametophyte phase. These plants inhabit the land but lack many of the terrestrial adaptations of vascular plants, such as specialized vascular or transporting tissues (e.g., xylem and phloem).

Terrestrial bryophytes are important for soil fixation and humus buildup. In pioneer vegetation, they provide a suitable habitat for seedlings of early pioneering plants. Bryophytes are also early colonizers after fire and contribute to nutrient cycles.

bubonic plague A bacterial disease marked by chills, fever, and inflammatory swelling of lymphatic glands found in rodents and humans. It is caused by *Pasteurella pestis* and transmitted by the oriental rat flea. The famous Black Death that devastated the population of Europe and Asia in the 1300s was a form of bubonic plague.

budding An asexual means of propagation in which a group of self-supportive outgrowths (buds) from the parent form and detach to live independently, or else remain attached to eventually form extensive colonies. The propagation of yeast is a good example of budding.

Also a type of grafting that consists of inserting a single bud into a stock.

buffer A molecule or chemical used to control the pH of a solution. It consists of acid and base forms and minimizes changes in pH when extraneous acids or bases are added to the solution. It prevents large changes in pH by either combining with H^+ or by releasing H^+ into solution.

See also PH SCALE.

bulk flow (pressure flow) Movement of water due to a difference in pressure between two locations. The movement of solutes in plant phloem tissue is an example.

C

C3 plant The majority of photosynthetic plants that produce, as the initial steps of CO_2 incorporation, a three-carbon compound, phosphoglyceric acid (PGA), as the first stable intermediate (CALVIN CYCLE). The PGA molecules are further phosphorylated (by ATP) and are reduced by NADPH to form phosphoglyceraldehyde (PGAL), which then serves as the starting material for the synthesis of glucose and fructose, which, when combined, make sucrose that travels through the plant. Velvetleaf (*Abutilon theophrasti*) is an example of a C3 plant.

C4 plant A small number of plants that incorporate CO_2 using a carboxylase for the CO_2 capture, producing a four-carbon compound (carboxylic acid) as a stable intermediary in the first step of photosynthesis. C4 plants (e.g., corn) supply CO_2 for the CALVIN CYCLE.

CADD *See* COMPUTER-ASSISTED DRUG DESIGN.

cage An aggregate of molecules, generally in the condensed phase, that surround the fragments formed by thermal or photochemical dissociation of a species.

calcitonin Calcitonin is a hormone produced by the thyroid gland that acts primarily on bone. It inhibits bone removal by osteoclasts and promotes bone formation by osteoblasts; lowers blood calcium levels.

calmodulin A Ca^{2+} binding protein involved in muscular contraction.

calorie An energy measurement unit; the amount of energy required to raise the temperature of 1 g of water by 1°C. A kilocalorie (1,000 calories) is used in food science to describe the energy content of food products.

calpain A calcium-activated neutral protease.

Calvin cycle The second major stage in photosynthesis after light reactions—discovered by chemist Melvin Calvin (1911–97)—whereby carbon molecules from CO_2 are fixed into sugar (glucose) and mediated by the enzyme rubisco (ribulose-1-5-biphosphate carboxylase). It occurs in the stroma of chloroplasts. The Calvin cycle is also known as the dark reaction, as opposed to the first-stage light reactions.

CAM (crassulacean acid metabolism) A metabolic adaptation of certain plants, particularly xerophytes (desert loving, e.g., succulents), in arid areas that allows them to take up CO_2 at night, not during the

day, store it as organic acid (malic), and release CO_2 by decarboxylation of the acids for fixing into sugar. This reduces transpirational water loss during photosynthesis. The CALVIN CYCLE occurs during the day.

Cambrian explosion A period about 530 million years ago (Cambrian age) when a large explosion of species, both in number and diversity, appeared on Earth. It lasted about 10 million years, and it is the first recorded evidence through the fossil record of larger and more complex life forms appearing.

Canadian shield A geographic area of Canada centered around Hudson Bay and composed of 2- to 3-billion-year-old igneous and metamorphic shield rock. It covers much of northern Canada.

cancer Diseases in which abnormal cells divide and grow unchecked and can spread from the original site to other parts of the body; often fatal.

capillary The smallest blood vessels in the circulatory system. Capillaries have thin walls that facilitate the transfer of oxygen and glucose into a cell and the removal of waste products such as carbon dioxide back out into the blood stream, to be carried away and taken out of the body via the lungs. They act as the bridge between the arteries, which carry blood away from the heart, and the veins, which carry blood back to the heart.

