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HISTORY AND FUTURE OF SPARK IGNITION ENGINES

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A REPORT

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UNITED STATES SENATE

BY THE

ENVIRONMENTAL POLICY DIVISION

OF THE

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SENATOR EDMUND S. MUSKIE

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LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON PUBLIC WORKS,
Washington, D.C., September 7, 1973.

Hon. JENNINGS RANDOLPH,
Chairman, Committee on Public Works,
U.S. Senate, Washington, D.C.

DEAR JENNINGS: At my request, the Congressional Research Service of the Library of Congress has prepared a history of development of the internal combustion engine for use in motor vehicles. This history provides valuable insights into many questions being asked about the role of the internal combustion engine today, and it provides important background on how the present situation evolves.

I believe that this document will be important to the members of the committee as they consider various issues relating to emissions from the internal combustion engine as part of the more general oversight of the Clean Air Act. Therefore, I request that this Library of Congress report be printed as a committee document for the use of the Members.

Sincerely,

EDMUND S. MUSKIE,
Chairman, Subcommittee on Air and Water Pollution.

LETTER OF SUBMITTAL

THE LIBRARY OF CONGRESS,
CONGRESSIONAL RESEARCH SERVICE,
Washington, D.C., August 3, 1973.

To: Honorable Edmund S. Muskie, attention: Mr. Don Alexander.
From: David E. Gushee, analyst, Environmental Policy Division.
Subject: History and Future of Spark Ignition Engines.

In response to your request of May 25, 1973, to Mr. Bowman, we transmit herewith a report summarizing the results of our studies.

To determine the basis of the industry decision in the early 1900's to utilize the spark ignition engine, we have reviewed not only studies made of that era—one of the most prolifically chronicled eras in American industrial history—but have also examined a number of writings of the era itself.

To provide perspective on the issues facing both the auto industry and society as a whole today, we have reviewed the literature of social change and of the sociology of technological progress, in addition to that surrounding the specific points currently at issue.

Should copies of any of the references used be of interest to you, we will be happy to supply them.

LETTER OF REQUEST

MAY 25, 1973.

Mr. WALLACE BOWMAN,
Library of Congress, Environmental Policy Section,
Congressional Research Service,
Washington, D.C.

DEAR MR. BOWMAN: The Subcommittee on Air and Water Pollution is currently examining the impact of auto emissions standards required to improve air quality. A key consideration in our examination is the role of the spark ignition internal combustion engine in the American transportation system, and its relationship to other alternative power systems which may be available.

I would appreciate it if the Library of Congress would conduct a study of the role of the present spark ignition engine in our transportation system. I would particularly like this study to focus on the history of the development of the spark ignition engine in America, other alternatives which were considered and the reasons why the spark ignition engine has become the engine of primary use, other alternative engines which may be available to date or in the near future, and factors which influence the auto manufacturers' continued preference for this engine over others which may be available.

I would appreciate it if this study could be completed by midsummer to aid in the committee's further considerations of auto emissions standards.

Sincerely,

EDMUND S. MUSKIE,
Chairman, Subcommittee on Air and Water Pollution.

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FACTORS AFFECTING SELECTION OF THE SPARK IGNITION ENGINE IN 1900 AND NOW

By David E. Gushee, Joseph P. Biniek, and John E. Blodgett, Environmental Policy Division, and Mauree W. Ayton, Science Policy Division

SUMMARY AND CONCLUSIONS

The present day turmoil surrounding the automobile engine and its performance bears many similarities to the turmoil within the "industry" in the early 20th century, when it was making the decisions that have shaped it for the past 50 years. Then, as now, there were a number of newly-important design variables. Then, as now, each type of engineering approach had its champions. Then, as now, the only way to determine the design that would meet all the performance paramters was to experiment in large scale in the marketplace.

The analogy, to the extent it is appropriate, is of considerable help in sorting out the issues involved in today's controversies and in predicting how they will shake out over time. In the beginning, some 20 years of full-scale competition in the marketplace were required before the spark ignition engine established its ability to meet the performance requirements and to defeat the challengers. Today, with heightened concern for reduced emissions and deep rumblings about the need for fuel economy, the question of relative performance of alternative engines is again raised. But this time, the spark ignition engine is in the saddle; a challenger must be not merely as good—it must in all probability be quite a bit better to justify that cost and trauma of replacement.

Factors Affecting Early Decisions in Favor of Spark Ignition Engines

The literature of the late 19th and early 20th centuries, as well as more recent studies of that literature and of that period, does not provide the answer to the question as to why the spark ignition engine became the engine of choice. However, that literature does support the following conclusions:

1. At the time of its original selection as the engine of choice, the spark ignition engine had no over-all intrinsic advantage over other types of engines.

2. The spark ignition engine became the engine of choice as the result of a number of circumstances and events rather than as the result of a formal decision-making process. Among the circumstances and events were:

(a) Although steam-powered road vehicles were developed in the 1820's, restrictive legislation in England in force be-

tween the 1830's and 1896 discouraged further developmental efforts during the period of conception and early development of the spark ignition engine.

(*b*) Henry Ford picked the spark ignition engine to power his cars. When the Model T succeeded, the spark ignition engine was assured of at least a place in the range of auto engines to be used. Why Ford picked the spark ignition engine is not clear, beyond his great concern for light weight.

(*c*) Once Ford was in mass production, his competitors had to pick a basis on which to compete against him. His most successful competitor, General Motors, decided to compete on the basis of financial and marketing values and not on the basis of engine type.

(*d*) Standard Oil Co., with its development of the Burton process to crack crude oil, assured a plentiful supply of inexpensive, though "highly refined," gasoline needed by the spark ignition engine but by none of the other types.

(*e*) Adding the electric starter, which removed the problem (and danger) of handcranking to start the engine, opened the women's market to spark ignition-powered cars. Up to that point, women had preferred the electric car.

(*f*) When Doble entered into competition against Ford with a steam-powered car, World War I came along, causing the Government to intervene in the interest of war production. Doble did not fill $27 million in standing orders; when the war was over, any momentum for Doble's steam-powered competitor that might have built up was gone forever.

(*g*) In the early 1920's, when roads were becoming good enough to support a demand for higher engine performance, Midgley discovered tetraethyllead which, when added to gasoline, provided the spark ignition engine with the performance capability to defend its position against the known high-speed performance of the steam-powered engine.

3. As car buyers increased the stringency of their demands for engine performance, the industry successfully modified the spark ignition engine to satisfy those demands. There has been no Achilles heel in its performance on which competitive types of engines could base a challenge.

Factors Influencing Continued Reliance on Spark Ignition Engines

Fierce arguments raged for a quarter century or more over whether the spark ignition engine, the steam engine, or the electric battery would be the best way to power a car. Reading those arguments today, one cannot help but wonder at the willingness of any entrepreneur to risk his all on any one of them. But at least he didn't have to worry about displacing an engine already performing satisfactorily.

1. In contrast to the situation in 1900, the spark ignition engine today has a fundamental intrinsic advantage over all other candidates. Over more than 50 years, hundreds of millions of them have been made, used. maintained, and repaired:

(*a*) Massive production facilities, tools, and methods exist for their large scale production.

(*b*) Designers have an immensely detailed and documented understanding of factors affecting their design, performance, and cost.

(*c*) Hundreds of thousands of people are trained in their maintenance and repair.

(*d*) A network of service facilities, with tools and spare parts distribution, has been built up.

(*e*) Millions of customers through personal experience have gained confidence in spark ignition engines.

(*f*) There is incontrovertible evidence that progress is currently being made in designing them to operate at lower emission levels without intolerable sacrifices in other parameters of performance.

2. There are no equivalents in knowledge, experience, or data with alternative engine designs. Thus it is not possible to prove that a change to one of these alternative designs would be beneficial—in either emission reduction or other performance parameters.

3. Reducing emissions is not the only change in engine design parameters that must be incorporated over the next decade. Fuel source, fuel economy, and transportation functions are in process of reconsideration as a result of major shifts in population, social values, and resources. Many of the factors involved in these changing parameters are not yet clear. In light of such uncertainty, decision makers seek to keep open as many options as possible for as long a time as possible or conversely, to make short term decisions as incremental as possible and to postpone major "change" decisions.

4. All technological innovation, including incremental steps, follows a pattern that can be expected to apply to the auto industry. Typically, an innovation is introduced on a small scale, tested, and proved; gradually it penetrates the market. The period of experimentation varies widely, depending on numerous factors, including those listed above in numbers 1 and 2, and involving the complexity of the innovation, the extent of the supporting system for the existing technology, and the social values affected. Several years is almost certainly the shortest period in which a major innovation can fill a market opportunity.

While the process of innovation can be shaped and directed to some extent by legislation, research and development, and investment, there are limits to how much it can be affected.

The issue is not only whether the evaluation period *can* be shortened, but also, in the light of the long-term changes in the offing, as noted in number 3, and the reductions in emissions from spark ignition engines currently being achieved, whether the evaluation period *should* be shortened.

EARLY HISTORY OF AUTO ENGINES

The task of determining why the internal combustion engine is the engine of primary use is as difficult as determining who discovered America. The historical record of locomotive power is an exercise in love and confusion. The affection of authors and historians for one or another of the electric, steam, or internal combustion engines results in the favored machine being bathed in rose-colored lights. Confusion exists because few sources—including the papers of the principals themselves—agree even on dates, let alone on the factors that influenced the ultimate success or failure of the power unit.

Nevertheless there are numerous identifiable factors, individuals, and circumstances involved in the trail that leads ultimately to our current automobile. Among these are the political, sociological, economic, technological (internal and external), and institutional forces that influenced the decisions of individuals and firms. Personal drives of engineers, promoters, and financiers were also instrumental in shaping the current automobile industry.

The critical period for the fledgling auto industry was from about 1900 to about 1920:[1]

> The period * * * was * * * one of ferment and growth for the entire automobile industry. That activity was in fact a phantasmagoria of bold ideas, ingenious and stubborn experimentation, enthusiastic promotion, dramatic accomplishment, and weird display. From it developed the steadier era of manufacturing in which Henry Ford would emerge as a leader.
>
> Although by 1900 at least fifty-seven American plants engaged in making motor cars, many were in an experimental state, the basic type of vehicle had not yet been determined, and it was uncertain where the chief centers for the new industry would develop. This year saw about 4,000 American cars manufactured, of which steam and electric models made more than three-fourths. One respectable set of figures lists 1,681 steam carriages, 1,575 electrics, and only 936 gasoline cars.

The Steam Automobile

Steam as a source of motive power has a long and illustrious history (see foldout). Road vehicles based on it were being road-tested at least a century before either electricity or internal combustion-powered vehicles.[2]

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[1] Nevins, Allan, *Ford: The Times, the Man, the Company* (New York: Charles Scribner's Sons (1954), pp. 193–94).

[2] Rae, John B., The American Automobile, A Brief History. University of Chicago Press, 1965, p. 2.

Most important to the development of the automobile was James Watt's invention of the connecting rod and throttles to control the force of steam and thus vary the speed of the engine. It is understandable that this English invention was improved on and applied by successive English engineers. Commercial application of steam to passenger transportation and agriculture grew rapidly in England in the early 1800's.

But in 1831 a special committee was established by the Parliament to look into the damages and benefits of the steam vehicle (an early example of technology assessment). Public pressure from various groups—primarily railroad and stagecoach interests—was instrumental in forcing Parliament to pass restrictive tolls and legislation aimed at suppressing road vehicles. A boiler explosion on one coach in 1840 resulted in the deaths of 5 people. The public impact of this accident led to attempts to legislate the steamers off the road. The prohibitive legislation was in the form of tolls and the requirement of an attendant to precede the vehicle and wave a red flag.

Tolls were reduced by an Act of Parliament in 1861. However, the Locomotive Act of 1865 restricted the speed of propelled vehicles to 4 miles per hour in the country and 2 miles per hour in town. The Road-Locomotive Act of 1878 did not provide additional freedom except it did not require the red flag.[3] [4] These Acts were repealed in 1896.[5]

The English institutional restraints undoubtedly had a pronounced effect on the early development of the steam road vehicle. By the time the acts were repealed, England's enthusiasm for steam had already waned and half a century of potential experimentation and operation experience were irretrievably lost.

Meanwhile Leon Serpollet of France, a man of limited financial means, made great improvements in the steam engine. He improved the carriage, developed the flash boiler, and won the world's land speed-record of 75.06 miles per hour in 1902. His vehicle was similar in appearance to petrol-cars and was as light for the same power.[6] His innovations died with him in 1907, as England and France turned to gasoline powered automobiles.[7]

The Stanley Brothers of Newton, Massachusetts, were the most successful steam car manufacturers and many of their cars were exported.[8] A number of circumstances hampered their ultimate role in the automotive industry. One author describes the Stanleys as "cussed New Englanders" who wanted a comfortable living and had no interest in building an automobile empire. They were content to produce 600 cars a year while Henry Ford's goal was 600–650 cars a day. Furthermore they did not believe in advertising.[9] They were reported to have screened prospective purchasers and, if they didn't like the prospective owners' personalities, would not take their orders.

The major promotional activity of the Stanley Brothers was speed racing. In 1907, Fred Marriot attained a speed of 197 mph in a Stanley Steamer at Daytona Beach. His crash at that speed did nothing to enhance the image of the steamer.

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[3] Davison, C. St. C. B., History of Steam Road Vehicles, Ministry of Education. Science Museum. London, 1953, pp. 1–2.
[4] Jamison, Andrew, the Steam-Powered Automobile, Indiana University Press, Bloomington, 1970, pp. 37–38.
[5] Davison, p. 26.
[6] Davison, p. 51.
[7] Jamison, p. 39.
[8] Davison, p. 52.
[9] Jamison, p. 42.

The Stanleys did not utilize a condenser until 1917 when Boston and Chicago threatened to ban the steamer from the streets. Objections to billowing steam from the boiler, plus public reaction to frequent water stops, convinced the Stanleys to change. Although they added the condenser, the Stanleys ran into new and avoidable troubles. They neglected to fit oil-traps between the engine and condenser, and filters between the condenser and water tank.[10] They would not however, switch to a flash boiler. The 20 to 45 minutes needed to get up steam was a major competitive weakness against the jump-in-and-go advantage of the gasoline powered vehicles.

The White brothers produced their first steam car in 1901. They advertised, innovated, competed, and built as many cars as they could. In 1906 they were producing about 1,500 cars a year but by 1909 they deserted steam for the gasoline engine. One author contends that White switched because of the development of service stations exclusively to service gas cars and the elimination of public water troughs (handy sources of boilerwater) because of hoof and mouth disease.[11]

"The finest of all steamers and a classic in its own right" is the way the Doble steamer is often described. Abner Doble produced his first steamer in 1901. His cars were built to exacting standards and cost $10,000 and up. Doble's cars were masterpieces, but not fit for a competitive market. The car could get underway in 15 seconds and cruise effortlessly at 75 mph. Unfortunately only a few could afford to purchase it. Nevertheless, despite its price, Doble was swamped with orders totalling $27 million after a showing in 1917. The War Emergency Board discouraged production, and none of the orders were filled.[12] Doble produced 40 cars between 1921 and 1932. The Doble factory ceased production in 1932.

In the early 1950's, Robert Paxton McCulloch established the Paxton Division of his McCulloch Motor Company. His objective was to develop the "Paxton", a high-class steam car that would make the Doble look cheap. The project was abandoned in 1954 because McCulloch felt it to be economically risky to attempt to compete with the established industry.[13]

Electric Cars

Scotty Anderson is credited with constructing an electric powered vehicle in 1839. The vehicle was crude and in no way competitive with the steam vehicles that had been plying the roads and rails of England since 1825. Interest in the electric vehicle was minimal until the heyday of the Locomotive Acts. By 1870, Sir David Salomons had devised a light electric motor and heavy storage batteries. The low power per weight of these batteries resulted in locomotion far inferior to the range and speed of the steam engine. No spectacular developments appeared to be forthcoming. But now the scene was changing to the United States.

The Pope Manufacturing Company of Hartford, Connecticut, began producing electric road vehicles in 1897. Five hundred electric cars were manufactured in the next two years. At this time, 1899, the Pope

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[10] Bird, Anthony and Lord Montagu of Beaulien, *Steam Cars, 1770--1970*. Cassel and Co., Ltd. London. 1971, p. 165.
[11] Jamison, p. 44.
[12] Jamison, p. 48.
[13] Jamison, p. 49.

Manufacturing Company, its numerous divisions, the Columbia Company and the Electric Vehicle Company went through a series of mergers. These mergers resulted in the Electric Vehicle Company becoming the holding company for assets of $200 million. This firm was the first large-scale operation in the American automobile industry, and the first to use many parts manufactured by other firms.

The mergers were instrumental in gaining complete rights to George Selden's patent for the internal combustion engine. Royalties were collected from all manufacturers except Henry Ford, who filed suit and won in 1911.

The Electric Vehicle Company manufactured 2,000 taxicabs, and by 1904 about one-third of the vehicles in New York, Chicago, and Boston were electrics. Besides these vehicles, they produced some trucks and buses. These vehicles were heavy, clumsy, and of course of limited range. The owners of the company had high hopes and visualized a need for a chain of electric charging stations. They set up subsidiary cab and car rental companies in every large city from New York to Chicago.

The dreams and hopes did not materialize. Out of the $200 million of assets, the company salvaged $2 million in the new reorganization as the Columbia Motor Company in 1909. The following year this firm became part of Benjamin Briscoe's United States Motor Company. The latter failed shortly afterward.

The demise of the leading producer of American electric cars was almost simultaneous with the Studebaker Corporation decision to discontinue electrics in 1911.

The Studebaker Brothers Manufacturing Company was a well established wagon and carriage company. In 1902, they were making 5 models of electrics. Only 20 electrics were sold in the first year. A recent author quotes from a Studebaker catalog:

> As may be imagined, we have not been indifferent to the introduction of the horseless carriage. We have not, however, believed that it would be wise on our part or good faith toward the public to push upon the market an imperfect or immature product. We have expended a large amount of time and money in experimenting and research conducted for us by experts in order that the machine of our adoption should be such that we could recommend and not discredit our standing in the vehicle world.[14]

In 1911 Studebaker decided that the opportunities were now with the gasoline engine, and they dropped the electrics.

The electric cars were popular with urban women. The first gasoline cars were noisy, and dirty. They rattled, spewed oil, and broke down. But most important from the standpoint of women drivers, neither hand cranking of gasoline engines nor broken arms were alluring. The electrics were smooth running, quiet, dependable, clean, and genteel; they were a real asset to the society women of the era.

The electrics could also perform more rugged duty. There were some large electric truck fleets in operation in 1915. A comparison of a few users of electrics is listed below:[15]

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[14] Erickson, C. R., Electric Vehicle History. Electric Vehicle News. November 1972, p. 27.
[15] Erickson, p. 26.

Company	Electric	Gasoline
American Express	220	154
Adams Express Co	326	160
Ward Baking Co	610	50
Marshall Fields	230	70
Jacob Ruppert	120	37
George Ehret Brewing Co	130	0
Commonwealth Edison Co	114	0
New York Edison Co	144	5
Gimbel Brothers	119	97

The early electrics were clumsy and heavy, but by 1915 they were greatly improved. The Edison cell was a lighter and longer-lived battery. The range was increased to 65 miles but speed was still slow, averaging less than 20 miles per hour.

The average cost of electricity had decreased from the 1903 level of 23 cents per kilowatt-hour to about 7 cents per kilowatt-hour in 1913. Thus the electric car had many things working for it, but it was still a casualty of the time. The era saw almost 2,900 automobile manufacturers come and go. The competition was keen and only a handful of the best and toughest remained. Even Henry Ford struggled and had to reorganize and/or refinance several times before he found the winning combination.

Unfortunately electric vehicle manufacture never found a winning combination. This deficiency probably resulted from the general character of the industry—numerous small producers with limited production capability. Consequently the costs were higher for electrics. The Columbia Electric cost about $3,000,[16] while the first Model A Ford (of 1902) cost $800.[17] Economics, a master of destiny, was at work.

H. L. Barber characterized the electric car industry this way:[18]

> But the electric car industry never has reached the proportions of the gasoline car industry. It has never advertised in the lavish manner adopted by gasoline car makers. It has not entered races to the extent its gasoline competitors have. It adopted conservative methods which have given it a slow growth. It is only within the last five years that shaft drives have been perfected in electric car construction, while producing controllers that would not arc, whatever the provocation, have been matters of slow evolution.
>
> But that the electric car is a perfectly balanced piece of mechanism and the one type of the automobile with the least fits and starts, is conceded, and this superiority will doubtless enable the electric type to make up in the future in the major truck field what it has lost to the gasoline type in the passenger field.

There is little else to say.

Spark Ignition

The internal "explosion" engine must have amused many daring men from 1825 (the gas-vacuum stage) to the true harnessing of in-

[16] Hebb, David, Wheels on the Road. Collier Books. New York, 1966, p. 49.
[17] Bird, Anthony, The Motor Car 1765–1914. B. T. Batsford, Ltd.
[18] Barber, H. L., The Story of the Automobile. A. J. Munson, 1917, p. 116.

ternal combustion by Nikolaus Otto. He invented the four stroke engine in 1867. The original Otto-cycle engine developed about three horsepower at about 180 revolutions per minute. It was a slow, heavy, and crude engine, but it was the seed for future work of Daimler and Benz. The Otto engine utilized illuminating gas as fuel.

Daimler converted this to gasoline, added hot tube ignition, regulated the engine speed by an "ingenious exhaust-valve operation" (since throttle valves were not developed),[19] and by 1876 had increased the speed from Otto's 180 rpm to over 800 rpm. This was a major breakthrough—engine weights dropped from 1,000 pounds per horsepower to a light 90 pounds per horsepower. Daimler mounted his engine in a car for the first time in 1885.

Another German inventor, Karl Benz, had been working on a two-stroke engine. Unaware of Daimler's accomplishments, Benz created a light weight four-cycle engine. In contrast to Daimler's hot-tube principle, Benz utilized an electric ignition system. The first Benz vehicle was light weight and reached speeds of 10 mph in 1885. By 1894, Benz was producing 500 vehicles per year, a 500 percent increase over the production of 1886.[20]

These early developments established the basis for new pioneering in the United States by men with diverse backgrounds. The Duryea brothers were bicycle builders, Edwood Haynes was a gas company representative who was tired of traveling behind a horse, and Henry Ford, a tinkerer in his spare time, was chief engineer at Detroit's Edison Illuminating Co.

Ford's first design was a "quadricycle," a light and simple vehicle. By 1896, it was powered by a 3 hp spark ignition engine and was capable of speeds of about 25 mph. He worked on a second car during 1897–1899; it was powered by a 2 cylinder, 4 cycle motor. The success of this machine was the basis for establishing the Detroit Automobile Company in 1899, which Ford resigned from Edison to join.

In January 1901 the Detroit Automobile Co. dissolved, Ford saying he could get no support for building a better car. After successfully building a racing car, however, Ford and several of his former associates reorganized, forming the Henry Ford Motor Co. in November 1901. Wanting to build another racer instead of a commercial car, Ford fell out with the others and left the new company in March 1902. The company then became the Cadillac Automobile Co.

Having completed his second racing car, in 1902–1903, Ford, together with Alexander Malcomson, formed the Ford Motor Company to produce commercial cars, beginning with the first Model A. However, in 1906 Ford and his partner split over a crucial decision. Ford wanted to concentrate on building a cheap, light car; his partner wanted to build bigger, more expensive models. Ford finally bought out Malcomson and focused his efforts on the inexpensive Model N, with volume production beginning in 1907. The price was $600.

The next major Ford model was the Model T, on which deliveries began in October 1908. With it Ford achieved his revolutionary goal—a low-priced car with a large sale volume. These two choices, mass production and catering to the low-price market, more than anything

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[19] Bird, p. 35.
[20] Bird, p. 38.

else established the future of the automobile industry and its basic components, including the spark ignition engine. Ford's overwhelming success can be seen in the extent to which he increasingly dominated the market:[21]

Year	*Percent of all production*
1908	9.4
1911	20.3
1913	39.6
1914	48.0

His dominance of the cheap car field was nearly absolute: In 1913, the year he introduced the assembly line technique, he made 96 percent of the 185,000 to 190,000 autos manufactured and priced below $625.

Ford's record of production is as follows:[22]

Year and number of cars:	
1904	1,708
1905	1,695
1906 (Model N)	1,599
1907	8,423
1908 (Model T)	6,398
1909	10,607
1910	18,664
1911	34,528
1912	78,440
1913 (assembly line introduced)	168,220
1914	248,307
1915	308,213
1916	533,921

The year 1911 was a momentous year for the automobile industry. The U.S. Court of Appeals decided that the Ford motor was not an infringement of the Selden patent of the motor invented by Brayton. This decision opened the way to free expansion of the entire industry.

In addition, 1911 was the year that Henry Leland adapted the storage battery and electric starter to the spark ignition engine. The following year William Bendix developed the "Bendix drive" for the starter. The electric self-starter expanded the car buyer market by at least a million, most of whom were women.[23] This market expansion made expansion of production and introduction of the assembly line worthwhile.

There is no argument that Ford's idea of quantity sales was correct and that it was paramount in giving the premiership of auto manufacture to the United States. All other manufacturers either adopted this philosophy and the associated production techniques—or failed to compete.

But from this period on, competition in the industry was no longer among autos with different types of power plants, although an occasional challenge continued to occur. Successful competition now involved incremental differences in design of the spark ignition engine plus differing views of customer attitudes toward style, convenience, and other variables.

While dozens of firms failed, Ford prospered. Rising to compete, slowly at first and then more rapidly, was General Motors, led by the market sensitivity of William Durant and the cool financial and or-

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[21] Nevins, pp. 488–89.
[22] Barber, H. L., Story of the Automobile. A. J. Munson & Co., 1917, p. 94.
[23] Barber, pp. 122–123.

ganizational genius of Alfred P. Sloan. Building on the known performance of the spark ignition engine, making innovations carefully and under controlled conditions, and moving firmly to exploit opportunities so identified, GM capitalized on Ford's original initiative, including his choice of engine.

The rapid growth in production, purchase, and operation of cars brought with it a corresponding demand for fuel. The Spindletop oil field in Texas, discovered in 1901, assured a plentiful supply of crude oil from which fuel for either the spark ignition engine or the steam engine could be refined. But the spark ignition engine demanded a more highly refined fuel (gasoline) than the steam engine, and the amount that could be distilled directly from crude oil was limited.

Thus, the development of the Burton cracking process by Standard Oil Co., by means of which more than twice as much gasoline per barrel of crude oil could be made, was a critical contribution to the continued expansion in use of the auto. That process assured a plentiful supply of "highly refined" gasoline at reasonable prices.

Despite the tremendous acceptance of the Model T, despite the choice by General Motors to compete on grounds other than engine type, and despite the improvements in oil refining that kept providing fuel for spark ignition engines as those engines improved, the steam engine was still not dead. Two more blows were required to kill it.

The first of these was World War I. Doble, of steam engine fame, displayed a new prototype of a steam-powered car in 1917 and was swamped with $27 million in orders. Before he could begin to fill them the War Emergency Board stepped in. It needed production capacity and materials for the tools of war. The WEB discouraged Doble from making cars—and none of his $27 million in orders were fulfilled.

The military needed proven vehicles for war—and so ordered trucks with spark ignition engines from Ford and General Motors. Although Doble got a few war-related orders, he came out of the war much weaker relative to Ford and GM than he was in 1917.

After World War I, when motorists became more numerous, roads became better, and improving economic conditions fostered demands for higher performance in cars and their engines, the refining process was having trouble providing gasoline for higher-compression-ratio engines. Then Midgley of General Motors discovered tetraethyllead [24] which permitted the spark ignition engine to be improved as rapidly as motorists escalated their expectations.

What Ford, GM, and World War I could not do, chemistry did. Steam was dead.

Diesel

The diesel is an internal combustion engine that relies on ignition by compression rather than by spark. The engine was developed by Rudolph Diesel in 1892. Its essential feature is a carefully timed injection of fuel into previously compressed air. Explosion of the fuel occurs when the temperature is raised to about 500° F. This temperature level is attained by compression ratios of 15:1 to 20:1.

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[24] Midgley, Thomas, "Some Fundamental Relations Among the Elements and Compounds as Regards the Suppression of Gaseous Detonation." Industrial and Engineering Chemistry, vol. 15, No. 4, April 1922, pp. 421–423.

The high compression ratio and the necessary bulk to withstand these pressures precluded the use of the engine in early road vehicles. This feature was not a deterrent to Franz Saurer and his son Adolph. The Saurer Works dates back to 1853 and is an outgrowth of a foundry. But in 1888, Adolph Saurer began manufacturing internal combustion engines for industrial uses. In 1898, the first Saurer automobile was built and by 1902 the Saurer cars were known for their toughness and hill climbing ability.

Rudolph Diesel collaborated with the Saurers in 1907 and 1908. This resulted in the first diesel powered truck. In 1911 a fully loaded diesel powered truck crossed the United States from coast to coast.[25] The Saurer firm continues to specialize in huge diesel engines for a variety of applications, including railroads, trucks, busses, and industrial applications.

Mercedes-Benz's interest in the potential of diesel began about 1935 and the first diesel powered Mercedes appeared 17 years later. Acceptance of the diesel powered Mercedes is limited by its lower road performance, its noise, its odors, and its higher price.

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[25] Wherry, Joseph H., Automobiles of the World. Chilton Book Co. Philadelphia, 1968, p. 560.

CONTEMPORARY ALTERNATIVE POWER SOURCES

In response to public and congressional demands for reduced auto emissions, numerous modifications to spark ignition engines and numerous resurrected alternatives to the spark ignition engine have been proposed. Few, if any, of the proposals are new. The heralded steam engine has its roots in the Aeolusphere of Hero in 150 BC and Giovanni Branca's spinning rotor of 1629. The fascinating turbine reaches back to John Barber's British patent on a gas turbine in 1791. The diesel was invented in 1892. Even the recently-heralded Wankel engine had precursors described in a number of patent applications filed before 1910 and a revived interest with an associated set of advances in the 1920's.[26]

Numerous studies have been undertaken to assess the alternative engines.[27] [28] In many cases the alternatives cannot be realistically compared with the spark ignition engine. Robert Ayres summed one major deficiency when he wrote: [29]

> Unfortunately, cost data derived from careful well-documented engineering studies based on first principles are virtually nonexistent. Most of the published cost estimates are not suitable for comparing the costs of different systems.
>
> Some are based on standard (unverifiable) sources, some offer too wide a range of costs, and some appear to be designed to prove a particular point.

But costs are only one of the important parameters. And comparisons are no more reliable—and thus no more meaningful for other parameters than they are for costs. Thus, all such comparisons are primarily tabulations of hopes for the new vs. reality for the spark ignition engine.

The recent study undertaken by the National Academy of Sciences Committee on Motor Vehicle Emissions is probably as objective as any other study. John W. Bjerklie, Chairman of CMVE's Panel on Alternative Power Systems summarized the results of this study with respect to the suitability of alternative engines for automobiles.[30] He concludes that no alternative engine surpasses all others in all the attributes needed, but each offers promise in one or more parameters and probably performance penalty in one or more other parameters. The Panel's assessment is based on information obtained through group and individual visits to manufacturers and research agencies. "The gathered information was used to estimate the characteristics to be

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[26] Cole, David E., The Wankel Engine. *Scientific American,* August 1972, p. 14.
[27] Ayres, Robert V. and Richard P. McKenna. Alternatives to the Internal Combustion Engine. RFF, Johns Hopkins University Press, 1972.
[28] National Academy of Science. Committee on Motor Vehicle Emissions, In Press.
[29] Ayres, p. 272.
[30] Bjerklie, John W., Chairman of the Panel on Alternative Engines, National Academy of Sciences. Statement before the Senate Commerce Subcommittee on Environment and on Science, Technology, and Commerce. May 1973.

expected from the various types of engines and power plants as to how they would be adapted to light duty vehicles. In some cases future engines were characterized based on recent work leading to probable improvements for specific engines." [31]

Early mass production of some alternatives assumes that society is willing to accept the hazards or deficiencies at the time of introduction. For example, mass production of the battery powered unit suggests that the consumer would accept the hazards of acid battery burns in case of accidents, as he now accepts the risk of gasoline explosions.

Major modifications to the spark ignition engine that hold a significant degree of promise include the stratified charge and rotary engine. The stratified charge approach has the significant advantage of being an incremental change from the current spark ignition engine. One system now being developed by Honda achieves charge stratification with a rich mixture pre-chamber and dual-carburetor intake system.

As the National Academy of Sciences Committee on Motor Vehicle Emissions reported to the Environmental Protection Agency earlier this year.[32]

> Although the general principle is not new, the particular design in question, incorporated into small size engines, has met the 1975 certification standards and bids fair to meet the 1976 standards. As compared with the catalyst-dependent systems * * *, this system offers the promise of lower initial purchase costs, greater durability in service, and significantly greater fuel economy.

Although this engine's fuel economy is superior to that of the catalytic-convertor-equipped conventional spark ignition engine, it does suffer a fuel economy penalty of about 10% when modified from maximum operating efficiency to meet 1975 emissions limitations, and an additional fuel penalty to meet the 1976 requirements as well.[33]

Two American versions of stratified charge engines have been developed by Texaco and Ford. Texaco's and Ford's PROCO engines are controlled-combustion injection systems. These engines have demonstrated adequate drivability. When equipped with oxidation catalysist, they have demonstrated emission control to the 1976 emission standards. These versions offer the best fuel economy at the 1976 emission levels.[34]

Professor Heywood of the National Academy Panel states: [35]

> The concept which offers the best compromise between good fuel economy, required degree of emission control, least demanding fuel characteristics, and good performance has yet to be precisely defined. Once the optimum system has been developed, many problems related to reliability and durability, as well as large scale production feasibility, would still remain to be solved. Nonetheless the stratified-charge con-

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[31] Bjerklie, *op. cit.*

[32] Handler, Philip, National Academy of Sciences, letter accompanying Report by the Committee on Motor Vehicle Emissions, Feb. 15, 1973 (CR, Feb. 28, 1973, p. S3617).

[33] Heywood, John B. Statement of Chairman of the Panel on Emission Control Systems for Spark-Ignition Internal Combustion. Engines of the Committee on Motor Vehicle Emissions. Statement before Senate Commerce Subcommittee on Environment and on Science, Technology and Commerce. May 1973.

[34] Heywood, *op. cit.*

[35] Heywood, *op. cit.*

> cept offers great promise of adequate emission control with good fuel economy and performance characteristics.

The Wankel engine, a new type of spark-ignition engine, is succintly described by Heywood: [36]

> The other new spark-ignition engine technology—the Wankel rotary combustion engine—is primarily being developed for its potential manufacturing cost reduction. The smaller engine size, lighter weight, smaller number of engine parts and possible re-design of the vehicle to take advantage of these different engine characteristics could all contribute to this cost reduction. The current production versions of this engine show adequate durability but poor fuel economy compared with conventional engines. The emission characteristics are not significantly better than those of a conventional reciprocating engine. Engine developments now underway indicate that the fuel economy penalty can be significantly reduced by improving the design of apex seals to minimize leakage. Preliminary experiments with a stratified-charge Wankel engine, with chamber fuel injection to control the fuel mixing and combustion process, indicate the possibility of combining these alternative spark-ignition engine concepts to obtain manufacturing, emissions, and performance benefits.

In summarizing the status of the status of alternative spark-ignition internal combustion engines, Professor Heywood said: [37]

> It must be stressed that the most advantageous designs of these alternative engines are not yet ready for mass-production on a large scale.

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[36] Heywood, *op. cit.*
[37] Heywood, *op. cit.*

TODAY'S TURMOIL IN PERSPECTIVE

The spark ignition engine had, as indicated earlier, no over-all intrinsic advantage over the steam engine in the early 1900's when the basic auto industry decisions were made. That is not the case today.

Now that hundreds of millions of spark ignition engines have been built and operated to exhaustion, design engineers' ability to predict their performance is great. Making an engineering change in the design of this engine introduces an element of risk concerning its future performance that is very small compared to the risk involved in predicting the performance of any alternative engine.

Further, the costs involved in tooling up to produce spark ignition engines with minor design changes are small compared to the costs that must be incurred to produce any other engine. For the spark ignition engine, only the portions to be changed require investment; for other engines, the entire production capability must be created.

Over the short term, therefore, an American auto company is faced with a choice of making a limited investment to modify an engine of known performance to achieve a result of which it can be highly confident versus making a large investment to build a new power plant of approximately equivalent performance about which it is very unsure. Little wonder, then, that the industry chooses to adapt the spark ignition engine to the new demands being placed upon it.

The auto industry has tried to make its values and its approach clear.[38]

> What has happened . . . is that an additional design criterion has been added to the automotive powerplant. In addition to effectiveness, efficiency, cost and convenience, we are now giving higher attention to environmental side effects.
>
> Every product as complicated as an automotive powerplant must, of course, represent a compromise of many tradeoffs. And it is the designers' job to respond first to government mandates and then, to the extent possible, make the tradeoffs between these criteria in such a way that the individual car owner and the community at large both get the optimum cost/benefit ratio.
>
> Of course, it is a long tedious process to find that optimum by refinement and trial-and-error, by creative engineering and carefully tested innovation. It is this process which the spark-ignition gasoline, piston engine went through for 50 or so years with the original criteria.
>
> With the introduction of an additional criterion in the optimization process, there obviously are shifts to be made, new tradeoffs to consider with the spark-ignition gasoline piston engine; and the possibility arises that totally new powerplants may be optimum in the new ball game.

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[38] Agnew, William G., General Motors, statement before the Senate Commerce Committee on the Environment and on Science, Technology and Commerce, May 14, 1973.

In addition, along with the introduction of the new environmental criterion, there are even some drastic changes appearing in the original criteria. Our transportation system itself is beginning to change in concept as a result of population pressures, thus altering what we consider to be effectiveness; and the energy crunch is inducing a new outlook on the efficiency of automotive powerplants.

> The design criteria for automotive powerplants have never changed faster than they are today, and yet the complexity of the optimization process has also never been greater. Time is required for optimization, time to invent new things, time to try new concepts, time to experiment with new combinations, time to make errors, learn what went wrong and correct them. The automotive powerplant designer is likely to go too far one way or the other in his attempt to optimize; that's how you find an optimum.

The industry has stated its readiness to change from the spark ignition engine to some other engine should the facts so dictate. Mr. Agnew's statement includes a reiteration of that readiness ("the possibility arises that totally new powerplants may be optimum . . .").

The auto industry is very large, however, and very complex. Technological forecasters studying the factors affecting such industries have concluded: [39]

> The speed with which a substitution takes place is not a simple measure of the pace of technical advance, or of manufacturing, marketing, distribution, or any other individual substitution elements. It is, rather, a measure of the unbalance in these factors between the competitive elements of the substitution. When a substitution begins, the new product, process, or service struggles hard to improve and demonstrate its advantages over the dominant product, process, or service. As the new substitution element becomes recognized by commanding a few percent of the total market, the threatened element redoubles its own efforts to maintain or improve its position. Thus, the pace of technical innovative effort—indeed, the competitive pace of all aspects of the substitution—may increase markedly during the course of the substitution struggle . . .
>
> The rate at which a given substitution proceeds seems to be determined by the complex interplay of economic forces responding to the inherent superiority of a new method.

In the auto industry, technological change seems to take a long time—at least it seems like a long time while one is in the period of change. Today's spark ignition engine produces about 10 times the horsepower per pound of engine that Henry Ford's best efforts could produce in 1900, but all seven decades have been needed for this progress to occur. In the area of technological substitution, these time lags

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[39] Fisher, J. C. and R. H. Pry, "A Simple Substitution Model of Technological Change," Technological Forecasting and Social Change, vol. 3, pp. 75–88 (1971).

are also apparent. It took 20 years for power brakes to be installed on half the new cars, 15 years for air conditioning on half the new cars, 10 years for power steering on half the new cars.[40]

Other innovations have failed to pass the tests of performance plus customer acceptance. A typical example is glass-fiber-reinforced plastic bodies to replace metals—this experiment has revealed a combination of losing attributes whose significance prior to market testing was greatly underestimated. Another innovation currently under evaluation is automatic speed regulation available as an option on some General Motors cars; this one may fail as a result of unexpected consumer hesitance.

These examples of both successful and unsuccessful innovation display characteristics about the process of technological change that are common to each other and common to the same process in other industries.[41] These characteristics include:

(1) The tendency of innovations to emerge from outside the industry. Several recent studies have shown this happening at a three to one ratio. The reason for this is that external industries do not have the commitment to the existing technology and do not have to worry about losing their existing market. If one considers Honda, Mazda, and Mercedes as outside the industry because they have had essentially no penetration in the American market, then the evolving pattern of innovation in response to emission control requirements is similar to that experienced in most other industries.

(2) Incremental commitment to innovations. Innovation typically occurs as a series of stages of increasing commitment of resources on the part of the innovator. In this way, by testing at stages the potential superiority of the innovation, the innovator can minimize his risk of error. The dozens of false starts in the auto industry at the turn of the century illustrate the hazards. Even with careful testing, unsuccessful innovations may reach commercial production, as with the fiberglass body of the Corvette. Studies of technological innovation show that this period of testing takes from a few to 20 or more years, depending on the state of the art, complexity of the technology, the investment, and the need for the innovation. Longer product life will lengthen testing time of prototypes.

