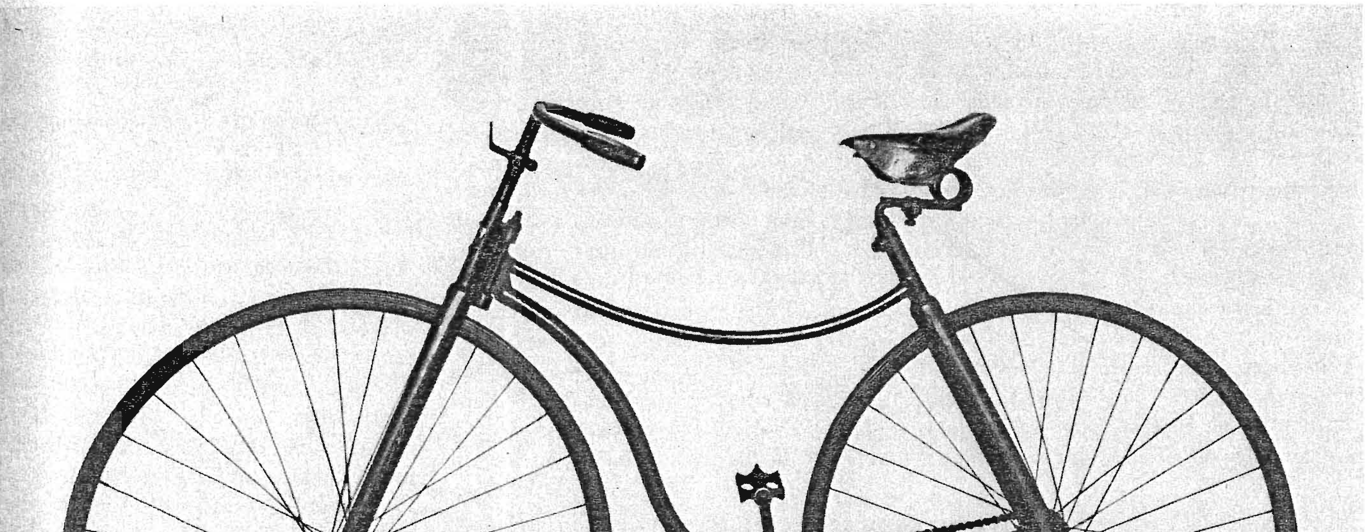
BICYCLE TECHNOLOGY

This humane and efficient machine played a central role in the evolution of the ball bearing, the pneumatic tire, tubular construction and the automobile and the airplane

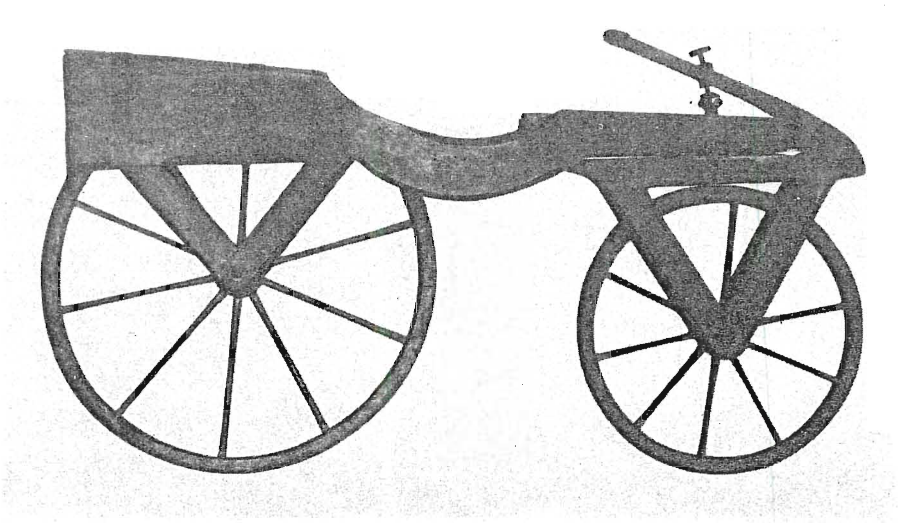
by S. S. Wilson

We tend to take the bicycle too much for granted, forgetting the important role it played in the evolution of modern technology. The first machine to be mass-produced for personal transportation, the bicycle figured prominently in the early development of the automobile. Thus in addition to its own considerable direct impact on society the bicycle was indirectly responsible for substantial social and economic changes. A remarkably efficient machine both structurally and mechanically, the bicycle continues to offer distinct advantages as a means of personal transportation in both developed and underdeveloped countries.

When one considers how long the wheel has served in transportation (more than 5,000 years), it seems odd that the first really effective self-propelled wheeled vehicle was developed only about 100 years ago. As with most epoch-making inventions, many men and many nations can claim a share in its development. The earliest legitimate claimant would be Baron von Drais de



ROVER SAFETY BICYCLE, introduced in 1885 by J. K. Starley of England, is widely regarded as marking the final development of the bicycle form. The Rover had most of the major features of the modern bicycle: rear-wheel chain-and-sprocket drive with a "geared up" transmission, ball bearings in the wheel hubs, tangentially mounted wire spokes, lightweight tubular-steel construction and a diamond-shaped frame. Unlike most modern bicycles, the Rover incorporated two curved tubes without the extra diagonal tube from the saddle to the bottom bracket; also the front forks, although sloping, were straight instead of curved. Unless otherwise noted, the old vehicles shown in the photographs used to illustrate this article are now in the Science Museum in London.



DRAISIENNE, a two-wheeled "pedestrian hobby-horse" devised between 1816 and 1818 by Baron von Drais de Sauerbrun of Baden-Württemberg, is considered the earliest forerunner of the bicycle. The vehicle, which was propelled by the feet pushing directly on the ground, was not, however, regarded as a serious means of transportation. This particular model, dating from 1817, was photographed at the city museum in Heidelberg.

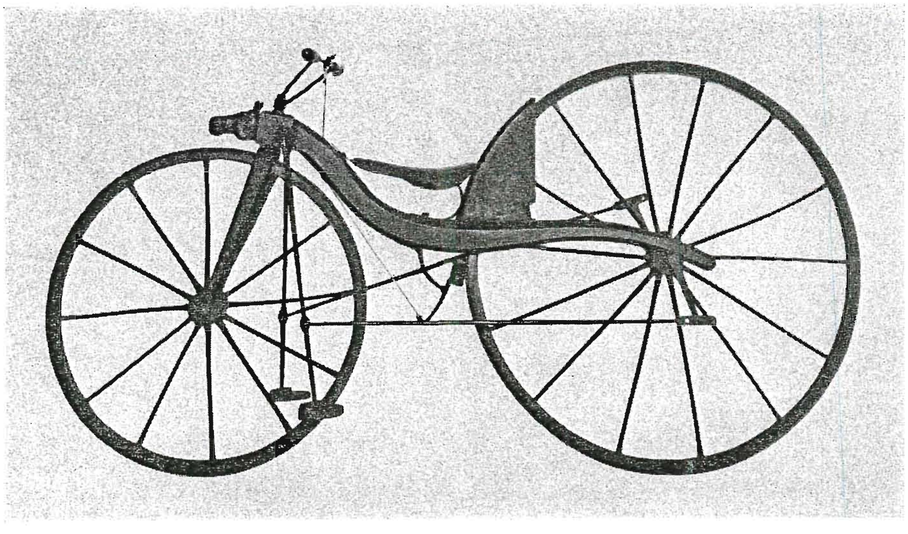
Sauerbrun of Baden-Württemberg, who between 1816 and 1818 devised the Draisienne, a two-wheeled "pedestrian hobby-horse" propelled by the feet pushing directly on the ground [*see illustration above*]. The vehicle had a brief vogue, but it was not taken seriously as a means of transportation. In 1839 Kirkpatric Macmillan, a Scottish blacksmith, succeeded in making a treadle-driven two-wheeled machine, which was copied but was never a popular success [*see illustration below*].