See also BLOOD.

capsid The outer protein coat or shell of a virus surrounding its genetic material. Also capsid bugs (capsidae), which number over 6,000 species and live on plants, sucking juice and damaging cultivated plants.

carbohydrate A large class of compounds that contain carbon, hydrogen, and oxygen in a general formula of $C_n(H_2O)_n$. Classified from simple to complex, they form mono-, di-, tri-, poly-, and heterosaccharides. Examples include sugars (monosaccharide, di- and polysaccharides), starches, and cellulose. Carbohydrates are used as an energy source by organisms, and most are formed by green plants and are obtained by animals via food intake.

carbon dioxide (CO_2) A colorless, odorless gas that makes up the fourth most abundant gas in the atmosphere. Used by plants in carbon fixation. Atmospheric CO_2 has increased about 25 percent since the early 1800s due to burning fossil fuels and deforestation. Increased amounts of CO_2 in the atmosphere enhance the greenhouse effect, blocking heat from escaping into space and contributing to the warming of Earth's lower atmosphere and affecting the world's biota. This is a major issue currently being debated by scientists around the world.

See also GREENHOUSE EFFECT.

carbon fixation The process by which carbon atoms from CO_2 gas are incorporated into sugars. Carbon fixation occurs in the chloroplasts of green plants or any photosynthetic or chemoautotrophic organism.

carbonic anhydrase A zinc-containing ENZYME (carbonate hydrolyase, carbonate dehydratase) that catalyzes the reversible decomposition of carbonic acid to carbon dioxide and water.

Carboniferous period A geological time period (360 to 280 millions of years ago) during the middle-to-late Paleozoic era. It is divided into the Pennsylvanian period (325 to 280 millions of years ago) and the Mississippian period (360 to 325 millions of years ago).

See also GEOLOGIC TIME.

carbon monoxide (CO) A colorless, odorless gas that is toxic.

carbon monoxide dehydrogenases ENZYMEs that catalyze the oxidation of carbon monoxide to carbon dioxide. They contain IRON-SULFUR CLUSTERs and

either nickel and zinc, or MOLYBDOPTERIN. Some nickel-containing enzymes are also involved in the synthesis of acetyl coenzyme A from CO_2 and H_2.

carbonyl group A functional group with an oxygen atom double-bonded to a carbon atom, e.g., aldehydes (joined to at least one hydrogen atom) and ketones (carbonyl group is joined to alkyl groups or aryl groups).

carboplatin A "second generation" platinum drug effective in cancer chemotherapy, named *cis*-diammine (cyclobutane-1,1-dicarboxylato)platinum(II). Carboplatin is less toxic than the "first generation" antitumor drug, CISPLATIN.

carboxyl group A functional group that consists of a carbon atom joined to an oxygen atom by a double bond and to a hydroxyl group; present in all carboxylic acids.

carcinogen Any substance that can produce cancer.

cardiac muscle One of the three muscle types (the others are skeletal and smooth); found in the walls of the heart, each rectangular heart muscle cell has one central nucleuslike smooth muscle, but it is striated like skeletal muscle. These cells are joined by intercalated discs, physical connections between the fibers of the myocardium, that relay each heartbeat through gap junctions (electrical synapses). Each strong and rhythmical contraction of the cardiac muscle is controlled by the autonomic nervous system and is involuntary.

cardiac output The amount of blood that is pumped each minute from the left ventricle into the aorta or from the right ventricle into the pulmonary trunk.

cardiotech A species radiolabeled with ^{99m}Tc with the formula $[Tc(CNR)_6]^+$(R=*tert*-butyl) known for IMAGING the heart after a heart attack.

cardiovascular system The human circulatory system; the heart and all the vessels that transport blood to and from the heart.

carnivore Any animal that eats the meat of other animals.

See also HERBIVORE.

carotenoids A large family of natural phytochemicals, accessory pigments found in plants (in chloroplasts) and animals that are composed of two small six-carbon rings connected by a carbon chain that must be attached to cell membranes. Their variety of colors absorb wavelengths that are not available to chlorophyll and so serve

The ribbon snake, a type of carnivorous tree snake in Venezuela, will eat birds and serves as a model for mimicry among caterpillars as well as a Batesian model. ***(Courtesy of Tim McCabe)***