(3) Substitution occurs relatively slowly. The replacement of one technology by another never occurs instantly; generally, substitution takes 10 to 25 years. The superiority of the new technology over the old is important in determining displacement time, although numerous examples exist where people have refused to accept new and superior technologies when the changes conflicted with existing cultural patterns. A significant feature of substitution is that typically the first introductions serve as experimental models, providing actual use experience. Until the new technology is proved, neither the innovator nor the purchaser is likely to commit himself substantially. Long product life will tend to draw out this process.

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[40] Blackman, A. W., Jr., "A Mathematical Model for Trend Forecasts." Technological Forecasting and Social Change, vol. 3, 1972, pp. 441–52.

[41] Rogers, Everett M., Diffusion of Innovations, New York: The Free Press of Glencoe, 1962.

Based on these characteristics of the innovation process, it appears that any replacement for the spark ignition engine will face a long and difficult task. The spark ignition engine has an inherent superiority over alternatives by virtue of its experience over a half century and the production of hundreds of millions of units. No alternative power plant has at this time any clear-cut intrinsic advantage over the spark ignition engine in terms of cost or performance. The product life of the auto power plant is long, necessitating longer periods of testing and thus extending both the testing and substitution periods. Most alternatives are still in the period of development; prototypes of steam engines are being tested in some buses, electrically powered fork-lifts have found a market in warehouses. The only alternatives to be commercially produced are the diesel, which for trucks has been produced in quantity for 50 years (20 years for cars), and two spark ignition variants, stratified charge and the Wankel. The status of these alternatives correlates with the stage of their development and fits the pattern of innovation.

THE EVOLUTION OF AUTOMOTIVE POWER SOURCES

SELECTED HISTORICAL EVENTS

STEAM

150 BC TO 1700 AD

Hero of Alexandria — 150 BC
Aeolusphere - the first primitive Steam engine.

Symon, Steven — 1600 AD
Zeylwagon (sail wagon) first land vehicle not using muscle power for locomotion.

Father Verbiest — 1670
Aeolus-Kugel,
Steam cart built for Emperor Khang-hi of China.

Sir Isaac Newton — 1680
Devised a machine propelled by jet action of steam escaping through oriface.

Dennis Papin — 1690
Invented simple steam engine with one vertical cylinder and piston.

1701 TO 1800

Thomas Newcomen — 1705
Developed "atmosphere engine" consisting of vertical piston fitted with crossarm, pivot and counterweight.

James Watt — 1769
Obtained patent on improved steam engine. A connecting rod connected the piston to a crank-shaft and flywheel.

Nicholas J. Cugnot — 1765
Developed military vehicle using 2 pistons and connecting rod to drive wheel.

James Watt and William Murdock
Developed a "fiery little devil" — a light, high pressure steam tricycle.

William Murdock — 1783
Developed steam powered wagon.

William Wymington — 1786
Developed a steam carriage.

Nathan Reed — 1790
Obtained patent for a four wheeled steam vehicle.

Oliver Evans — 1789
Obtained American patent on steam carriage.

1801 TO 1825

Oliver Evans — 1803
Orukter Amphebolus – a 20 ton self propelled steam dredge. 1st American.

Richard Trevithick — 1801
First self propelled passenger vehicle. (Patented in 1802 in Britain).
Steam coaches operated in and around London in 1825.

Thomas Blanchard — 1825
Second American to operate a steam car successfully.

1826 TO 1850

Goldsworthy, Gurney — 1827
Steam Coach service between Gloucester and Cheltenham, England.

Walter Hancock — 1832-38
Paddington to London steam coach service.

British Locomotive Act
Restrictive tolls placed on steam powered road vehicle.

1851 TO 1875

Sylvester Roper — 1863
Made ten steam cars, then invented motorcycle.

Locomotive Act of 1865
Restricts speed of vehicles to 4 mph in country and 2 mph in city and required a red flag to precede the vehicle. Restrictive tolls were also in effect. Suppression continued till 1896 but interest in steam had waned.

1876 TO 1900

Leon Serpollet — 1888
Invents flash steam generation. Innovations died with inventor.

Rollin White — 1899
Improves flash boiler.

Stanley Brothers — 1899
Most successful sales of steam car.

1901 TO 1920

White Brothers — 1901-1909
Advertised, innovated, completed and built as many cars as they could. Discontinued steam because of growth of service stations exclusively devoted to gasoline. Switched to gasoline trucks.

Stanley Brothers — 1901-1923
Produced only 650 cars a year because of interest in comfortable living and no dreams for auto empire.
– Selective screening of customers.
– Reluctance to use condenser and when accepted did not use oil trap between engine and condenser and neglected to use filter between condenser and oiler. This resulted in fouling of engine.

Doble
Develops flash boiler and begins making cars. Had orders for $27 million in 1917 but War Emergency Board discouraged production. Orders not filled.

1921 TO 1950

Doble
Builds "finest of all steamers and a classic in its own right." Priced over $10,000. Bankrupt in 1932. Company sold to Bessler Co.

Steam engines replaced by diesel on railroads and some ocean vessels.

Stanley Brothers — 1923
Discontinued production after one brother's death.

1939 – Chrysler began work on turbine.

1951 TO 1972

Robert Paxton McCulloch
Paxton Division of McCulloch Motor Company plans steamer to make Doble look cheap. Abandoned plans in 1954.

1963-66
Chrysler road tests turbine engine but 50 percent of drivers were non-committal. Not produced.

SPARK IGNITION

Issac de Rivay — 1806
First internal combustion road vehicle utilized electric ignition and hydrogen for fuel.

Brown — 1826
Patented internal combustion engine that operated without explosion. Utilized alcohol and water as fuel.

Lenoir — 1860
Non-compression IC engine.

Edwin L. Drake — 1859
Commercial production of crude petroleum.

Nikolaus Otto — 1867
Invents 4 cycle IC engine using illuminating gas for fuel. Patented in Germany and United States in 1878.

Gottlieb Daimler — 1876
Converts "Otto engine" to gasoline using "hot tube" ignition.

Karl Benz — 1879
Develops high speed "Otto engine" i.e. 450 rpm utilizing electric ignition.

George Selden — 1879
Patents Brayton engine. Sues manufacturers for infringement of patent.

1895 —
Over 500 applications for patent on automobiles and components.

Gottlieb Daimler — 1883
Develops high speed engine i.e., 800 rpm thereby reducing weight from 1000 lbs. per hp to 100 lbs. per hp.

Karl Benz — 1894
Benz factory producing 500 vehicles per year.

Spindletop Oil Field — 1901
Reliable supply of Crude Oil Gasoline 10¢ a gallon.

Standard Oil Co. — 1909
Burton process of cracking oil doubles gasoline supply.

Henry Ford — 1905-1915
– Wins contest on Selden patent, 1911.
– Utilizes assembly line technique.
– Emphasis on cheap car and mass production.

Charles F. Kettering and Henry M. Leland — 1911
Electric starter.

Vincent Bendix — 1912
Bendix drive for starter.

United States Motor Car Corp.
Takes over 129 companies but goes broke in 3 years. Remains go to GM.

Durant — 1910-1920
Instrumental in assembly of huge GM empire including Chevrolet, Buick, Cadillac, Oakland (i.e. Pontiac) Oldsmobile etc. Also assembled companion industries, e.g.: Hyatt Roller Bearing, Fisher Body, Guardian Frigerator Co. and GMAC. Adopted Ford Technology, added financial controls, market orientation.

Studebaker
Abandons electrics in favor of internal combustion engine.

Buick — 1901
Developed valve in head engine, but did not produce it. Utilized later by Chevrolet in its competition with Ford.

World War I
Auto manufacturing curtailed but war contracts keep major companies viable. Many produced IC airplane engines.

Charles F. Kettering and Thomas H. Midgley — 1922
Developed anti-knock additive tetraethyllead permitting increased compression.

1929-1940
Marginal automobile manufacturers discontinue production during depression.

1946
Kaiser-Frazer enter automobile field only to discontinue production in early 1950's.

GM
Introduced Buick's 1901 valve in head engine in the Chevrolet to compete with Ford's Model T.

Félix Wankel invents Wankel rotary engine, 1954.

Curtis-Wright purchases manufacturing and licensing rights to Wankel for $2.1 million.

Ford develops Prico engine in cooperation with Army.

Honda unveils stratified charge engine.

– Studebaker discontinues production of automobiles.

– Kaiser-Frazer discontinues production of automobile.

DIESEL

Rudolph Diesel — 1892
Developed the "Diesel" engine, a high compression, heavy engine.

Diesel engine utilized for stationary power source primarily manufactured by Saurer.

1911
– First diesel truck traverses U.S.

Diesel engine adopted for locomotive power on railroads and some ocean vessels. World War II light vessels powered by diesels.

1952 –
Mercedes Benz adopts light diesels for expensive automobiles in Europe. Increased use of diesel for railroads. Steam engines virtually eliminated.

ELECTRIC

Scotty Anderson — 1839
First electric powered road vehicle. (Magnetized rod and steel drum). Power expended in few feet. No match for steam, therefore, it was dropped.

Sir David Salomons — 1870
Devised batteries and light weight motor. Batteries too heavy resulting in limited capacity.

Colonel Pope — 1887
Successful electric cars used as cabs in New York City 1888-89.

Pope Manufacturing Co. sold to Columbia Automobile Co. (Name changed to Electric Vehicle Co.). This company secured complete rights to Selden's patent and spent 13 years collecting royalties and fighting Henry Ford. Ford won case in 1911.

Electric Vehicle Company with holding of $200 million produced 2,000 electric cabs. Ten years later the company capitalization was reduced to $2 million. Merged with Briscoe's United States Motor Company which failed shortly thereafter.

Studebaker Brothers — 1902-1911
Began manufacturing electric cars in 1902. The Studebaker Corp. was established in 1911 and electrics discontinued. Their catalog on the electric car said proudly "We have not, however, believed it would be wise on our part or good faith toward the public to push upon the market an imperfect or immature product".

Electricity cost 23¢ kwh.

General Electric — 1906
Abandons hybrid gas electric car, four years after Porsche Lohner Mixt (in Austria) was considered a success.

Electric cabs used extensively in New York, Boston, and Chicago.

Spark ignition engine defeats electric powered vehicles.

SELECTED WRITINGS ON THE CHOICE OF THE SPARK IGNITION ENGINE TO POWER AUTOMOBILES

Selected Writings on the Choice of the Spark Ignition Engine To Power Automobiles

To provide background for the discussion, findings, and conclusions of the preceding section of this report, a selection of writings has been chosen to portray the industry in its formative days and to give the historian's perspective.

The development of the automobile was accompanied by a prodigious amount of literature describing all aspects of its innovation. Virtually every sort of journal observed the development of this new transportation mode and commented on its implications. By 1900 several trade journals had appeared, including some which evolved from bicycle magazines. Doubtless the very size and diversity of this literature best indicates the ferment of this period as the automobile was emerging as the replacement for the horse.

Existing histories miss much of this ferment. There are descriptions of the evolution of the machine, analyses of the business, and nostalgic reminders of the past. But the excitement that led to the formation—and dissolution—of dozens of companies to manufacture automobiles of all types and styles is largely lost. Nevertheless, they provide useful perspective.

The selected writings fall into four categories:

1. The first selection identifies the birth of the automobile: The great race of 1895.

2. The second category includes writings of the period 1900–1905. It was during this time that the choice of engine was made. In 1900, the choice was still open; by 1905 the spark ignition engine was dominating the market, although it was still possible that electric and steam cars would maintain a portion of the market.

3. The third group includes two articles on the spark ignition engine's fuel. By 1909 the success of the spark ignition engine and new performance requirements were imposing overwhelming demands on the quantity and quality of available gasoline. The direction of innovation was to improve the fuel situation, not to change the engine.

4. Two historical accounts, one concerning the gasoline engine, the other steam, make up the fourth part. These articles add the advantages of hindsight to the contemporary writings.

While these articles are highly diversified and sometimes disagree in their evaluations of what was happening, certain common themes appear in many of them.

First, the articles suggest that in the United States in 1900, electric, steam, and gasoline engines were each viable alternatives. The willingness of entrepreneurs to invest in any one—or more than one, like E. C. Stearns—is testimony to the potential each engine possessed. The

electric was generally described as the most "perfected" automobile, but its short range and battery weight were seen as severe limitations. Steam engines were well developed, but on automobiles involved frequent stops for water and had poorer fuel economy than gasoline. Gasoline automobiles were the least well developed, had numerous problems—including noise, vibrations, and odor—but were more efficient than steam.

Second, several of the articles—for example, the ones by Krarup, Burnett, and Hanchett—seem to assume that because the gasoline engine was the least developed, its potential had to be the best. It appears that the disadvantages of the spark ignition engine were commonly seen as challenges, while the disadvantages of the electric and the steam automobiles were often seen as fixed, although the work of Edison on batteries and of Serpollet on steam powered automobiles showed that the potential for new developments on these alternatives existed and was being explored.

Third, innovations on electric and steam powered vehicles tended to lag behind those of gasoline autos. Articles frequently commented on this lag, especially in the development of the steam automobiles, for example the *Cycle and Automobile Trade Journal* editorial. Several authors like Wherry saw this lag resulting from entrepreneurial conservation. But Krarup saw an intrinsic reason: he suggests that the radical changes involved in constructing gasoline engines, a totally new technology, caused manufacturers of the gasoline automobile to be more innovative, whereas builders of steam automobiles tended just to place existing steam technologies on carriages.

Fourth, many of the articles comment on the social, economic, and political forces affecting the development of the automobile. Tolls and other restraints were particularly telling in England, as discussed by Kingman, and also in France. As a result, in these countries developmental efforts tended to focus on the gasoline engine, and by 1900 most automobile manufacturers in France openly condemned steam vehicles, apparently because of fear of competition, as noted in the article "Steam Abroad." Nevertheless, Serpollet invented several key improvements of the steam powered vehicle, but these were slowly adopted in the U.S.

Ickx, Jacques. "The Great Automobile Race of 1895." *Scientific American* (May 1972) 102–111

The thesis of this article is that the automobile was born—became viable—in the great automobile race of 1895. The event proved the potential of the automobile, and fired the public interest in this new technology. It is noteworthy that the race took place in France, for over the next decade, the French auto industry was generally looked to as the most highly developed. The greatest number of racers were powered by spark ignition engines, the power source most experimented with in Europe. Gasoline powered vehicles finished in the first eight places, and Ickx says that the race proved the superiority of the internal combustion engine over steam; but, in fact, the best steam vehicles in the race failed for reasons other than any inherent problems with the power plant.

The Great Automobile Race of 1895

BY JACQUES ICKX

The birth of anything, living or inanimate, is generally considered to occur at the moment when it becomes viable. In this sense we can fix a definite date for the birth of the automobile. It came into the world as a lively, healthy phenomenon on June 13, 1895. The idea of an automobile had had innumerable conceptions and miscarriages prior to that time, but on that date the horseless carriage at last emerged as a useful creation ready for growth. The labor that led to its "delivery" was an event now long since forgotten but one that created worldwide excitement at the time. It was called the Great Paris-Bordeaux-Paris Race."

A century of abortive efforts to produce a viable motorcar had set the stage for the drama. The efforts had begun even before James Watts' invention of the steam engine, although they were not serious until Oliver Evans in the U.S. and Richard Trevithick in England had developed high-pressure steam engines with a power-weight ratio appropriate to self-propelled vehicles, The attempts by Trevithick and many others to develop a road vehicle at the beginning of the 19th century were unsuccessful primarily because the leaf-spring suspension had not yet been invented. It was to be the railroads that would first introduce travel by machine.

Starting in 1858, with the further development of the steam engine, efforts to build a road vehicle were renewed, at first with no greater success. Finally in 1873 the French inventor Amédée Bollée *père* made steam-driven cars possible and indeed capable of high performance. They did not become practicable for general use, however, and after 12 years of tinkering Bollée abandoned his experiments, having concluded that the future belonged not to the steam car but to the emerging new "thundering engine" powered by gasoline.

The need for motive power in light industry had stimulated much work on the creation of an internal-combustion engine. It was first realized in a reliable form by Nikolaus August Otto of Germany with his construction of the four-stroke engine that was to be the basic forerunner of the modern automobile power plant. The company for which Otto worked, Gasmotorenfabrik Deutz, was not interested in developing motorcars. It remained for two independent German inventors, Carl Benz and Gottlieb Daimler, to take up the problem.

Benz concentrated on producing a three-wheeled vehicle propelled by an Otto engine running at 250 revolutions per minute. He turned out his first vehicle and

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road-tested it in the streets of Mannheim in 1886. Meanwhile Daimler, the former general manager of Gasmotorenfabrik Deutz, and his "disciple" Wilhelm Maybach had devoted themselves to the goal of developing a light engine that would be marked by a high shaft speed to give a favorable ratio of power to weight. They reached 720 r.p.m., which was a fantastic shaft speed in their day. A motorcycle powered by a Daimler engine ran in 1886 and a buggy in 1887.

Neither the Benz nor the Daimler demonstrations generated any great stir. Benz's successive three-wheelers found no buyers. As for Daimler, he was not interested in building road vehicles; his curious object was to produce a universal engine that could be used in every way for every purpose. Hence the gestation of the automobile might have dragged on for some time had it not been for the intervention of an enterprising widow.

Daimler's representative in France was Edouard Sarazin, a Belgian who had unsuccessfully tried to bring the new technique to the attention of car-builders in Paris, particularly his friend Emile Lavassor, who in assocation with René Panhard ran a workshop with 50 employees for the manufacture of internal-combustion engines. When Sarazin met a premature death in 1887 at the age of 47, his widow, a Frenchwoman from the Midi, obtained from Daimler the right to continue her husband's work in France. Mme Sarazin had fallen in love with Levassor, which doubtless intensified her efforts to put the Daimler engine before him. At all events the Panhard & Levassor organization ultimately bought the French production rights to the engine.

Levassor's intention was to build the motors and leave to others the task of installing them in automobiles. Accordingly he took considerable trouble to approach Armand Peugeot, an important industrialist of Doubs (near the German border) who ran three big workshops manufacturing tools, household equipment (particularly coffee grinders) and bicycles. He offered Peugeot the Daimler motor on an exclusive basis in return for a minimum purchase of 30 motors a year. This would have been an enormous order for the time, and Peugeot declined, reserving the right to acquire Daimler motors for automobiles as he went along.

Panhard and Levassor were now obliged to look into making automobiles themselves. The production of Daimler motors in France began in 1890, and almost immediately afterward both Panhard & Levassor and Peugeot made prototype vehicles. The Panhard & Levassor machine was in the form of a carriage; the Peugeot was rather like a four-wheeled bicycle. By the second half of 1891 both companies had achieved a certain amount of success. The Panhard & Levassor vehicle had covered the 225 kilometers (140 miles) between Paris and Étretat in two days. The Peugeot quadricycle, participating unofficially in a bicycle race, had covered the 1,200 kilometers (745 miles) from Paris to Brest and back to Paris in 10 days.

Panhard & Levassor took the lead in the production of its vehicle: it had made five improved machines by October, 1891. Peugeot, however, had also produced additional vehicles by the first days of 1892. The interest aroused by the new machines now brought Carl Benz the customers he had been awaiting in vain for his three-wheeled vehicles.

By 1894 it seemed that the horseless carriage might be ready to give a better account of itself. A total of some 200 Panhard & Levassor, Peugeot and Benz vehicles had been built, and there was an assortment of various other motorcar prototypes in France, some of them steam-powered. The automobile was still only in the fetal stage, however, as far as its technical and social impact was concerned. Very few people had ever seen one of the horseless carriages; at least nine-tenths of the population did not even know they existed. Pierre Giffard, the editor of France's largest daily newspaper, *Le Petit Journal*, was inspired to sponsor a show designed to bring the automobile to public attention and at the same time promote his newspaper's circulation.

The event would be a run from Paris to Rouen and back: a modest distance of 126 kilometers (about 73 miles). The cars able to reach the finish within a set limit of 12½ hours were to be judged on the basis of safety, comfort and economy of performance. It was to be a demonstration of the utility of the horseless carriage as a means of transportation, not as a sport vehicle. The regulations stipulated that the speed of the cars would not be recorded, because, Giffard said, a speed of 16 to 17 kilometers per hour was sufficient for the run.

There were 102 entries in "the Race of the Horseless Carriages." Most of them were for vehicles that did not yet exist and that were intended to utilize astonishing sources of energy: the weight of the occupants, levers, pedals, compressed air, a hydraulic motor—even an animal motor. All the fantasies, all the dreams, all the illusions of misunderstood inventors were included in the list.

Hence only 25 cars appeared at the elimination tests of July 19, 20 and 21, 1894, which called for covering 50 kilometers in four hours. Twenty gasoline- and steam-powered vehicles met the test. The gasoline-powered cars were five Panhard & Levassors (four of which were entered by the builder), seven Peugeots (five of which were entered by the builder), a Benz and a Gautier with a Daimler motor; the steam-powered vehicles were a de Dion-Bouton tractor towing an open carriage, a Serpollet omnibus, a Scotte omnibus, an old steam tricycle and two Le Blant delivery trucks with Serpollet motors.

In the run from Paris to Rouen and back Giffard hoped that the cars would proceed one after the other about 150 meters apart. Some of the cars, however, could not go fast enough to keep up with the car ahead, and some could not go slow enough to stay behind. As a result when the cars reached Mantes for the midday rest, some were an hour ahead of schedule and some an hour behind. Therefore Giffard decided to let the cars proceed at their own pace in the afternoon run. This presented an opportunity for a race between the steam-propelled de Dion-Bouton machine and one of the gasoline-driven Peugeots, and the race was won by the de Dion-Bouton. The impromptu match gave rise to the legend that the Paris-Rouen-Paris run was a race, whereas it was only, as it was intended to be, a reliability trial. In this trial 13 of the 14 gasoline-driven cars met the requirements and only one of the seven steam vehicles (the de Dion-Bouton) did so. The first prize was shared by Panhard & Levassor and Peugeot. The second prize went to the firm of Bouton.

The de Dion-Bouton machine had been sponsored by the wealthy Comte de Dion. Immediately after the finish of the run the Count, knowing that his vehicle was the fastest, proposed for the following year a race on a much more ambitious scale. Giffard declined to go along, but the Count's fellow contestants were willing. The *petroliers* (builders of internal-combustion-engine cars) were confident that their products would perform, provided that the race was over a distance great enough to demonstrate their engines' reliability and durability.

The Count and the others drew up an audacious set of plans and conditions for the race. It was to cover a distance of about 1,200 kilometers over the road from Paris to Bordeaux and back to Paris. The race would be run nonstop, night and day. All repairs along the way were to be made by the drivers and their crews with tools to be carried in the vehicles. Each car was to have all its seats occupied by passengers, and to be eligible for the first prize a car would have to carry at least four people. A carbuilder was not allowed to enter more than one car of the same type. A draconian condition required the contestants to complete the 1,200-kilometer run within 100 hours. Considering that the average cruising speed of the cars of the time was not much more than 25 kilometers per hour, this was a formidable challenge.

Race No.	Car	Type	Propulsion	Finish
5	Panhard & Levassor	2-passenger prototype	Gasoline	1
15	Peugeot	2-passenger classic	do	2
16	do	4-passenger phaeton	do	3
8	do	4-passenger vis-à-vis	do	4
12	Benz	do	do	5
7	Panhard & Levassor	4-passenger classic	do	6
28	do	6-passenger prototype	do	7
13	Benz	4-passenger phaeton	do	8
24	Bollée "La Nouvelle"	7-passenger omnibus	Steam	9
1	de Dion-Bouton	4-passenger tractor	do	No
3	do	4-passenger break	do	No
6	Panhard & Levassor	2-passenger classic	Gasoline	No
14	Hildebrand & Wolfmuller	Motorcycle	do	No
18	Gautier	2-passenger classic	do	No
20	Serpollet	4-passenger classic	Steam	No
21	do	4-passenger prototype	do	No
25	Jeantaud	4-passenger	Electric	No
26	Rossel	4-passenger vis-à-vis	Gasoline	No
37	Vincke & Delmer	5-passenger	do	No
42	Millet	Motorcycle	do	No
43	Gautier-Wehrlé	4-passenger back to back	Steam	No
46	Peugeot/Michelin	2-passenger, pneumatic tires	Gasoline	No

Note: Starting vehicles are identified according to the numbers they bore in the race and according to type. Of 97 vehicles entered for the competition only 22 started, and only 9 finished within the allotted span of 100 hours. Although the Panhard & Levassor No. 5 finished 1st, it did not qualify for the 1st prize because it was a 2-passenger vehicle and the rules of the race stipulated that to be eligible for the prize a car would have to carry at least 4 passengers. Accordingly the 3d-place Peugeot No. 16 was the official winner.

The Count de Dion personally raised 69,000 francs for prizes and expenses of the event from his friends, notably James Gordon Bennett, the founder of the Paris edition of the *New York Herald* and a racing enthusiast. The organizing committee for the race was formed at a meeting in the Count's hotel on the Quai d'Orsay, the distinguished assembly included his fellow car-makers, political officials, journalists, sportsmen, engineers and men of wealth. The date for the start of the race was set for June 11, 1895.

The list of entries grew to 97, but only 23 vehicles were to gather for the competition. There were six steam-propelled cars: two de Dion-Boutons, two Serpollets, a Gautier-Wehrlé and an antique Amédée Bollée *père* omnibus *La Nouvelle*. The gasoline-propelled vehicles numbered 14: four Panhard & Levassors, three Peugeots, a Peugeot-Michelin, a Gautier, a Rossel, two Benzes, a Vincke & Delmer and a Lepape. There were also a Jeantaud electric car and two motorcycles: a Millet and a Hildebrand & Wolfmuller.

We can quickly dispose of 10 of the entries. The Lepape car, which had two driving front wheels, two steering rear wheels, and a friction transmission on the flywheel of a three-cylinder planetary motor never reached Versailles. One of the Serpollets, a prototype, with advanced steering and close-set front wheels, got no farther than Versailles. The 118 kilometers from Paris to Orléans were too much for the Gautier, the Rossel, the Gautier-Wehrlé, the Jeantaud electric car (which had to change its batteries every 20 kilometers) and the Millet motorcycle (propelled by a five-cylinder planetary motor built into the rear wheel). Angoulême (at 446 kilometers) was the end of the line for the Belgian Vincke & Delmer (it collided with a cart), the de Dion-Bouton tractor of the Paris-Rouen-Paris run (it had been lagging since the start) and the Hildebrand & Wolfmuller motorcycle.

This leaves what might be called the serious contestants. They were the two Benzes (coming from Mannheim and driven by Germans), the second Serpollet the three Peugeots (all of which had participated in the Paris-Rouen-Paris run) and two classic Panhard & Levassors (also veterans of Paris-Rouen-Paris). The Panhard & Levassors, the two-seat No. 6 and the four-seat No. 7, were equipped with an oversize Daimler motor, a Maybach jet carburetor (on which Levassor had exclusive rights) and a new transmission with steel-toothed gears and two chains.

Then there was *La Nouvelle*, the doughty relic from 1880, and four protoype vehicles. One was the Peugeot-Michelin, a machine developed by the brothers André and Édouard Michelin for the purpose of demonstrating a remarkable innovation: the pneumatic automobile tire. Called *l'Éclair* (*Lightning*), it was a combination an ancient Peugeot chassis and a Daimler marine engine. It had no differential gearing, which accounted for the zigzag trajectory that had given the car its name. Behind the two occupants of the car was an immense compartment carrying not only tool kits but also some 30 tires.

The second prototype also foreshadowed a future development. The Panhard & Levassor No. 28 was a heavy six-seater with an eight-horsepower rear motor that was a giant for its time. The last two prototypes represented the most advanced techniques in the two contemporary power plants: steam and gasoline.

The de Dion-Bouton No. 3 carriage repeated the technical features and construction of the Paris-Rouen-Paris tractor but in more modest proportions. Its motor developed only 11 horsepower instead of 20, but the entire machine weighed only 538 kilograms (about 1,200 pounds). This meant that it could be mounted on light wheels with steel spokes and solid rubber tires. It was as fast as the de Dion-Bouton tractor and much more maneuverable. Moreover, it was self-sufficient for 70 kilometers because it had a water reserve of 200 liters.

The Panhard & Levassor No. 5 emerged as the first grand touring car in automobile history. It duplicated the structure of the classic Panhard & Levassor, but it was more elegant in its proportions. Among its assets were a weight of barely 604 kilograms (compared with 650 for the classic two-seater), the first complete gearbox (with the gears bathed in oil and protected from road dust) and a secret weapon that calls for a fuller description: the Phoenix motor.

The Phoenix was the newest creation of Daimler and Maybach, a perfectly functioning two-cylinder in-line engine that weighed only 20 kilograms per horsepower compared with 40 kilograms for the most recent version of its predecessor: the two-cylinder V-type motor. More precisely, it developed 4.2 horsepower at 800 r.p.m. for a weight of 83 kilograms instead of 3.5 horsepower at 720 r.p.m. for a weight of 140 kilograms.

The Phoenix had been produced by Daimler and Maybach outside the firm of Daimler-Motoren-Gesellschaft; Daimler had founded the company, but he was now in a state of cold war with it. That was why the motor did not carry the name of Daimler, which belonged by contract to Daimler-Motoren-Gesellschaft. And since the motor did not bear the Daimler name, Levassor had been able to use it exclusively, as he had done with the Maybach carburetor, instead of having to share it with Peugeot on the terms of their contract on the Daimler motor.

Car No. 5 could attain the formidable speed of 30 kilometers per hour, and Levassor did not hesitate to plan his race on the basis of an average speed of 20 kilometers per hour. Several days before the race he refined his estimate to 22 kilometers per hour. In entering cars with only two seats Levassor had imposed on himself the serious limitation of having available in case of breakdown only two men instead of four. Moreover, since in order to be eligible for the first prize a vehicle had to carry four people, he had also forfeited winning the first prize. He had not forgotten the lesson of the Paris-Rouen-Paris run. He understood very well that the public, whose favor it was essential to court, would accept as the real victor only the driver who crossed the finish line first. Panhard & Levassor's entry of two two-seaters had caught Peugeot's attention, and he included a two-seater among his entries.

With the advantage of hindsight one can say that the Great Paris-Bordeaux-Paris Race was destined to be fought out by the de Dion-Bouton No. 3, the Panhard & Levassor No. 5 and the ancient Bollée (whose performance was not dependent on untested new equipment). This was not perceived in the newspaper dispatches of the time, perhaps because the journalists believed it was impossible to predict the reliability of any mechanical device. Instead they confined themselves to estimating the respective chances of steam and gasoline (which showed that they had not understood the verdict of Paris-Rouen-Paris) and coming to the conclusion that steam-driven cars were speedier than gasoline-propelled ones but that the latter required less upkeep on the road. They were careful, however, not to take sides.

Prediction was further complicated by a tactical question. The organizers of the Great Race had never entertained the idea that the entire distance was to be covered with one man at the wheel. Article 11 of the regulations had recognized in advance that crews would have to be changed in the course of the race. How were the relays to work?

The Panhard & Levassor, de Dion-Bouton and Benz entries had adopted the simplest system: divide the course into three sections. A first crew would go as far as Ruffec (405 kilometers), a second would go on to Bordeaux and back to Ruffec while the first crew rested, and the first crew would take the vehicle back to Paris. The Peugeot entries attempted to be more methodical. They divided the course into six sections of about 200 kilometers; at each stage half of the crew would be replaced, so that there would always be someone present who had been able to observe the performance of the machine over the preceding section.

The Serpollet entries chose sections of 150 kilometers; when one team was relieved, it would take the train to rejoin the vehicle for the next section. Finally there was Amédée Bollée *père*, whose vehicle had six seats. He decided to cover the entire route with the same team, its members taking turns at sleeping during the race. He had therefore installed in *La Nouvelle* a kitchenette and a toilet. In addition there was a device of his own invention fastened to the wheels that ran a paper tape on two spools announcing such pertinent information (by means of symbols) as the irregularities of the terrain, changes in level, sharp turns and dangerous downgrades. In order to set up this tape with rigorous precision, Bollée's son Léon had surveyed the entire route in advance with a bicycle that carried the same contraption. The bicycle was now perched on the roof of the vehicle; it would enable someone to go for help in case of need.

The race was to start at the Palace of Versailles. The route ran to Bordeaux by way of Étampes (38 kilometers), Orléans (118 kilometers), Blois (175 kilometers), Tours (235 kilometers), Poitiers (338 kilometers), Ruffec (405 kilometers), Angoulême (446 kilometers) and Libourne (551 kilometers), each of these towns serving as a checkpoint. The first section, from Paris to Étampes, was over a second-rate road and involved climbing three steep hills. The total distance of the round trip (back to Versailles and then to Paris) was 1,183 kilometers.

At 10 o'clock on the morning of June 11, 1895, the entrants met at l'Arc de Triomphe at the head of the Champs Élysées and set out in a procession for

Versailles. At noon the contestants were sent off in the race at about two-minute intervals in the following order: the Peugeot No. 15, the de Dion-Bouton No. 3, the Peugeot No. 8, the Benz No. 12, the Panhard & Levassor No. 5, *La Nouvelle* and the Peugeot No. 16, followed by the rest.

Although the organizers of the contest had designed it as a technical contest, it actually took on the character of a suspenseful sporting event. The run developed a series of melodramatic incidents, and the spotlight of public interest fell more on the human contestants than on their machines. Up to that time the drivers of the experimental motor-cars had been disregarded as being colorless mechanics, receiving little more attention than would be given the engineer of a railroad locomotive. Now, however, the Great Race would create a new type of celebrity: the racing driver who, as "king of the wheel," was to win fame, glory and fortune in the automobile age.

As could have been predicted on the basis of speed potential, Bollée had the fastest time halfway along the first leg (to Étampes), with the Comte de Dion four minutes behind (on time) in his No. 3 (driven by the Comte de Chasseloup-Laubat), followed by Levassor in his No. 5. For Bollée it seemed a good opportunity to stop and correct a tight connecting rod. The rod was wrapped in wet rags to cool it off; when the crew started the car again, they forgot to remove the rags, which became fouled in the mechanism and caused irreparable damage. Bollée and his sons managed to mend the broken parts somehow, but these precarious repairs failed repeatedly at intervals of about 100 kilometers. He just managed to continue heroically to a late finish, completely out of the running.

At Étampes the Comte de Dion arrived first, with a four-minute lead (in corrected time) over Levassor. His car required 10 minutes of maintenance work, however, and Levassor, experiencing no delay, forged ahead. De Dion passed him again on that leg. At the second checkpoint, Orléans, he had rebuilt his lead to six minutes (corrected time), and on the third leg to Blois, which the Comte de Chasseloup-Laubat covered at the extraordinary average speed of 35 kilometers per hour, De Dion raised his lead to 19 minutes. On the following leg, just as he was entering Vouvray at sunset, he was overtaken by disaster. A universal joint broke, and it could not be repaired with the facilities carried in the car. By this time the second de Dion-Bouton entry (the tractor) was also in difficulties, and the other steam vehicles in the race were late. The internal-combustion engine was already demonstrating its superior reliability, with gasoline-propelled vehicles now holding the first eight places.

Levassor arrived at Tours at 8:40 P.M. Unaware that he had a lead of more than an hour and a half over the second vehicle, the two-passenger Peugeot, he did not tarry but pressed on at full speed. The Paris papers of the next morning, giving an account of the race to this point, reported with wonderment that Levassor had averaged 27 kilometers per hour for the distance from Versailles to Tours. Levassor continued his pace through the night, although he had only four carriage lamps to light his way, and he arrived at Ruffec three hours before his scheduled time (on the basis of an average speed of 22 kilometers per hour). The relief crew he had expected to take over there was not yet on hand. Disregarding assurances by the officials that his lead was so great he could well afford to wait for his relief men, Levassor, who had already driven for 15 hours, got back behind the wheel to push on for 15 more. At precisely 10:40 A.M. on the 12th, just 22 hours 30 minutes 30 seconds after he had left Versailles, he arrived at Bordeaux, beating the record of racing cyclists for this course by more than four hours.

Levassor did not even leave his seat: after a four-minute pause for the refueling and servicing of the car, he set off on the return to Paris. He had reached Libourne, more than 32 kilometers from Bordeaux, before he met the second car in the race, still on its way to Bordeaux. It was not the Panhard & Levassor No. 6 that he had hoped to see but the Peugeot two-seater. His advantage now amounted to 64 kilometers, equivalent to more than three hours. Levassor did not pass the third car, the Peugeot No. 8, until he had reached Guitres. The fourth car made its appearance 34 kilometers farther along; it was the Peugeot No. 16.

An hour later Levassor believed he would surely see his No. 6, but this time it was the heavy Panhard & Levassor No. 28 on which he had not counted. The sixth car, the Benz No. 12, did not go by until about 3:00 p.m.; it was 8½ hours behind. Thirty-five minutes later Levassor came to the Panhard & Levassor No. 7, the classic four-seater that had been entrusted to an exclusively amateur

crew (to prove that the presence of professional mechanics was not essential in running an automobile).

Thus a provisional grouping was established in the following order: one Panhard & Levassor, three Peugeots, a second Panhard & Levassor, a Benz, a Serpollet and a third Panhard & Levassor. To Levassor this signified that De Dion and Bollée, his two principal adversaries, were out of the contest. On the other hand, No. 5 was the only one of the Panhard & Levassor vehicles that could still block the massive success of the Peugeots. It was absolutely necessary that No. 5 reach the finish line.

Levassor was of course exhausted. His mechanic Charles d'Hostingue kept offering to take his place at the wheel, but Levassor refused. In the grip of a kind of superstition, he felt that his motor had signed a contract with him and with him alone, and that it would fall apart if he ceased to control it all by himself and in every detail. At about 4:30 p.m. No. 5 arrived at the checkpoint at Angoulême. It was there that he found the Panhard & Levassor No. 6. About 10 hours earlier it had reached the checkpoint at Ruffec in third place. In trying to overtake the second-place Peugeot the new driver had struck a curb and broken a wheel. The wheel had had to be repaired at a blacksmith's, which resulted in the car's being disqualified at the next control point.

This incident confirmed Levassor in his conviction that he could not count on anyone except himself. He had already begun to mull over an idea. In the 23 kilometers from Angoulême to Ruffec he met the de Dion-Bouton tractor, the Hildebrand & Wolfmuller motorcycle and the second Benz, which had traveled half as fast as he had. When he arrived at the Ruffec control point, 33 kilometers farther on, there was a most unexpected scene. This time the reserve crew was at its post and was ready to take the wheel of No. 5. Now, however, Levassor, who had been driving for 30 hours, did not want to turn over his post, even to the crew of his choice. He announced that he would take the car to Paris himself.

When Levassor insisted on remaining at his post, d'Hostingue refused to abandon his own. The two of them, exhausted but stubborn, departed to cope with a second night on the road. It must have been a terrible ordeal. First of all, on the leg from Ruffec to Poitiers the engine began to sputter. The ignition-timing mechanism was jammed with dust. (There were no distributors in those days.) In the evening semidarkness Levassor and his assistant took the mechanism apart, freed the stuck parts, repolished the scarred surfaces and reassembled the mechanism, all within 22 minutes. After Poitiers it was the driver who gave out. Levassor fell asleep at the wheel and plunged into a bank off the road. Fortunately the only damage was a dented fender and a wrenched lantern. In the chill of a very cold night the two pioneers in summer clothes hurried on, singing loudly to keep themselves unfrozen and awake. At exactly 57 minutes 30 seconds after noon on June 13 the Panhard & Levassor No. 5 crossed the finish line.

The Panhard & Levassor had covered the course of 1,183 kilometers in an elapsed time of 48 hours 48 minutes—nearly 12 hours less than Levassor had dreamed possible. Levassor, 52 years old, had driven it almost nonstop, with only brief halts for maintenance and clearing through checkpoints. For the entire distance the vehicle had managed to achieve an average speed of 24.24 kilometers (15.07 miles) per hour.

The two-passenger Peugeot came in second, five hours 47 minutes after Levassor. The contest for first prize under the rules of the event devolved into a close race between the two four-passenger Peugeots, No. 8 and No. 16. The latter car nosed out the victory by just one minute, in a total elapsed time of almost 60 hours. After these four cars the rest of the finishers arrived one by one at long intervals stretching over June 14 and 15. The first Benz came in fifth, the Panhard & Levassor four-passenger classic sixth, the heavy Panhard & Levassor seventh, the second Benz eighth, and finally, bravely lumbering in at 90 hours, the Bollée managed to finish under the 100-hour time limit.

We must not overlook the Michelin enterprise. Although the brothers did not finish within the time limit, they had nevertheless achieved a milestone. For a car to run on pneumatic tires was almost incredible at the time. Indeed, before the race the brothers had had to deflate one of their tires to demonstrate to skeptics that the tires really ran on air. The tires were still in an early stage of development; during the race they lasted for no more than about 150 kilometers. Teams of cyclists had to be called on to accompany the car and help change the tires, and each change took about 30 minutes. *L'Éclair* encountered

many other troubles; finally some wheel spokes broke and the crew found it necessary to have a blacksmith forge replacements, which caused the car to be disqualified. Still, unpromising as the birth of their tire may have been, the Michelins had demonstrated one of the most essential elements in the making of the modern automobile. The pneumatic tire, useful for the bicycle, was indispensable for the motorcar.