The first commercially important machine in this lineage was the French velocipede, developed by Pierre and Ernest Michaux in Paris in 1863 [*see top illustration on opposite page*]. This vehicle, sometimes called "the bone-shaker," had cranks fixed directly to the hub of the front wheel, like the simplest child's tricycle. As a result it suffered from the limitation of having too low a "gear ratio," to use the modern term. This meant that one turn of the pedals advanced the machine a distance equal to the circumference of the front wheel, perhaps only 10 feet. (In a modern bicycle one turn of the pedals, by means of a chain drive from a large sprocket to a small one, advances the machine 16 feet or more.) The only way to overcome this limitation while retaining the simplicity of direct drive was to use a very large front wheel. Thus the next stage in the evolution of the bicycle, the famous "high-wheeler," was characterized by a front wheel as much as 60 inches in diameter accompanied by a back wheel with a diameter of 20 inches or less.

The high-wheeler, also known as the "penny farthing" or "ordinary" machine, evolved primarily at Coventry in England, now the center of the British automobile industry. It was largely the work of one family, the Starleys. This sequence of events ensued from the accident that the Coventry Sewing Machine Company had a representative in Paris, one Rowley Turner, who brought a Michaux velocipede back to Coventry in 1868. James Starley, a self-taught engineer and inventor, was works manager at the time, and he immediately saw the possibilities of bicycle manufacture. The firm promptly became the Coventry Machinists' Company, Limited, and began to take orders for the manufacture of several hundred machines of the Michaux type for the Paris market. As it happened, the Franco-Prussian War of 1870 intervened, so that the machines were sold mostly in England. This episode led to a period of intense technical and commercial development that resulted not only in the bicycle's achieving its definitive form but also in the emergence of the motorcycle, the motor tricycle and the automobile.

Before considering these developments in detail it is worth asking why such an apparently simple device as the bicycle should have had such a major effect on the acceleration of technology. The answer surely lies in the sheer humanity of the machine. Its purpose is to make it easier for an individual to move about, and this the bicycle achieves in a way that quite outdoes natural evolution. When one compares the energy consumed in moving a certain distance as a function of body weight for a variety of animals and machines, one finds that an unaided walking man does fairly well (consuming about .75 calorie per gram per kilometer), but he is not as efficient as a horse, a salmon or a jet transport [*see illustration on page 90*]. With the aid of a bicycle, however, the man's energy consumption for a given distance is reduced to about a fifth (roughly .15 calorie per gram per kilometer). Therefore, apart from increasing his unaided speed by a factor of three or four, the cyclist improves his efficiency rating to No. 1 among moving creatures and machines.

In order to make this excellent performance possible the bicycle has evolved so that it is the optimum design ergonomically. It uses the right muscles (those of the thighs, the most powerful in the body) in the right motion (a



TREADLE-DRIVEN TWO-WHEELER was built in 1839 by Kirkpatric Macmillan, a Scottish blacksmith, for his own use. Although copied, the machine was never a popular success.

smooth rotary action of the feet) at the right speed (60 to 80 revolutions per minute). Such a design must transmit power efficiently (by means of ball bearings and the bush-roller chain); it must minimize rolling resistance (by means of the pneumatic tire), and it must be the minimum weight in order to reduce the effort of pedaling uphill.

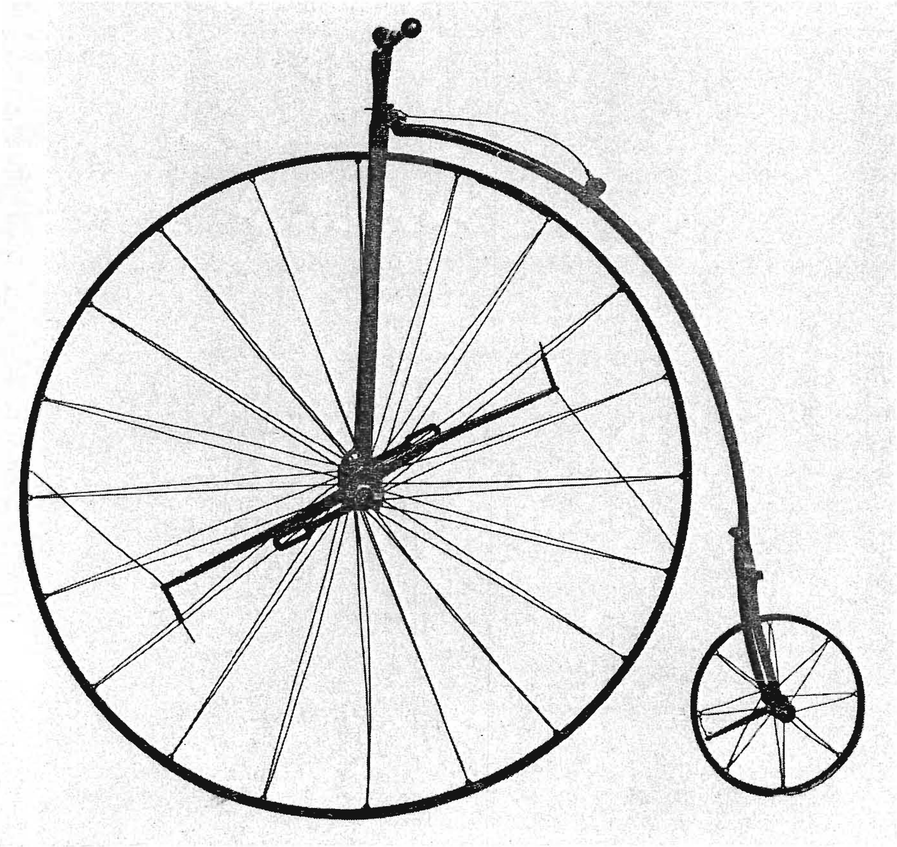
The reason for the high energy efficiency of cycling compared with walking appears to lie mainly in the mode of action of the muscles. Whereas a machine only performs mechanical work when a force moves through a distance, muscles consume energy when they are in tension but not moving (doing what is sometimes called "isometric" work). A man standing still maintains his upright posture by means of a complicated system of bones in compression and muscles in tension. Hence merely standing consumes energy. Similarly, in performing movements with no external forces, as in shadowboxing, muscular energy is consumed because of the alternate acceleration and deceleration of the hands and arms, although no mechanical work is done against any outside agency.

In walking the leg muscles must not only support the rest of the body in an erect posture but also raise and lower the entire body as well as accelerate and decelerate the lower limbs. All these actions consume energy without doing any useful external work. Walking uphill requires that additional work be done against gravity. Apart from these ways of consuming energy, every time the foot strikes the ground some energy is lost, as evidenced by the wear of footpaths, shoes and socks. The swinging of the arms and legs also causes wear and loss of energy by chafing.