Levassor, however, remained the great hero of the Great Race and the automobile's birth. He was greeted by an enthusiastic crowd at the end of the race, and after his death (of an embolism, only two years later) a massive monument in his memory was erected in Paris. From the lessons learned in the race Levassor decided that the No. 5 should be the basis for a production model with certain improvements, particularly a four-speed gear-box, and that the next steps should be an ignition-timing mechanism enclosed in a casing and a four-cylinder engine powerful enough to enable the machine to climb hills without faltering and provide a reserve of power in level locomotion.

The most important effect of the Great Race was its firing of the public imagination. It is no exaggeration to say that the 1895 event, truly a spectacular birth, was the seminal stimulus that ushered in the new age of technology and the transformation the automobile has brought about in the life of man.

Baxter, William, Jr. "The Evolution and Present Status of The Automobile"; "Electric Automobiles"; "Gasoline Automobiles." ***The Popular Science Monthly,*** **LVII (1900), 406–419, 479–490, 593–604**

These three articles give an overview of the steam, electric, and gasoline engines as of 1900. Each is seen as having advantages and disadvantages, and no one is portrayed as being best for all uses. Indeed, the articles imply the possibility that each may fill a niche in the marketplace.

The Evolution and Present Status of the Automobile

In this closing year of a century which is marked by unparalleled advances in science and its applications to the industrial arts, we are very much inclined to take it for granted that none of the inventions that are regarded by us as indicative of the highest order of progressive tendency, could by any possibility have been thought of by our forefathers; and as the automobile is looked upon as an ultra-progressive idea, no one who has not investigated the subject would believe for a moment that its conception could antedate the present generation, much less the present century. The records, however, show that the subject engrossed the attention of inventive minds many hundreds of years ago. In fact, as far back as the beginning of the thirteenth century a Franciscan monk named Roger Bacon prophesied that the day would come when boats and carriages would be propelled by machinery.

The first authentic record of a self-propelled carriage dates back to the middle of the sixteenth century. The inventor was Johann Haustach, of Nuremburg. The device is described as a chariot propelled by the force of springs, and it is said that it attained a speed of two thousand paces per hour, about one mile and a quarter. Springs have been tried by many inventors since that time, but always without success from the simple fact that the amount of energy that can be stored in a spring is practically insignificant.

In 1763 a Frenchman by the name of Cugnot devised a vehicle that was propelled by steam, and a few years after the date of his first experiment, constructed for the French Government a gun carriage which is shown in Fig. 1. As will be seen, the design was of the tricycle type, and it was intended to mount the gun between the rear wheels. The boiler, which resembles a huge kettle, hung over the front end and was apparently devoid of a smoke stack. Motion was imparted to the front wheel by means of a ratchet. Although this invention is very crude,

it must be regarded as meritorious if we consider that it was made before the steam engine had been developed in a successful form for stationary purposes.

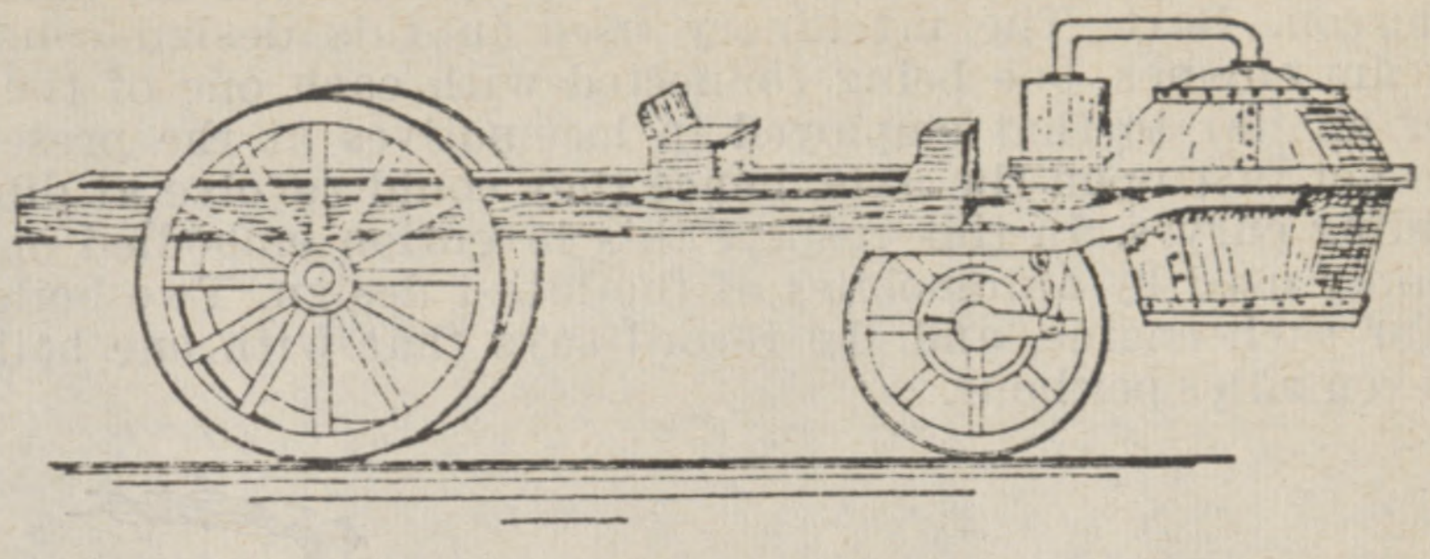

FIGURE 1.—Cugnot's Steam Gun Carriage, made in 1763.

The next effort to solve the problem was made by W. Symington in the year 1784, the carriage devised by him being illustrated in Fig. 2. This coach, although pretentious in appearance, was crude mechanically, but it actually ran. The service, however, was not what could be called satisfactory.

In 1803, Richard Trevithick brought out the carriage shown in Fig. 3, which could run, but was artistically a failure. Moreover, the machinery was such as would soon give out, even if well designed, on account of its exposed position.

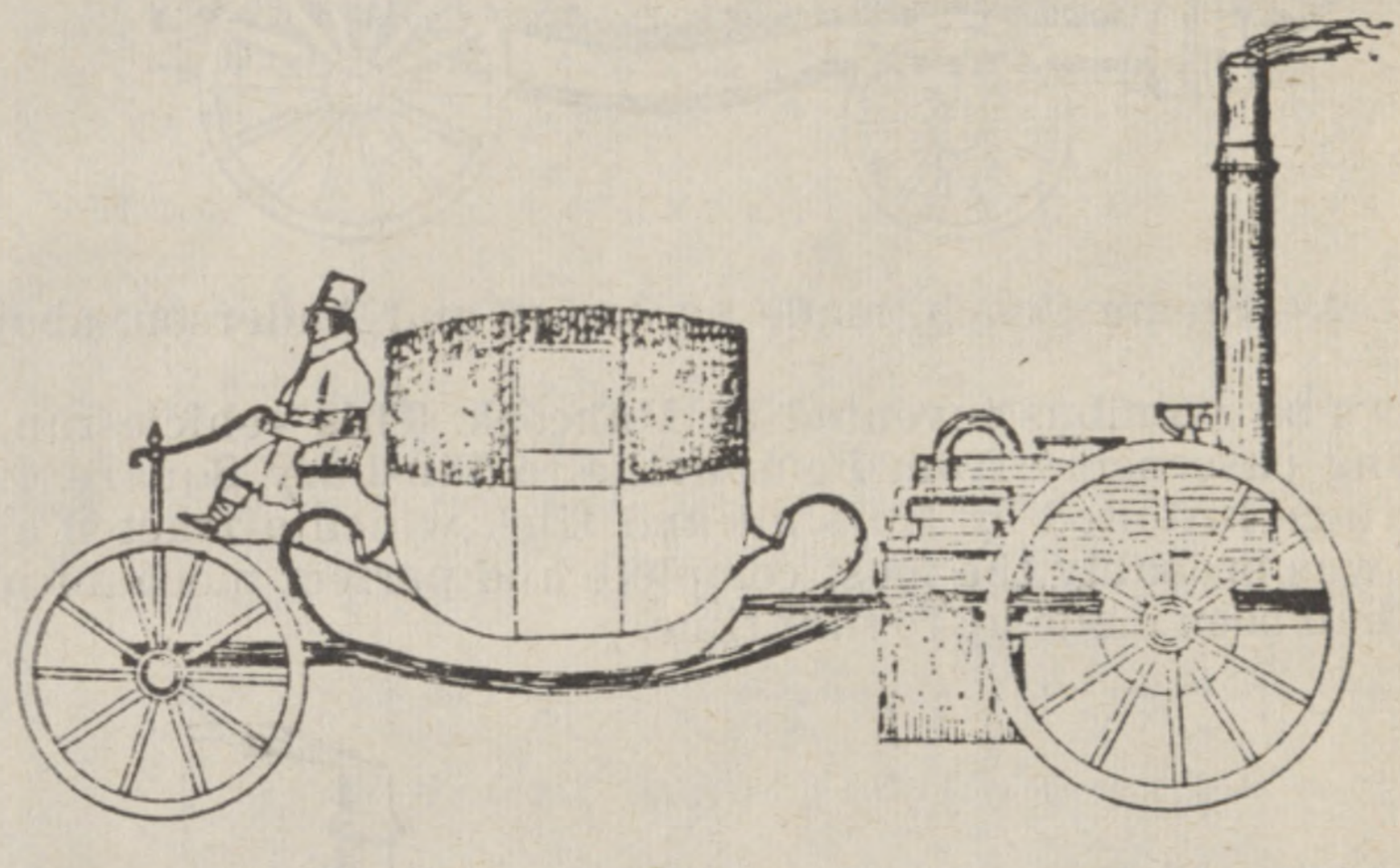

FIGURE 2.—Symington's Steam Coach, made in 1784.

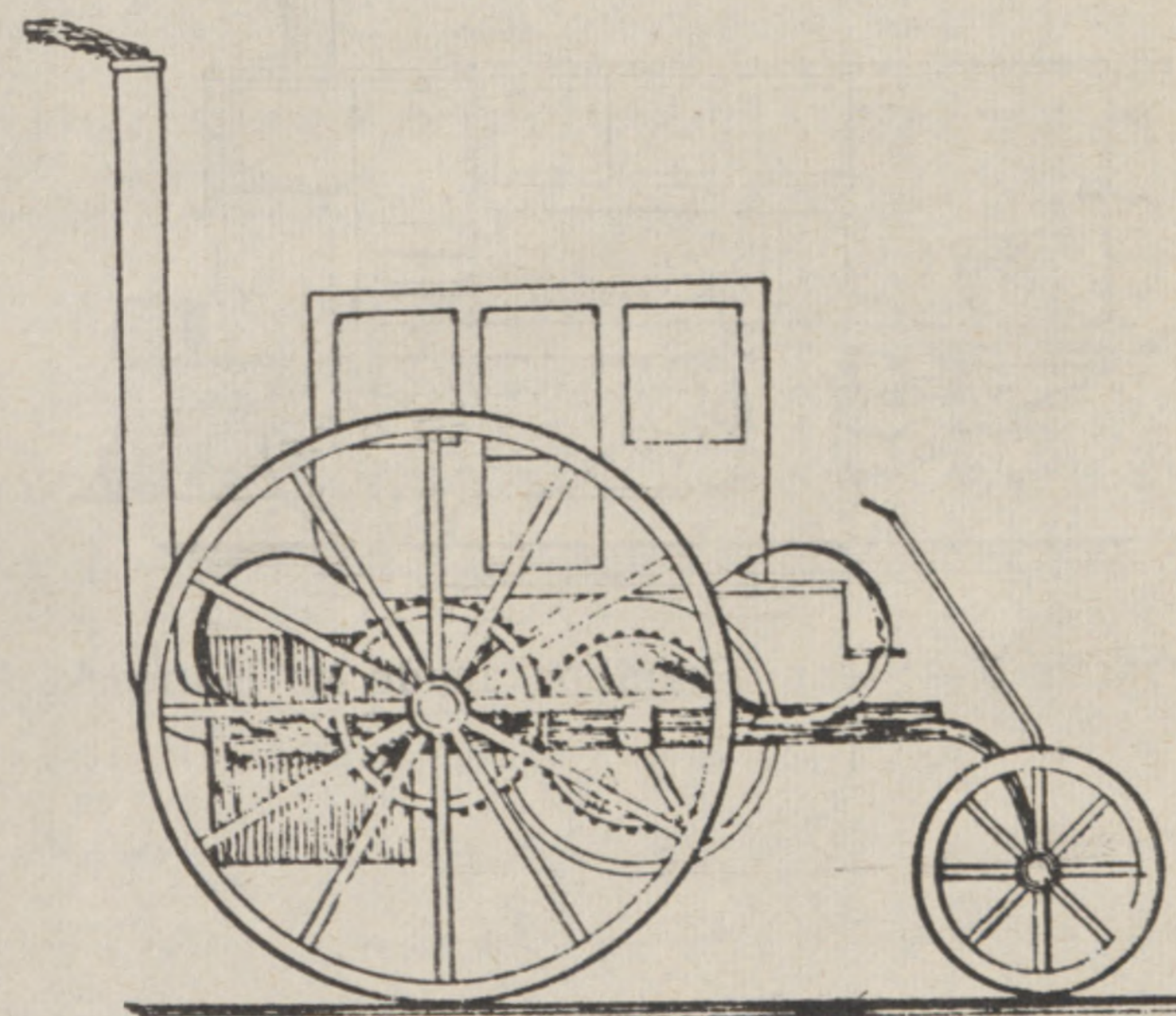

FIGURE 3.—Trevithick's Steam Carriage, made in 1803.

Between 1805 and 1830, quite a number of steam vehicles were invented and put into practical operation. Fig. 4 shows a very elaborate coach of this period, which was invented by W. H. James and constructed with the assistance of Sir James Anderson, Bart. The machinery used in this design consisted of two powerful steam engines, one being connected with each one of the hind wheels in a manner similar to that employed in locomotives at the present time. The wheels were not fast upon the axle, hence they could revolve at different velocities in rounding curves. In this respect this invention embodied one of the features commonly used by automobiles of the latest design. Two boilers were provided, one for each engine, and the record says that with one boiler the speed was six to seven miles per hour.

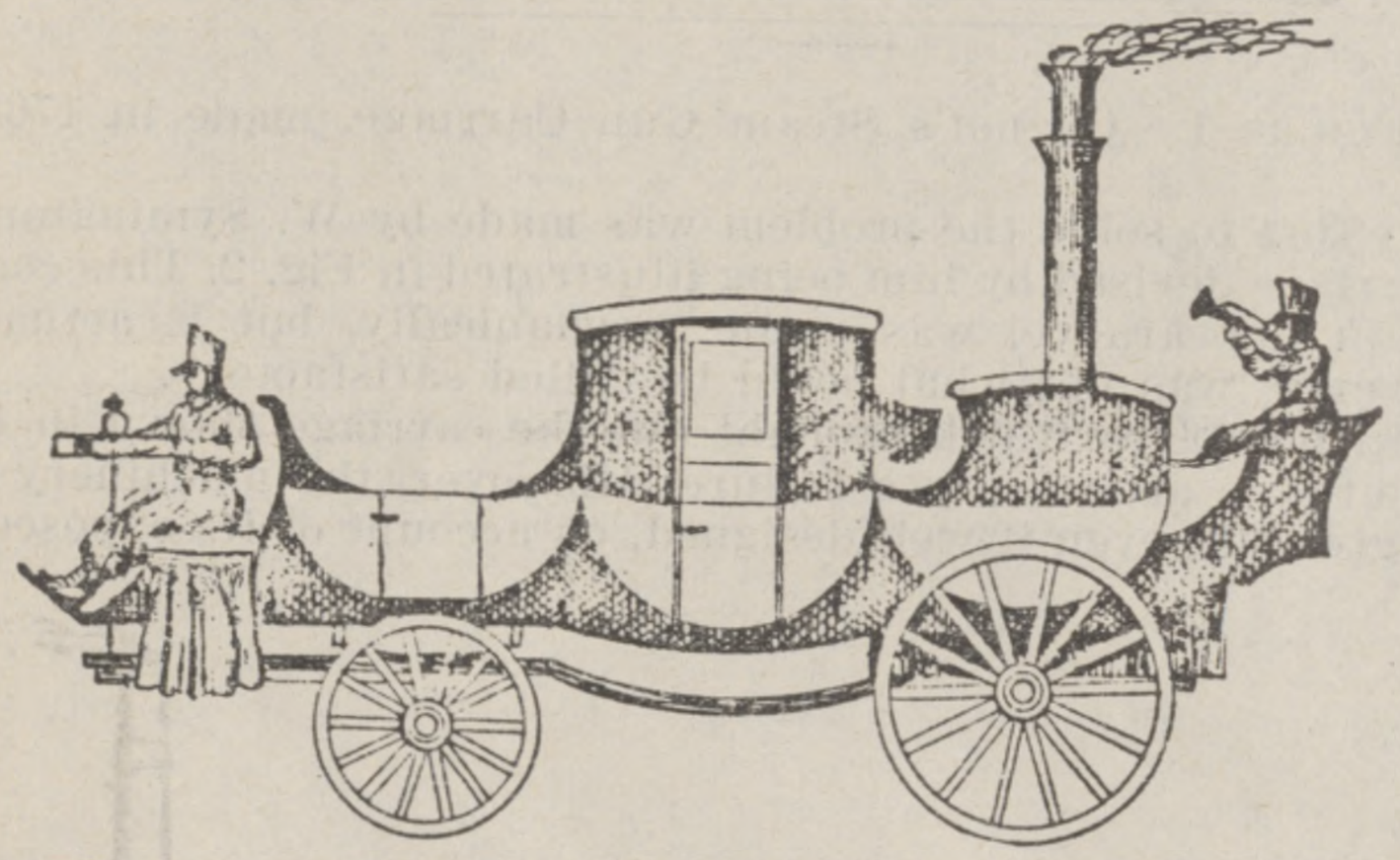

FIGURE 4.—Steam Coach, made by James and Anderson, about 1810.

Fig. 5 shows an omnibus invented by Hancock. This vehicle ran on a regular route, carrying passengers from Pentonville to Finsbury Square, London. Fig. 6 shows a carriage invented by Burstall and Hiel, which attracted a great deal of attention. It was probably the most complete and perfect mechanically of any invention that had been made up to that time.

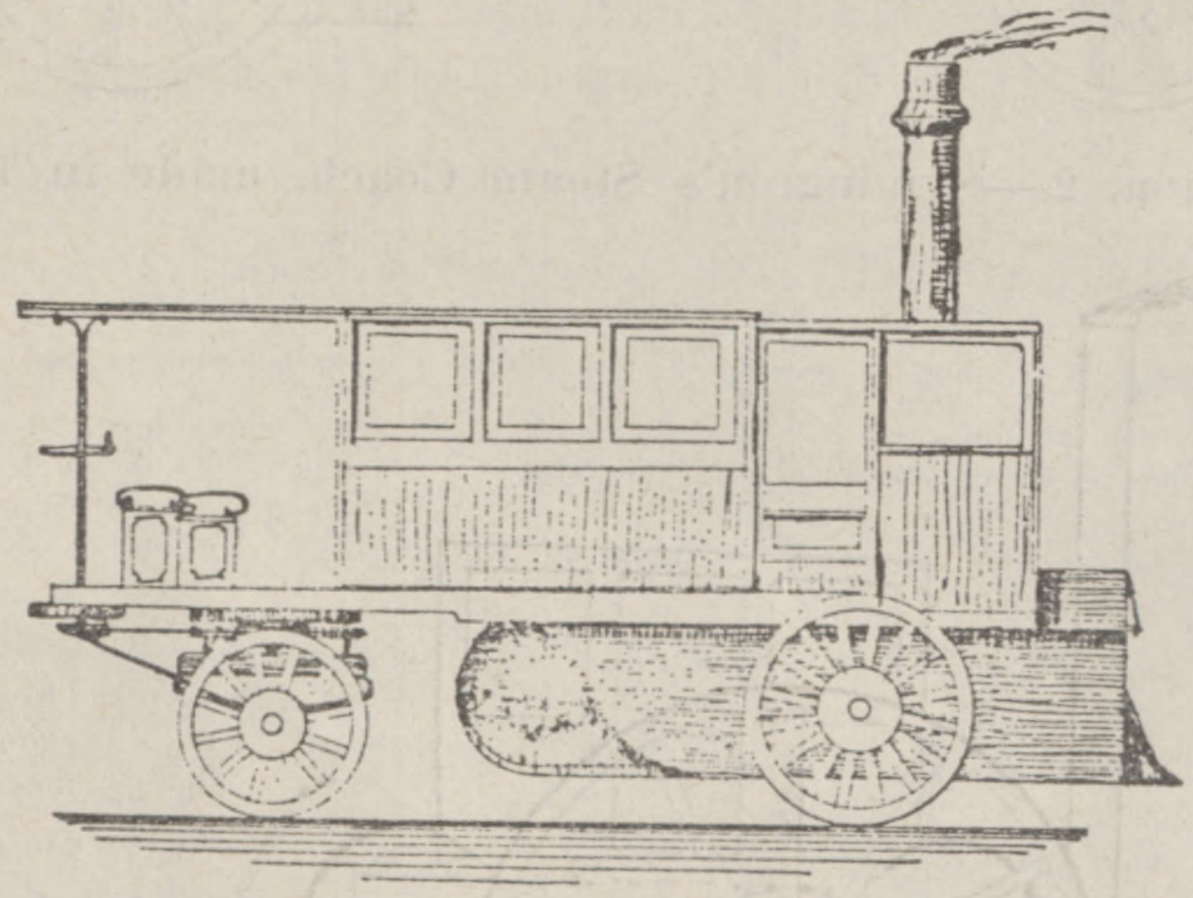

FIGURE 5.—Steam Omnibus, made by Hancock.

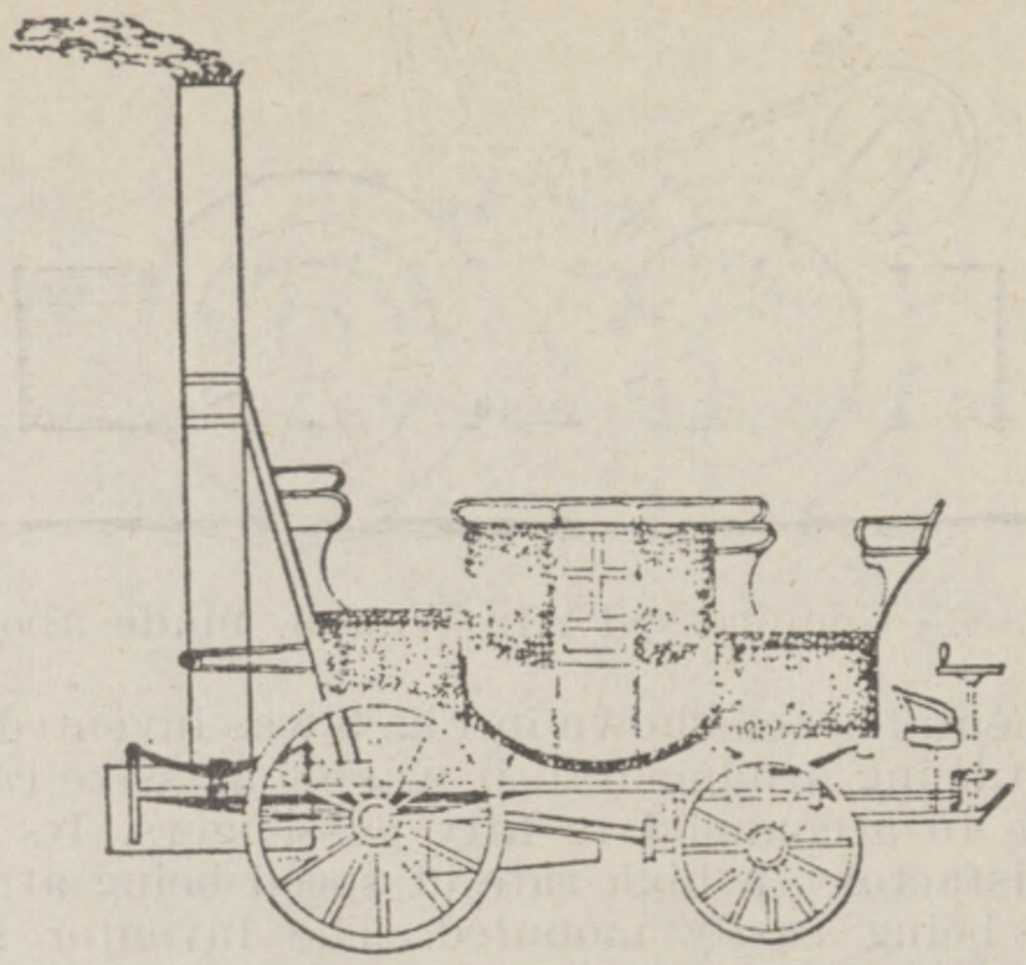

FIGURE 6.—Burstall and Hiel's Steam Carriage, made prior to 1825.

Fig. 7 shows a carriage invented by Squire and Maceroni, who had been for a long time in the service of Goldsworth Gurney, one of the most noted experimenters of his day in steam propulsion. A number of carriages were made by these workers, on designs similar to Fig. 7, and it is said that they ran at a high rate of speed, probably ten miles per hour.

Fig. 8 illustrates an invention that is interesting from the fact that it was to be operated by compressed air, and perhaps was the first effort to utilize this form of stored energy for the propulsion of vehicles. It was not a success, but its failure was due to the fact that the inventor labored under the delusion that the laws of nature could be circumvented by skillfully contrived mechanical devices so as to obtain something from nothing. The body of the carriage was used as a reservoir for the compressed air, and within the wheels were placed a number of pumps, the short bars projecting from the peripheries being the ends of the plungers. The expectation was that as the wheels revolved, the plungers would be depressed, and thus air would be pumped into the reservoirs and this air would operate the engine that propelled the vehicle; hence the apparatus would supply its own power, and realize perpetual motion. If this attempt to controvert the laws of nature had not been relied upon, better results might have been obtained.

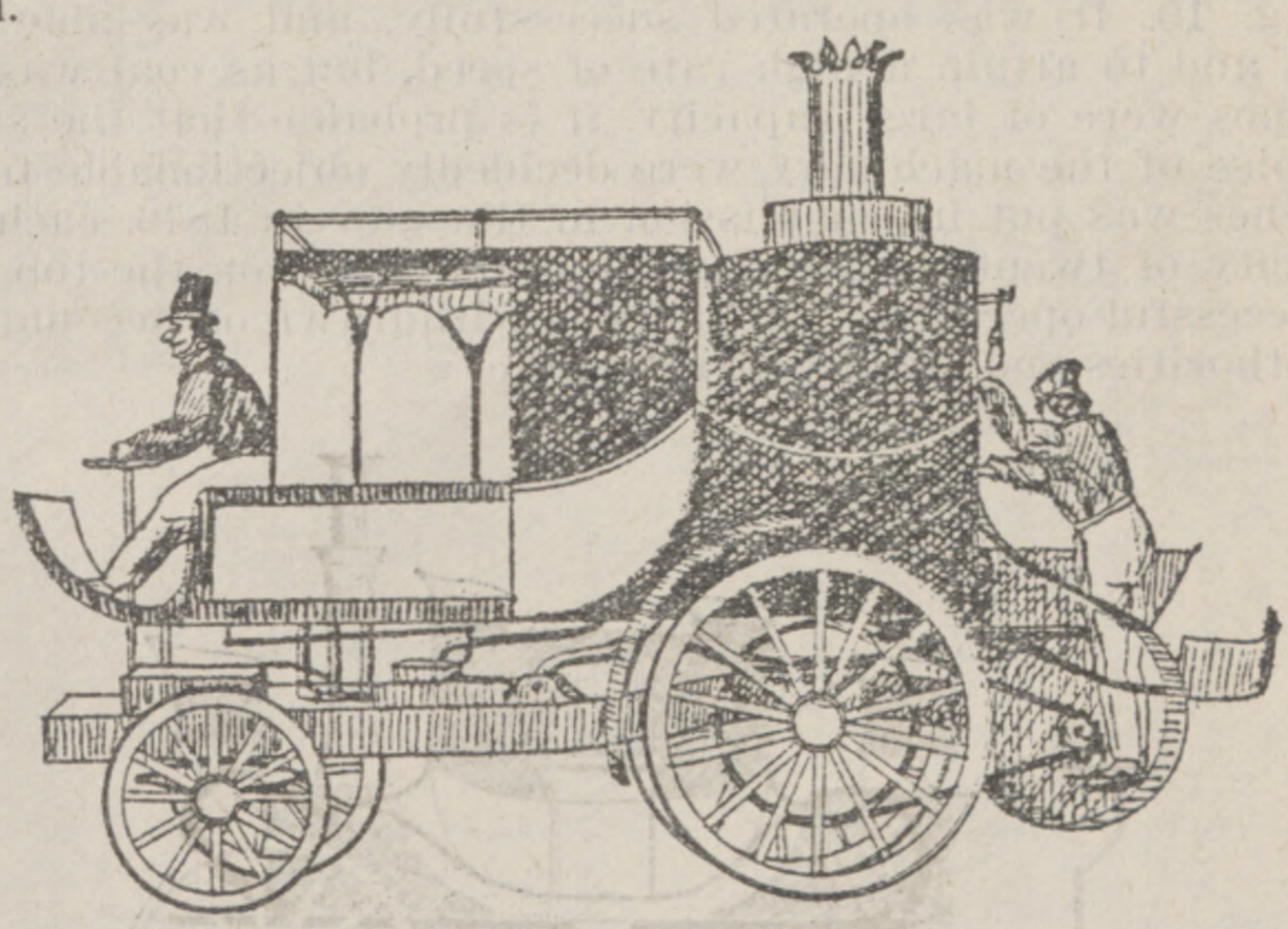

FIGURE 7.—Steam Carriage, made by Squire and Maceroni.

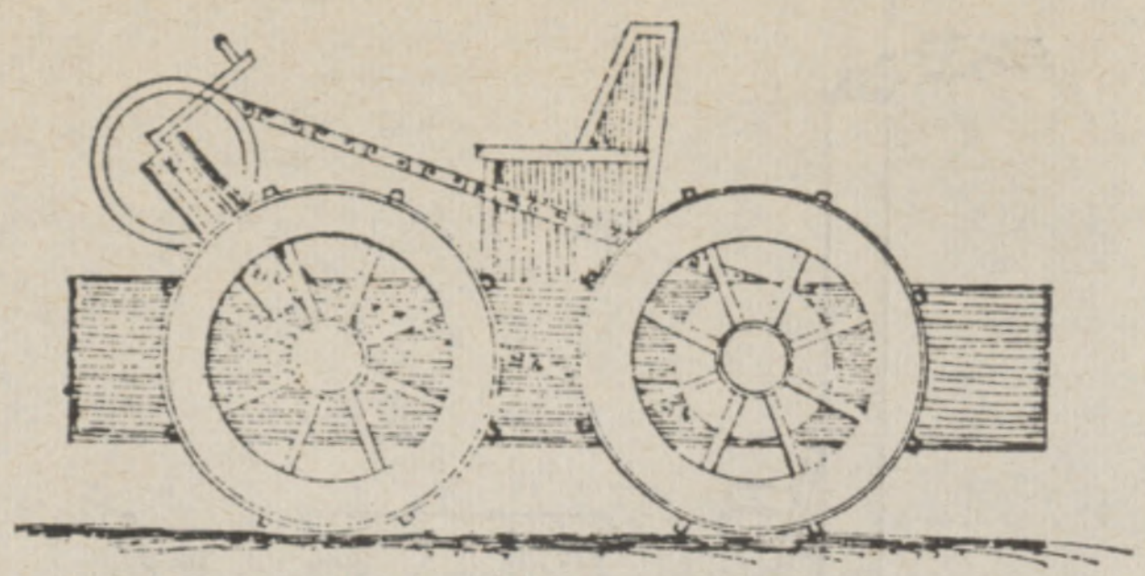

FIGURE 8.—Compressed Air Wagon, made about 1810.

The highly ornamental coach shown in Fig. 9 was invented by Dr. Church about 1832. In addition to being ornamental, it was of massive construction and large capacity, being able to accommodate fifty passengers. Its operation is said to have been very satisfactory, a high rate of speed being attained and all grades on ordinary roads being easily mounted. The inventor swamped himself in endeavoring to compete with railroads.

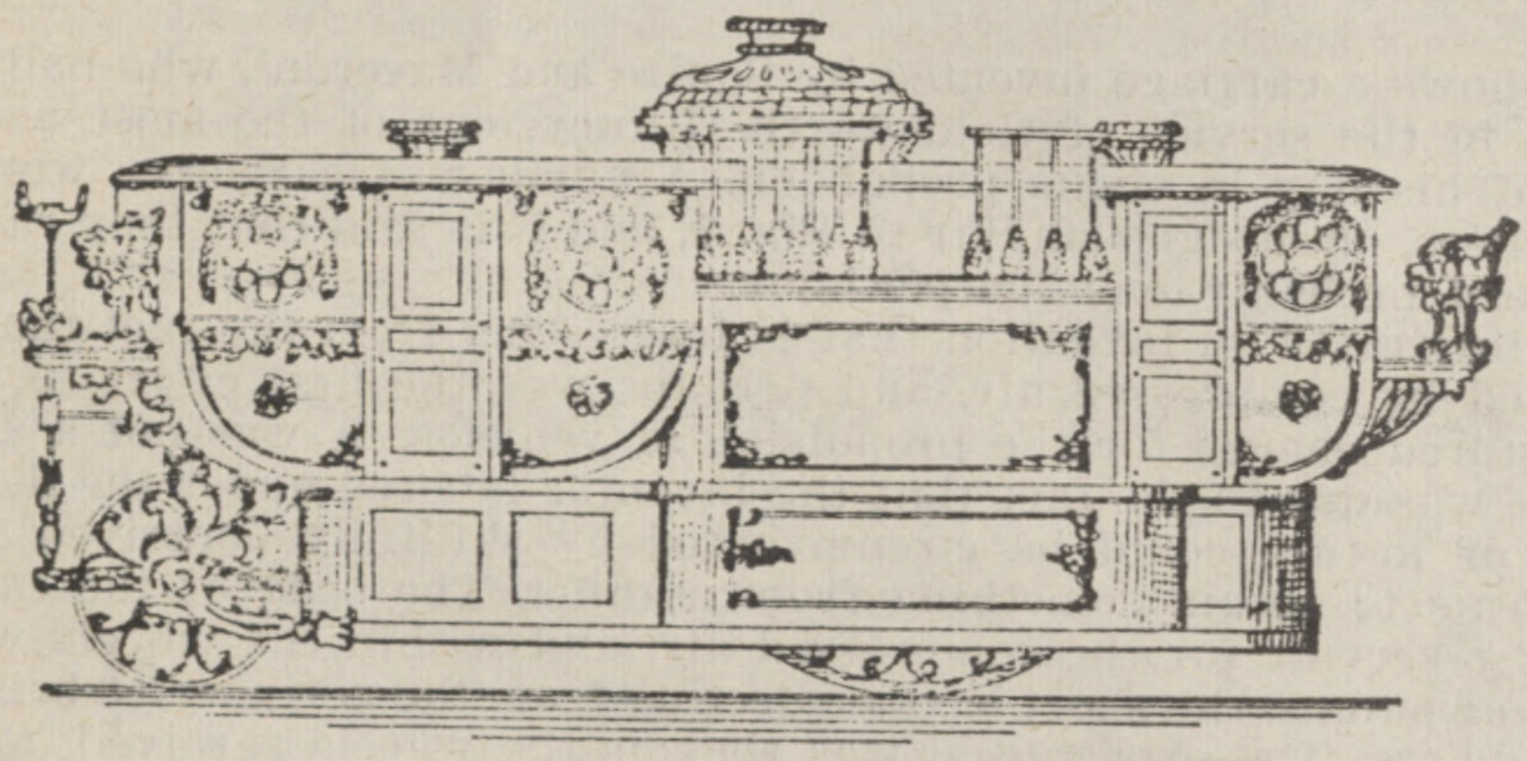

FIGURE 9.—Side View of Dr. Church's Steam Coach, made in 1832.

Perhaps the most perfect of all the early automobiles was the one devised by Scott Russell, the celebrated designer of the Great Eastern. This carriage is shown in Fig. 10. It was operated successfully, and was able to mount the steepest hills and to attain a high rate of speed, but as coal was used for fuel and the engines were of large capacity, it is probable that the smoke, exhaust steam and noise of the machinery were decidedly objectionable features. A line of these coaches was put in commission in Glasgow in 1846, each one having a seating capacity of twenty-six, six inside and twenty on the top. After several months of successful operation, the line was withdrawn on account of the opposition of the authorities and of the general public.

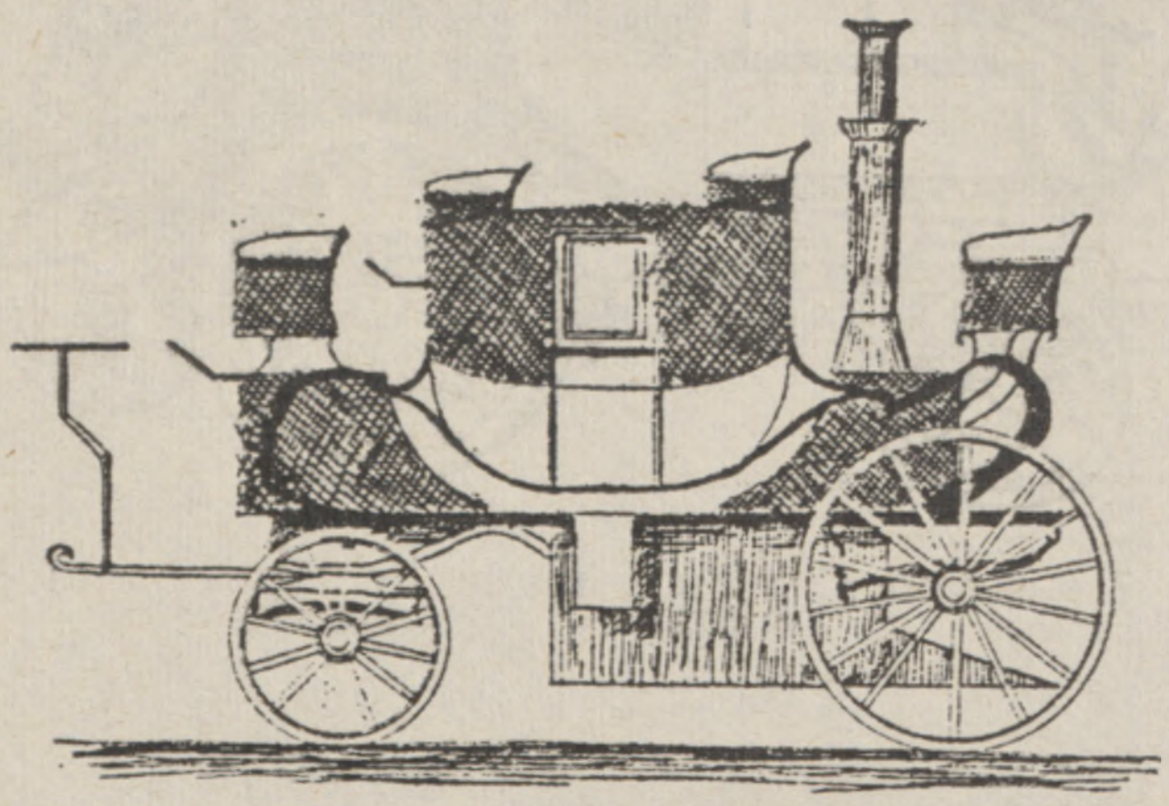

FIGURE 10.—Scott Russell's Steam Carriage, made in 1845.

These few examples of the early attempts to solve the problem of mechanical propulsion of vehicles are sufficient to show that the automobile is not entirely a creation of the progressive mind of the latter part of the nineteenth century, but that it engrossed the attention of inventors more than one hundred and thirty years ago. The success attained by the workers in this field at different periods was directly in proportion to the degree to which the form of power used had been perfected at the time. The first inventors attained but slight success, owing to the fact that, in their time, the steam engine was in a crude form, but as the construction of the latter improved, so did that of the vehicles operated by it.

From 1845 up to the early nineties, a period of nearly half a century, very little was done in the way of developing the automobile. From time to time inventors in various parts of the world devoted themselves to the subject, but they were generally looked upon as visionary cranks, and their work attracted little attention. During this period there was an almost universal prejudice against the use of any kind of mechanical power upon the streets or public highways, and it is even possible that if during these years any one had invented a horseless carriage, perfect in every way, he would have failed to obtain proper recognition. Prejudice against mechanically-propelled vehicles has gradually worn away, probably because of the introduction of cable and trolley cars, and at the present time the majority of people desire to see the substitution of mechanical for animal power. As a result of this change in public opinion, self-propelled vehicles are accepted as entirely satisfactory, which a few years ago would have been regarded as failures. Notwithstanding this tolerant feeling, however, it is very doubtful whether the cumbersome coaches of the early part of the century would be received with favor at the present time when taste and requirements are entirely different. What is now desired is a light, fast-running and attractive vehicle, which could not be constructed along the lines followed by the inventors of former days. The automobile of today is a far more perfect device than its predecessors, although it can not be said to have reached a state of perfection. As motive power, steam, gasoline and electricity are used. Which of the three is the best, taking all things into consideration, it would be difficult to say, as each one has its defects as well as its advantages, and the evident superiority of each one in a certain direction is offset by deficiencies in other directions.