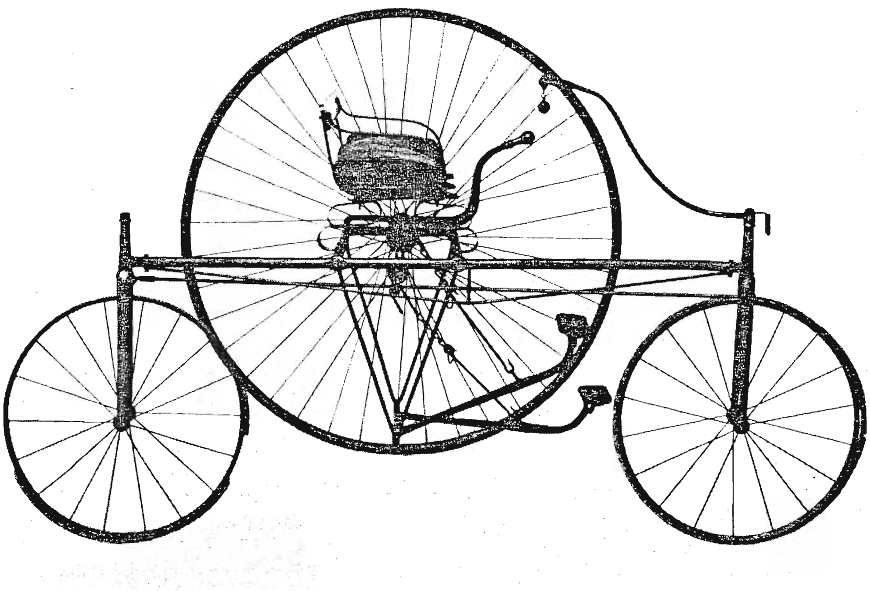
Contrast this with the cyclist, who first of all saves energy by sitting, thus relieving his leg muscles of their supporting function and accompanying energy consumption. The only reciprocating parts of his body are his knees and thighs; his feet rotate smoothly at a constant speed and the rest of his body is still. Even the acceleration and deceleration of his legs are achieved efficiently, since the strongest muscles are used almost exclusively; the rising leg does not have to be lifted but is raised by the downward thrust of the other leg. The back muscles must be used to support the trunk, but the arms can also help to do this, resulting (in the normal cycling attitude) in a little residual strain on the hands and arms.

A less comfortable attitude is adopted by a racing cyclist in order to lessen wind resistance, perhaps the worst feature of

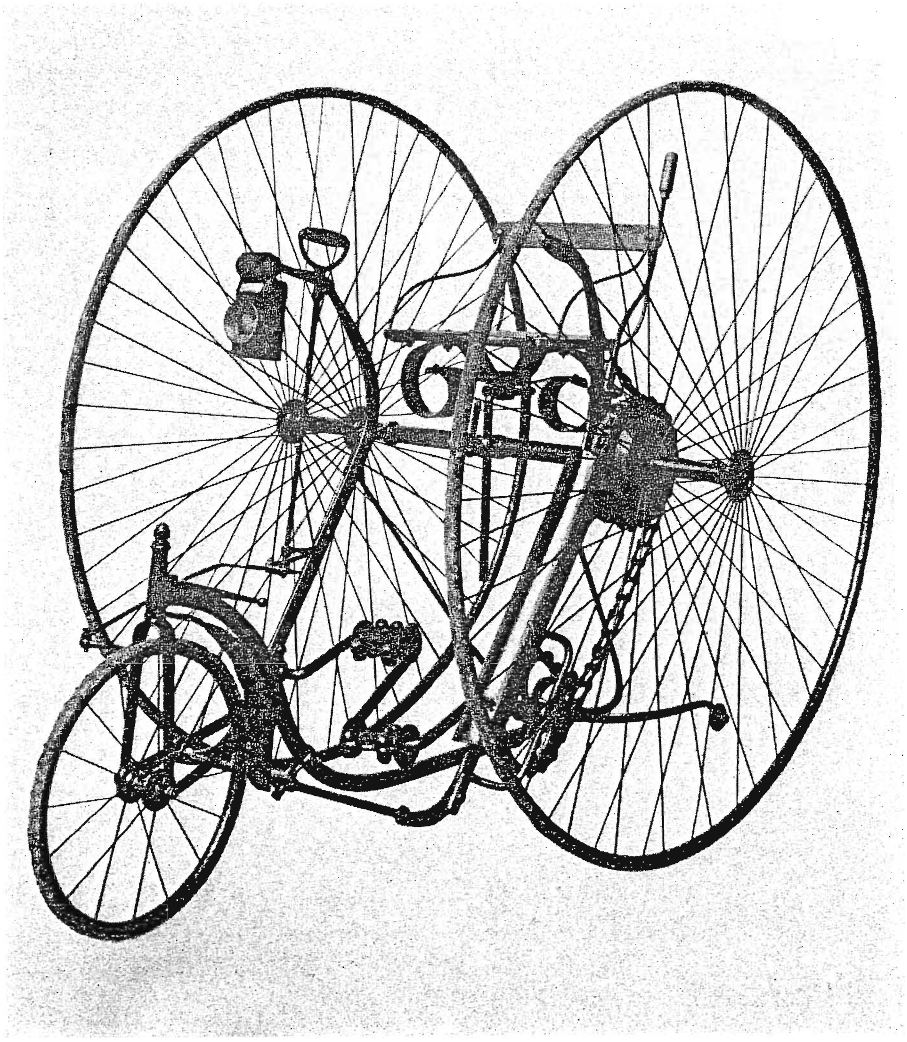
FRENCH VELOCIPEDE, produced by Pierre and Ernest Michaux in Paris in 1863, was the first commercially important machine on the way to the modern bicycle. The "bone-shaker," as the vehicle was sometimes called, had cranks with pedals fixed directly to the hub of the front wheel and hence suffered from the limitation of having too low a gear ratio.



HIGH-WHEELER, developed primarily by the Starley family, was designed to overcome the low gear ratio of the Michaux-type velocipede while retaining direct drive. The high-wheeler, also known as the "penny farthing" or "ordinary" machine, had a front wheel as much as 60 inches in diameter and a back wheel only 20 inches or less. This particular all-metal design, called the Ariel, was produced in 1870 by James Starley and William Hillman. Its spokes, which were radial, were not well adapted to resist the large torque exerted by the pedals on the hub. Hence the two extra rigid bars, each with its own adjustable spoke, were added to help transmit the torque from the hub to the rim. The definitive solution to this problem, the tangent-spoked wheel, was patented by Starley four years later.



COVENTRY LEVER TRICYCLE was designed by James Starley in 1876 as a way of circumventing the difficulties encountered in mounting the high-wheeler and then staying aloft.



ROYAL SALVO TRICYCLE, also designed by James Starley, attracted the attention of Queen Victoria, who ordered two of the machines, thereby establishing the respectability of the new fad of cycling. This tricycle, which incorporated one of the earliest differential gears, invented by Starley in 1873, was considered particularly well suited for female riders.

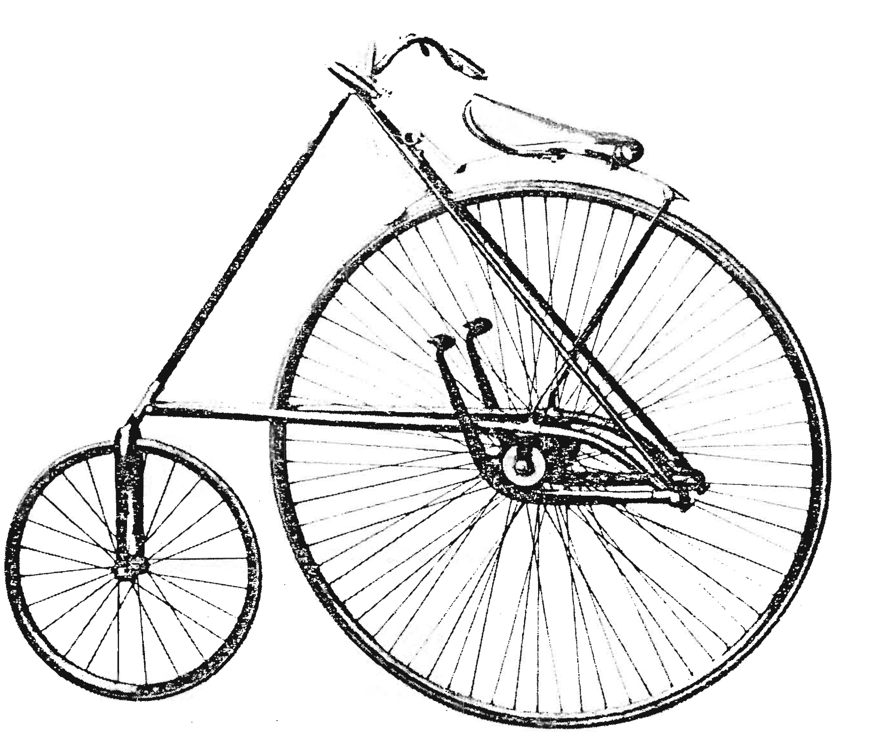
the bicycle for energy loss. Wind resistance varies as the square of the velocity of the wind with respect to the cyclist. Hence if one were to cycle at 12 miles per hour into a wind blowing at six miles per hour, the wind resistance would be nine times greater than if one were to maintain the same road speed with a following wind of six miles per hour. In practice, as every cyclist knows, one's speed can be adjusted to suit the wind conditions with a change of gear ratio to maintain an optimum pedaling speed. Apart from wind resistance the only significant form of energy loss is due to rolling resistance, which with normal-size wheels and properly inflated tires is very small on a smooth surface and is almost independent of speed.