In every civilized country, where the mechanic arts are far enough advanced, automobiles are now being manufactured, but France is the country where modern development first began, and up to the present time it has maintained its leading position, although in quality of product, other nations, if not on a par with it, are certainly not very far behind.

The perfection to which the steam automobile has been developed in these latter days is due mainly to the efforts of L. Serpollet, a distinguished French engineer. Other highly successful steam carriages are now manufactured in England and in this country, as well as in several European nations, but Serpollet was the first to bring forth a successful fast-running and attractive vehicle, and the others have profited by his work.

One of the many designs of Serpollet carriages is shown in Fig. 11; Fig. 12 shows more fully the arrangement and location of the machinery. The engine used in these vehicles is made with four cylinders of the single action type; that is, they take steam at one end only. By using this construction, while the number of cylinders is increased, the other parts are greatly simplified, as the piston rods, crossheads and guides can be dispensed with. In addition, the whole engine can be made very compact.

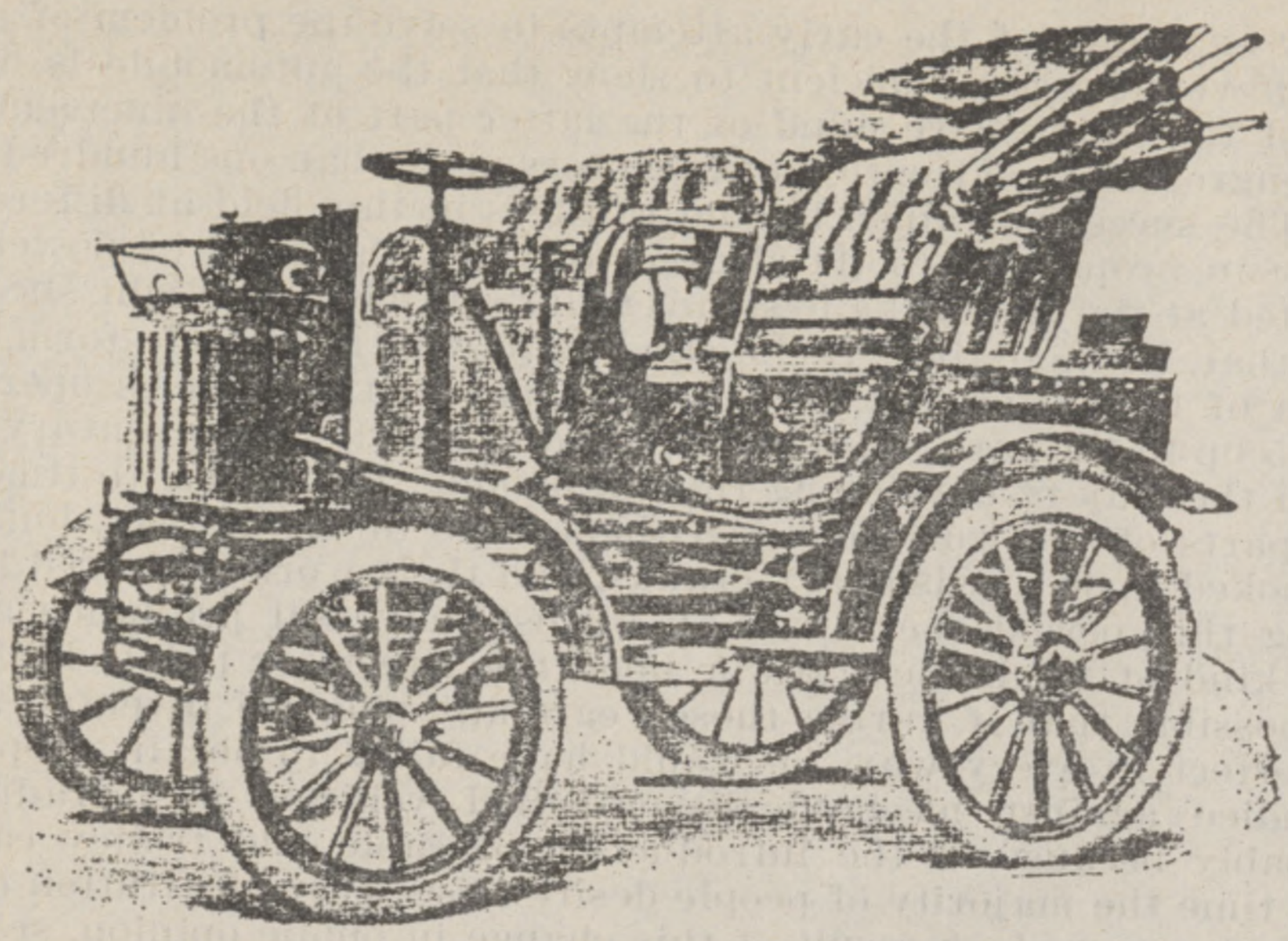

FIGURE 11.—Serpollet Carriage, a modern steam automobile of French design.

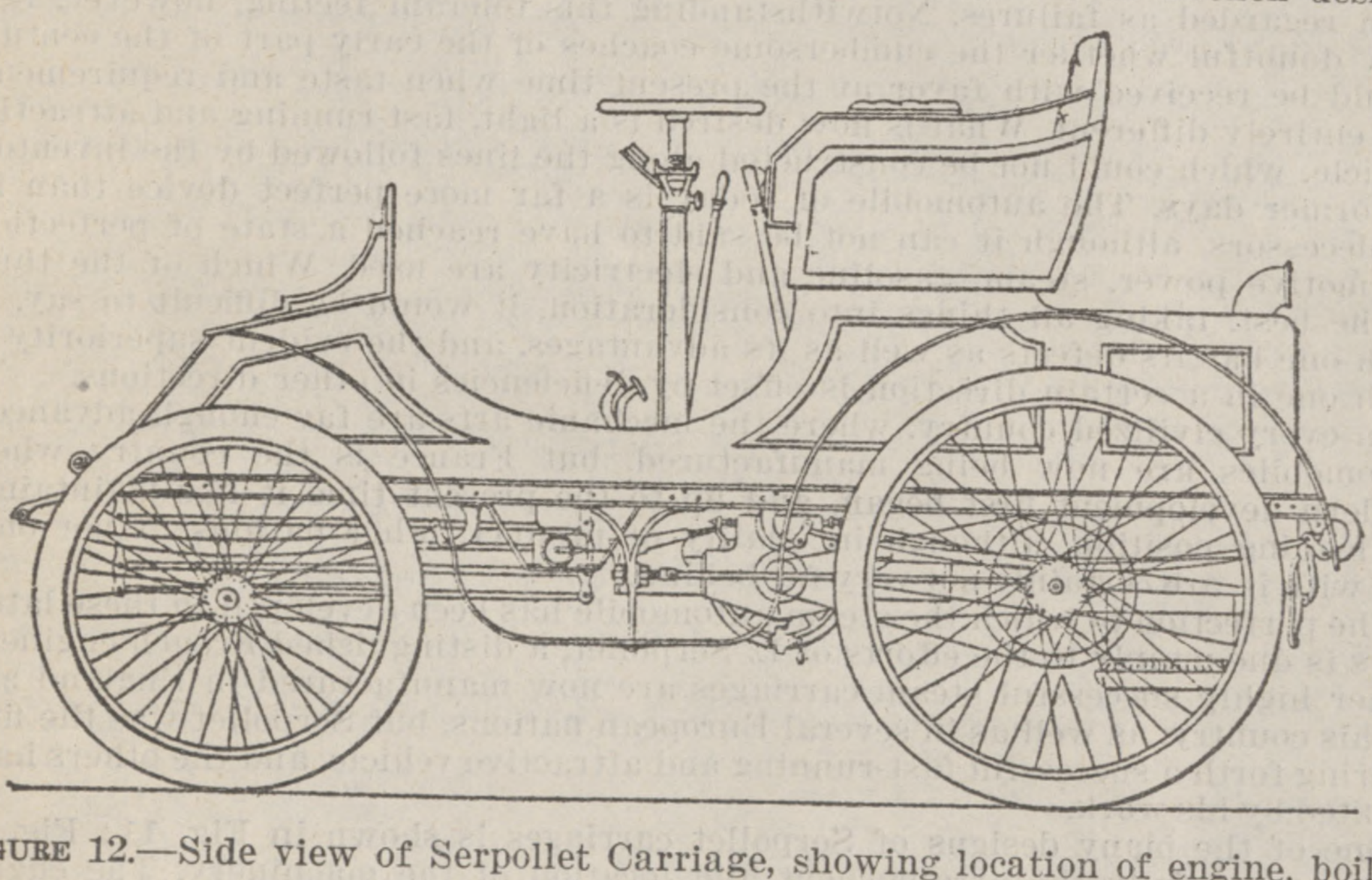

FIGURE 12.—Side view of Serpollet Carriage, showing location of engine, boiler, condenser, et cetera

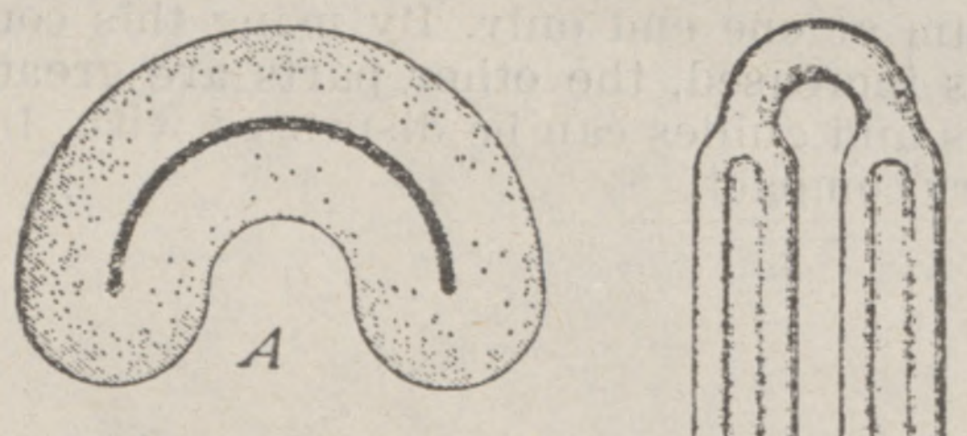

FIGURE 13.—Showing details of the boiler of the Serpollet Carriage.

The boiler is of the flash type; that is, it carries no water ordinarily, but when the engine is in operation, a pump injects into the boiler at each stroke of the engine as much water as may be required to generate the steam necessary to propel the vehicle; the instant the water enters the boiler it is converted into steam. As the amount of steam is proportional to the amount of water, it can be seen that by regulating the water supply, the power of the engine and thereby the speed of the carriage, can be controlled. This is the method actually employed to control the speed. In starting, a handle is moved which connects the engine, the boiler and the pump in the proper relation; and while under way the velocity is varied by the manipulation of a lever which controls the amount of water injected into the boiler. The fuel used is kerosene, which is vaporized and then fed into a properly constructed burner. The amount of oil supplied to the burner is regulated by the same lever that regulates the supply of water, so that both are increased or reduced in the proper proportion. The boiler is constructed of a number of steel tubes, which are about two and a half inches in diameter, and from three eighths to half an inch thick. These tubes are pressed into the form shown in Fig. 13, the dark line in the section marked A representing the interior space. A number of tubes collapsed in this form and bent into the shape B, are assembled as shown at C. The number of tubes depends upon the capacity of the boiler. As the tubes are very thick, they can, without any danger of bursting, be heated to so high a temperature that the water injected into them is at once turned into steam.

In Fig. 12 it will be seen that the engine is located under the body of the carriage between the two axles, and that motion is imparted to the hind wheels by means of chains and sprocket wheels. The boiler is located at the back of the vehicle, the lower part projecting some distance below the rear axle. A small smoke stack at the rear of the body allows the gases of combustion to escape. Between the front wheels, a compact condenser is located, and into this the steam from the engine is exhausted. The condenser serves two purposes; it recovers a portion of the water that would otherwise escape into the air, and thus increases the distance the carriage can run without a new supply, and at the same time it lessens the noise produced by the exhaust, and also the volume of steam escaping into the atmosphere, which in cold or rainy weather becomes plainly visible.

Although we have been rather slow in this country in taking up the the automobile, inventors and manufacturers are now working at a pace that will soon make up for lost time. We already have a number of designs of steam carriages whose operation is highly creditable. Fig. 14 illustrates one of these. The design of the engine, boiler and other mechanism can be well understood from Fig. 15, in which a portion of the body is removed to expose the internal parts.

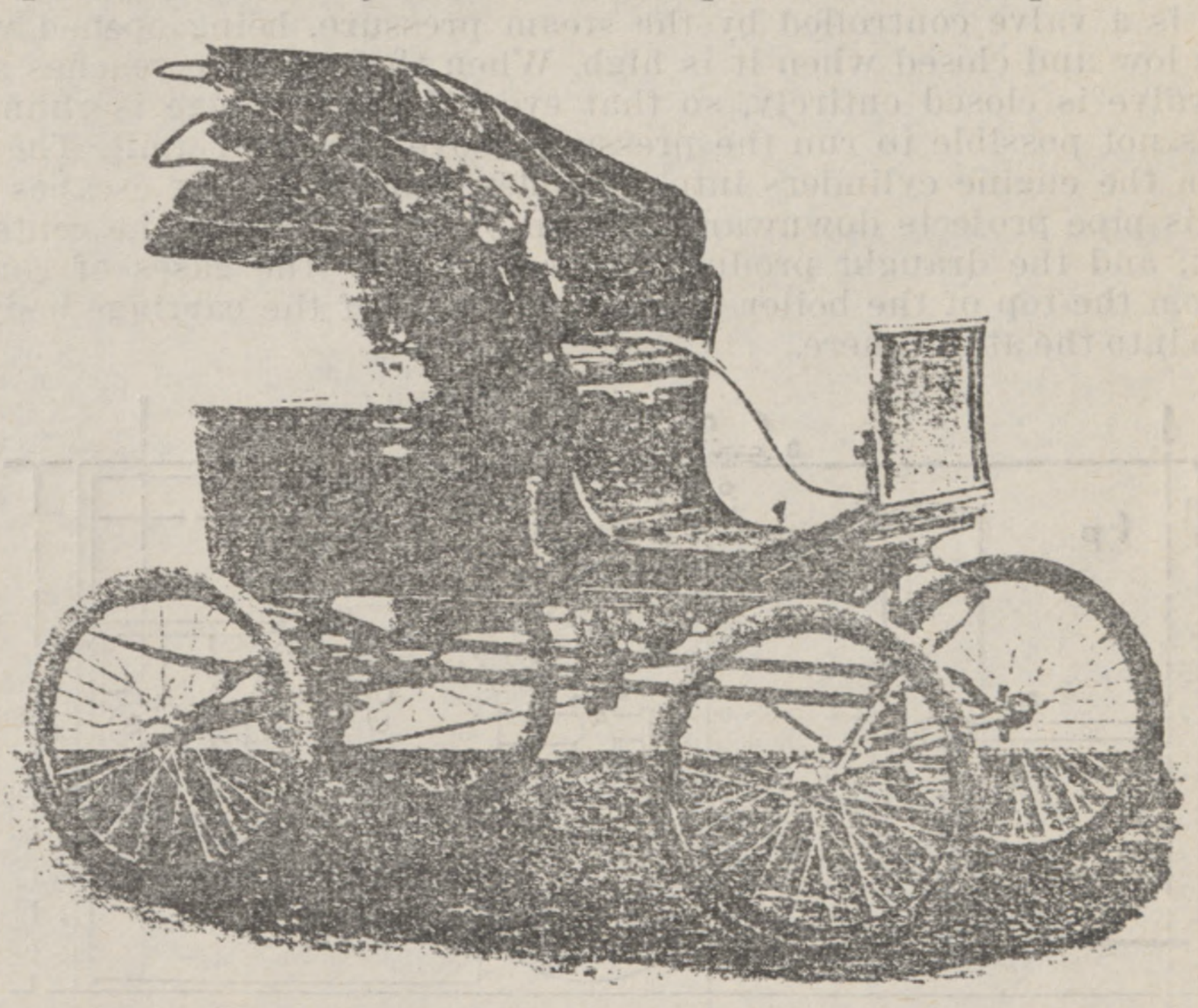

FIGURE 14.—An American Steam Carriage of 1900.

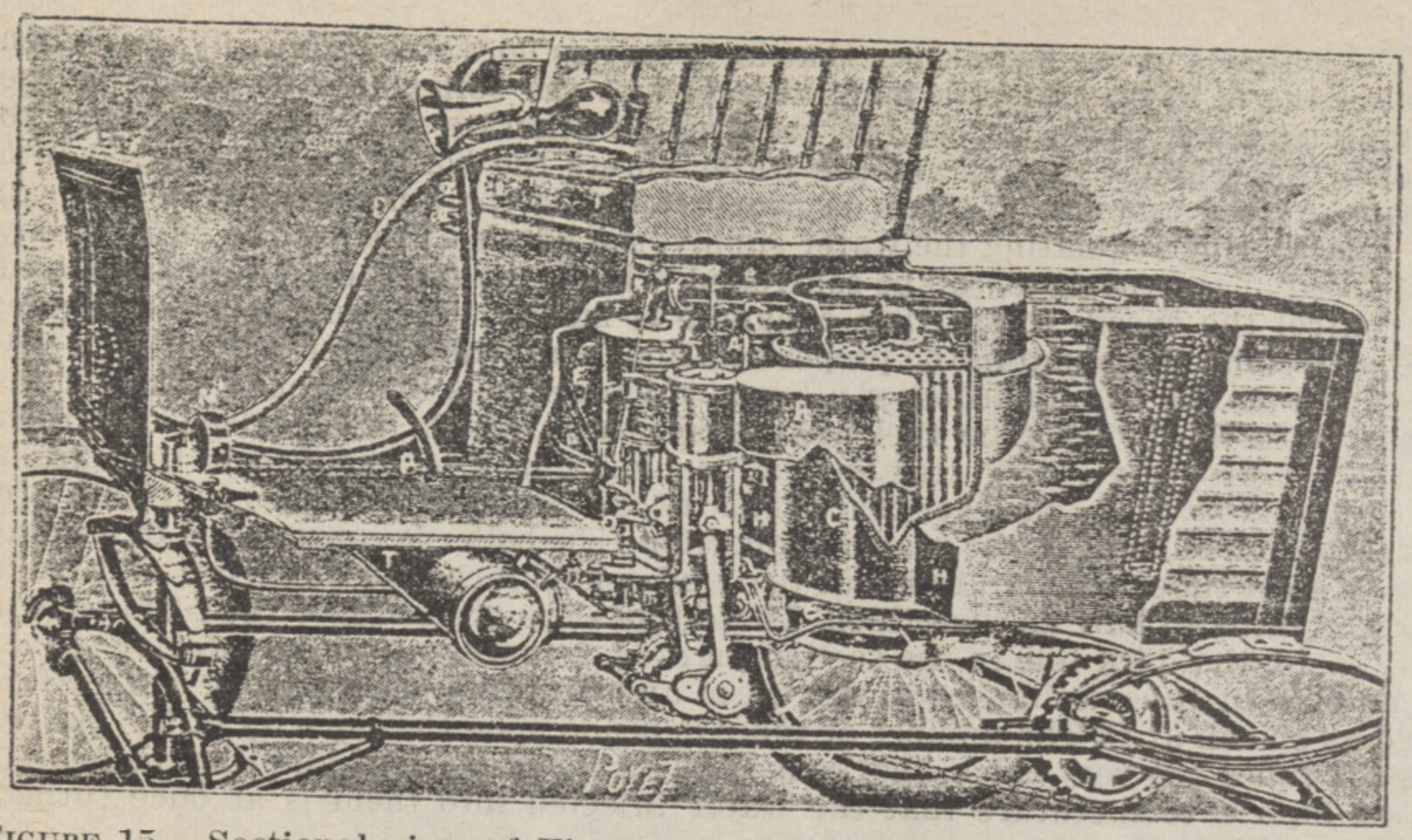

FIGURE 15.—Sectional view of Figure 14, showing location of engine, boiler and other details.

The boiler is a very compact form of the upright type, such as is used in fire engines. It is about fourteen inches in diameter and twenty inches high. To increase its strength, it is surrounded with two layers of piano wire. The engine is of the locomotive type, consisting of two cylinders, the pistons of which are connected with cranks on the end of the shaft, these cranks being set at right angles, so as to prevent catching the engine on the dead center. The direction of rotation is reversed by means of the ordinary link motion. The fuel used is gasoline, which is carried in the cylindrical tank located under the front of the carriage. The gasoline is vaporized and then, mixed with a proper proportion of air, passes to a burner placed under the boiler. The amount of steam generated is regulated by the amount of gasoline supplied to the burner, and this supply in turn is regulated by the pressure of the steam, so that the action is entirely automatic. The cylinder H is a reservoir of compressed air, connected with tank I, so that the gasoline is under pressure, and therefore is forced through the pipe to the burner under the boiler. Between the burner and the tank there is a valve controlled by the steam pressure, being opened when the pressure is low and closed when it is high. When the pressure reaches a certain point the valve is closed entirely, so that even if the carriage is running very slowly, it is not possible to run the pressure above the fixed limit. The exhaust passes from the engine cylinders into a muffler, from which it escapes into the pipe K. This pipe projects downward into an opening through the center of the water tank, and the draught produced thereby draws the gases of combustion through from the top of the boiler to the under side of the carriage body, where they escape into the atmosphere.

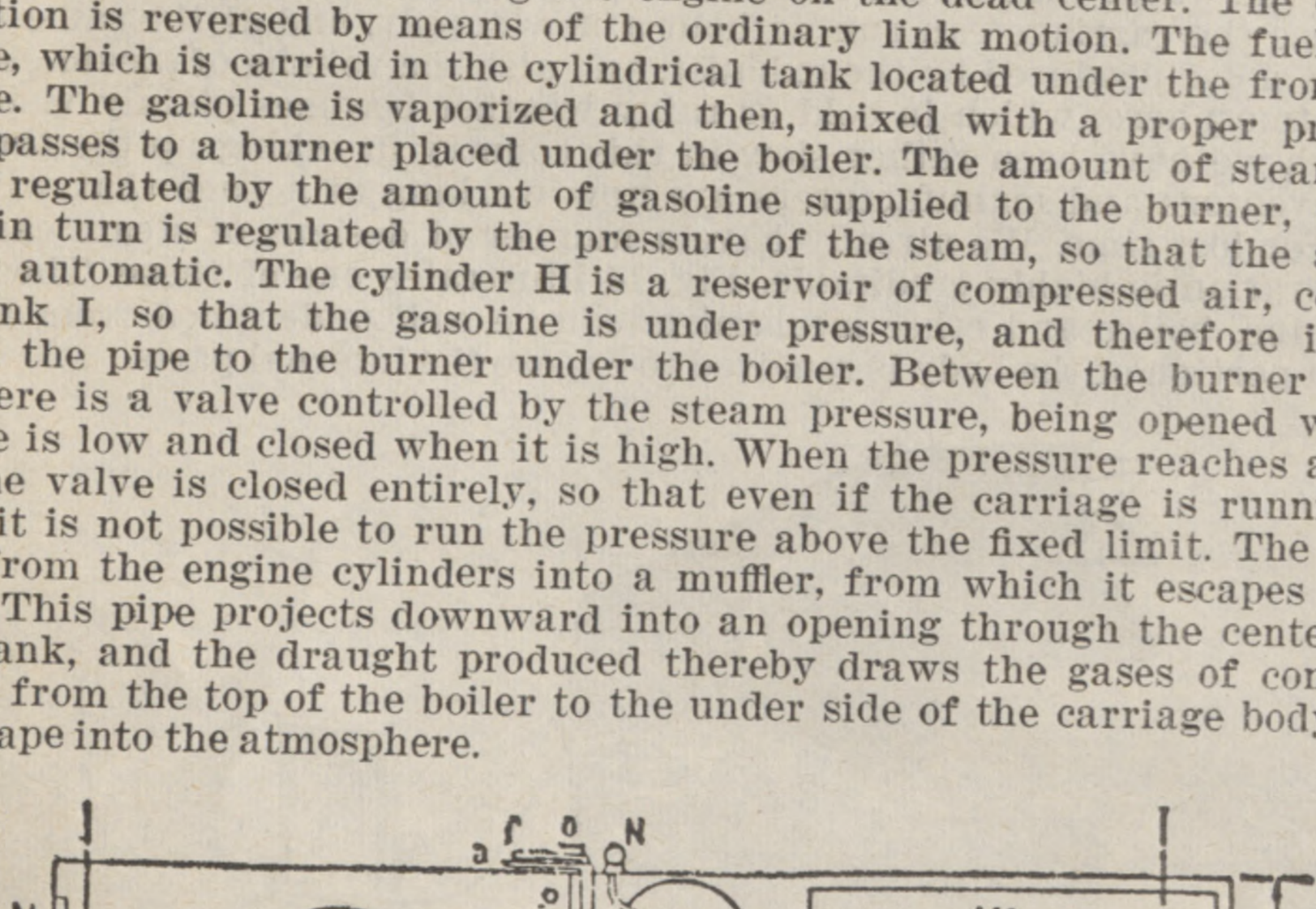

FIGURE 15A.—Plan of Steam Carriage shown in Figures 14 and 15.

Directly in front of the exhaust muffler is seen the water gauge, which is in such a position as to be outside of the carriage body, as shown in Fig. 14. A mirror is placed at the front of the vehicle, and by looking into this the water gauge can be seen. Fig. 14 also shows clearly the position of the operating levers at the side of the carriage.

The actual construction of the engine is better shown in Fig. 16, in which A A are the cylinders, B is the steam chest and G G are the valve rods. The piston rods connect with the crossheads C. The connecting rods D transmit motion from the latter to the cranks E, and thus rotate the shaft S. The link motions, by means of which the direction of rotation is reversed, are at I I, and are operated by the lever G, which is mounted upon the shaft F F. This shaft is directly connected with the starting lever. The boiler feed pump is located at M. The motion of the engine is transmitted to the rear axle of the carriage by means of a chain that runs over the sprocket wheel L located between the eccentrics K K. In Fig. 15, this wheel is located at D, and the chain F connects it with the axle sprocket E.

Fig. 17 shows another American steam carriage. In this vehicle the running gear is a complete truck, upon which the carriage body is supported. The appearance of the truck with the body removed is shown in Fig. 18. The boiler is of the tubular type and the double cylinder engine is secured to its side. In this particular the construction differs from that of the previously described carriage, for in that the engine is attached to the cross-framing of the body of the vehicle. Although the general appearance of the mechanism of these two carriages is very similar, there are many differences in the details of their construction. In both, vertical tubular boilers are used, and the steam is generated by the use of gasoline, which is burned in the vaporized state in specially constructed burners. The engine in both cases is of the vertical double cylinder type, and motion is transmitted to the hind axle by means of sprocket wheels and a chain; but here the similarity ends; the minor details, which it is not necessary to refer to in this connection, are with few exceptions very different.

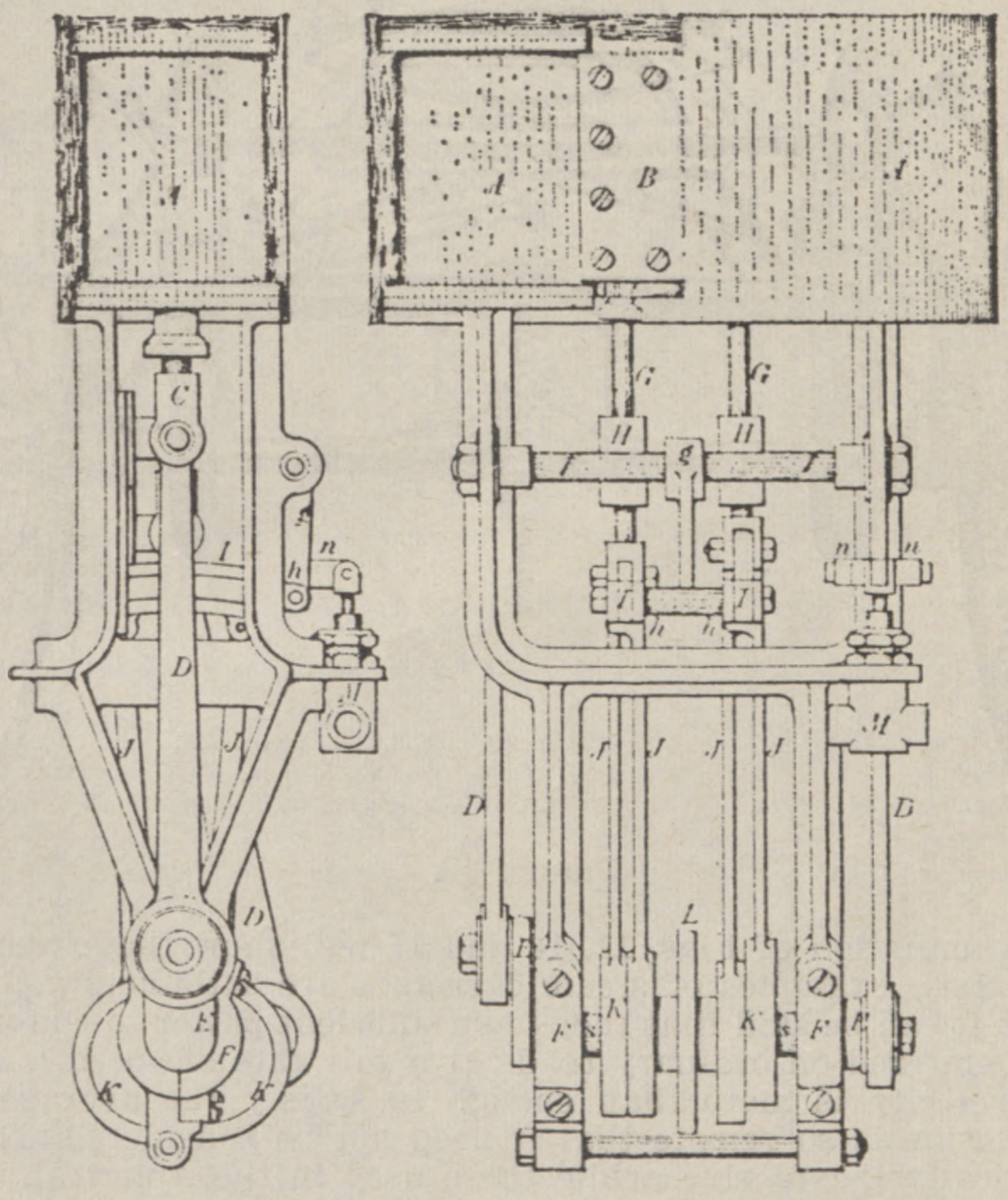

FIGURE 16.—Engine of Carriage Shown in Figure 14.

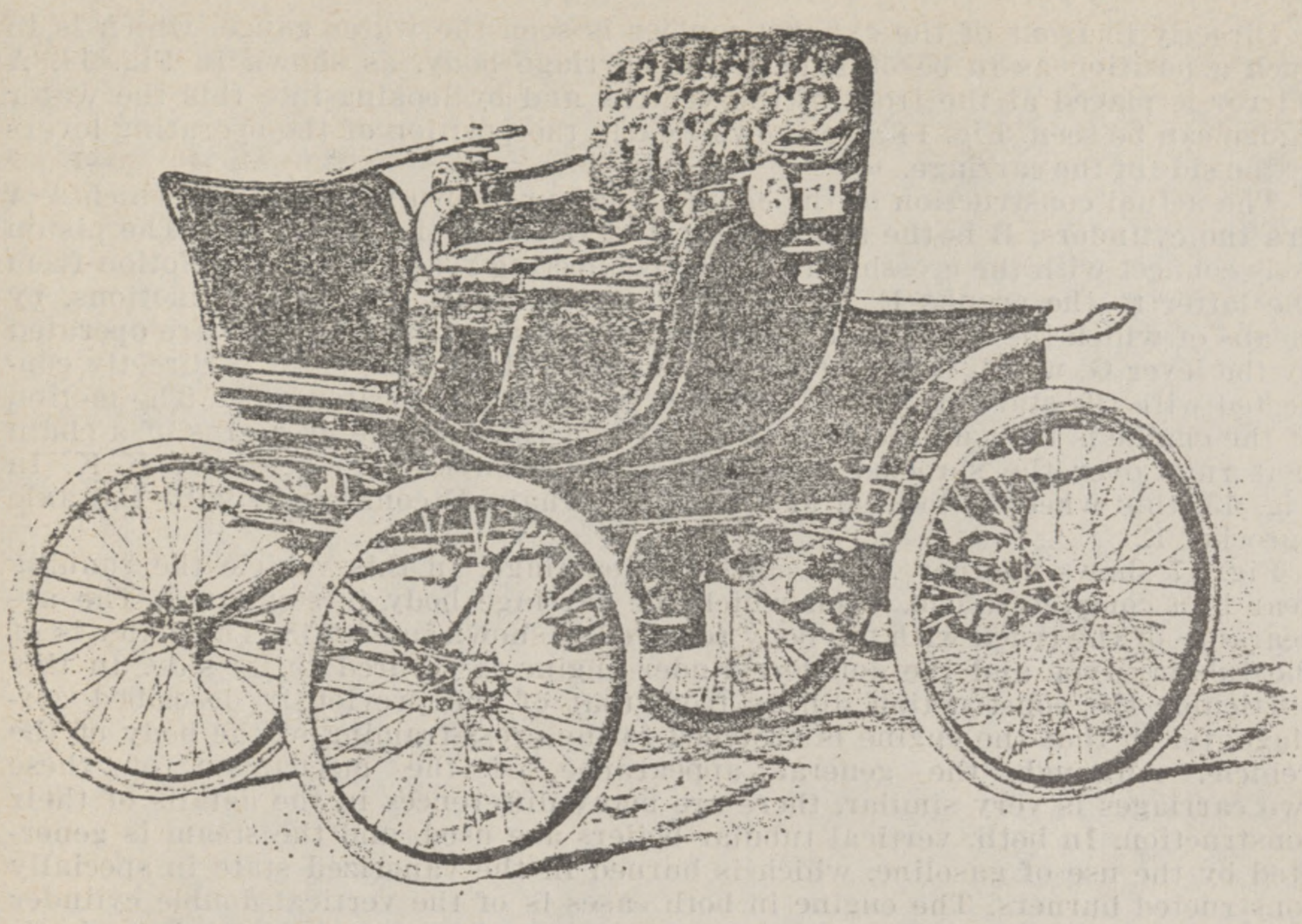

FIGURE 17.—American Steam Automobile of 1900.

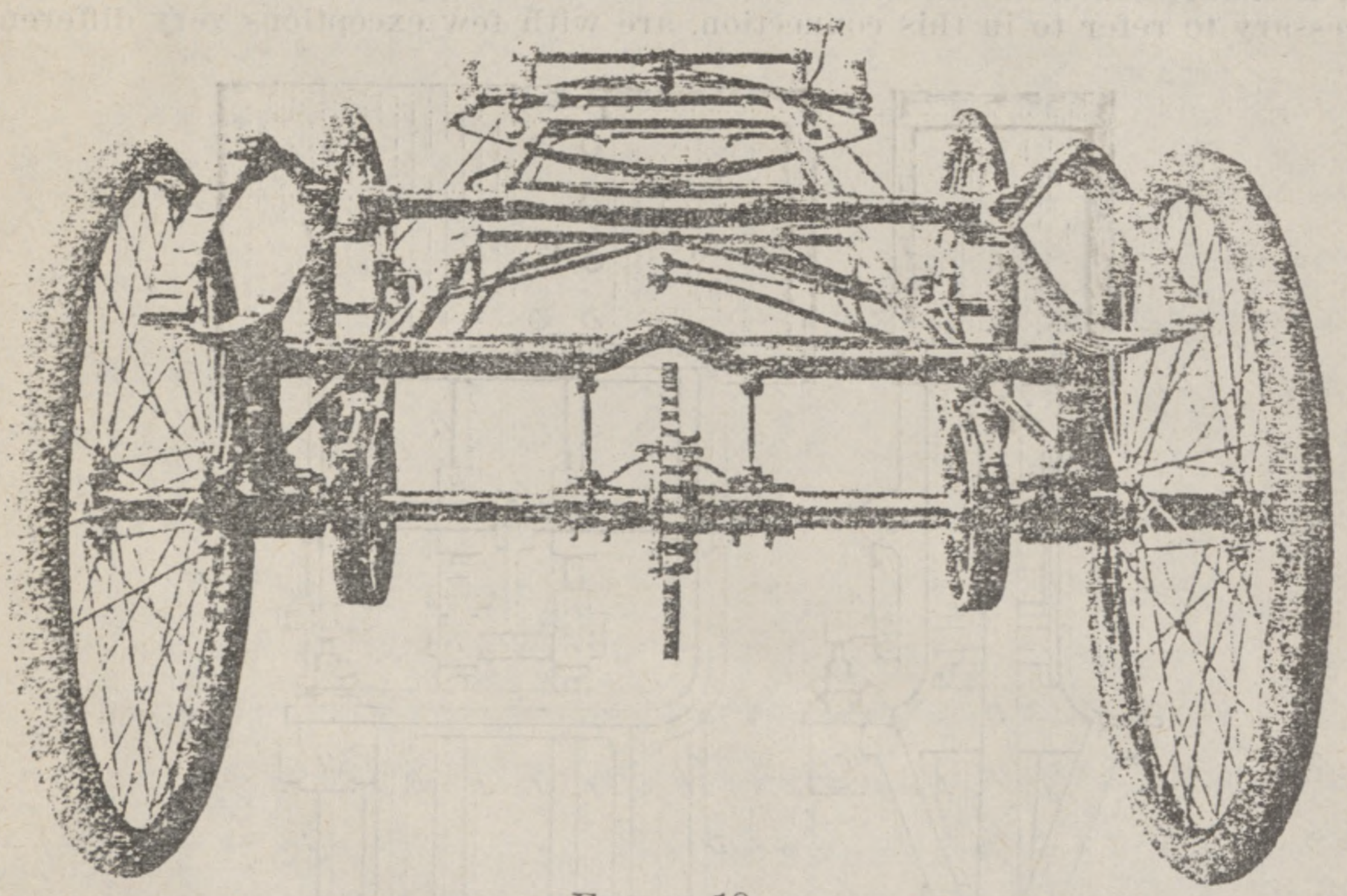

FIGURE 18.

A careful examination of Figs. 11, 14 and 17 will show that from an artistic point of view these examples of steam carriages are satisfactory. In regard to their operation it can be said that they have sufficient power to run up the steepest grades encountered on ordinary roads at a fair rate of speed, while on level ground their velocity is more than enough to satisfy the average rider. The danger of explosion is so remote that it need not be considered. The Serpollet boiler is practically inexplosive, while those used in the American vehicles are so constructed that they can withstand a pressure far greater than any they can be subjected to in practice. It might be expected that the motion of the machinery would produce an unpleasant vibration, but on account of the lightness of the

moving parts and careful balancing, this effect is much reduced. The use of gasoline as fuel, in connection with automatic burners, eliminates the smoke and ashes incident to the use of coal, and in addition reduces the labor of handling the vehicle, as no attention need be given to the mechanism other than to see that the water in the boiler is maintained at the proper level. In the case of the Serpollet carriages, not even this point need be looked after, as the feed of the boiler is perfectly automatic.

Electric Automobiles

As electricity has been so successful in the street railway, where it has superseded all other forms of motive power, it might naturally be supposed that it would do equally well in the automobile; but when the difference in the conditions is taken into consideration it will be found that such a conclusion is not justified. In the street railway systems the cars run continuously over the same route, and on that account the electric current required to operate the motors can be conveyed to them from a central power station by means of wires. With the automobile the case is very different; the vehicle has no fixed course, but is required to go everywhere, and the current must be supplied from a source carried by it. If primary batteries could be made so as to furnish electric currents at a low cost, then the electric carriage would be in the same position as those operated by steam or gasoline, and it could go wherever the proper chemicals to renew the battery could be obtained. But as there are no such primary batteries, the only way in which the current can be supplied is by the use of storage batteries, and these cannot give out any more energy than is put into them, and in practice cannot give quite as much. Thus if the capacity of the battery is sufficient to run the vehicle forty miles when this distance has been traversed the propelling power will be exhausted, and the batteries will have to be recharged before the carriage can go any further. If the recharging could be done in a few minutes, the storage battery would be as good as a primary battery that would generate electricity economically; but as it requires three or more hours, the electrical vehicle cannot be used for long runs, unless the user is willing to make long stops each time the battery has to be recharged. Even then an electric vehicle could not go everywhere, for it would be compelled to follow routes along which facilities for recharging the batteries could be found. From this fact it can be seen that the electric automobile carriage cannot cover the same field as the steam or the gasoline (in the present state of electrical development). Within the limits to which it is applicable, however, it can perform its work in the most satisfactory manner, and, in fact, no possible objection can be raised against it. Its operation is noiseless and vibration of the vehicle is impossible. There is no heat to inconvenience the passengers, no disagreeable smell, no escaping steam. Any desired speed can be obtained, although, of course, a heavy delivery wagon cannot be used also as a racer. The power can be made sufficient to propel any desired load up any grade, including grades far steeper than any to be encountered on streets or highways.

The only point in which the electric vehicle suffers in comparison with the others is in the weight. The capacity of a storage battery is proportional to its weight, and if it is made light, the power derived from it will be small or the time during which it is furnished will be short. To furnish one horse power for one hour requires about one hundred pounds of battery, so that if the average consumption of energy is at the rate of two horse power, one thousand pounds of battery will keep the vehicle in motion for five hours. The weight of batteries used in automobiles ranges from four or five hundred to about two thousand pounds, and the distance traversed without recharging varies from twenty-five to ninety miles, so that the radius of action of electric vehicles can be said to vary from about twelve to forty-five miles from the charging station.

The general arrangement of an electric carriage can be understood from Fig. 1. The rectangle shown in broken lines at *A* represents the storage battery. The circle *B* under the seat represents the controlling switch. The motor is at *C* and imparts motion to the axle or wheels through the gearing contained in the casing *D*. When the carriage is stopped the controller *B* is turned into such a position that all electrical connections between the battery and the motor *C* are broken. To start the vehicle the controller *B* is turned so as to make the necessary electrical connection between the battery *A* and the motor *C*, and then the electric current

passes from the battery through the controlling switch to the motor, and thence back to the controller and the battery. The heavy broken lines indicate the path of the current and the arrows show the direction. The velocity of the motor and the speed of the carriage are varied by varying the strength of the current, and this is effected by the movement of the controlling switch *B*. There are many ways in which the movement of this switch can vary the strength of the current, but an explanation of any one of them would be dry and rather technical; hence it is sufficient to say that whatever the arrangement of the connections of the controller with the other parts of the system, their relation is such that by the movement of the switch handle the speed of the motor is changed from zero to the maximum velocity.

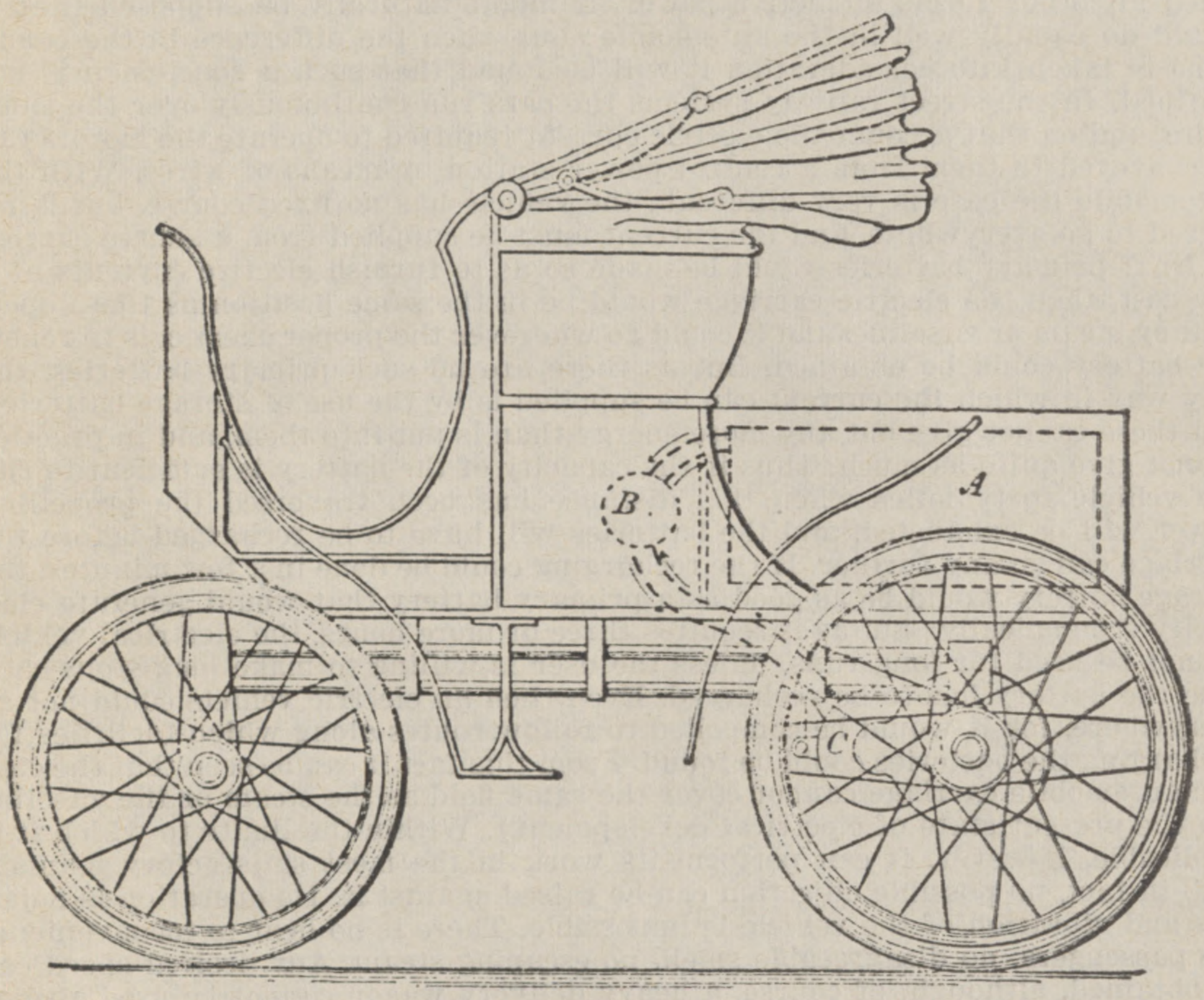

FIGURE 1.—General arrangement of an Electric Carriage.

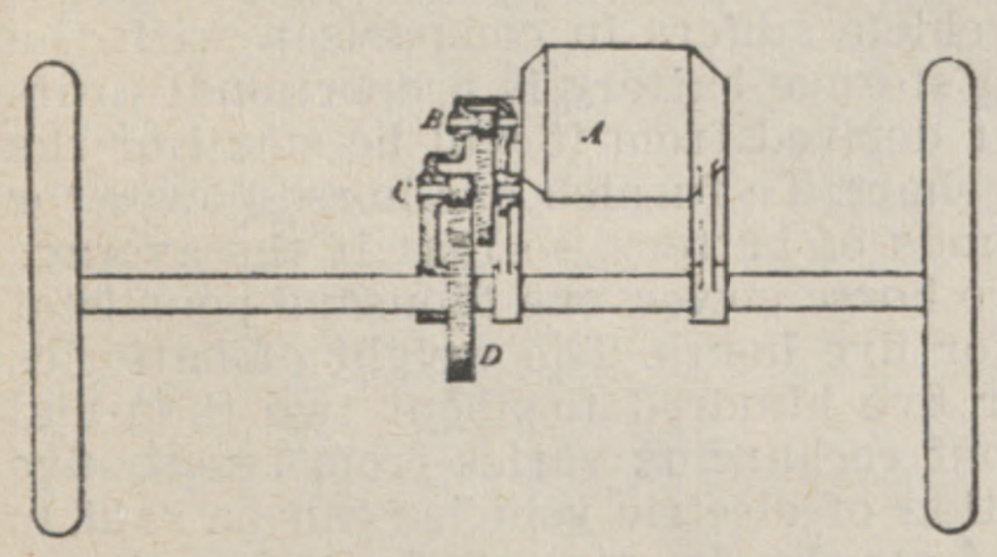

FIGURE 2.—Double reduction.

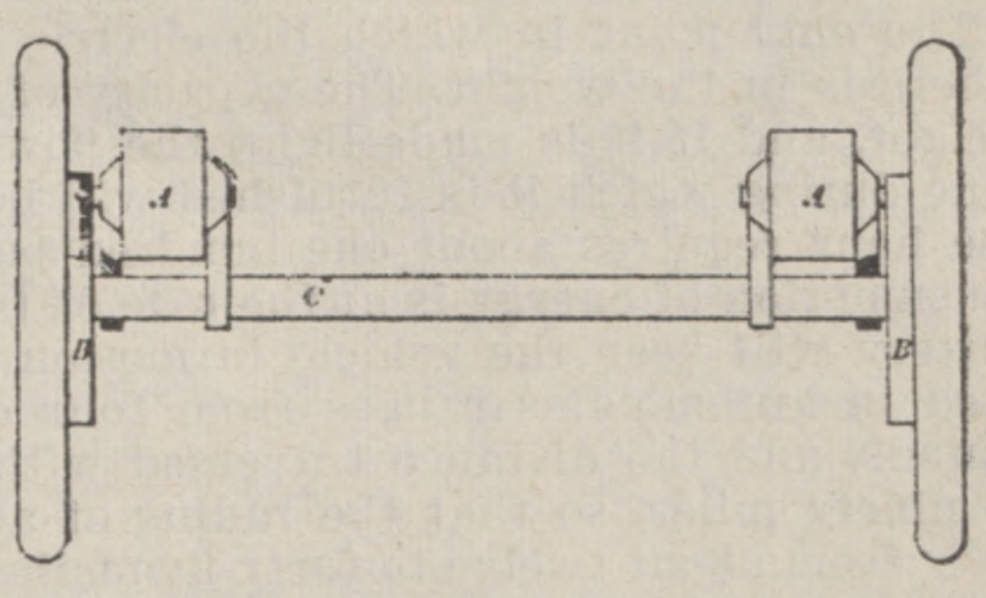

FIGURE 3.—Single reduction.

In the majority of American vehicles the motion of the motor is transmitted to the wheels by means of spur gearing. In some cases a single motor is used, in others two; and in one or two designs that have come to public notice, four motors are employed, one for each wheel of the carriage. Fig. 2 illustrates what

is commonly called a double reduction gear for single motor equipment. The outline *A* represents the motor, *B* being the shaft. Upon this shaft is mounted a small pinion which meshes into a larger wheel on the intermediate shaft *C*. This shaft carries a pinion which meshes into the wheel *D* mounted upon the axle of the vehicle.

Fig. 3 illustrates a single reduction double motor equipment, the motors being located at *AA*. In this arrangement the pinion on the end of the motor shaft meshes directly into a large gear secured to the carriage wheel, thus dispensing with the intermediate shaft *C* of the previous figure. The single reduction gear is the more simple in construction, but the motors run at a lower velocity, and on that account must be larger for the same capacity. With the double motor construction each wheel is driven independently and the axle *C*, in Fig. 3, remains stationary, as in any ordinary vehicle; but in a single motor equipment, arranged as in Fig. 2, the wheels are fastened to the axle and the latter rotates. When a carriage runs round a short curve the outer wheels will revolve faster than the inner ones, if free to move independently, as in Fig. 3. If they are rigidly attached to the axle, as in Fig. 2, one or the other will have to slide over the ground, and this is decidedly objectionable with rubber tires. To prevent this slipping of the wheels in rounding curves, the axles, in designs following the construction of Fig. 2, are made in two parts, and the gear *D* is arranged so as to drive the two halves, imparting to each one the proper velocity. Gear wheels of this kind are called compensating gears; they are made in many designs, but the most common form is that illustrated in Fig. 4. In this drawing *A* is the gear *D* of Fig. 2, and *BB* are bevel gears which are mounted upon studs *C*, which are virtually the spokes of wheel *AA*. Large bevel gears *E* and *F* are placed on either side of *A E*, being secured to *G*, which is one-half of the axle, and *F* and *H*, which is the other half. If the carriage is running in a straight line, the two parts of the axle *G* and *H* will revolve at the same velocity and the gears *BB* will not revolve around the studs *C*, but in rounding a curve one of the halves of the axle will revolve faster than the other and then the gears *B* will rotate round the studs *C*. The compensating gear is not a feature peculiar to electric vehicles; it is used on all kinds of automobiles when the construction is such as to require it.

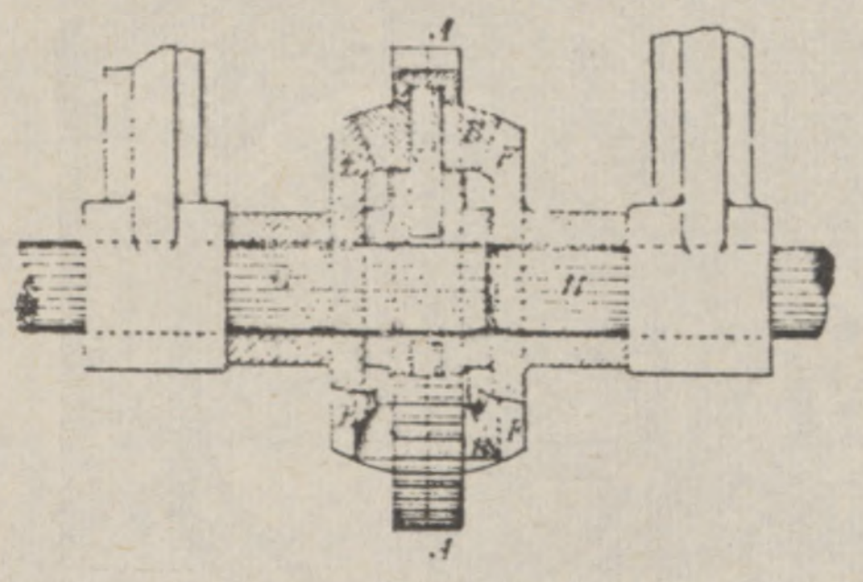

FIGURE 4.—Compensating gears.

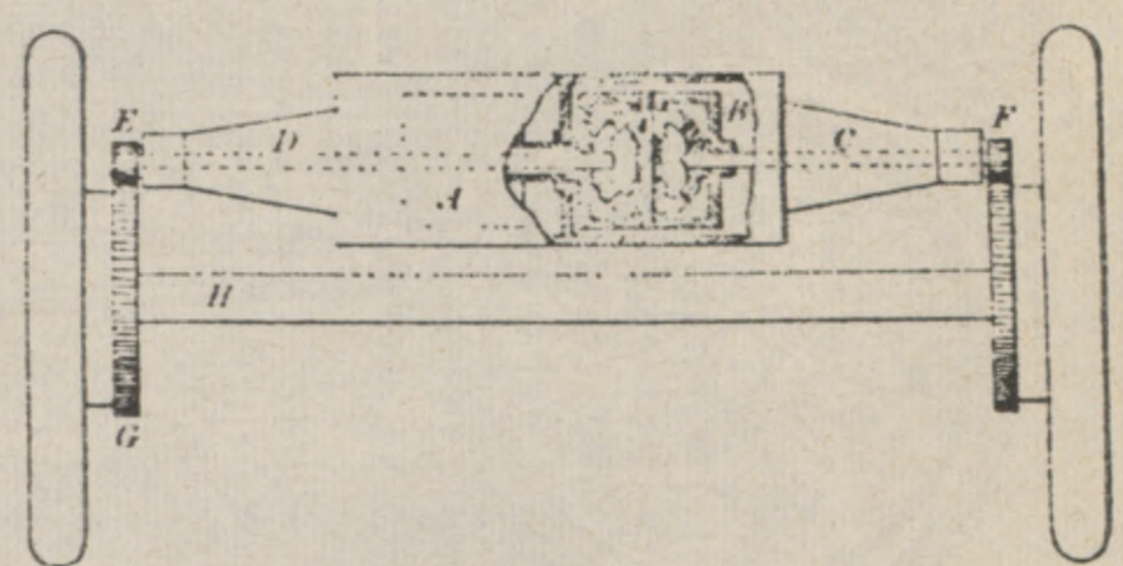

FIGURE 5.—Single motor equipments.

If a compensating gear is placed upon the axle the latter, instead of supporting its end of the vehicle, will itself have to be supported, for as it is cut in two at the center, it has no supporting strength. By placing the compensating gear on another shaft this difficulty can be overcome. Fig. 5 shows the construction used by the Columbia Company in its single motor equipment. In this arrangement the motor casing is made of sufficient length to reach from one side of the vehicle to the other. The armature and field magnets of the motor, which are the parts that develop the power, are located at *A* and the compensating gear is placed at *B*. The motor armature is mounted upon a hollow shaft, which is connected with the compensating gear. The shafts *D* and *C*, upon which are mounted the pinions *E* and *F*, are turned by the side wheels of the compensating gear, and therefore will run at such velocities as the motion of the carriage wheels may require.

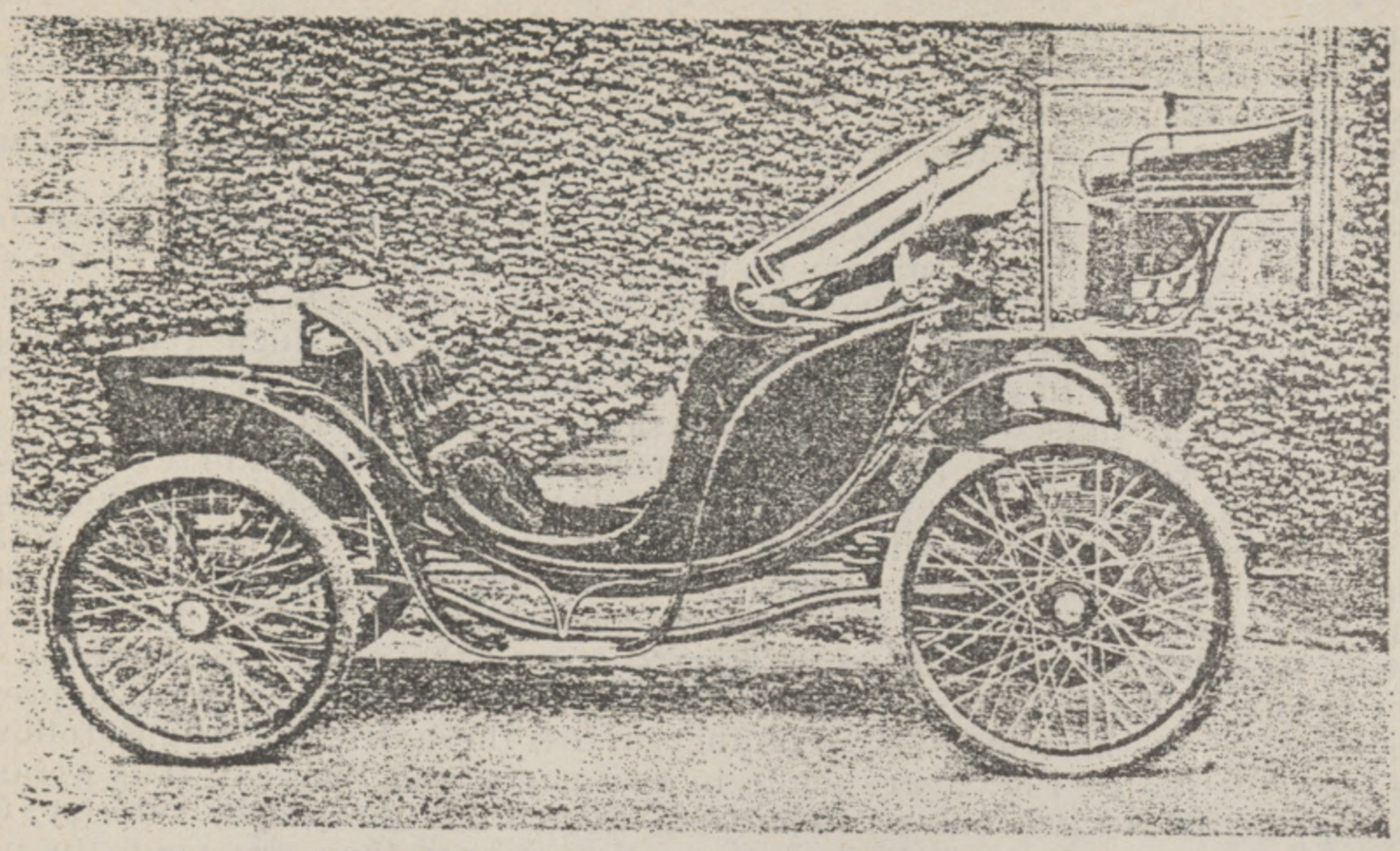

FIGURE 6.—A Columbia Victoria.

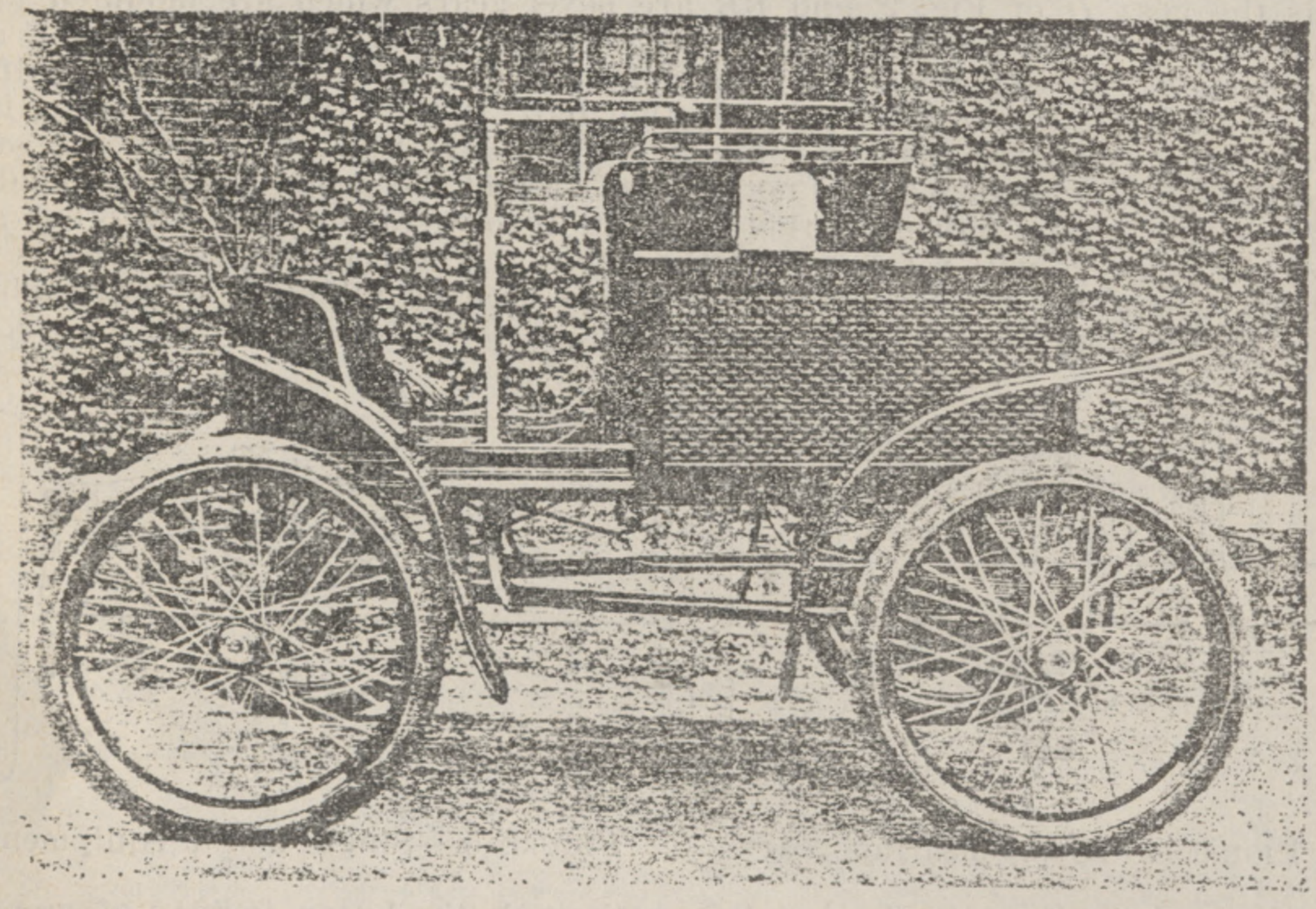

FIGURE 7.—Columbia vehicle with double motor equipment.

FIG. 6 shows a Columbia Victoria provided with a single motor equipment arranged in accordance with the diagram, Fig. 5. Fig. 7 shows another Columbia vehicle in which a double motor equipment is employed. The position of the motor, with reference to the carriage wheel, in the single motor design, is shown in Fig. 8. The gear attached to the carriage wheel is used also as a brake wheel, a friction band being located so as to bear against the periphery, while the pinion on the end of the motor shaft meshes into teeth on the inner side of the rim. This single motor design is also used in the omnibus made by the Columbia Company, a number of which are now in regular service on Fifth Avenue, New York. These omnibuses, which are illustrated in Fig. 9, seat eight passengers, and are able to carry as many as are willing to crowd into them. One feature of the electric motor which fits it admirably for automobile service is the fact that for a short time it can put forth an effort far greater than its normal capacity, and it can do this at all times without any special preparation. Owing to this feature it is practically impossible to stall the vehicle. If the wheels run into a rut or sink into a mud hole, the motor will be able to turn them around, and if they do not slip the carriage will be moved ahead.

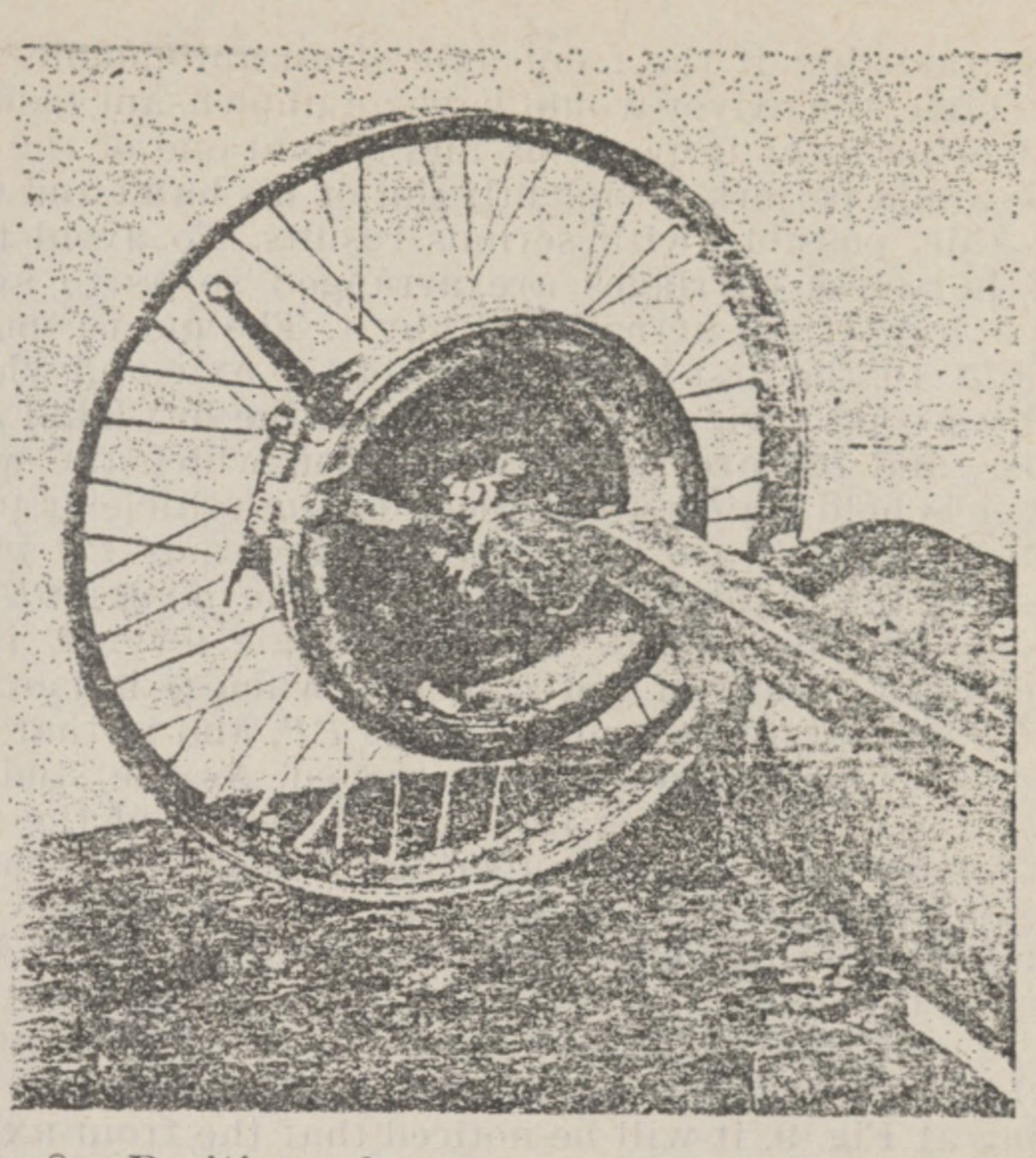

FIGURE 8.—Position of motor in the single motor design.

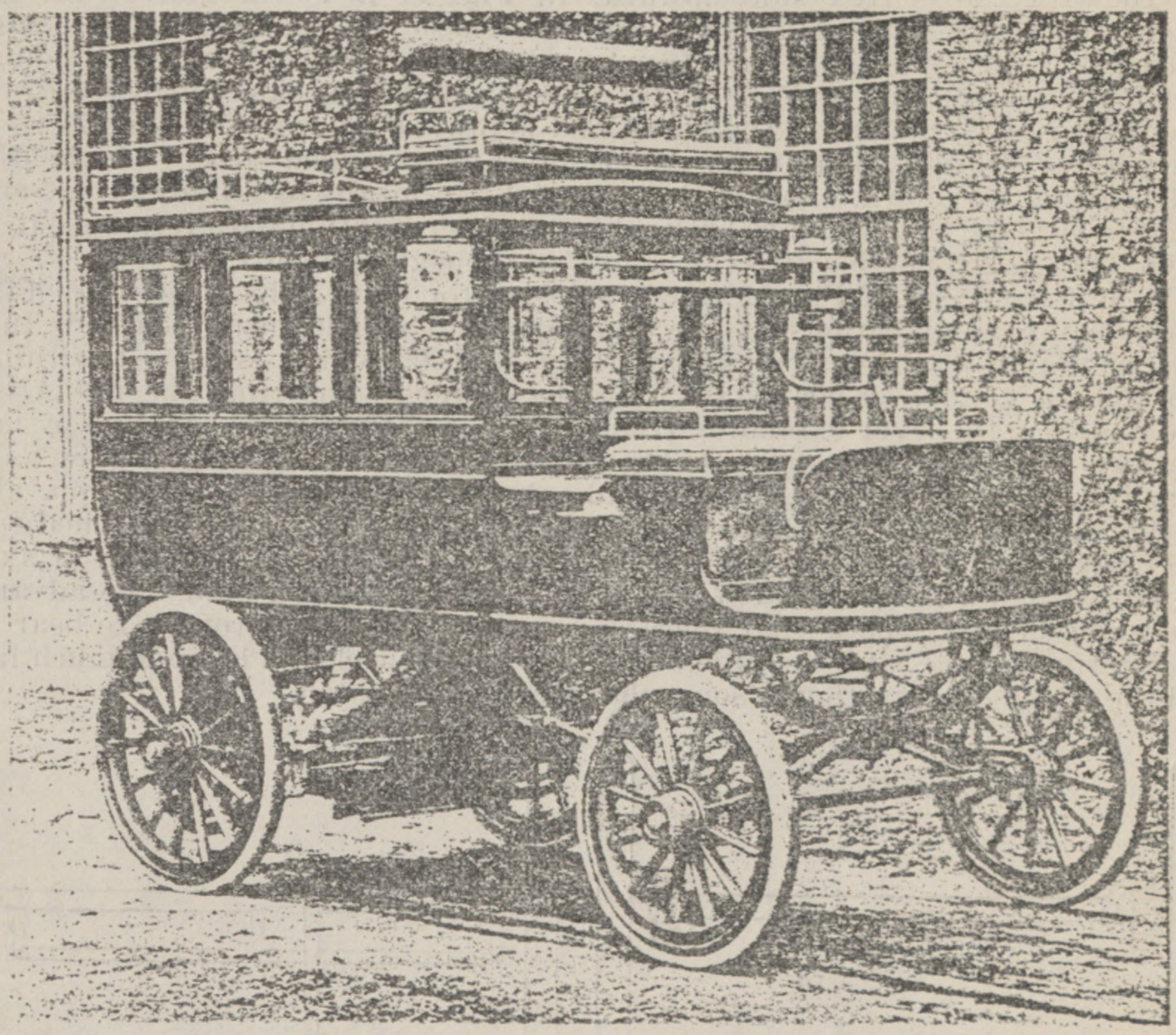

FIGURE 9.—A Columbia Omnibus.

The management of the vehicle is exceedingly simple and entirely free from care, the driver having nothing to tax his mind but the steering lever and the handle of the controlling switch. As the moving parts all have a rotatory motion and are perfectly balanced, there is no possibility of vibration, and there is an entire absence of heat or disagreeable odors.

Any one who has observed the action of a two-horse team will have noticed that, unless the pavement is very smooth, the tongue continually swings from side to side, and occasionally with a considerable amount of violence. It will be

evident from this fact that if the front axle of an automobile were the same as that of a horse vehicle, the driver would have an unpleasant task, to say the least, in holding the steering lever in position, and should one of the wheels drop into a rut, the handle would be jerked violently out of his hand and the vehicle would sheer off to one side, possibly with serious results. To avoid this difficulty the front wheels of horseless carriages are arranged so as to swing round on a center close to the hub, if not actually within it. The most common construction is illustrated in Fig. 10, the first being a view of the axle and wheels as seen from the front, and the second a view from above. On the left-hand side of Fig. 10, *A* is the axle proper, and *BB* are the portions upon which the wheels are placed. The central part *A* is held rigidly to the body of the vehicle or to the truck which carries it, and the ends *BB* are swung round the studs *PP* in a manner more clearly indicated on the right-hand side. Here the levers *CC* are shown, and these extend from the side of *BB*. The right-angle lever *E* is connected with the steering lever *G* by means of rod *F*, hence, when *G* is moved, rod *D* moves, and thus levers *CC* are rotated round the studs *PP*, and in that way the supporting studs *BB* which carry the wheels are turned. As the studs *PP* are not exactly in line with the plane passing through the center of the rim of the wheel, there is a slight tendency to jerk the steering handle round when a wheel drops into a hole in the pavement, but the leverage of *B* being very short, this tendency is so small as to be hardly noticeable.

Fig. 10 illustrates the general principle upon which the front axle is designed, but the construction of the swivel joints *P* is far more elaborate, as can be seen from Fig. 11, which illustrates the actual design employed in the vehicles just described. Looking at Fig. 9, it will be noticed that the front axle consists of two bars, one of which runs in a straight line from side to side, while the other is curved with the convex side upward. In Fig. 11 *B* is the end of the upper curved rod and *C* is the lower straight one. These two rods are secured into the casting *A*, which holds the part *D* upon which the wheel is carried, *D* being the part *B* at the left side of Fig. 10. The end *E* which is broken off in the drawing extends through the hub of the wheel and is provided with ball bearings so as to run without friction. The upper end *F*, of *D*, is arranged so as to be held by a ball bearing, as shown, against the end of *J*. By means of an adjusting screw *I* at the lower end, the parts are brought into proper position with reference to each other. The shaded portion *H* is the lever *C* at the right side of Fig. 10.

The left-hand end of Fig. 12 shows a design for front axle wheels which is one of the many modifications of the general arrangement just described. In this construction the wheel swings round the stud *C*, which is placed within the hub, and in a line, or nearly so, with the center of the rim. The rod *A* is the axle and *F* is the lever extending from the inner part of the wheel hub by means of which the steering is effected. The left-hand side of Fig. 12 is a view as seen from the front and the right-hand side shows the device as seen from above. In this last drawing it will be observed that as the lever *F* is attached to the inner portion of the wheel hub, if it is moved to one side or the other of axle *A*, by pulling or pushing on rod *G*, the wheel will be swung round. The advantage of designs of this type is that there is no strain whatever brought to bear upon the steering handle, and the objection is that the wheel hub is made much larger and the whole construction is somewhat more complicated.

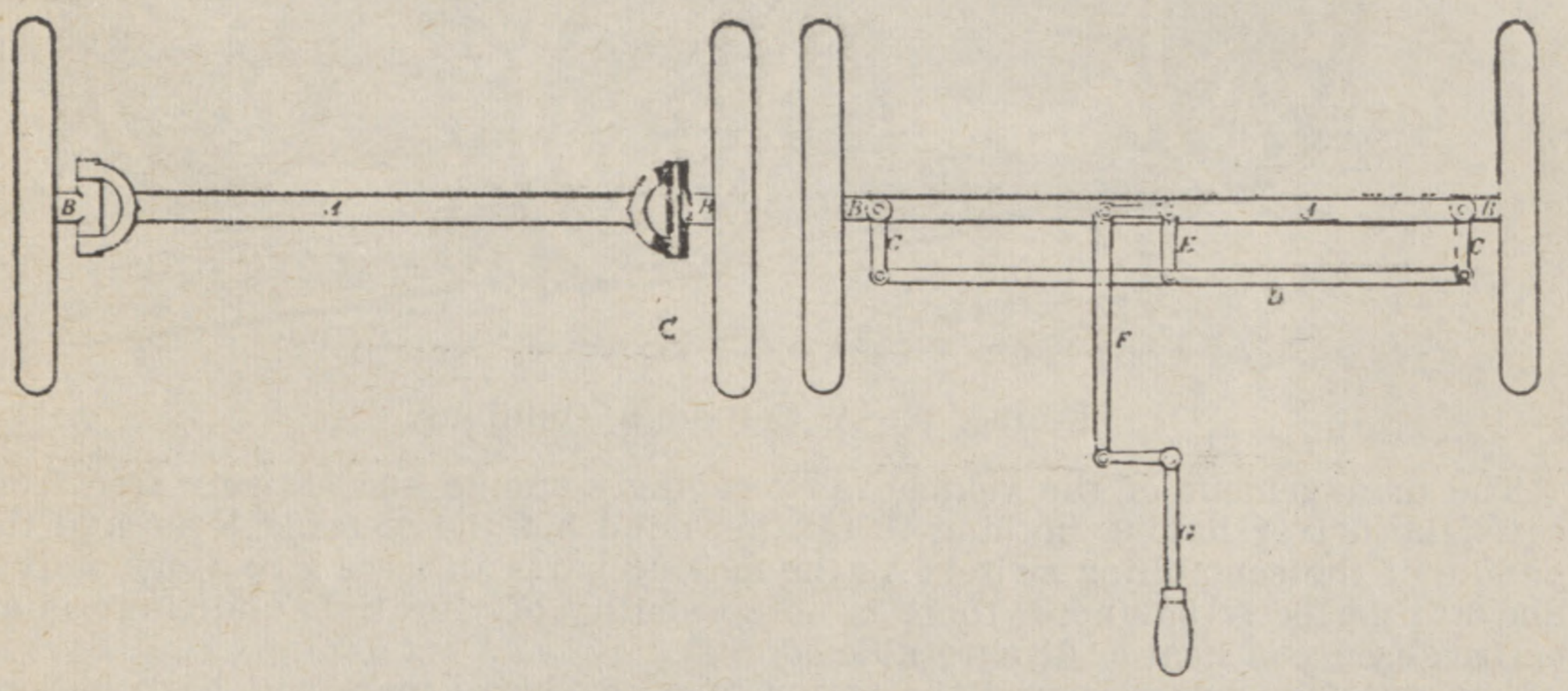

FIGURE 10.—Arrangement of axles and wheels.

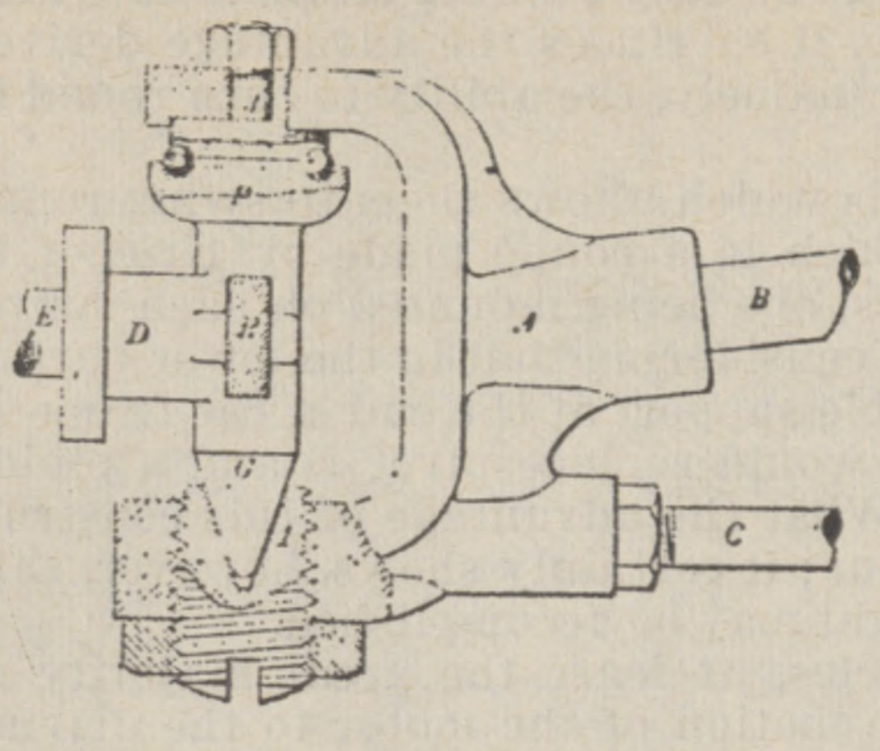

FIGURE 11.—Front axle.