It is because every part of the design must be related to the human frame that the entire bicycle must always be on a human scale. The lightness of construction, achieved mainly through the development of the wire-spoke wheel and the tubular frame, was dictated not only by the fact that the machine has to be pedaled uphill but also by the desirability of making it easy to lift. Since the bicycle makes little demand on material or energy resources, contributes little to pollution, makes a positive contribution to health and causes little death or injury, it can be regarded as the most benevolent of machines.

To return to the story of the bicycle's evolution, in 1870 James Starley and William Hillman (who later founded the automobile firm named after him) designed the Ariel machine: an elegant all-metal high-wheeler with wire-spoke wheels [*see bottom illustration on preceding page*]. The spokes, which were radial and could be tightened as desired, were not well adapted to resist the large torque exerted by the pedals on the hub. Four years later Starley patented the definitive solution to the problem: the tangent-spoked wheel. In this design, now universal, the spokes are placed so as to be tangential to the hub in both the forward and the backward direction, thus forming a series of triangles that brace the wheel against torque during either acceleration or braking. The usual number of spokes in a modern bicycle is 32 in the front wheel and 40 in the back; they are of uniform thickness or else butted (thickened toward both ends) for greater strength with lightness.

The major flaws of the high-wheeler bicycle were the difficulty in mounting the machine and then staying aloft. To overcome these dangers tricycles were developed during the 1870's. Again

Starley took the lead with his Coventry lever tricycle of 1876 [*see top illustration on opposite page*]. Another notable attempt to make the high-wheeler safer was the Star bicycle made by the Smith Machine Company of New Jersey in 1881 [*see illustration at right*]. That machine had the small wheel in front and used a system of levers to drive the large wheel at the rear. The Star bicycle had some success, but the tricycle was much more suitable for women riders, one of whom attracted the attention of Queen Victoria; she ordered two of Starley's Royal Salvo tricycles, met the designer and presented him with an inscribed watch. Nothing could have been more effective in establishing the respectability of the new craze of cycling. It made it possible for well-brought-up young ladies to get out and away from the stuffiness of their Victorian homes and led to such new freedoms as "rational dress," a trend led by Amelia Jenks Bloomer. It is not too farfetched to suggest that the coincidence of cycling with the gradual spread of education for women played a significant part in the early stages of women's movement toward political and economic equality.



STAR BICYCLE, built by the Smith Machine Company of Smithville, N.J., in 1881, was another notable attempt to make the high-wheeler safer. The machine had a small wheel in front and used a system of levers, drums and straps to drive the large wheel at the rear.

The Starleys were also responsible at about this time for a technical innovation in one of their machines that was to be of major importance for the automobile. That development arose from a difficulty encountered with a side-by-side two-seater machine in which James Starley and one of his sons, William, each pedaled a driving wheel. The result of young William's superior strength was a spill into a bed of nettles for his father. While recovering, James thought up the idea of the differential gear (actually a reinvention), which spreads the effort equally between the wheels on each side and yet allows the wheels to rotate at slightly different speeds when turning a corner. William Starley himself went on to be a prolific inventor, having 138 patents to his name, many for bicycles, when he died in 1937.

Two major developments of 1877 were the introduction of the tubular frame and ball bearings. In neither case was the concept altogether new, but it was its widespread adoption for the bicycle that brought each technique to fruition and universal use. This pattern was to be repeated later with the pneumatic tire and other innovations.

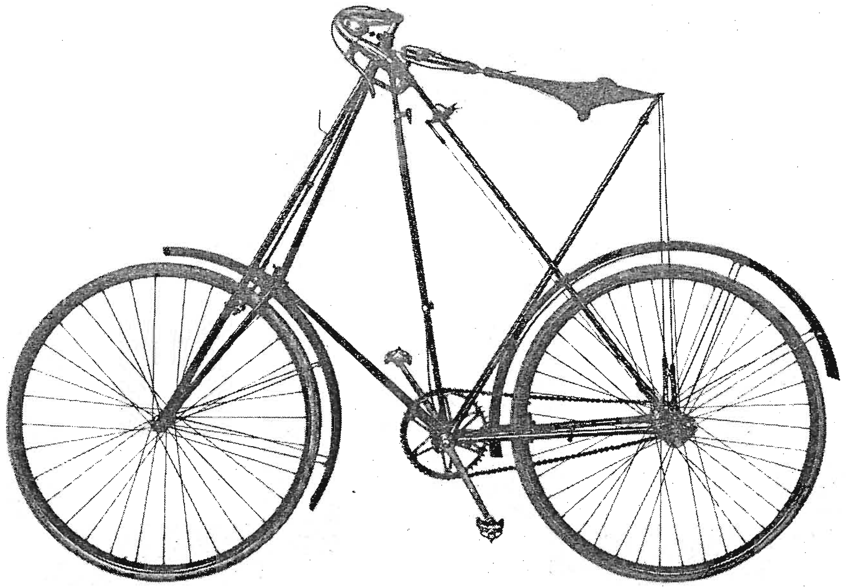
The thin-walled tube of circular cross section is a most efficient structural member; it can resist tension or compression, bending, torsion or the combination of stresses that are exerted on the frame of a vehicle. Although for bending in a particular plane an *I*-section joist may be more efficient, if the bending load can be applied in any plane, then the thin tube is to be preferred. It is for this reason that tubes are used as a strut or compression member in which failure could occur by elastic instability, or bowing. For torsion there is no better section, hence the tube in the typical main transmission shaft of an automobile. The stem of the bamboo plant is an excellent example of the properties of a hollow tube, as is attested by its use in the Far East for buildings, bridges, scaffolding and so on. Indeed, bicycles have been made of bamboo.

For the smallest stresses the design of a structure should be such as to result in tension or compression, not bending or torsion. That is the principle of the "space frame," which is used in bridge trusses, tower cranes and racing cars. Such construction is not practical in a bicycle, and so a compromise emerged in the classic diamond frame. In such a frame the main stresses are taken directly, even though there are bending stresses in the front fork and torsional stresses in the entire frame as the rider exerts pressure first on one pedal and then on the other. On a high-wheeler the rider feels these forces through the handlebars.

An alternative to the diamond frame that first appeared in 1886 and has recently reappeared is the cross frame. It consists of a main tube, extending from the steering head above the front wheel directly to the rear axle, crossed by a second tube from the saddle to the bottom bearing carrying the pedals. This is a simple arrangement, but it relies entirely on the strength and stiffness of the main tube, unless further members are added to obtain a partial triangulation of the frame.

Here an improvement is to increase the cross-sectional area of the main tube, thereby obtaining the full benefit of thin-tube construction. This principle, used in most airplane fuselages since the 1930's, is described as monocoque or stressed-skin construction. Some recent motorized bicycles ("mopeds") have gone further and incorporate an enlarged main tube that forms the gasoline tank, a principle applied also in the construction of certain modern racing cars, which have a tubular fuel tank on each side of the driver. One advantage of the cross-frame bicycle is that it is equally suitable for men and skirt-wearing women.