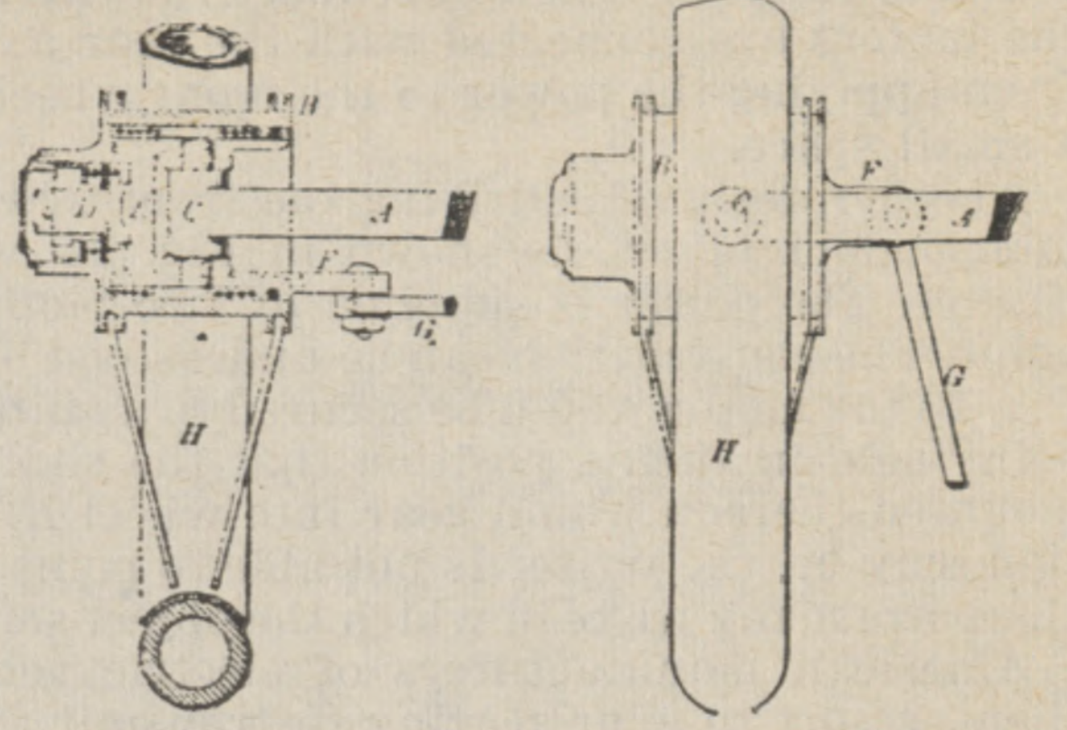

FIGURE 12.—Front axle wheels.

The arrangement of the front axle, so as to swing the wheels round a center close to the hub or within it, as described in the foregoing paragraphs, is used on all types of automobiles and is not a distinguishing feature of the electric carriage. In some of the lighter vehicles the front wheels are held in forks of a design substantially the same as that of the front wheel of the ordinary bicycle, the tops of the forks being connected with each other by means of a rod, as in the lower part of Fig. 10, so as to obtain simultaneous movement of the two wheels by the movement of a single steering handle.

In the majority of electric vehicles the power is applied to the rear axle, but some are made with the motors geared to the front axle. In a few of these designs the wheels and axle are made the same as in an ordinary carriage, so as to swing round a pivot or king bolt located at the center of the axle and reinforced by a fifth wheel. When this construction is used the steering gear is made so as to hold the axle in position more firmly than in the other designs; but even with this assistance the driver has a harder task than with the independently swinging wheels. The advantage derived from swinging the whole axle is that the carriage can be turned round in a very small space, and on that account the construction is well adapted to cabs.

Several arrangements have been devised by means of which the power can be applied to the front wheels, while these may at the same time swing round independent centers. One of these constructions is illustrated in Fig. 13, the first drawing presenting the appearance when seen from above, the second being a view from the front. In the first diagram the motor is shown at *A*, and by means of pinion *B* and gear *C*, motion is transmitted to the axle, which is shown more clearly in the right-hand figure. On the ends of the axle are bevel gears *FF*, and these mesh into other bevel gears which revolve round the vertical studs *D*. Through this train of gearing the bevel wheels *E* are driven, and these are attached to the hubs of the carriage wheels. From the first diagram of Fig. 13 it can be seen at once that the gears *EE* can swing round *D* in either direction without in any way interfering with the transmission of motion from gears *FF*. The levers *HH* are secured to the sleeves *GG* which swing round the studs *DD*, hence, by connecting these with the rod *J* and moving the latter to one side or the other by means of the steering handle, the wheels are turned in any direction desired.

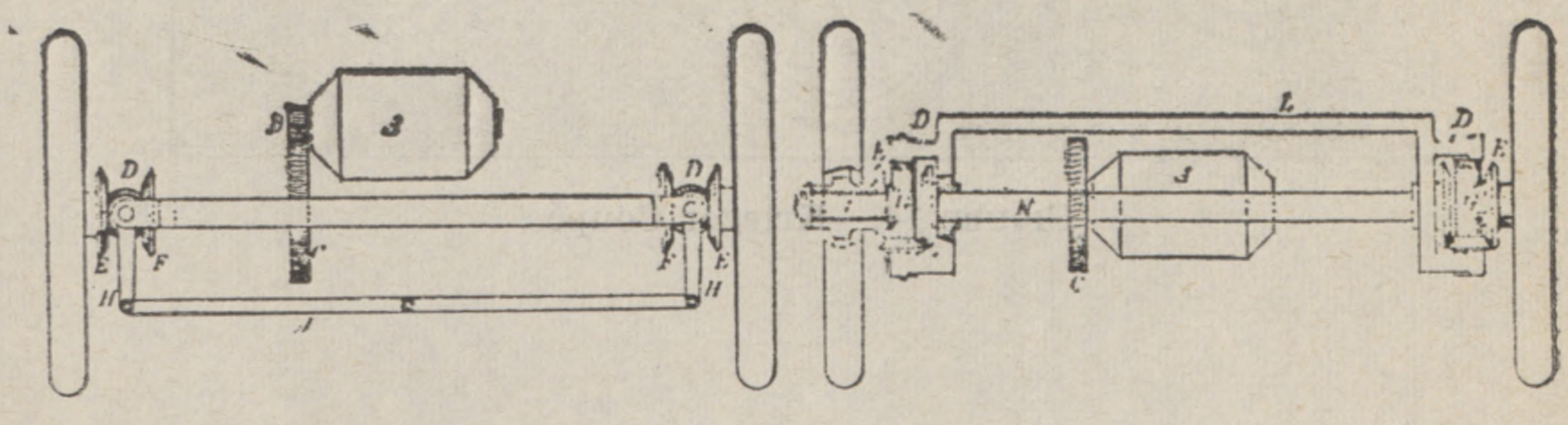

FIGURE 13.—Constructions showing power applied to front wheels.

While this construction renders the carriage as easy to steer as those in which the motors are connected with the rear axle, it sacrifices the advantage derived from applying the power to the front wheels, namely, the ability to turn round in a small space.

Another design for driving the front wheels which allows them to swing round independent pivots, is shown in Fig. 14, which is a coupé made by Krieger in France. The power is supplied by two motors, one being mounted on each swivel point. The construction can be understood by considering that in the lower part of Fig. 13 the motor would be secured to a suitable support at the end of the frame *L*, being held in such a position that the shaft would replace pivot *D* and a pinion mounted thereon would gear into wheel *E*. What the advantage of this construction may be, the writer is not able to point out; it certainly shows, however, that there are many ways in which the object sought may be accomplished.

American manufacturers of electric vehicles, at least the great majority of them, resort to spur-gearing to transmit the motion of the motor to the driving wheels, but with the French designers the chain and sprocket appears to be in great favor. Fig. 15 shows a Jenatzy vehicle (French), in which the chain is used. This construction would not be received with favor by Americans, who as a rule desire to have the mechanical part of the apparatus hidden from view as much as possible. In the Jenatzy vehicle two chain gears are used, one on each side of the body, and from the engineering point of view this is the most desirable arrangement, as with it the driving wheels are independently operated and a compensating gear need not be placed upon the axle. The American designer, however, would in most cases be controlled more by the artistic appearance and would use a single chain which would be placed under the body of the carriage, and thus as much out of sight as possible.

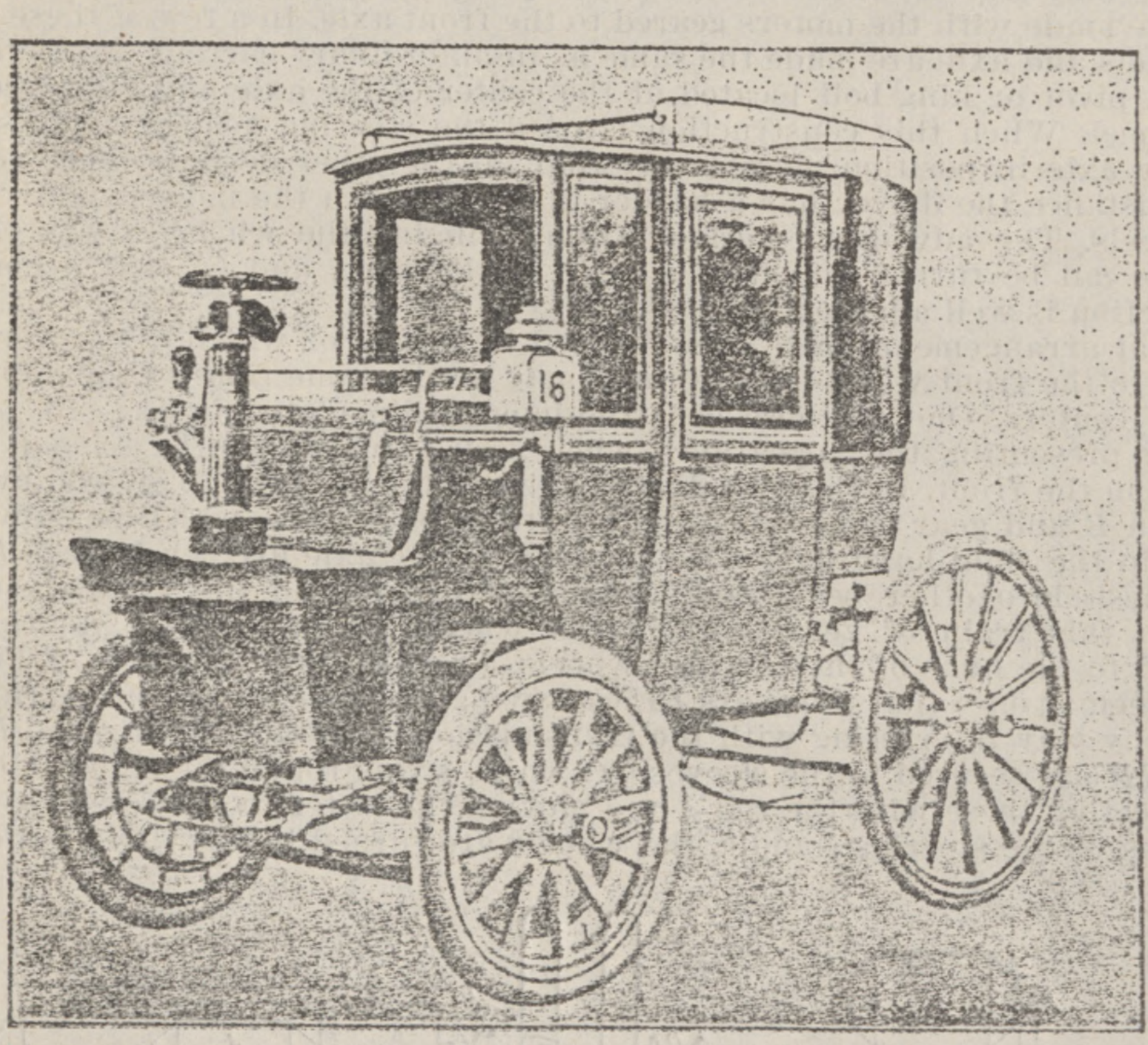

FIGURE 14.—Krieger Coupé.

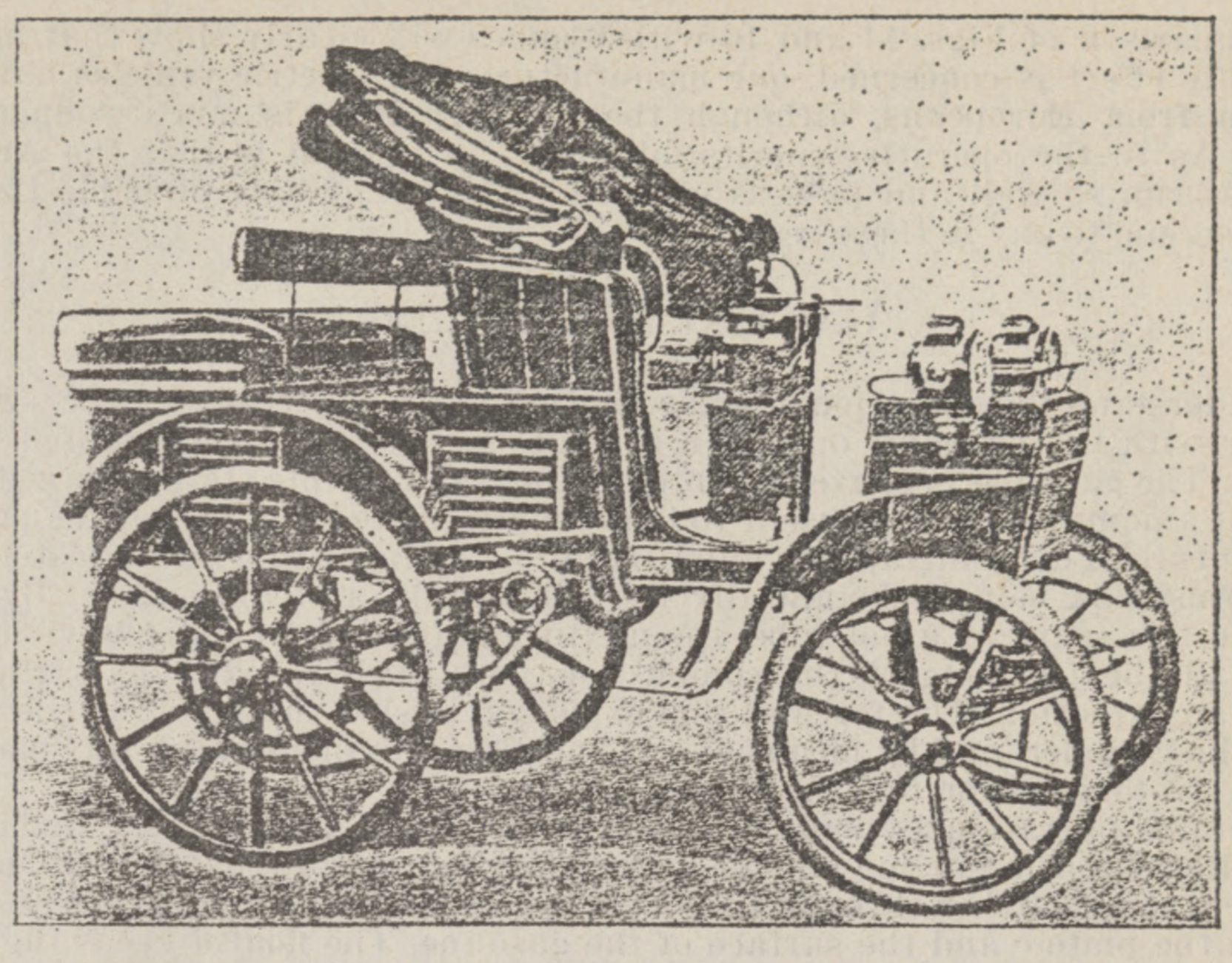

FIGURE 15.—Jenatzy Dog-Phaeton.

Fig. 16 shows an English design of electric dog cart. The mechanism consists of a single motor which is connected with the axle by means of spur gearing, this being so arranged that several different speeds can be obtained for the vehicle with the same velocity for the motor. To obtain variable speeds by means of gearing it is necessary to introduce a considerable amount of complication, and in this country the opinion of most designers appears to be that the gain effected thereby is not sufficient to compensate for the increased complication, and differential speed gearing is not often used.

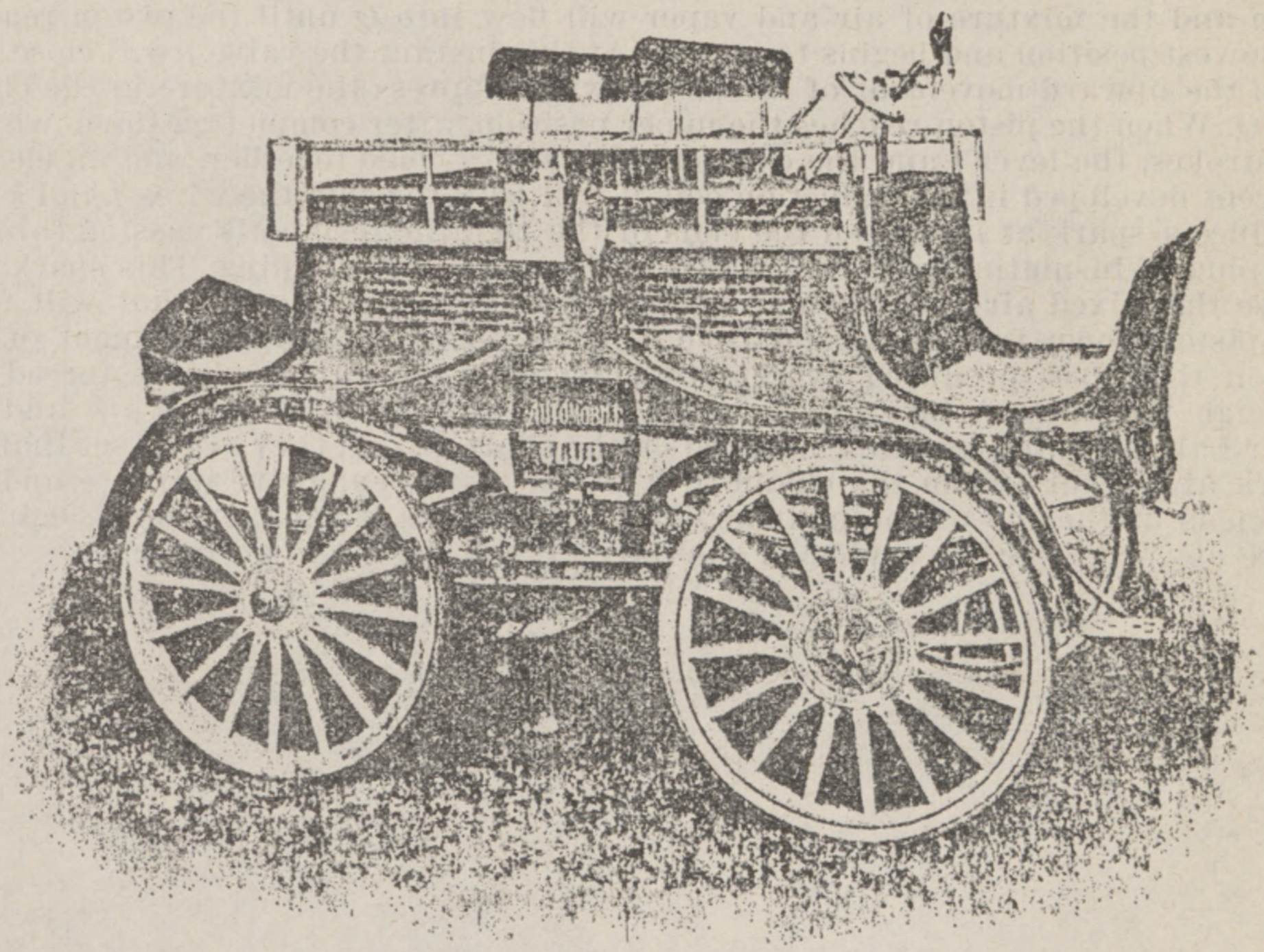

FIGURE 16.—The Electric Motive Power Co.'s Dog Cart.

A comparison of Figs. 14 and 16 with 6 and 9 will clearly show that in so far as artistic effect is concerned, our manufacturers of electric vehicles have little to learn from Europeans, although the industry here is much younger than abroad. As to the operative merits, all that can be said is that the American carriages run so well and possess such endurance that it is probable that they are not second to any in these respects.

Gasoline Automobiles

To understand the operation of a gasoline vehicle it is necessary to be somewhat familiar with the principle on which gasoline motors act. Briefly stated, it is as follows: The gasoline is converted into a vapor, and in this state is mixed with a sufficient amount of air to cause it to ignite when heated to a proper temperature. This mixture of air and vapor is admitted into a cylinder in which a piston moves freely, this part being substantially the same as in a steam engine. By means of an electric spark or a hot tube, the mixture is ignited, burning so violently as to expand the products of the combustion with such rapidity as virtually to become an explosion. The force of this explosion pushes the piston to the further end of the cylinder, and by means of a connecting rod and a crank this movement imparts a rotary motion to a shaft.

The entire operation is made perfectly clear by the aid of Fig. 1, which is a simple diagram of a single cylinder motor. The chamber *R* contains the gasoline. Air enters this chamber through tube *b*, as indicated by the arrow, and passes out between the plate *c* and the surface of the gasoline. The float *d* keeps the plate *c* in the proper position regardless of the amount of liquid in the reservoir. The heated gases exhausted from the cylinder pass through the pipe *r*, and thus heat the gasoline so that it vaporizes freely and the air passing under *c* becomes charged with the necessary proportion of vapor. The mixed air and vapor enter a valve chamber *S*, from which the flow into pipe *e* is regulated by the movement of handle *a*. In this chamber there is another valve, operated by an independent handle, and by means of this more air can be admitted into the mixture when desired. Through the pipe *e* and the valve *f* the vapor enters chamber *Q*, which connects with the top of the cylinder. Suppose the shaft *G* is rotating, then the piston will be drawn down from the position in which it is shown and thus a vacuum will tend to form in chamber *Q*. This action will cause the valve *f* to open and the mixture of air and vapor will flow into *Q* until the piston reaches its lowest position and begins to ascend. At this instant the valve *f* will close, and then the upward movement of the piston will compress the mixture in the chamber *Q*. When the piston reaches the upper position, after completing the down and up strokes, the lever *l* and the contact point *p* will come together, and an electric current developed in the induction coil *M* will pass through the wires *j* and *k* and produce a spark at *i* between the ends of the metallic terminals passing through the plug of insulating material, which is shown in dark shading. This spark will cause the mixed air and vapor to ignite, producing an explosion that will force the piston down for the second time. On the second upward movement of the piston the gases produced by the combustion of the vapor will be forced out through the valve *h* into the chamber *T* and the pipe *r*. The valve *h* and the lever *l* are operated by cams mounted on the shaft *m*, and they are so set that the spark at *i* occurs when the chamber *Q* is full of the explosive mixture and the piston is at the top of the cylinder. The valve opens when the piston begins to move upward after the explosion has forced it to the bottom position.

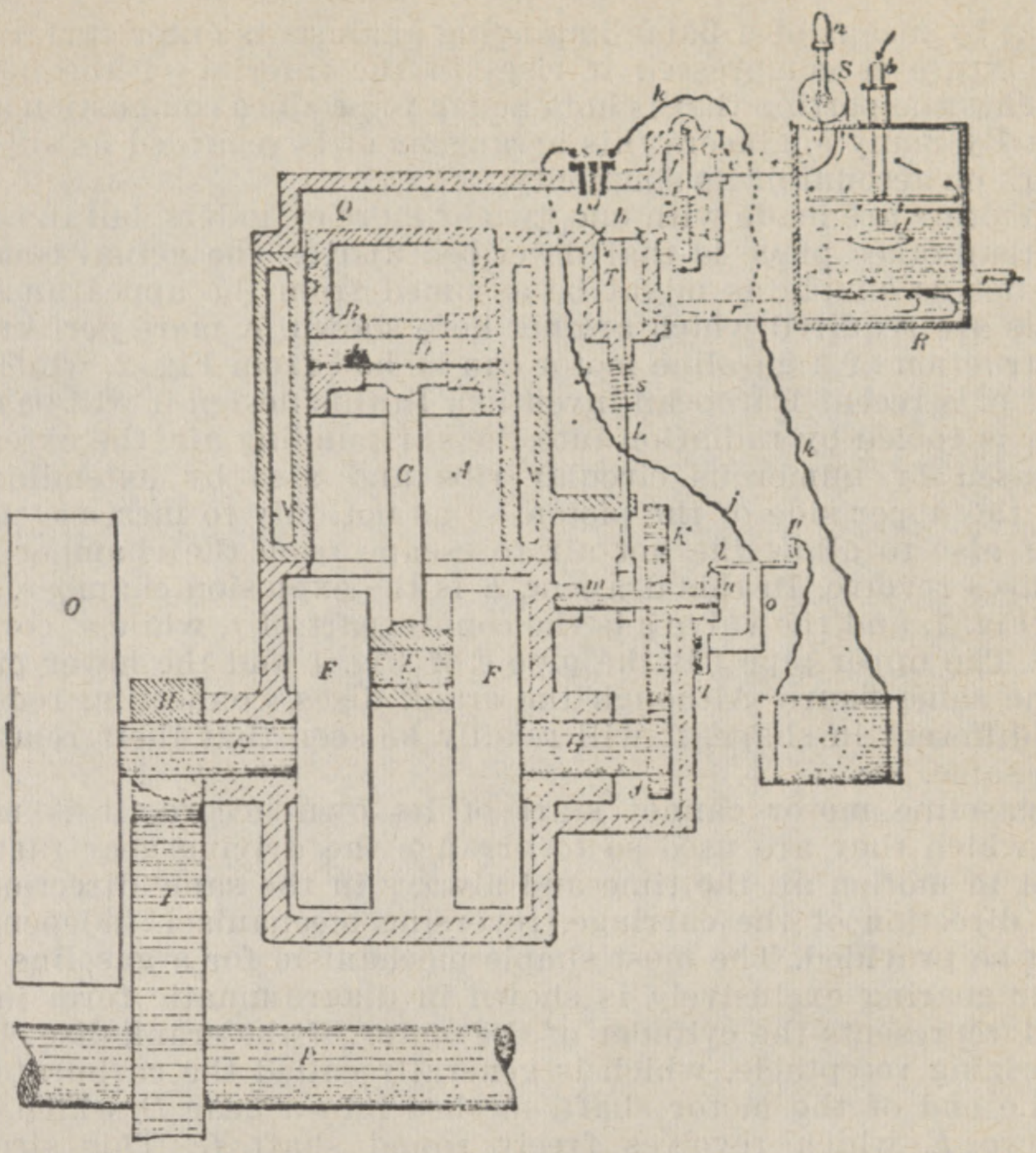

FIGURE 1.—Gasoline motor.

As will be seen, the piston must move down to draw in a supply of the explosive mixture; it then moves upward to compress it, and on the second down stroke it is pushed by the force of the explosion. From this action it can be clearly realized that the power developed by the motor comes from the force exerted by explosions at every alternate revolution of the shaft. On that account the cams that move the valve *h* and the lever *l* are placed on a separate shaft, which is geared to the main shaft in the ratio of two to one; that is, the wheel *K* is twice the diameter of the wheel *J*. As the force of the piston acts on the shaft only once in every two revolutions it is necessary to provide a heavy fly wheel *O*, which will store up enough momentum to continue the rotation of the motor through the ineffective revolution. Before the motor can put forth an effort it is necessary for the piston to move downward so as to draw in a supply of explosive gases and then to move up so as to compress them and produce an explosion; therefore, the motor will not start of its own accord, but must be set in motion. In the act of starting the wheel *O* is turned by hand.

The combustion of the gasoline vapor within the chamber *Q* and the upper end of the cylinder develops a large amount of heat, and unless means are provided for dissipating it the temperature will soon rise to a point that will interfere with the proper action of the motor. Two ways are employed to carry off the heat. One is by surrounding the cylinder with a water jacket, as shown in the diagram at *NN*; and the other is to provide the exterior of the cylinder with numerous thin ribs so as to increase the surface exposed to the air and thus increase the radiation.

The electric spark is a very effective igniter for the explosive mixture, and, by properly setting cam *n* the explosion can be made to take place just at the position of the piston that may be found the most desirable; but the points at *i* are liable to get out of order, and the battery that actuates the induction coil *M* and the coil itself can become a source of more or less trouble, and on that account the igniting is effected in some motors by means of a hot tube. When this is used the cam *n*, the lever *l* and the electrical parts of the apparatus are not required. In their stead a tube is placed on the upper side of the chamber *Q* and this tube is maintained

at a red heat by means of a flame impinging against its outer surface. When the explosive mixture is compressed it rises in the interior of the hot tube, and when it reaches the portion that is hot enough to produce combustion an explosion takes place. By many engineers this arrangement is regarded as superior to the electric spark on account of its simplicity.

Gasoline motors are made with one, two or more cylinders, but in each cylinder the action that takes place is that described above. The actual construction of a motor is not so simple as might be assumed from the appearance of Fig. 1; many details are required which are not here shown. A more perfect idea of the actual construction of a gasoline motor can be had from Fig. 2, which is a working drawing of a recent European invention. In this design it will be noticed that the cylinder is cooled by radiation into the surrounding air, the exterior surface being increased by numerous circular ribs and also by extending a hollow trunk from the upper side of the piston, so as not only to increase the radiating surface, but also to allow the hot air to escape from the champer *T* in which the crank discs revolve. In this drawing *E* is the explosion chamber, corresponding to *Q* in Fig. 1, and the valve *s* is the counterpart of *f*, while *s'* corresponds to the valve *h*. The upper pipe *t* is the pipe *e* of Fig. 1 and the lower pipe *t'* is the pipe *r* of the same figure. Although the crank discs, connecting rods and other details are different in shape, it will readily be seen that their relation to each other is the same.

Since a gasoline motor cannot start of its own accord, it is necessary in vehicles in which they are used so to arrange the driving gear that the motor may be kept in motion all the time and always in the same direction, hence, to reverse the direction of the carriage, reversing mechanism, independent of the motor, must be provided. The most simple mechanism for a gasoline vehicle employing spur gearing exclusively is shown in diagrammatic form in Fig. 3. In this figure *A* represents the cylinder of the motor, *B* the crank disc chamber and *M* the vaporizing receptacle, which is generally called the carburator. The pinion *C*, on the end of the motor shaft, meshes into a gear *D* which is mounted upon a sleeve *E* which revolves freely round shaft *G*. This sleeve has its ends formed so as to engage with the gears mounted upon shaft *G*, and by means of a lever, which is not shown, but which works in groove *a*, the clutch either *s* or *ss* can be thrown into engagement with its corresponding gear. If *s* is thrown into gear, as shown in the drawing, the wheel *F* will turn *H* and the pinion *I* will rotate the gear *J* which is mounted upon the axle of the carriage. If the clutch *ss* is thrown into engagement, the gear *G* will turn *K* and this wheel will turn *l*; but, as can be clearly seen, the direction in which *l* will revolve will be opposite to its motion when driven through *F* and *H*, therefore, if when *F* drives the carriage runs forward, when *G* drives it will run backward, and when *E* is moved to the central position, so that neither *s* nor *ss* engages with their respective gears, the vehicle will stand still, but the motor will continue to revolve.

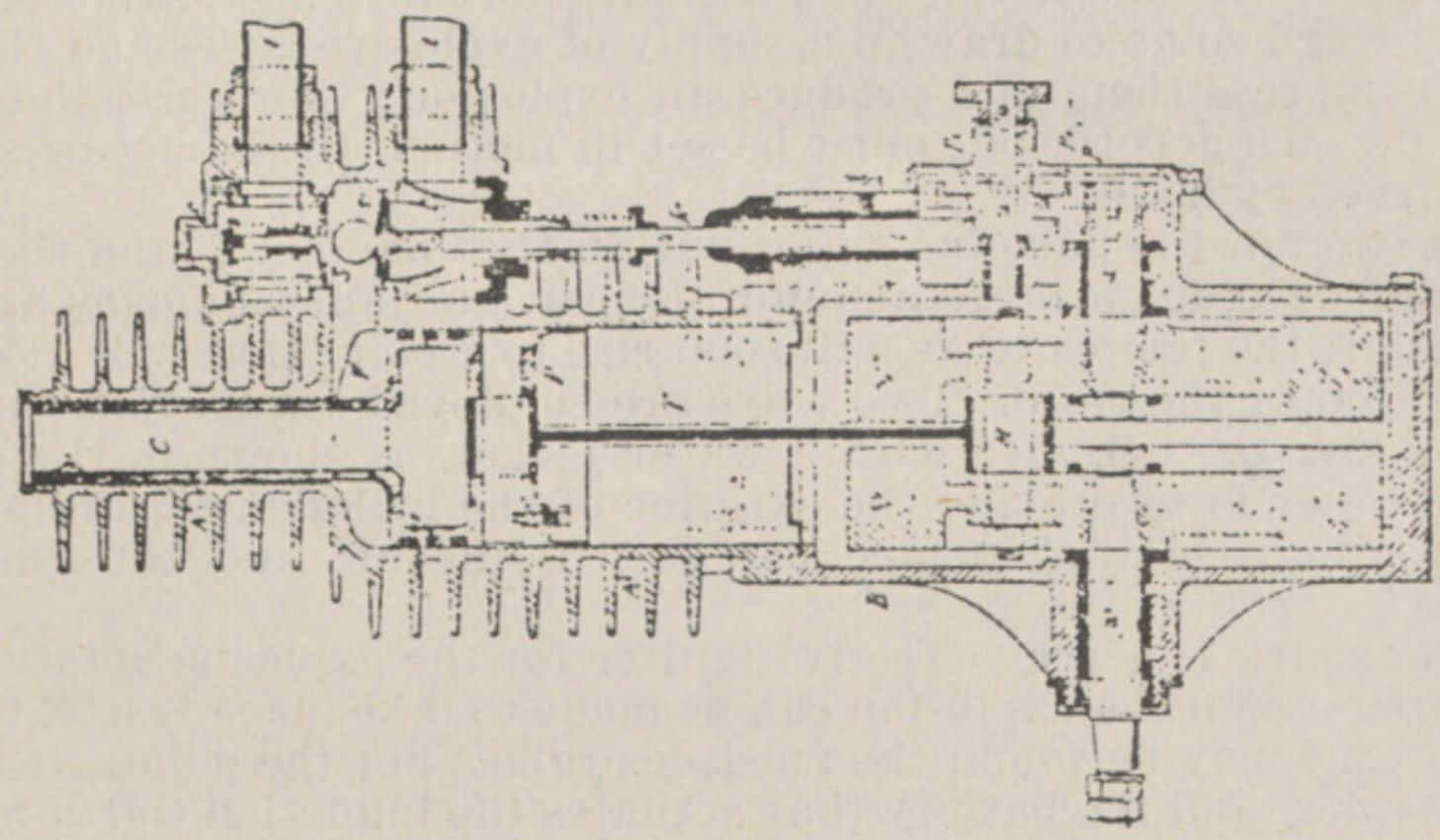

FIGURE 2.—Petroleum spirit motor.

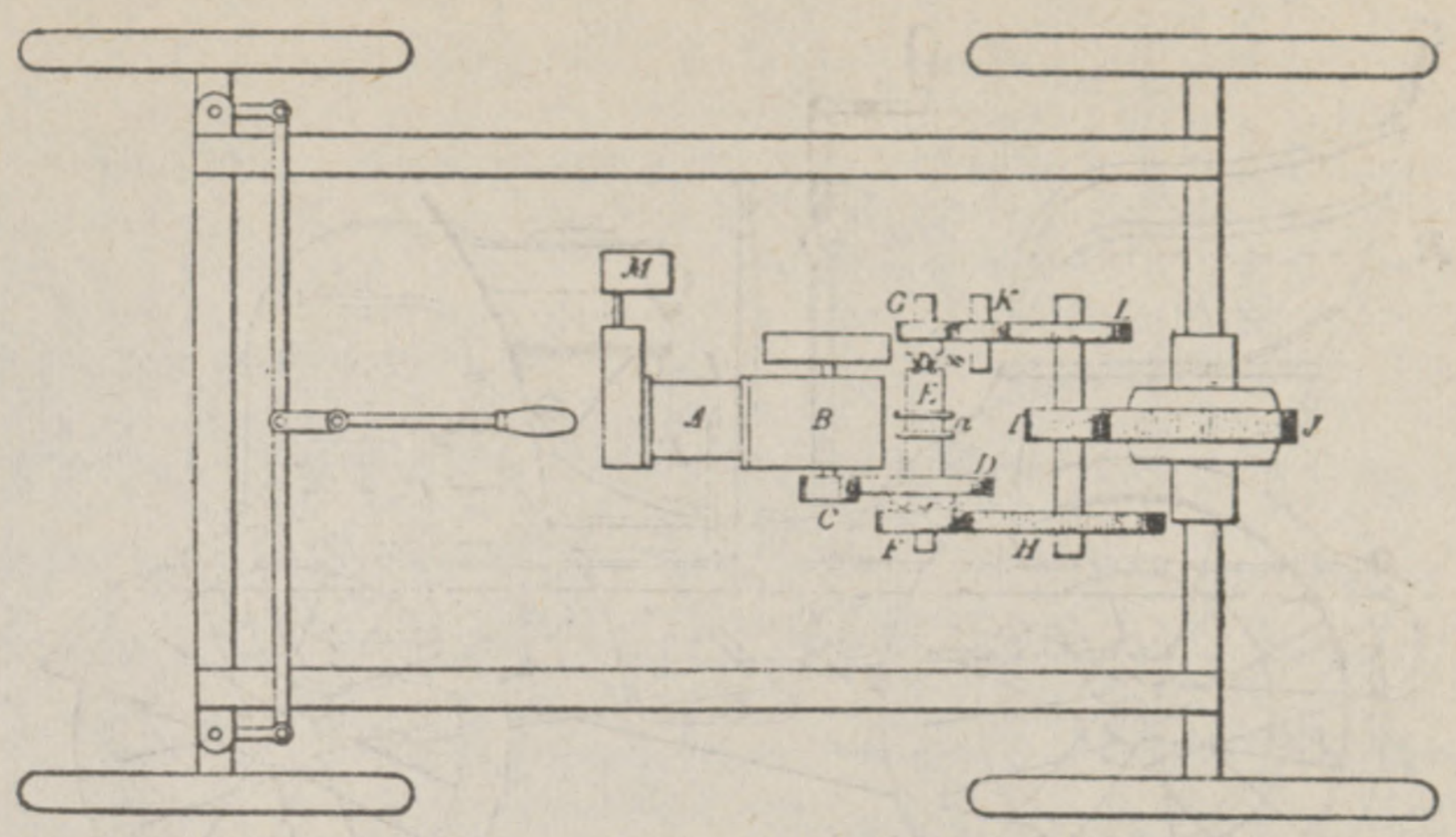

FIGURE 3.—Reversing mechanism.

This diagrammatic arrangement is more simple than the gearing actually used and is not as complete in action as many of the devices, as it only provides means whereby the direction of rotation of the axle may be changed, while in many carriages the gearing also varies the ratio between the speed of the motor and the driving wheels. It is also quite common to combine in the train of gearing spur gears and sprocket wheels, and in some instances even belts. Fig. 4 illustrates a French gasoline automobile made by Underberg, of Nantes. The first figure is a side view, and the second is a plan of the truck and driving mechanism.

The motor, which is of the single cylinder type, cooled by radiation into the air, is located at *N*. The pinion on the end of the motor shaft engages with the wheel on the end of shaft *A*. This shaft carries four gears, which can be moved by means of lever *C*, so as to engage with corresponding gears on shaft *B*, thus providing four different speeds. The motion of *B* is transmitted to the rear axle by means of a belt that runs over the pulleys *p* and *P*, the later being carried by a differential gear, so as to run the two driving wheels at proper velocities. The circular ribs surrounding the motor cylinder are well shown in the figure, in which the carburetor of *C* is also seen. The housing for the motor is open at the sides so as to give air currents free access. In Fig. 4 the speed changing gears are shown, the reversing train being omitted; but if it were also drawn in, the diagram would be far more elaborate than Fig. 3.