At least one early example of a fully triangulated frame achieved some success: the Dursley-Pedersen, which used small-diameter tubes in pairs and weighed only 23 pounds [*see illustra-*



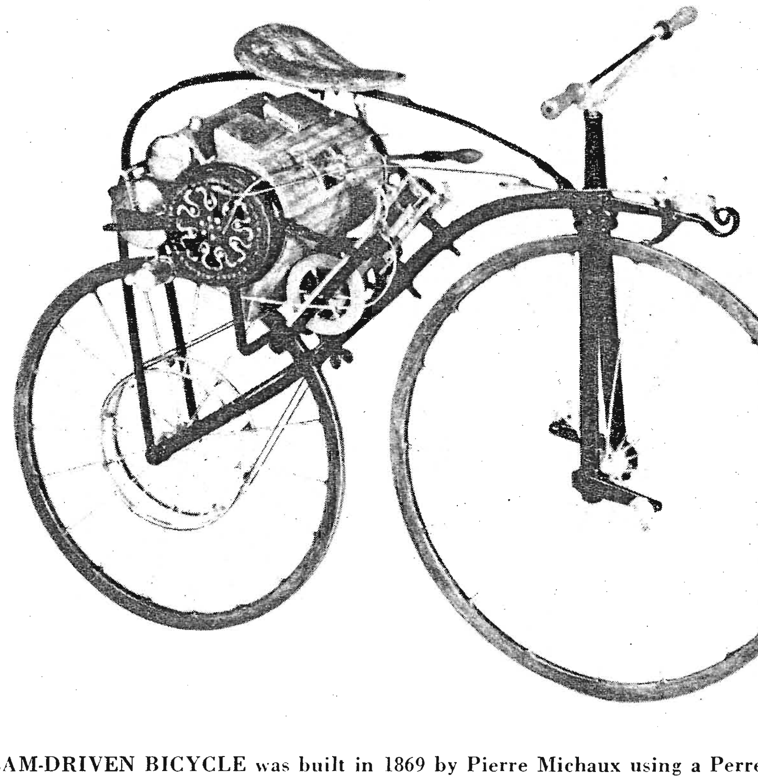
FULLY TRIANGULATED FRAME was the most distinctive feature of the Dursley-Pedersen bicycle, which achieved some success in England in the 1890's. This machine used small-diameter tubes in pairs and was remarkably light, weighing in at only 23 pounds.

tion above]. Some remarkably low weights were achieved at a very early date, mainly for racing machines. For example, a Rudge "ordinary" of 1884 weighed only 21.5 pounds. For purposes of comparison, a modern racing bicycle weighs about 20 pounds and a typical modern tourer weighs about 30 pounds. Steel tubes are still the normal choice, but light alloys, titanium and even plastic reinforced with carbon fibers have been used. The steel tubes, usually of a chrome-molybdenum or a manganese-molybdenum alloy, are butted and then brazed into steel sockets to form a complete frame. The result is a structure able to carry about 10 times its own weight, a figure not approached by any bridge, automobile or aircraft.

The use of a roller to reduce friction finds its ultimate development in ball bearings and roller bearings. The main bearings of a modern bicycle have at least 12 rows of balls, all rolling between an inner cone and an outer cup. All the bearing surfaces are hardened steel for resistance to deformation and wear. If such bearings are lubricated and properly adjusted, their life can be surprisingly long. Even if they are neglected, they continue to function for a long time, and all their parts can easily be renewed if necessary.

Another important advance, the adoption of chain-and-sprocket drive to the rear wheel, was made by Harry J. Lawson in 1879. The following year Hans Renold produced the definitive form of the bicycle chain, the bush-roller chain, which combines the virtues of long life, efficiency and low weight. At first sight the design seems to have little subtlety but a closer look reveals just how significant its various features are [*see illustration on page 88*]. The progenitor was the pin chain, or stud chain, in which the pins bear directly on the sprocket teeth and the link plates swivel on the studs at each end of the pins. In such a chain there is undue wear and friction both at the teeth and at the holes in the plates. An improvement devised by James Slater in 1864 was the bowl chain, or roller chain, in which friction and wear of the sprocket teeth was reduced by rollers on the pins, but wear of the plates on the studs was still too great. Renold's design, by the addition of hollow bushes to spread the load over the entire length of the pin, overcame this final shortcoming and led to the foundation of the precision-chain industry. The bush-roller chain spread from bicycles to textile machinery and other power-transmission applications, in competition with the Morse "silent chain." Bush-roller chains replaced belt drives for motorcycles, and they served as the main drive for the rear wheels of automobiles until they were replaced by shaft drive. Today the bush-roller chain drive remains virtually the universal choice for automobile camshafts, although it is threatened now by the toothed-belt drive. The demands of increased power, greater speed and longer life for chain drives meant that the makers were pioneers in metallurgy, heat treatment, lubrication and production.

The satisfactory solution to the problem of an efficient drive giving a "step up" ratio of any desired value made possible the final evolution of the bicycle to



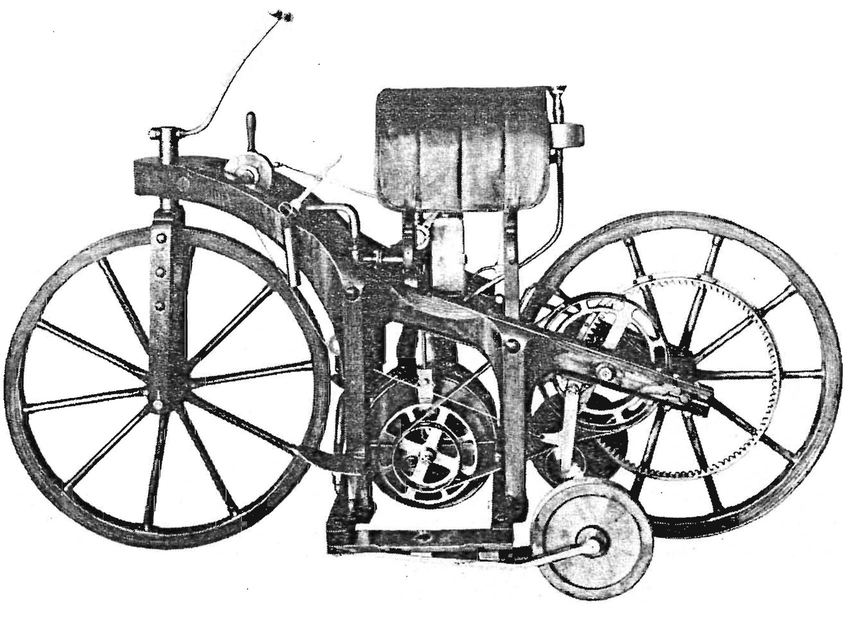
STEAM-DRIVEN BICYCLE was built in 1869 by Pierre Michaux using a Perreaux steam engine. Although earlier steam-driven road vehicles had proved too heavy and cumbersome, the technology of the lightweight bicycle seemed at this time to offer new possibilities. The later evolution of the internal-combustion engine ended this line of development.

its modern form. This last step was achieved mainly by J. K. Starley, a nephew of James Starley. James, honored in Coventry as the "father of the bicycle industry," had formed a partnership with William Sutton in 1878 to produce tricycles. In 1885, however, J. K. independently brought out his famous Rover safety bicycle [*see illustration on page 81*]. This machine can be regarded as the final development of the bicycle form. From that form the bicycle has not departed, in spite of a recent attempt to use a spring frame in conjunction with small wheels. The Rover bicycle had a diamond frame, incorporating two curved tubes without the extra diagonal tube from the saddle to the bottom bracket. The front forks were straight, although sloping. The slope was used to give a self-centering action to the steering. The later development of curved front forks such that the line of pivoting of the steering head meets the ground at the point of contact with the tire results in a reduction of steering effort because side forces do not tend to turn the handlebars.

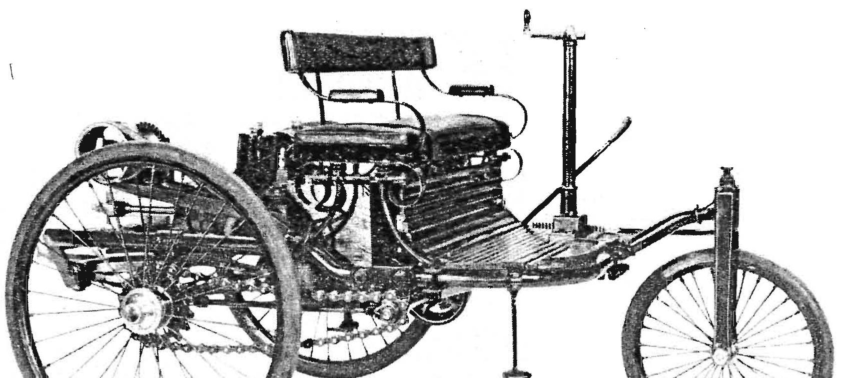
The appearance of the Rover safety bicycle started a boom in bicycles that quickly established them as an everyday means of transport, as a sport vehicle and as a means of long-distance touring. For Coventry and other Midlands cities there was a trade boom that lasted until 1898. Then there was a disastrous slump, largely because of the financial manipulations of one Terah Hooley. The bicycle spread all over the world, and it was adapted to local needs in such machines as the bicycle rickshaw of the Far East. Among the early manufacturers in the U.S. were the Duryea brothers, builders of the first American automobile in 1893. By 1899 there were 312 factories in the U.S. producing a million bicycles a year.

Before this time, however, there was one more signal development: the pneumatic tire. This feature had actually been patented as far back as 1845 by R. W. Thomson, a Scottish civil engineer, to reduce the effort needed to pull horse-drawn carriages. It failed to establish itself until it was reinvented in 1888 by John Boyd Dunlop, a Scottish veterinary surgeon practicing in Belfast. This time success was rapid, owing to the enormous popularity of the bicycle and to the obvious superiority in comfort and efficiency of the pneumatic tire over the solid-rubber tire. Further developments came quickly. Charles Kingston Welch of London produced the wire-edged tire in 1890, and at almost the same time William Erskine Bartlett in the U.S. produced the bead-edged tire. Then David Mosely of Manchester patented the cord-construction tire, consisting of layers of parallel cords rather than a woven fabric, which gave rise to undue internal friction. Even the tubeless tire, which was not used for automobiles until the 1940's, was invented for bicycles in the late 1890's. E. S. Tompkins, a student of the pneumatic tire, has written: "This richness of invention in the very earliest years arises from the fact that the cycling enthusiasts were young folk and they had a young and enquiring approach to the design of tyres for their machines."

A further result of the popularity of



DAIMLER MOTOR BICYCLE, the forerunner of the modern motorcycle, was designed and built by Gottlieb Daimler in 1885. The vehicle was equipped with a single-cylinder internal-combustion engine. The two smaller jockey wheels retracted when the machine was under way. The original Daimler machine, shown in this photograph from the Bettmann Archive, is now in the restored Daimler workshop at Bad Cannstatt near Stuttgart.



BENZ MOTOR TRICYCLE, the forerunner of the modern automobile, also made its appearance in 1885. This first attempt of Carl Benz incorporated such features as electric ignition, effective throttle control, mechanical valves, horizontal flywheel and even a comfortably upholstered seat. In tests through 1886 the vehicle was developed to deliver a reliable nine miles per hour. The original Benz car is now in the Deutsches Museum in Munich; this photograph shows a replica of the original in the Daimler-Benz Museum in Stuttgart.

bicycles was the demand for better roads. In Britain the Cyclists' Touring Club was founded in 1878 and the Roads Improvement Association in 1886, leading to successful pressure for better roads. A similar movement in the U.S., founded by Colonel Albert A. Pope, a pioneer bicycle manufacturer of Boston, was also influential. The bicycle quite literally paved the way for the automobile.

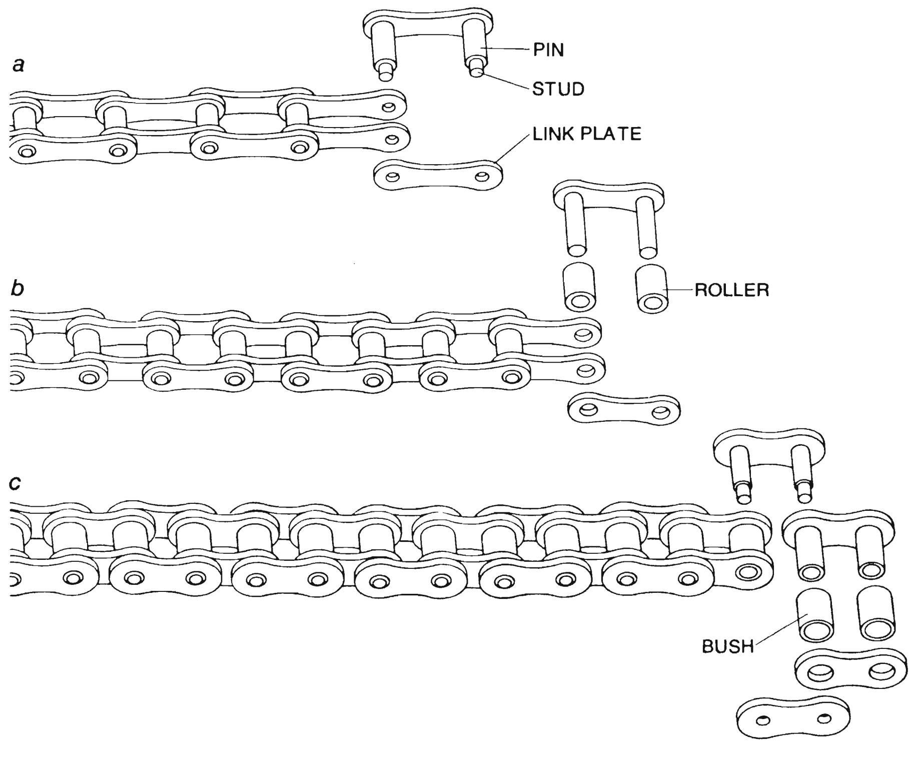
How the bicycle led directly to the automobile is described by the inventor Hiram P. Maxim, Jr., in *Horseless Carriage Days* (published in 1937): "The reason why we did not build mechanical road vehicles before this [1890] in my opinion was because the bicycle had not yet come in numbers and had not directed men's minds to the possibilities of independent long-distance travel on the ordinary highway. We thought the railway was good enough. The bicycle created a new demand which was beyond the capacity of the railroad to supply. Then it came about that the bicycle could not satisfy the demand it had created. A mechanically propelled vehicle was wanted instead of a foot-propelled one, and we now know that the automobile was the answer."

Looking backward after another 36 years, one is tempted to ask whether the automobile is really as good an answer as it once appeared to be. Steam-propelled road vehicles had been tried earlier, but they had failed to establish themselves because they were heavy and cumbersome. The technology of the lightweight bicycle seemed to offer new possibilities, and a steam-driven motorcycle was actually built in France in 1869 by Pierre Michaux, using a Perreaux engine [*see bottom illustration on page 86*]. The internal-combustion engine was successfully applied in 1885 by Gottlieb Daimler to a velocipede of the Michaux type [*see top illustration on preceding page*] and by Carl Benz to a lightweight tricycle [*see bottom illustration on preceding page*]. From then on development was rapid, particularly in France and later in the U.S.