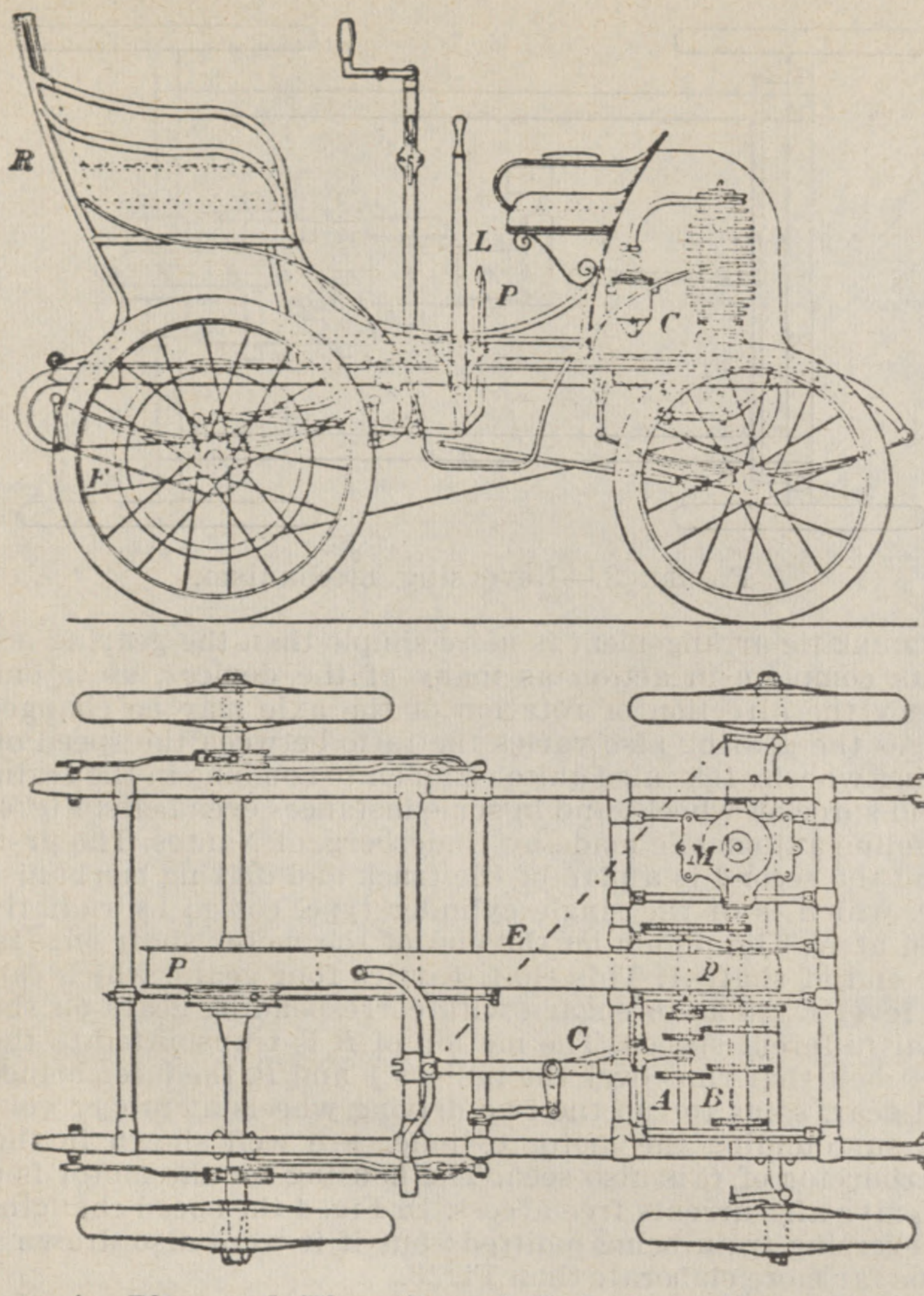

FIGURE 4.—Plan and Elevation of Underberg Motor Voiturette.

Another form of variable speed gear is shown in Fig. 5. This provides for two speeds. The large wheel *E* is on the carriage axle, and it is driven either by a pinion *F*, or by *J*. Upon the shaft *O* there are two friction clutches *C D*, and when *C* acts the pinion *F* drives *E*, and when *D* acts the pinion *G* drives *H*, which in turn drives *I*, and this wheel is mounted on the same shaft as *J*.

Some of the best-known makers of gasoline vehicles do not employ variable gears and depend for changes in the speed wholly upon variation in the velocity of the motor. The De Dion carriages are made in this way, the gearing being substantially as illustrated in Fig. 3.

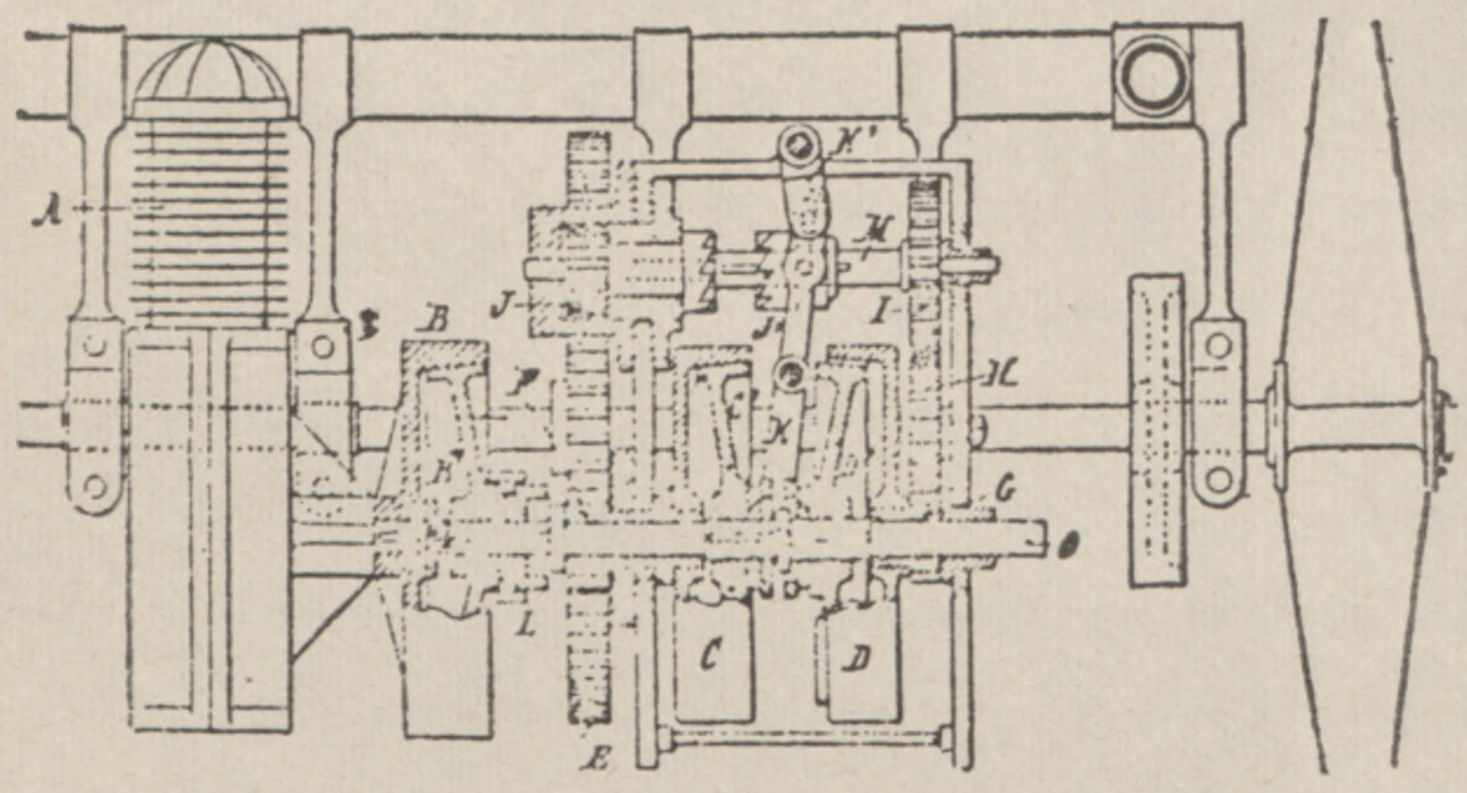

FIGURE 5.—Cherrier 2-speed gear.

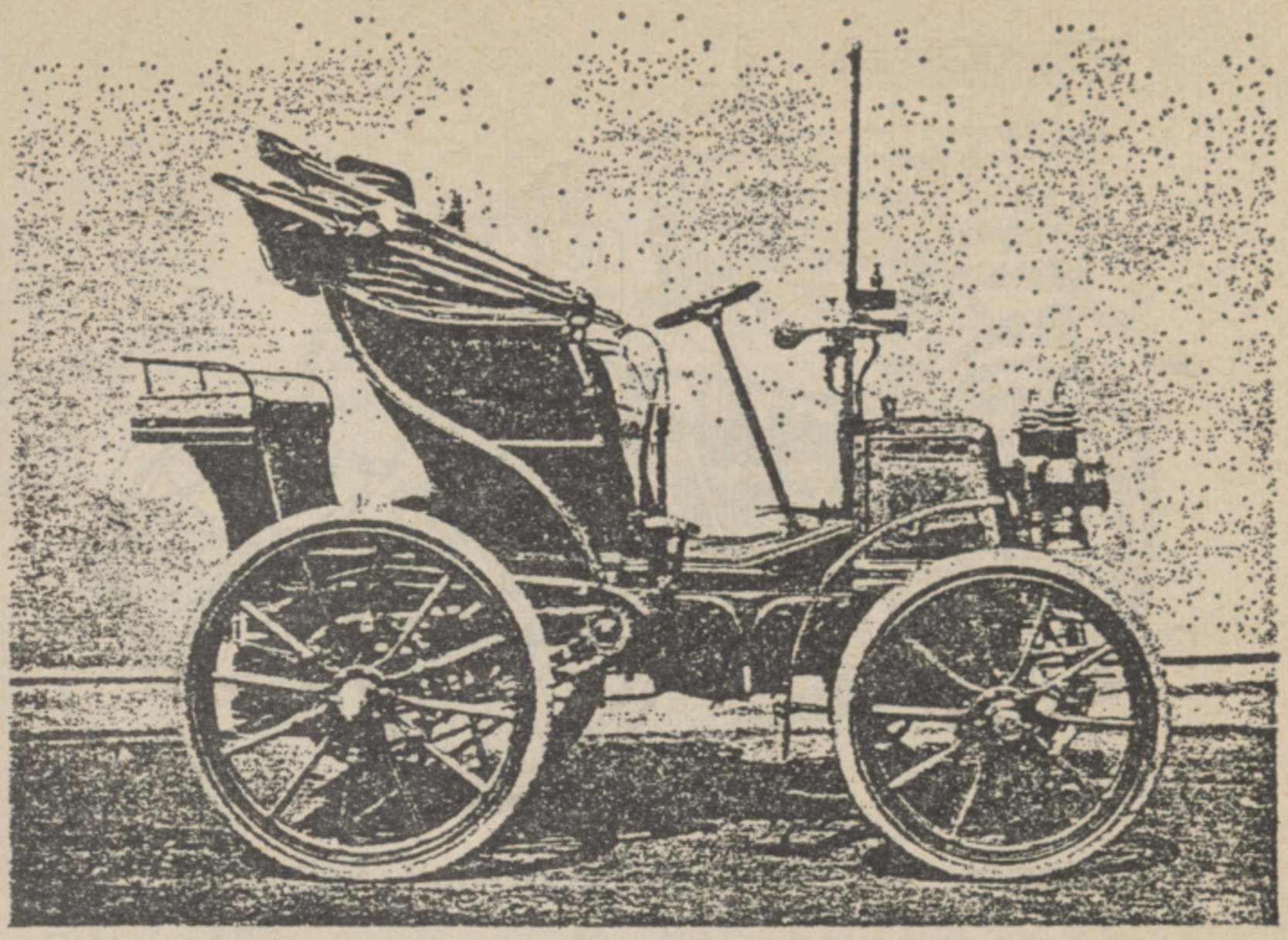

FIGURE 6.—Panhard and Levassor vehicle.

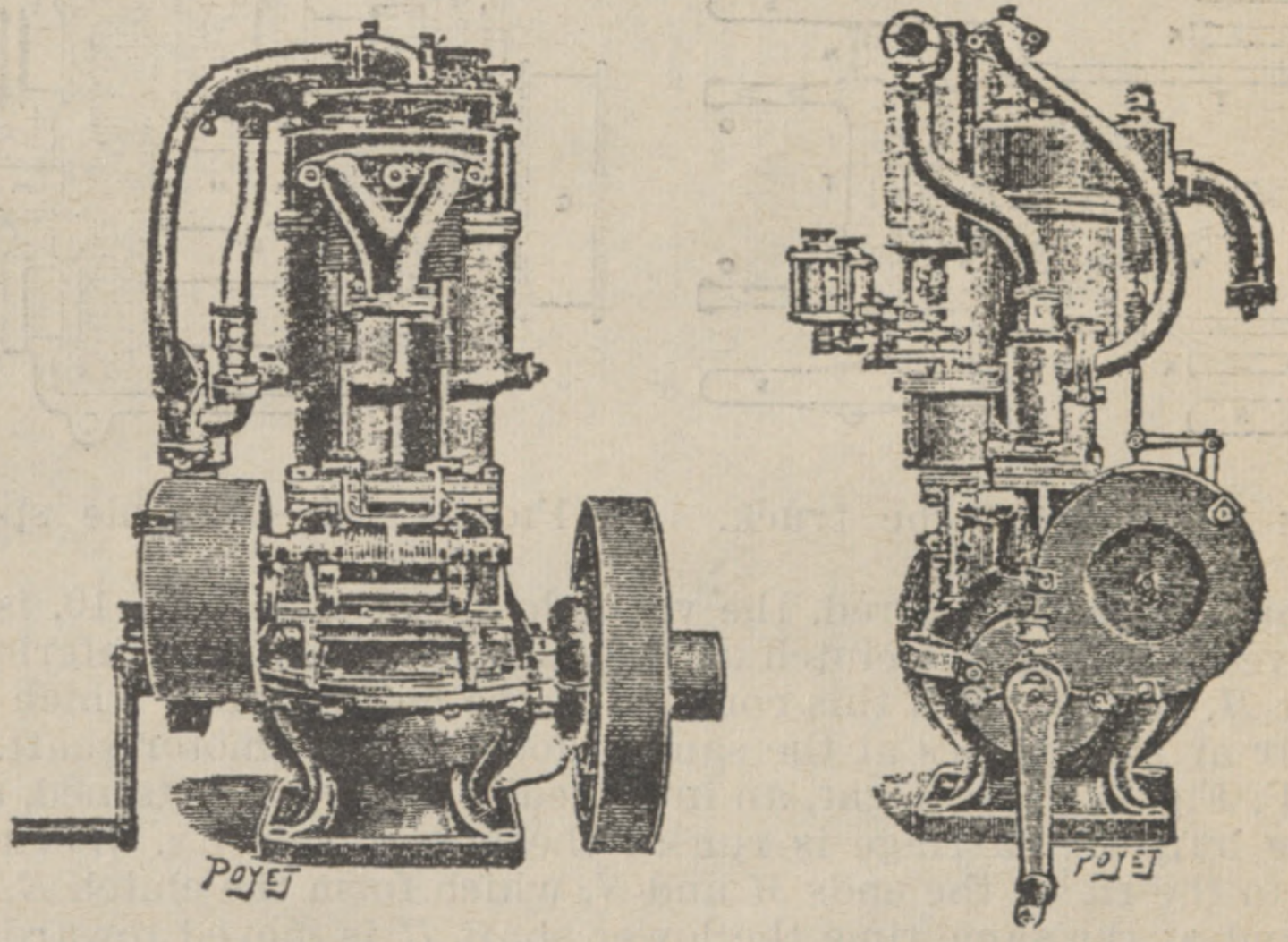

FIGURE 7.—Motor of vehicle.

Fig. 6 shows a gasoline vehicle made by Panhard & Levassor, who are perhaps the best known French manufacturers of automobiles, as their vehicles have been the winners in all the notable races held within the past few years. The motor they use is shown in Fig. 7, and, as can be readily seen, is of the two-cylinder type, cooled by a water jacket, just as in Fig. 1. The explosion is produced by means of a hot tube, as explained in connection with the last-named figure. This motor is placed under the body of the vehicle, and is connected with the rear axle by means of a train of gearing which terminates in sprocket wheels and chains that connect with driving wheels, each one being operated by a separate chain. In Fig. 6 the sprocket wheel and chain are well defined, and forward of these can be seen the outline of the casing enclosing the gearing.

Fig. 8 shows another European design, in which a variable-speed gear is used. The plan of the truck, showing the general arrangement of the mechanism, is presented in Fig. 9, and the details of the variable-speed gear are shown in Fig. 10. The motor is located at *A*, and through a friction clutch *B*, and the variable-speed gear *C*, it rotates the shaft *H*, which runs lengthwise of the vehicle. Motion is imparted to the hind axle by means of bevel gears contained within the casing *D*. The large bevel gear on the axle is of the differential type, so as to drive the wheels *RR* at the proper velocities.

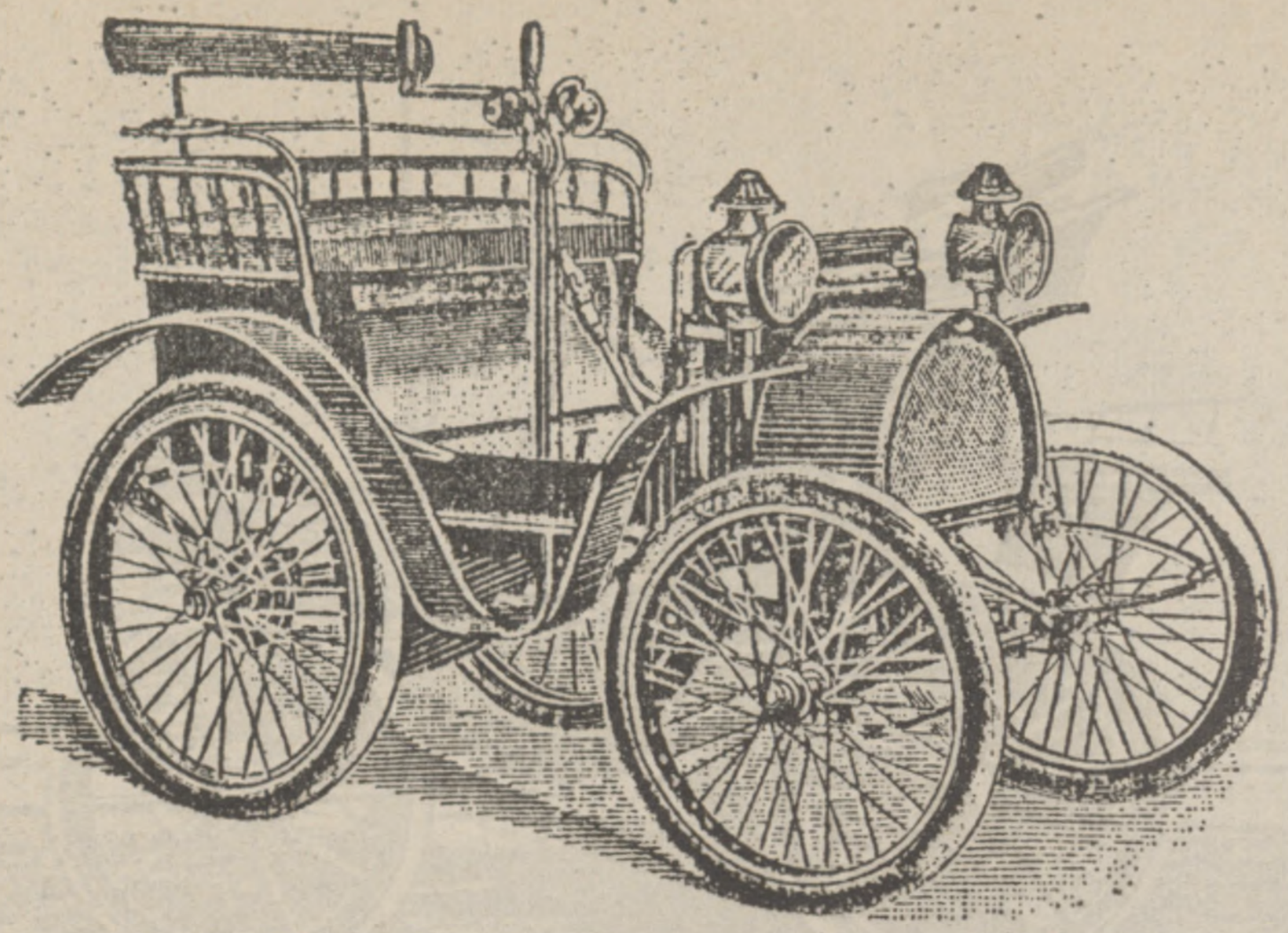

FIGURE 8.—General view of Renault Voiturette.

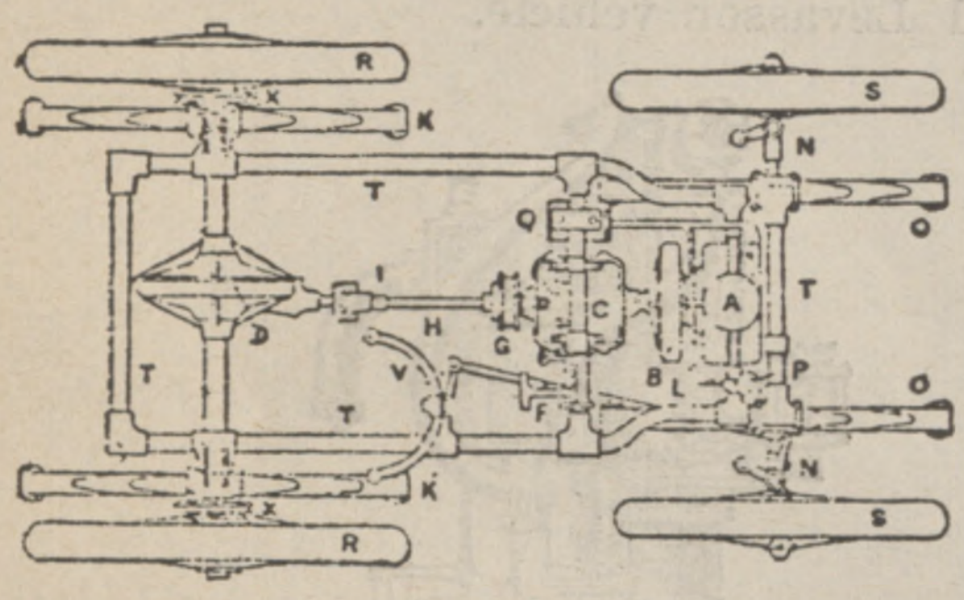

FIGURE 9.—Plan of the truck.

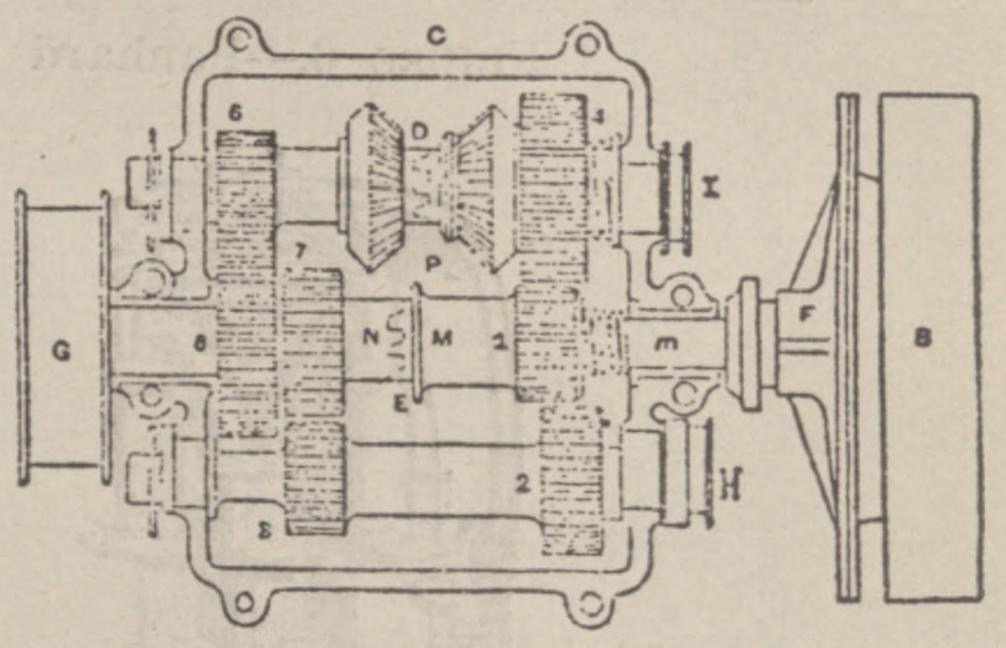

FIGURE 10.—Variable speed gear.

When a high speed is desired, the variable speed gear, Fig. 10, is set so that shaft *M* drives *N* direct, the clutch at *E* being moved so as to interlock. *N* is the end of shaft *H*, so that with this connection the bevel pinion, which meshes into the axle gear at *D*, revolves at the same velocity as the motor shaft. By moving the handle *V*, Fig. 9, to the right, an intermediate speed is obtained, and by moving it to the left, the carriage is run at the lowest velocity. When the handle *V* is turned to the right, the ends *M* and *N*, which form the clutch *E*, Fig. 10, are separated, and at the same time the lower shaft *H* is moved toward *M*, so as to cause gear 1 to mesh into gear 2, and also 3 into 7. By this means the end *N* of the axle-driving shaft is rotated through the train of gears 1, 2, 3 and 7. If the handle *V* is turned to the left, the shaft *I* is moved toward *M*, so as to cause gear 1 to mesh into gear 4, and gear 6 into 8, the latter being secured to end *N* of the axle-driving shaft. The speeds obtained by these changes are in the ratio of nearly 1, 2 and 4.

Fig. 11 shows the plan of a light French carriage, which is equipped with a double cylinder motor, set in a horizontal position above the front axle, and arranged to impart motion to the hind axle by means of belts. The motor, which is located at *A*, turns a vertical shaft, and this, through spur gears, rotates a horizontal fly wheel, *B*. Two pulleys are mounted upon the motor shaft, and from these belts run to tight and loose pulleys on a countershaft, *S*. From the latter the rear axle is driven through two sets of spur gearing, which give two different speeds. By means of the belts, two other speeds are obtained, thus giving, in all, four different velocities. To stop and start, the belts are shifted from the tight to the loose pulleys by a belt-shifter, *f*. At *h*, a muffling chamber is located, into which the motor exhausts, so as to reduce the noise.

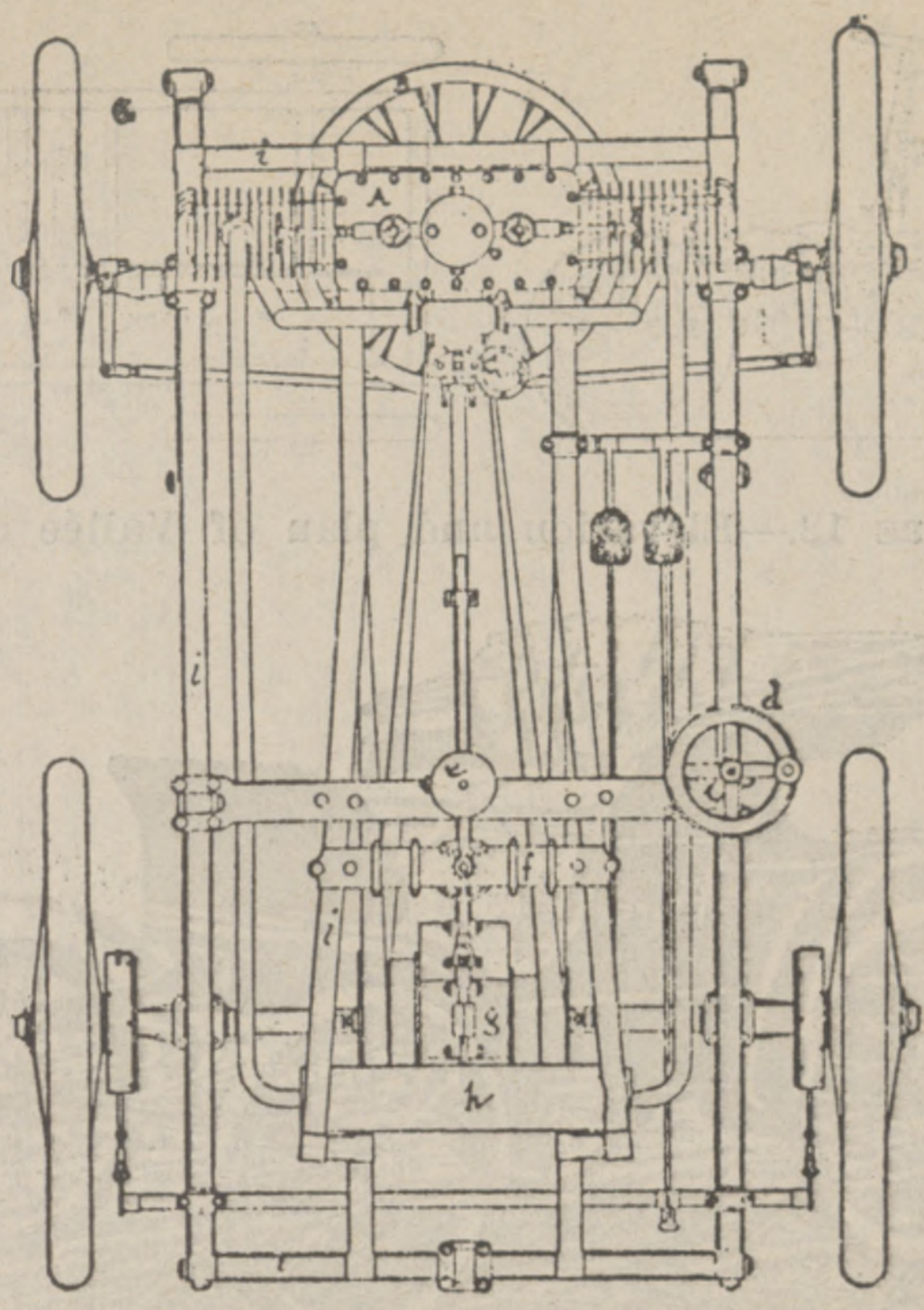

FIGURE 11.—Plan of the Turgan-Foy Voiturette.

The elevation and plan of one of the celebrated French racing-machines, the Vallée car, is shown in Fig. 12. The motor of this machine is of sixteen horse-power capacity, has four cylinders, and is connected so as to impart motion to the hind axle by means of a single wide belt, which is marked *G* in both the line drawings. The driving-pulley on the motor shaft is located at *H*, and the axle pulley at *H'*. Within the latter there is a train of gears for reversing the direction of rotation of the axle, and also for obtaining the differential velocities of the two driving wheels. There is no mechanism for variable speed, this being obtained wholly by changes in the velocity of the motor. The motor speed can be made to vary through a wide range by using four cylinders, with which it is possible to reduce the velocity so low that it would be likely to bring the machine to a standstill if provided with one, or even two, cylinders. The change in the motor velocity is obtained in part by the action of a governor located in a chamber at *A*, and in part by the action of the electric ignition device which is arranged so that the time when the spark is produced can be varied. The rear axle is so held that it can be moved through a short distance, horizontally, by manipulating the lever *D*, and in this way the belt *G* can be made tight or loose, thus affording another means for varying the speed. A brake is provided which presses against the inner side of the axle pulley, *H*. This brake is used ordinarily, but in the case of an emergency another brake can be operated which presses against the outside of the wheel in the space between the two sides of the belt. It is claimed for this vehicle that by the elimination of mechanical speed-changing devices, a great deal of weight is saved, and that this is more than enough to compensate for the extra weight of the motor, arising from the use of four cylinders. In most gasoline carriages it is necessary to provide a slow-speed gear for hill-climbing, as the motor cannot put forth a sufficient effort to ascend a steep grade at the normal velocity. With this racing-machine such a gear is not required owing to the enormous power of the motor.

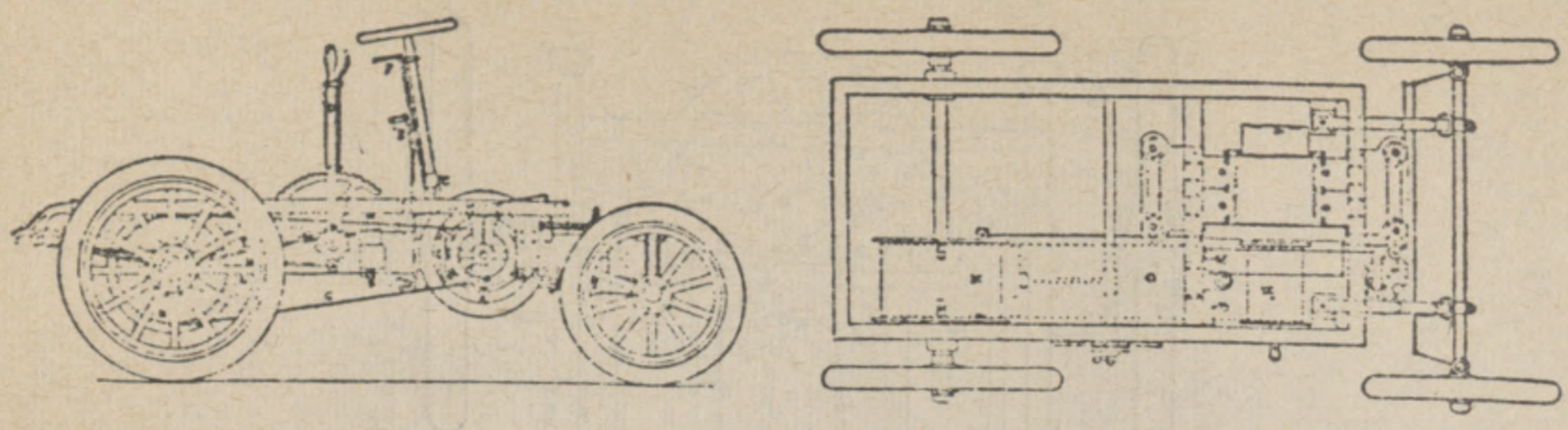

FIGURE 12.—Elevation and plan of Vallée car.

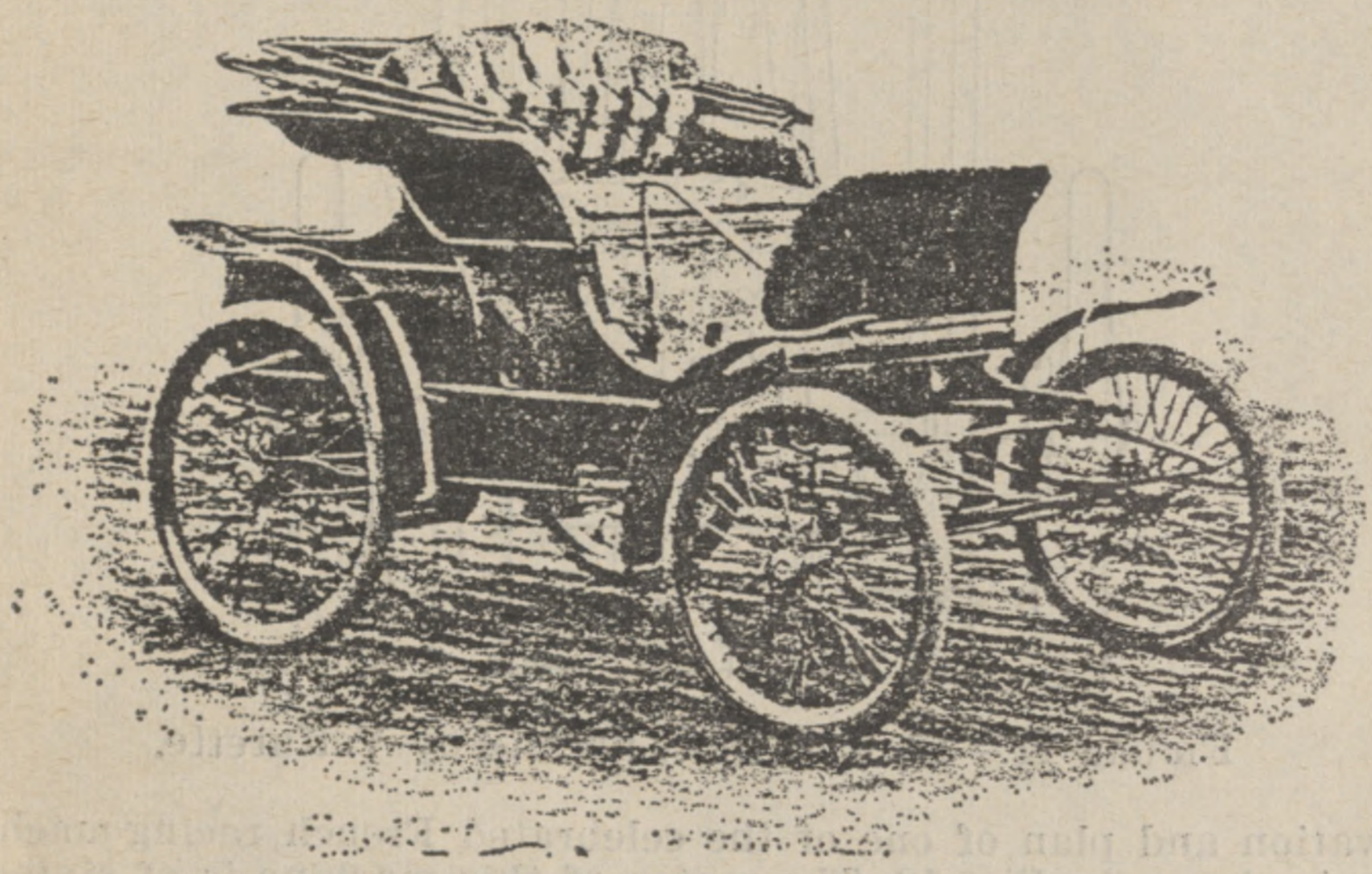

FIGURE 13.—Winton Phaeton.

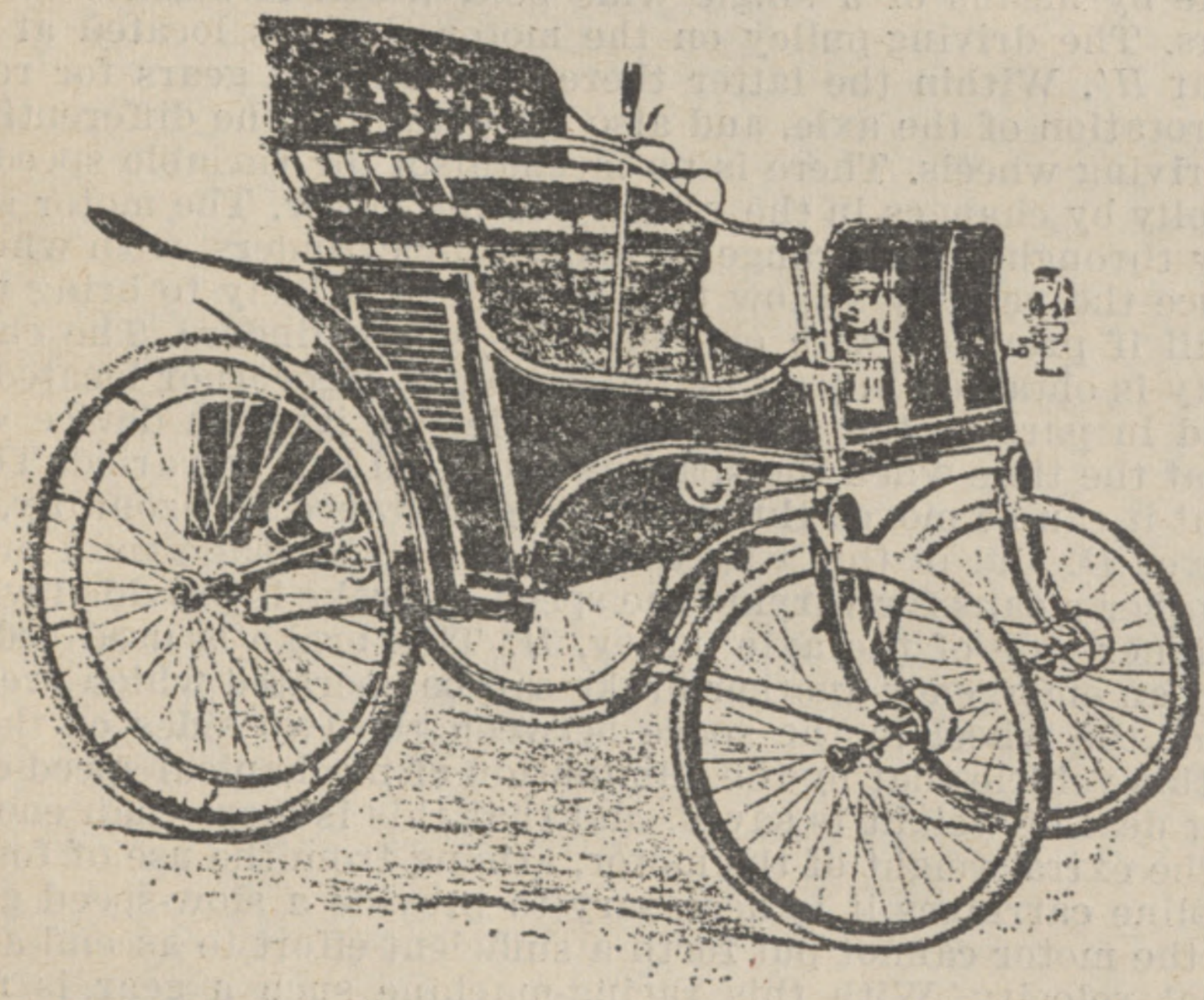

FIGURE 14.—Oakman vehicle.