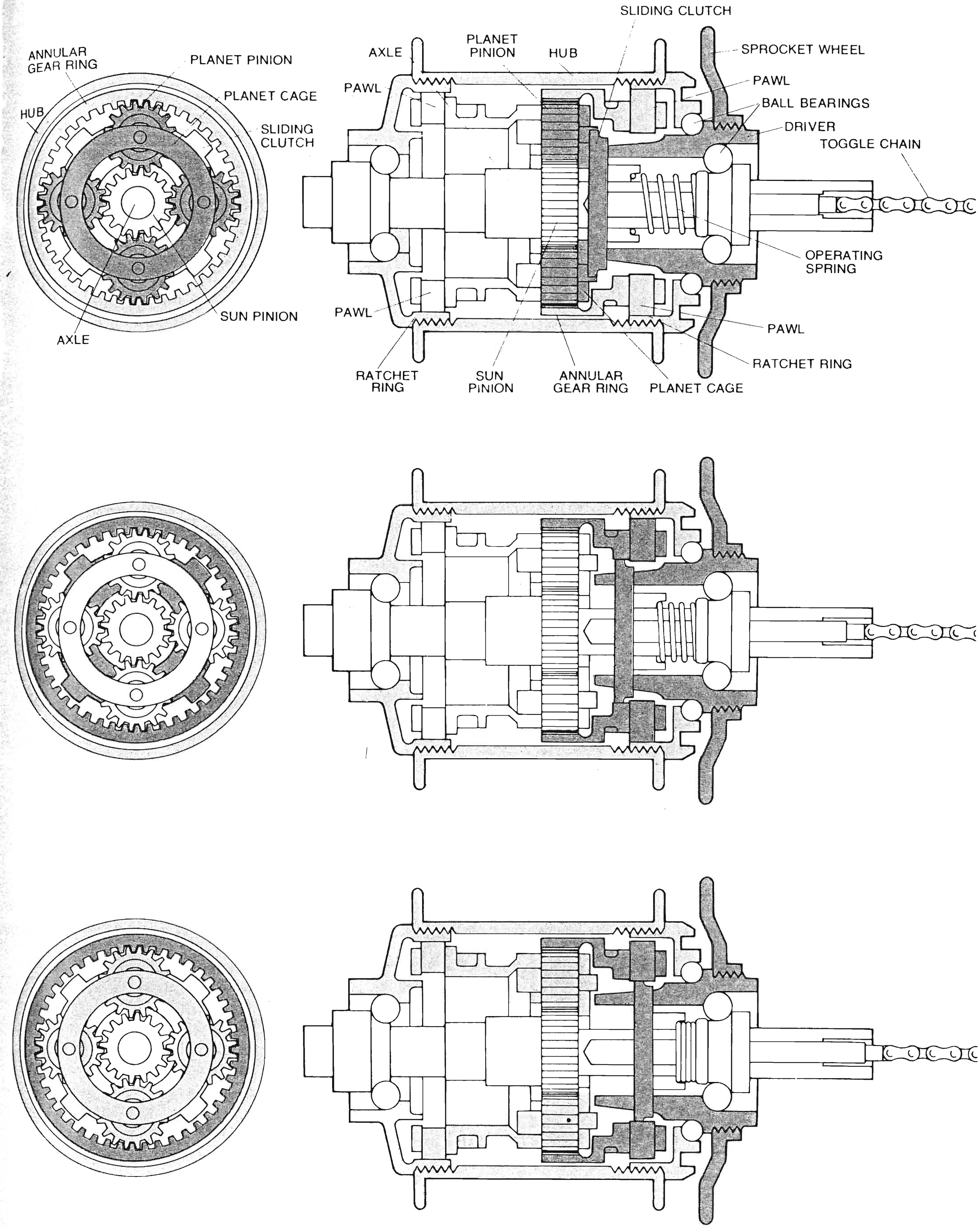
Many of the pioneer automobile manufacturers started as bicycle makers, including Hillman, Colonel Pope, R. E. Olds, Henry M. Leland and William Morris (later Lord Nuffield). Meanwhile in Coventry the firm of Starley and Sutton became the famous Rover Company, producing an electrically driven tricycle in 1888, a motorcycle in 1902 and an automobile in 1904. Both Morris and Rover are now part of the British Leyland Motor Corporation, the largest British automobile company. Henry Ford's first car used bicycle wheels and chains, as did other early vehicles of the "motorized buggy" type. The Wright brothers were bicycle makers, and the early flying machines benefited considerably from the lightweight and efficient design features evolved so successfully for bicycles.

Perhaps the most interesting modern application of the technology of the lightweight bicycle to flying is in man-powered aircraft. There were attempts to develop such aircraft in Germany and Italy before World War II, and recently much interest has been aroused in England by the offer of a prize of £10,000 by Henry Kramer for the first man-powered flight over a figure-eight course around two poles half a mile apart. Several designs have succeeded in flying for distances of up to some 1,000 yards in a straight line; the best flight so far is one made by Flight Lieutenant John Potter of the Royal Air Force in a monoplane designed by Christopher Roper [*see illustration on page 91*]. This aircraft, with a wingspan of 80 feet and a weight of only 146 pounds, clearly shows the debt owed to the bicycle in the design of efficient and lightweight machinery for the production and transmission of power. The Kramer prize has not yet been won, but it represents a goal that will no doubt eventually be achieved.

Production engineering also owes much to the sudden demand created by the bicycle for precision parts in quantity. The average bicycle has well over 1,000 individual parts. Admittedly nearly half of these parts are in the chain, but the rest of them call for high standards of pressing and machining, and the methods worked out for producing them represented a big step forward. A comparable demand for automobile parts had to await the Ford assembly line. Perhaps the most ingenious process used in producing bicycle parts is the procedure for forming the complicated bottom bracket of the frame, which has four tube sockets and a threaded barrel to receive the outer races for carrying the pedals. The bottom bracket is made in a series of press operations, a method evolved by the Raleigh Cycle Company of Nottingham in 1900. This company, which is now by far the largest bicycle



DEVELOPMENT OF BICYCLE CHAIN went through several stages before arriving at the definitive form, the bush-roller chain invented by Hans Renold in 1880. The progenitor was the pin chain, or stud chain (*a*), in which the pins bore directly on the sprocket teeth and the link plates swiveled on the studs at each end of the pins. In such a chain there is undue wear and friction both at the teeth and at the holes in the plates. A subsequent improvement was the bowl chain, or roller chain (*b*), in which friction and wear of the sprocket teeth was reduced by rollers on the pins, but wear of the plates on the studs was still too great. Renold's invention of the bush-roller chain (*c*), by the addition of hollow bushes to spread the load over the entire length of the pin, overcame this final shortcoming.



STURMEY-ARCHER HUB GEAR commonly used in British touring bicycles is shown here in both transverse section (*left*) and longitudinal section (*right*). In both cases the driving elements are indicated in dark color and the driven elements in light color. In this three-speed system a single epicyclic gear train is used in such a way that when the bicycle is in high gear (*a*), the cage is driven by the sprocket and the wheel is driven by the annulus. When the bicycle is in middle gear (*b*), the drive is direct to the wheel. When it is in low gear (*c*), the sprocket drives the annulus and the cage drives the wheel at a reduced speed. If the "sun" wheel (which is fixed to the stationary axle) has the same number of teeth as the "planet" wheels, and the annulus gear has three times this number, then high gear will have a step-up ratio of 4/3 compared with direct drive and low gear a step-down ratio of 3/4.

manufacturer in Britain, was founded by Sir Frank Bowden in 1887.

Other accessories that made their appearance during the 1880's and 1890's include the freewheel mechanism, originally introduced as an aid to mounting, since with the old "fixed" drive some form of mounting step was needed. The abandonment of a fixed drive created the need for better brakes. Originally bicycle brakes were of the simple "spoon" type, pressing on the front tire. Rim brakes came in later, first the stirrup brake, which acts on the underside of the rim, then the caliper brake, which presses on the flat outer sides of the narrow rim used in racing bicycles and lightweight touring machines. The original purpose of the caliper brake was to make it easier to change the wheel without disturbing the brake. Such a brake is operated by a cable in which an inner flexible wire in tension is contained within a flexible outer tube in compression. This system provides a most effective means for the remote operation of a mechanism such as a brake, for which it was first developed. It has since been widely used for such purposes as operating the clutch and throttle mechanisms of motorcycles and the control surfaces of airplanes.

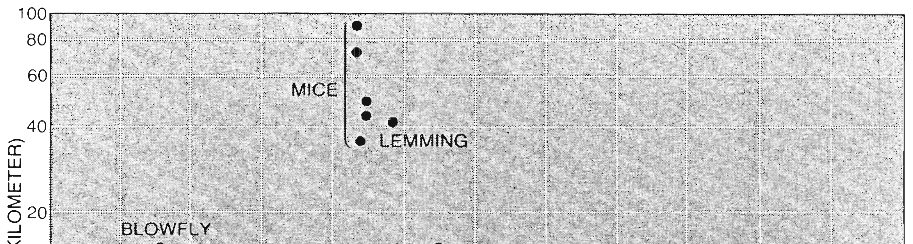
Two other types of brake made their appearance later. One is the coaster brake, or back-pedaling brake, which is particularly popular in the U.S. The other is the hub brake, or drum brake, of the type used in automobiles and motorcycles. Both types have the advantage of remaining effective in wet conditions.

The desirability of being able to change the gear ratio of a bicycle to provide for pedaling uphill or against a head wind is fairly obvious. This gear ratio is still defined by the diameter of the equivalent wheel of the original high-wheelers. Thus a wheel 27 inches in diameter driven by sprockets of 44 and 18 teeth has a "gear" of $(27 \times 44)/18$, or 66 inches. The idea of having different sizes of sprockets on the rear wheel led to the *dérailleur* change-speed gear of 1899, in which the rider can transfer the chain from one sprocket to another while pedaling. The necessary variation in the length of the chain on the tight side of the drive is accommodated by the use of a spring-loaded jockey pulley on the slack side of the chain. This type of gear is light and efficient but needs proper adjustment and lubrication if it is to last.

The alternative form of change-speed gear is the Sturmey-Archer hub gear [*see illustration on preceding page*]. In this system a single epicyclic gear train is used in such a way that when the bicycle is in high gear, the cage is driven by the sprocket and the wheel is driven by the annulus. When the bicycle is in middle gear, the drive is direct to the wheel, and when it is in low gear, the sprocket drives the annulus and the cage drives the wheel at a reduced speed. If, for example, the "sun" wheel (which is fixed to the stationary axle) has the same number of teeth as the "planet" wheels, and the annulus gear has three times this number, then high gear will have a step-up ratio of 4/3 compared with direct drive and low gear a step-down ratio of 3/4. A five-speed version is available incorporating two epicyclic gear trains of different ratios. The advantage of hub gears is compactness and the fact that the mechanism is well protected against dust and damage.

A large number of firms grew up to supply bicycle parts or accessories. One firm in particular, Joseph Lucas Limited, owes its early prominence to the manufacture of the first successful bicycle lamp, an oil-burning wick lamp rejoicing in the name of the King of the Road Cycle Hub Lamp. Later this company made acetylene lamps and then electric lamps, so that they were in a good position to develop the market for automobile lights and other electrical equipment for automobiles. An early form of an electric generator for bicycles was invented by Richard Weber of Leipzig in 1886. The modern hub generator, which requires a minimum of additional effort on the part of the rider, was first produced by Raleigh in 1936.

Bicycle manufacture is still a big business, accounting for a worldwide production of between 35 and 40 million vehicles per year. The leading manufacturing country is still the U.S., with about six million bicycles per year, followed closely by China, with about five million. By any standards these figures demonstrate the importance of the bicycle. If one examines the extent to



MAN ON A BICYCLE ranks first in efficiency among traveling animals and machines in terms of energy consumed in moving a certain distance as a function of body weight. The rate of energy consumption for a bicyclist (about .15 calorie per gram per kilometer) is approximately a fifth of that for an unaided walking man (about .75 calorie per gram per kilometer). With the exception of the black point representing the bicyclist (*lower right*), this graph is based on data originally compiled by Vance A. Tucker of Duke University.

which bicycles are in use today, one finds that in most of the world they play a role far more significant than that of the automobile. China with its 800 million inhabitants relies heavily on the bicycle for the transport of people and goods. So do the countries of Southeast Asia and Africa. Even the U.S.S.R., with only about 1.5 million automobiles, has an annual production of 4.5 million bicycles. Europe and North America are therefore in a minority in relying so heavily on the automobile. The true cost of doing so is becoming increasingly evident, not only in the consumption of resources but also in pollution and other undesirable effects on urban life.

For those of us in the overdeveloped world the bicycle offers a real alternative to the automobile, if we are prepared to recognize and grasp the opportunities by planning our living and working environment in such a way as to induce the use of these humane machines. The possible inducements are many: cycleways to reduce the danger to cyclists of automobile traffic, bicycle parking stations, facilities for the transportation of bicycles by rail and bus, and public bicycles for "park and pedal" service. Already bicycling is often the best way to get around quickly in city centers.

Two important factors must gradually force a reappraisal of the hypertrophic role the automobile plays in Western life. The first is the undoubted diminution of fossil-fuel resources and the accompanying increase in fuel prices. The second is the sheer inequity in per capita energy consumption between automobile-using and non-automobile-using countries. In these days of universal communication such a situation will appear more and more inequitable and a source of resentment. It is inconceivable that 800 million Chinese will ever become consumers of energy on the per capita scale of 200 million Americans, and the end result must be a gradual reduction of energy consumption in the U.S. To this end the bicycle can play a significant part and thereby become a great leveler.

For the developing countries the bicycle offers a different set of opportunities. With the continuing spread of bicycles from cities to towns and villages go the accompanying mechanical skills and essential spare parts. Thus bicycle technology serves the purpose of technical education on which the peoples of these countries can build in the same way that we in the developed countries

RECENT APPLICATION of bicycle technology to flying is in the design of man-powered aircraft, a goal that has attracted a great deal of interest in England lately following the offer of a prize of £10,000 by Henry Kramer for the first man-powered flight over a figure-eight course around two poles half a mile apart. The best flight so far is one made by Flight Lieutenant John Potter of the Royal Air Force in a monoplane designed by Christopher Roper. The Roper aircraft, shown in the photograph with Potter in the driver's seat, has a wingspan of 80 feet and a weight (without Potter) of only 146 pounds. In actual flight an aerodynamic nose canopy completely encloses the rider and drive mechanism.

did only 70 to 100 years ago. There is evidence of such a process at work. The Chinese are replacing the wooden wheel on their traditional wheelbarrow with a bicycle wheel, thereby making it both easier to push and kinder to road surfaces. Threshing and winnowing machines have been designed that incorporate bicycle bearings and chain drives. It is this kind of do-it-yourself, village-level technology that offers the best route to self-improvement, a route far more plausible than any form of large-scale aid from outside. The power of the bicycle with respect to the power of the most sophisticated modern technology is perhaps best shown in Indochina, where the North Vietnamese have used it as a major means of transport. The Japanese who captured Singapore in World War II also traveled largely by bicycle. Nonetheless, the bicycle remains essentially a peaceful device, and we do not need to include it in strategic-arms-limitation negotiations. We might do well, however, to go all out in encouraging its use. If one were to give a short prescription for dealing rationally with the world's problems of development, transportation, health and the efficient use of resources, one could do worse than the simple formula: Cycle and recycle.