There are quite a number of gasoline automobiles manufactured in this country, and, as in the case of the steam and the electric carriages, they compare most favorably with the best European products in so far as the artistic effect is concerned. That such as the case can be realized at once by an examination of Figs. 13 and 14. We regret our inability to illustrate the mechanism of these vehicles, but the truth is, that the manufacturers appear to be unwilling to make

public the details of their designs. In the phaeton shown in Fig. 13, a single-cylinder motor is used, and it is so arranged that it can run at different velocities, so that no variable speed mechanism is required, except a single train of gears, which is thrown into action when running uphill. The motor itself can be run at any velocity from 200 to 800 revolutions per minute, thus giving a speed variation of four to one. A carriage of this make competed in the last international automobile race from Paris to Lyons, France, and although it failed to come in first, it made a remarkable showing, which might have been considerably improved if it had not been for an accident which compelled it to retire from the contest.

The vehicle shown in Fig. 14 is of small size and light construction, although amply strong for the purpose for which it is intended. The powar of the motor, which is located under the seat, is transmitted through friction wheels. In looking at the illustration it will be noticed that the hind wheels have a circular rim attached to the inner side, and of a diameter somewhat smaller than the wheel itself. Two small friction wheels are placed so that either one may be pressed against the inner surface of this rim. The shape of the rim, as well as that of the small wheels, is such that they hug each other firmly, so that the rim is carried around in a direction which corresponds with the direction of rotation of the friction wheel. In operating the carriage the motor is set in motion, and then one or the other of the two friction wheels is pressed against the rim on the driving wheel, according to whether it is desired to run forward or backward. While this arrangement might not operate with entire success if applied to a heavy vehicle, it appears to be all that could be desired for a light carriage.

Three-wheel vehicles have been used, but there is a difference of opinion as to their value, as the construction has disadvantages as well as advantages. It is evident that such a vehicle can be steered with greater ease than one running on four wheels, but on country roads, where the wagon wheels roll down a smooth surface, and leave the space between in a rough condition, it is equally evident that the third wheel, in passing over this uneven surface, would jolt the vehicle to a considerable extent. On a smooth pavement the three-wheel vehicle will run fully as well as the four-wheel; but, on the other hand, on such a pavement the latter can be steered with as little effort as the former, so that the question of superiority of design is one that probably depends upon individual taste.

From the descriptions of automobiles given in this and the two preceding articles, it will be seen that although many of them are used, especially in France, they are not entirely free from objectionable features. The electrical vehicles are provided with the most simple and durable machinery, and, being noiseless, odorless and free from smoke, are all that could be desired in so far as their operation is concerned; but they are heavy and can only be used in places where the batteries can be recharged. The stream vehicles are light, have simple mechanism and can run anywhere; but they exhaust steam into the air, which is clearly visible in cold or wet weather, and the heat from the engine and boiler is an objection, at least in summer time. The gasoline vehicles run well, but are noisy, and the odor of the gasoline is disagreeable as well.

Anon. "Stearns' Big Trio," *The Motor World*, 1 (October 4, 1900), 8

In 1900 it was so unclear which type of engine was best for propelling automobiles, that several companies produced autos of more than one type. The entrepreneur E. C. Stearns, as noted in this report, bet on all three.

Stearns' Big Trio

To those who know E. C. Stearns it is not necessary to state that any plans he may have in connection with the automobile industry, are plans which have been well and carefully thought out and which will not in the end fail to place their originator and his business associates in a very commanding position in the trade.

Refusing at this time to pass upon the question of whether electricity, steam or gasoline is the best motive power, Mr. Stearns will make vehicles propelled by each of these methods and allow the public to decide for itself.

* * * The Stearns Electric runabout [is] a vehicle which has been in constant use upon the road for the past year, and to exploit and manufacture which a stock company is now being organized. The vehicle * * * not only presents an unusually graceful exterior appearance, but its use has shown [it to be] extremely comfortable to ride in, the motion being smooth even at the highest rate of speed. The ability to turn within a short radius is noteworthy, and upon steep grades it has been found quite adequate to the work. The total weight of the vehicle, with two passengers, 900 pounds of battery and 200 pounds of motor and controller, is only about 2,200 pounds, but there is a remarkable stability and substantiality about the whole construction, guaranteeing endurance, but which would given heaviness to the general appearance were it not for the exceptionally fine, sweeping lines of the whole—a point that has still to be mastered by many excellent automobile designers, who have not had the training building bicycles Mr. Stearns has had and profited by.

In the realm of steam the Stearns Steam Carriage Co., with a capital of $750,000, has purchased the expensive plant of the Frontenac Mfg. Co. at Syracuse, and is now refitting and putting in it the newest and most improved machinery. Details of this vehicle, which is said to be in many ways far ahead of any other steam propelled one on the market, are for patent office and trade reasons not yet where the owners care to make them public.

Coming to the hydro-carbon propelled vehicle finds the Stearns Automobile Co. with a capital of $1,000,000. This company has succeeded to all the right of the Anglo-American Rapid Vehicle Co., and has E. C. Stearns for president, and W. W. Gibbs, of Philadelphia, formerly connected with the Chloride Storage Battery Co., vice-president. The Stearns Automobile Co. will proceed to promptly assume a very important place in the trade, and to this end the company has leased and is now operating the plant of the Barnes Cycle Co. in Syracuse as a factory for producing these hydro-carbon vehicles.

Before doing anything along either of the three lines above noted, Mr. Stearns, following the same thorough methods which made him a success as a manufacturer of bicycles, went to Europe and there personally examined into every vehicle of prominence in either France or Great Britain. One of the results of this will be a light runabout on entirely different lines from anything yet attempted, which, while extremely light in weight, like the famous Stearns bicycle, which most critics admit was the most graceful and perfect bicycle ever put on the market, will be sufficiently strong to safely carry its occupants over roads in any condition.

Barrett, George Kellogg. "Gasoline Motors for Automobiles," *Scientific American Supplement*, 49 (February 24, 1900), 20193–20194

This article lists the requirements of the "ideal" power plant for an automobile. The author believes that engineers should focus on developing the gasoline engine because of limitations in steam and electricity powered vehicles. That the author felt constrained to point out the demand for automobile power plants and to urge developmental work on the gasoline engine indicates the extent to which American inventors and entrepreneurs of the time were devoting efforts to steam and electric vehicles.

Gasoline Motors for Automobiles

BY GEORGE KELLOGG BARRETT

As many manufacturers as there are of stationary gas and gasoline engines, it seems strange that but few or none of them have turned their attention to the making of gasoline engines suitable for use in automobiles. Doubtless the case would be different if it were known what a ready sale awaits any thoroughly practical motor and if the objects necessary of accomplishment were understood.

As to the former, there is no maker of automobiles who has anything practical to offer who is not flooded with orders. No deliveries are promised within three months of the placing of orders. To add to the stringency, the inability to secure the vulcanite cells for the accumulators of electric vehicles makes those vehicles less active competitors of the gasoline rigs than would otherwise be the case, although the electric is surrounded by so many restrictions in the way of limited area of travel that it is not a really dangerous competitor, except for strictly city use, and even in cities a well constructed gasoline vehicle answers all purposes.

Steam-driven autos are a factor in this country greater than they are beyond the Atlantic, but the objections which apply to the electric also apply—in a much more restrictive degree, however—to the steam vehicle. In France, the home of the automobile, steam and electricity are little known for private traction purposes. In England the same condition prevails. At a recent exhibition in London, there were shown but one electric and one steam vehicle, the latter an American one, out of a total of 100 exhibited. While this does not prove that gasoline is to furnish the exclusive motive power of the future, or even the greatest percentage of vehicles, it does prove that it is practical and capable of being made the basis of a lucrative business by many concerns.

That there are so few automobiles seen in America is not due to any lack of demand but to a scarcity of practical vehicles. This scarcity, again, is not due to any lack of capable men working to supply the demand, but to the shortness of the time during which they have been at work, and, no doubt, in many cases, a lack of knowledge concerning the basic principles of the motors on which they are working. Particularly is this noticeable in regard to gasoline motors.

There are numerous difficulties in the way of constructing automobiles, especially steam and gasoline, and the constructor has other problems, quite as difficult of solution, in the building of a thoroughly practical motor. If the constructor were able to buy his motor in an approximately perfect state and then devote his attention to elucidating the other problems, he would be working to far greater advantage. In fact, the other problems are far nearer solution than the one of building a thoroughly practical gasoline engine for this particular work.

Now, those men who are engaged in the manufacture of gas and gasoline engines on a commercial scale, with all the facilities of well equipped shops, with no other problem to divert them from the building of practical motors, and—not the least important advantage—with an intimate acquaintance with the idiosyncrasies of gasoline engines in general, should be able to arrive at the solutions of the problem—there are more than one—in a more rapid and a more economical manner than those who have not these advantages. The only thing necessary is to start with a knowledge of the requirements of gasoline motors as applied to traction purposes. It is the object of this article to outline briefly these requirements.

An engine for a vehicle designed to carry two to four persons should develop at least from four to six horse power, to make it practical under all conditions. Engines of this power will be most in demand for some time to come, if not permanently. Larger sizes will be needed for omnibuses and freight vehicles as well as a few of the more elaborate private conveyances, but the present demand in America is for a motor adapted to private passenger vehicles. Engines of smaller power are suitable for motorcycles—the generic term for two, three, and four-wheeled conveyances built on the lines popularized by cycle building.

Both horizontal and perpendicular engines are used successfully abroad.

Naturally the ideal engine should be economical, but for private traction purposes this is a consideration of minor importance, as the cost of travel is, at the greatest, comparatively small. Other features are more important.

One of them is the desirability of a long period of service without the necessity of replenishing the fuel, which, however, involves the question of fuel economy.

The desirability of compactness is so apparent that it seems almost needless to mention it.

Another equally apparent desideratum is light weight, which involves and is inter-dependent upon other desirable features, like constant torque, the absence of large flywheels, the use of multiple cylinders and some provision for cooling without complicated and heavy devices for water circulation. Finally, the engine should provide an exhaust that is as nearly noiseless and odorless as possible.

Taking up the question of weight, there can be set no definite bounds beyond which it is not safe to transgress, as other desirable features might well counter-

balance a little weight in excess of what an expert would set down as the maximum allowance. Gasoline motor-vehicles to accommodate two persons have been built as light as 450 pounds. While such light weight is not necessary, it is certainly desirable, for more reasons than one, the most important of which is the many stresses put on the wheels. In a vehicle of this weight, not more than 150 pounds can be devoted to the motor, carburetor, fuel tank and cooling devices. If water cooling is used, it will be seen that there must be light and efficient devices for reducing the temperature of the water after it has reduced the temperature of the cylinder or cylinders, or else the amount of water that must be carried will be too great.

In a one-cylinder engine the weight of the flywheel necessary to maintain anything like constant torque would be too great. Therefore it is desirable to have more than one cylinder, if for this reason alone. Two have been used successfully; three seem, at present, to be the most practical in actual service; while four, and even a greater number, have been tried with results that have been claimed to be excellent. The use of a multiple number of cylinders makes it easier to provide sufficient cooling without the use of water. It is possible to construct a multiple-cylinder engine in which the flywheel will be an unimportant feature. Of course the construction of such an engine involves expense, but expense will not prevent the general use of a successful engine.

The necessity for eliminating vibration and maintaining lightness is another very cogent reason for using more than one cylinder. Involving several other problems, is the one of constructing an engine that will work well under loads of varying amount and frequent change. Whether this can best be done by running the engine at an approximately constant speed, leaving the matter of the transmission of that speed to the vehicle constructor, or by varying the speed of the engine itself, is a question that is best left to the experimenter to solve. Either expedient will serve. It would seem almost necessary, however, to adjust either the quality or the quantity of the explosive charge in proportion to the amount of work to be done—automatically, of course. Both quality and quantity may be changed, but to keep the quality constant and vary the quantity appears to offer the best results as applied to automobiles. The hit-and-miss plan is not feasible.

In this connection, it may be well to say that there appears to be opportunity for great improvements in the way of introducing a measured quantity of liquid gasoline into a measured quantity of air and of having little more than enough of the explosive mixture on hand at any one time than is necessary for the charging of the cylinder at the next inspiration.

Taking up the question of eliminating vibration, that may be accomplished in a number of different ways which will suggest themselves to the experimenter. The use of two opposed cylinders with a flywheel of moderate weight has been found satisfactory. The result, however, can doubtless be better accomplished by the use of three or four cylinders, set in any manner that is found most convenient. It will be well to construct the driving shaft to run parallel to the axles of the vehicle, to do away with the use of bevel gears in transmission.

One highly important consideration is the proper cooling of the engine without the addition of weight of any great amount. This includes the use of little water, if water be used at all. Where water is used, the French, who have arrived at the greatest degree of advancement in the building of gasoline automobiles, utilize water-cooling tubes provided with fins for radiation, the whole arranged in coils. The copper tubes are provided with very thin fins of iron or aluminum, according to the requirements of weight and economy.

The motors of small horse-power or numerous cylinders, however, are provided with no means of cooling other than thin fins for radiation on the outside of the cylinder. Exception may be made in the case of one Frenchman who provided, within the piston, itself, a cooling device, by the aid of simple auxiliary mechanism. It is possible to construct a six horse-power, three-cylinder gasoline engine that will need no cooling device not integral with the cylinders themselves.

The actual speed of the engine itself need cut little figure, as the speed of the vehicle to which it is attached will be regulated in the transmission, unless an attempt be made to regulate the speed of the engine in proportion to the load, in which case the speeds of engine and vehicle are so closely connected as to be inseparable.

The engine should have provision of some sort for starting itself or of being started by the use of light manual power which is operative from the seat of the vehicle.

Finally, an engine that is reversible will prove valuable, as it will relieve the builder of the vehicle of the problem of providing a reverse transmission.

If the features outlined in the foregoing can be accomplished with the use of kerosene instead of gasoline, the results will be still more satisfactory.

That it is a difficult task to accomplish all these results is a foregone conclusion, but that it is a task too difficult for American inventive genius, the writer will not admit. We already have the results accomplished by the French and Germans in this line to help us, and it would be an insult to American ingenuity to admit for a moment that we can not excel the foreign designers, once we set ourselves to do so. It is no task to be accomplished in a day, but, when it is accomplished, the financial results will be more than sufficient to pay for long and studious work.—Modern Machinery.

Anon. "Steam Abroad," *The Motor World*, 1 (November 8, 1900), 94

In this article, the French rejection of the steam automobile can be seen to derive from extremely stringent regulations and also from the fear of competition. As indicated, the advanced French auto technology was predominately committed to the gasoline engine, and opposed steam. Nevertheless, in the face of these social and economic factors working against the steam powered car in France, Leon Serpollet made significant advances in developing the flash boiler and automatic feed devices.

Steam Abroad

Paris, *Oct. 26.*—I had a very interesting chat the other day, before he left for home, with Mr. Overman, of the Overman Automobile Co., who brought his steam car to Paris, and is in a fair way of convincing the French that he has got something which will change the whole aspect of the automobile question. When any one talks of revolutionizing the industry you may be disposed to regard him as visionary, but you who know him, know that Mr. Overman is not of this class, though he goes as far as most inventors in his claims for the new vehicle. Mr. Overman expects that his light steam car will force its way to the front and become popular among automobilists on this side. If so, it will produce a great change in the position of the industry here.

NO FRENCH FAITH

The French have very little faith in steam for small carriages, because they argue that, while there can be no possibility of explosion in the gasolene motor, there is not the same immunity in the steam boiler which would send the driver sky high if anything should go wrong with the feed pump, for example. It may be said that there are more accidents arising from gasolene tanks igniting and setting fires to the cars, than from exploded boilers, but the French will tell you that is not exactly the question.

One of the reasons why the French object to light steam cars is that the Department of Mines, which in France controls steam generators, and in fact motors of all descriptions, apply extremely severe regulation to steam boilers, and these imply such a high standard of security that people doubt whether boilers can be fitted to small road vehicles which will be passed by the authorities.

PROTECTING HOME INDUSTRY

Again, it must be remembered that makers here have taken a big lead in automobile construction through their skill in the manufacture of internal combustion motors. All French motor cars are of the gasolene type, excluding, of course, those driven by electricity, and it is not surprising that they look upon the probable competition of steam with anything but a favorable eye. The length to which makers here are prepared to carry their opposition to steam was seen

during the late Automobile Congress in Paris, when only one member had the courage to get up and declare that all the arguments put forward by the Frenchmen against steam were heresies.

WHAT THE MAJOR DID

That man was Major Howard, of New York. During the discussion the Major whispered to me that it was nothing but a concerted attack on American steam cars, and appearances certainly bore out that idea. All the resolutions in condemnation of steam carriages fired with light oils were carried, despite the protests of Major Howard, who said that the French were not going the right way to promote amicable relations with American manufacturers by doing what they could to stifle a great and promising industry.

I have referred to this part of the Congress just to show the attitude of the French toward light steam vehicles, and to demonstrate the difficulties that an American like Mr. Overman must encounter in trying to introduce his vehicles into this country. A steam car, to be successful here, must be absolutely safe. This is one of the claims made for the Overman automobile; that is, it is not only safe, but Mr. Overman has aimed at making it absolutely automatic, so no part is liable to derangement, or, if an accident should take place to the mechanism, it will not give rise to any danger. He has started by conceiving what a perfect automobile should be, and he has attempted to build a car according to his ideal.

ALMOST FOOL PROOF

He has taken every objection that can be raised against the motor car, and has tried to meet them until, as a result, he has produced a vehicle which he thinks is above criticism. The future of the automobile, Mr. Overman argues, depends upon the good will of the pedestrian. People who go afoot are legion, and it is hardly likely that the pleasure of a few thousand automobilists will be allowed to clash with the interests of millions who have to peregrinate on Shank's mare. Wherefore, says Mr. Overman, there must be nothing in any automobile which may cause any annoyance to pedestrians. It must be silent and absolutely devoid of unpleasant odors, and, moreover, must be under such perfect control that it can be stopped instantly. Judged from this standard the Overman car is all that can be desired.

Kingman, J. A. "The Steam Automobile," *Cassier's Magazine*, 19 (December 1900), 117–128

The significance of this article lies in Kingman's analysis of the development of steam carriages. He notes that their improvement was slow but progressive during the early part of the 19th century, but then the industry died out in 1840, and did not regenerate until near the end of the century, when much of the work was done in the United States. Kingman concludes that the steam engine itself is the best source of motive power for automobiles, and contends that it was other factors—such as poor roads, tolls (imposed in response to pressure by horse-drawn vehicle interests), (an unjustified) fear of explosions, and the success of railroads—which explain the hiatus in development of the steam vehicle and retarded its "natural and steady growth."

The Steam Automobile

BY J. A. KINGMAN

The application of steam as a motive power for road vehicles is not a new thing. It is not even modern, for the first successful steam carriage was built over a hundred and twenty years ago. The power of steam was well known to the

ancients, and from the time of Hero to the latter part of the eighteenth century we find numerous allusions to the possibility of steam as a prime mover.

James Watt, in one of his letters, wrote:—"My attention was first directed to the subject of steam-engines by the late Dr. Robinson, then a student of the University of Glasgow, afterwards professor of natural philosophy in the same institution. He, in 1759, suggested the idea of applying the power of the steam-engine to the moving of wheel carriages and to other purposes, but the scheme was soon abandoned on his going abroad." It will be noticed that this suggestion of Dr. Robinson antedates Watt's experiments on the steam-engine, and may have influenced his remarkable series of inventions.

The first steam automobile was built in France in 1769 by Nicholas Joseph Cugnot, a French military engineer, after his retirement from the army. The vehicle was built with public funds, Cugnot having interested the Minister of War in the matter. The first carriage was unsuccessful, either on account of the small size of the boiler or of inefficient feed pumps. It could not run for more than a short distance without stopping to get up steam. It possessed considerable power, however, and broke down a stone wall in one of its erratic journeys. A second machine was a three-wheeled vehicle, the boiler being placed in front and the forewheel driven by a double-cylinder engine. This carriage, together with an excellent model of it, is now preserved in the Conservatoire des Arts and Metiers at Paris. Cugnot may thus be credited with having made the first successful steam motor carriage.

In England, Watt was apparently too much engrossed with other work to pay much attention to steam carriages. He applied for a patent for one in 1781, but there is no record of his having followed up the matter further. In later years Watt was opposed to steam carriages and would not let them pass his residence.

In 1772 Oliver Evans, in America started his investigation of the steam-engine. In 1776 he petitioned the Legislature of Pennsylvania for the exclusive right to use his invention for flour mills and steam carriages. The petition was partially granted in 1787, but the steam carriage part of it was entirely ignored. The Legislature of the State of Maryland granted a similar petition in 1787. Evans succeeded in making for the Board of Health of Philadelphia a curious steam dredging machine, which, when finished, was mounted on wheels and run by steam from the shop where it was built to the water, a distance of a mile and a half. There the wheels were removed, the boat was launched, and steam was used to turn the paddlewheels.

Returning to England, we find that William Murdock, a contemporary of Boulton and Watt, made a most successful model of a steam carriage in 1784, but did not proceed further. William Symington, who built the first practical steamboat ever made, also made a model in 1786 which gave excellent results. No successful steam motor carriage was, however, made in England until 1801, when Richard Trevithick produced a steam carriage, which, although crude in the extreme, was a practical locomotive. This carriage was first tested on Christmas Eve, in 1801, and ran for several trips. Trevithick's success was very marked, and much is due to his experiment. He was the first to introduce exhaust steam in the smokestack. Still another carriage intended for use on common roads was that of Julius Griffith, built for him by Bramah in 1821. The whole outfit was of excellent design and construction. The boiler, however, was so designed that it made the regular generation of steam impossible, as water was expelled from the tubes and could not be re-introduced. Although the carriage was often experimented with in the yard or shop grounds where it was constructed, there is no record of any trips or tests being made.

From the time of the construction of Griffith's carriage, in 1821, until 1840 steam carriages were built for operation on common roads. Most of these were experimental and were built by private individuals at great labour and expense. All were heavy and clumsy, and could not run more than seven or eight miles without stopping to take on fuel and water. As a rule, they were mechanically successful and could run at rates of speed ranging from eight to twenty miles an hour.

J. Scott Russell, who designed and built the *Great Eastern*, built also a number of steam coaches of excellent design. These were run successfully between Glasgow and Paisley until hostile legislation prevented their further operation. Sir James Anderson, an Irish baronet, devoted thirty-one years of his life to steam carriages and spent £30,000 on experiments, but achieved little or no success. Undoubtedly the three most successful early builders of steam carriages were

Gurney, Hancock, and Maceroni. Of these three, Gurney has received the most credit, and at one time a committee from the House of Commons recommended a grant of £16,000 as reimbursement for his expense in experimenting with steam carriages. Sir Goldsworthy Gurney started his experiments in 1825, and built steam coaches until 1832. They were fitted with his patent water-tube boiler, and with slide-valve engines, a feature of the boiler being a system of chambers or separators to prevent priming. Steam could be raised in about five minutes, under favourable conditions.

In 1831 Sir Charles Dance started a steam stage-coach line between Gloucester and Cheltenham, using Gurney's coaches. The line was successfully operated for four months, when determined opposition, coupled with excessive turnpike tolls, caused the venture to be abandoned. At one time eighteen inches of broken stone were laid on the Gloucester road, and the carriage, loaded with twenty passengers, twice ploughed through the obstruction; but the strain so weakened an axle that it broke. During the existence of this stage-coach line 396 journeys were made, covering 3,644 miles in all. Four hundred passengers were carried, and £78 were expended for coke, or about 5d a mile for fuel.

In 1831 Gurney petitioned to have the excessive rates of toll removed. In the same year a select committee of the House of Commons took evidence for three months from the leading stream carriage builders and civil engineers of the country. Among these were such men as Davies Gilbert, M. P., president of the Royal Society; Thomas Telford, president of the Institution of Civil Engineers; James MacAdam, inventor of the macadam pavement, and others of similar standing. This committee inquired most thoroughly into the proportion of tolls which should be imposed upon coaches and other vehicles propelled by steam upon turnpike roads, also the rate of tolls actually levied, and, further, into the state at that time and future prospects of the steam carriage on common roads. Their conclusions were:

First. That carriages can be propelled by steam on common roads at an average rate of ten miles an hour.

Second. That at this rate they have conveyed upwards of fourteen passengers each.

Third. That their weight, including engine, fuel, water and attendants, may be under three tons.

Fourth. That they can ascend and descend hills of considerable inclination with facility and safety.

Fifth. That they are perfectly safe for passengers.

Sixth. That they are not, or need not be, if properly constructed, a nuisance to the public.

Seventh. That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

Eighth. That, as they have a greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages cause less wear of roads than coaches drawn by horses.

Ninth. That rates of toll have been imposed on steam carriages which would prohibit their being used on several lines of roads, were such charges permitted to remain unaltered.

A bill for the repeal of the "Turnpike Act" was twice referred to a select committee, but did not pass the House of Lords. On the failure of this bill Gurney gave up the manufacture of steam carriages. Walter Hancock was the most successful builder of steam carriages in England at this date. He built ten carriages, nine of them large omnibuses, and the last two carriages were successful in every way. Hancock began working on steam carriages in 1825, and continued his labours until 1840. The boiler employed by Hancock consisted of a series of chambers arranged vertically. The bosses of one chamber rested against the bosses of another, the whole being stayed by strong bolts. The engine had two cylinders and was placed vertically, motion from the crankshaft being communicated to the rear axle by a chain. It is stated that Hancock was the first steam carriage builder to run his carriage in the streets of London, where they were operated without noise, smoke, or appearance of steam. They did not frighten horses, and created a most favourable impression. Hancock's carriage ran between London and Paddington for five months. The London & Paddington Steam-Coach Company was formed with the intention of using Hancock's machines, but the company treated Hancock in anything but a business-like way, retaining one of his

carriages for a considerable period for the purpose of taking it apart and copying it. Many important improvements were introduced by Hancock, and his carriages were very successful, mechanically. He introduced exhaust steam into the fire, and it was usually invisible. The safety valve was arranged to blow off in a separate box. The system of springs used was excellent.

The connection of Colonel Maceroni with the manufacture of steam carriages has been more or less ignored by historians. Maceroni built two of the best steam carriages ever made, although he was handicapped by lack of funds. He was also particularly unfortunate in business ventures, and did not succeed in making more than two vehicles. The arrangement of his machinery was very compact, and Gordon describes the carriage as being "a fine specimen of indomitable perseverance." The boiler was an excellent one, of the vertical water-tube type, with steam connections at the top and water connections at the bottom. It was fitted with a steam dome. A pressure of 150 pounds was carried. The vehicle ran with great speed, twenty miles an hour being often attained.

Maceroni and Squire were in partnership for a considerable period. After this partnership was dissolved Maceroni became short of money and allowed a man named Asda to take the two carriages abroad. Asda agreed to pay Maceroni a certain percentage of the price received for patents, and departed. The carriages created a sensation on the Continent, and Asda was successful both in the demonstration of the capabilities of the vehicle and in the sale of the patents. On his return, however, he refused to make any settlement with Maceroni, and took all of the money, as well as the credit, to himself.

Since, then, up to that time a number of successful steam carriages had been built, the question naturally arises why the steam carriage industry did not have a natural and steady growth instead of dying out completely about the year 1840? This question cannot be answered off-hand, as the failure of steam carriages was due to a variety of reasons. There were, to begin with, poor roads. The condition of roads in Great Britain at that time was generally bad, and the excessive vibration caused by travelling at a fairly good rate of speed was too much for the machinery, so that repairs were frequently necessary. Rubber tires had not yet been invented, and springs were just beginning to be used. The steam carriage industry, moreover, was strongly opposed by numbers of country gentlemen, landlords, stage-coach companies, and others who did all they could to have the steam carriages turned off the roads. Excessive tolls were a direct result of this opposition, and it is said that at one time there were no less than forty bills presented to Parliament for the purpose of having steam carriages removed from common roads.

Then, too, there was the unfortunate tendency of inventors to disregard previous inventions. Many of the builders of steam carriages at that time were unwilling to accept well-tried ideas, but went their own way, trying to introduce their own patents. As a result, almost all the steam carriages built were, in every particular, experiments, instead of being an assemblage of tried devices with a few improvements or later inventions.

Another factor opposing steam carriage progress was the growth of the steam railway. Following Stephenson's successful run with his locomotive, *The Rocket*, in 1829, this growth was very rapid. The leading scientific and moneyed men devoted most of their time to this subject, and in conseqeunce the steam carriage naturally suffered.

There are few records at this date of any accidents with steam carriages. While Roberts was running a steam carriage in the streets of Manchester, several of the boiler tubes burst, but the accident was a slight one, though greatly exaggerated at the time. Little damage was done. A serious accident, however, happened to one of Scott Russell's steam carriages while running from Glasgow to Paisley. Somebody, opposed to the steam stage-coach line, had placed eighteen inches of broken stone in the road, and, while ploughing through, the carriage was overturned, and the great weight resting on the boiler caused it to explode. Several of the passengers were killed and others injured. In 1840 the subject of steam locomotion on common roads ceased to be a matter of public interest, and from that time on there was no marked development other than in connection with the traction engine. The steam carriages of Rickets, Carrett, and others were simply traction engines arranged to carry passengers. In America, J. K. Fisher devoted much study to the steam carriage, although he was discouraged in his attempts by those who claimed that in Great Britain, on better roads, little or nothing had been accomplished. Fisher experimented as late as 1870 and pro-

duced several steam carriages, which were rather light and may be considered as generally unsuccessful. Other steam carriages were built in America during the period from 1840 to the present time, but most of these were experimental and were not permitted to run on the highways for any length of time. The steam carriage of Richard Dudgeon, shown on page 120, was built in the early fifties, and is still in excellent working condition. This machine was run in New York City and on Long Island, and it is at present stored at Locust Valley, L.I.

The regeneration of the steam carriage has been recent, and in great part has taken place in the United States. Three years ago there were probably less than a dozen steam automobiles in the country, while now there are about three thousand in actual use. This striking development has been greatly assisted by the introduction of liquid fuel and a wider knowledge of the properties of steam. Mention should be made of the excellent heavy steam vehicles of British manufacture, and the successful vehicles of DeDion and Bouton, Scott, Serpollet, and others in France, but the general tendency in these countries has been toward the development of gasolene carriages.

Serpollet invented his flash boiler in the early seventies, and has worked consistently on steam automobiles. A boiler of this type must be expensive to manufacture, and the time required to heat the elements before starting may be considered a disadvantage, particularly in pleasure vehicles. The success of Serpollet, however, should stand as a proof of the desirability of steam as a motive power for automobiles. Probably few engineers will deny the statement that steam is the best power for heavy automobiles. The successful operation of steam truck and omnibuses in Great Britain and France supports this view, particularly when we consider the almost general adoption in those countries of the gasolene motor for pleasure carriages.

Of the several thousand steam carriages of American manufacture a large number have been in use a long time,—certainly long enough to dispel any doubts regarding their practicability.

The results have been satisfactory to a high degree, both to the manufacturer and to the user. It has been demonstrated that the driver of a steam-motor vehicle need not be an engineer, and that carefulness and common sense are all that is required. The question of economy is not an important one, as the steam carriage may be operated by any one for less than a cent per mile per passenger, including lubricants.

The question of repairs is an interesting one. If a man expects to save money by disposing of his horses and adopting a motor carriage, he must give the latter good care and attention. Repairs are necessary to all machinery, but with proper inspection and maintenance, and common sense operation, the repair bill should be very small. Repairs to a steam carriage can be made almost anywhere, and this is an important advantage of the steam-driven vehicle.

As a hill-climber the steam carriage has proved its worth. Pike's Peak, in the United States, has been partially ascended, and an elevation of 11,000 feet has been attained. The highest peaks in the Yosemite also have been reached, and Mt. Washington has been ascended and descended twice by a steam carriage. In the 1000-mile trip of the Automobile Club of Great Britain, a steam carriage of American make competed against fifty-seven gasolene motor carriages, and its hill-climbing performances were a revelation. The steepest hill encountered on the trip was near Nottingham, and a record of the performances of the vehicles on this grade placed the steam automobile at the head of the list in a class by itself.

With the use of steam, great power can be stored in small space, and consequently the weight of a steam automobile is low—much less than the weight of an automobile driven by a gasolene or an electric motor. The reserve force in the boiler can be used to propel the carriage up a very steep hill, in which case the engine may be developing more than its indicated horse-power for a short time, and the boiler will supply a sufficient quantity of steam to the engine, provided the speed is not too great. Thus a four horse-power engine which may be developing but a single horse-power on a level road may be forced to do six or even eight horse-power. This flexibility of the steam system is an advantage.

A carriage driven by a gasolene motor does not possess this feature, and, consequently, in order to ascend the same hill at the same speed as the steam carriage, it must have an engine of greater horse-power. With increased horse-power comes an increase of weight. A standard type of gasolene phaeton of eight-horse power weighs about eighteen hundred pounds. A standard make of steam carriage of four horse-power weighs half this amount in service condition.

As to the electric carriage, the storage battery necessary to do the same work must be very heavy. The fault is not in the motor, this, indeed, being an ideal type, but in the battery, which, if forced, will be discharged too quickly, and this, as is well known, will ruin the cells.

Assuming, then, that the steam carriage has the advantage in weight, it follows that it is less expensive than the other types, and this is borne out in practice. The matter of speed is not important. It is requisite, however, that changes of speed be readily effected. A slight touch on the throttle lever of a steam carriage varies the speed instantly, and any speed from rest to the fullest capacity of the engine can be produced by this lever. It is an interesting sight to watch the performance of a steam carriage in a crowded thoroughfare. The speed can be varied so quickly as to give the operator thorough control of his machine, and it glides in and out among street cars and trucks like a thing of life. The carriage has a smooth motion, and the general adoption of the chain as a method of transmitting power has reduced the noise to a minimum. The exhaust is muffled and the quantity of visible steam is very small—never enough to frighten horses or to be considered as a serious objection.

A word as to generators! For automobile use the Stanley type boiler is, undoubtedly, the best known. It is of copper, of the fire-tube pattern, contains 44 square feet of heating surface, and weighs 100 pounds. Steam can be produced in less than five minutes from cold water, and the boiler seems to steam as well at one water level as another. It is absolutely inexplodable under all conditions. One of these boilers was tested to 1225 steam pressure, at which point no further increase in pressure could be produced owing to slight leaks. The boiler was then cooled, tested to 600 pounds cold water pressure, and is at present in regular service.

The engine for a steam automobile is preferably of the slide-valve type and need not be compounded. Two simple pressure cylinders are generally used. It must be remembered that the cylinders in a steam carriage are small and that the stroke is short; consequently the conditions are quite different from those ruling in a larger engine. Economy is not the most important consideration, and, generally speaking, it is not advisable to use a compound engine in a steam automobile. It is important that a steam-engine for automobile purposes should be of the very simplest type and one that can be most easily repaired. In a slide-valve engine fitted with a link motion, it is possible to vary the point of cut-off so as to work the steam expansively. It is very doubtful, however, if this is advisable, as the stroke of the piston is very short and the steam does not have much opportunity to expand. Moreover, when the engine is hooked up, the valves are given an excessive amount of lead, and unless the valve adjustment is very good, the engine will pound. When the valves are properly set and all the bearings and wearing parts are clean and well adjusted and thoroughly lubricated, the engine will run very easily and will use very little steam.

The ultimate success of any automatic boiler feed is very doubtful. Even though the boiler be fitted with a device of this nature, the water tank should have an alarm, otherwise the boiler will become dry. Generally speaking, automatic devices are not reliable, and must be watched if they are to give good results. It is advisable that the operator have control of the water supplied to the boiler. In going up a very steep hill it may be necessary to shut off the pump in order that the boiler may make steam faster; also in going down a steep grade, it ought to be possible to cut off the pump in order that the boiler may not be flooded. The operator of a steam carriage will not find it troublesome to regulate the supply and to glance at his gauge occasionally. A geared pump attached to the crosshead has been universally used, and this gives very good results, in spite of its small size. It is absolutely necessary to have two methods of filling the boiler with water, and a hand pump is probably better for this purpose than an injector. It is more simple, and can be operated by any one. An injector has not been used very much, the chief objection to it being that its orifices are small and apt to clog up. It is also apt to flood the boiler.

The subject of condensation has not received much attention. The exhaust from a steam carriage is practically invisible the greater part of the year, and in no case is it objectionable to the operator. A condenser of any type would certainly add cost and weight to the outfit. If a surface condenser be used, it would be necessary to separate the oil from the exhaust steam before returning the water to the reservoir. An atmospheric condenser would probably be better, as in summer the condenser is not needed, and in winter the low temperature would make this type very efficient.

In the United States the steam truck has not been developed to any great extent. It is obviously more expensive to experiment with a vehicle of this nature than with a small steam pleasure vehicle, and the conditions of operation, moreover, are entirely different. But as it is generally agreed that the demand for motor trucks and omnibuses is practically unlimited, and that steam is the proper power to use in heavy vehicles, substantial development may be expected before long in this field also.

Krarup, M. C. "Automobile Development," *Outing*, 37 (February 1901), 548–554

This article evaluates the development of the automobile. The author notes that no engineers are masters of all the questions of automobile construction; rather, automobiles are constructed through individual experience and learning. As a result, says Krarup, the question as to the present status of automobilism cannot be answered on technical grounds.

Krarup observes that the gasoline motor vehicle is "cruder in the quality of its performance" than steam or electric, but he believes the latter two are more limited in usefulness, while the "gasoline motor vehicle is more like an unbroken horse." Like many observers, Krarup notes the conservatism of steam carriage builders, and he suggests that the steam carriage would be more efficient if the engine were placed under the carriage. He suggests that the "necessity for new design in the gasoline vehicle is more pronounced, and the necessity has caused the radical departures from ordinary carriage lines * * *."

Automobile Development

BY M. C. KRARUP

Three "cycles of Cathay" have been concentrated in the few years which separate the opening of the twentieth century from the first practical application of the electric storage battery and the first mounting of a gasoline engine on a mechanical vehicle.

Automobilism rests squarely on these and the steam-engine; the three physical pillars of modern civilization. It would be impossible except on this foundation. It stands as the most important attack upon our wonted mode of living, which without yet being brought to a successful close, seems destined to succeed completely because it involves no really new problems, but only painstaking application of knowledge which the world has already made its own. There is hardly room for the assumption that automobolism may be a huge fallacy, and that the thousands of motor vehicles now existing may disappear as completely under the horizon of a few years hence as did the steam road-wagons, which, since 1784, have appeared and reappeared on the scene at intervals of about thirty years; in each instance springing into a brief notoriety, only to vanish by reason of their inherent defects.

With perhaps 50,000 mechanical vehicles in use all over the world, it seems preposterous even to think of the possibility that further experience might condemn them to disuse. They are regularly used for carrying mail and provisions to military forts through a wild, roadless country in French Soudan; they have proved of high value in solving the transportation problems in the war against the Boer republics; they form a much-illustrated feature in French and German army maneuvers; physicians are employing them for professional calls, and in all the centers of civilization they are being more and more widely used for pleasure-driving, and for short hauls of freight, for trucking and merchandise delivery.

Nevertheless the question is asked: Are they being used on their merits, or for the sake of a theory in their favor, or perhaps for advertising, or in order to satisfy personal vanity?

It has been alleged that in a society where financial disparity did not exist, automobile pleasure-carriages could not be sold; that they are made and used only because there are persons to whom cost is a subordinate question. And it is reasoned that, this being the case, the present use of automobile pleasure-carriages decides nothing as to their real merits compared with older methods, and furnishes no decisive argument for their continued use, which must eventually be determined on the point of merit alone.

Perhaps, it is also said, the automobile movement, with its hopes and its disappointments, will prove such a fillip to the energy of horse-breeders, that soon the horse and its animal mechanism will become the subject of close and intelligent study, on entirely new lines, with the result of largely increasing its usefulness and decreasing the cost of its keep, even as we know that many half-civilized tribes get much more and better work out of their horses than we do.

The warmest friends of automobilism themselves feed the pessimism of the doubters when they point to the great benefit which will be derived from automobilism through the road improvements that must go hand in hand with it. At the rate of $4,000 per mile only a small percentage of the road mileage in the United States could be radically improved for one thousand millions of dollars; and if road improvement on this extensive scale is really required to assure the successful operation of another one thousand million dollars' worth of automobiles, how shall the initial difficulty of introducing them in earnest, for all classes of work, be overcome? considering that no automobile will show its full value before a large portion of the road system has been improved.

Nobody undertakes to answer these questions, or other expressions of doubt in regard to the future of the automobile. They must be answered by facts accomplished. It is realized by those best informed that a good deal of faith is required to be a stanch automobilist, and while many are strong believers on the basis of very poor reasoning, there seems to be no shorter road to the true faith than through a thorough study of automobiles in their practical workings, following upon a very complete technological education.

It is in this respect rather characteristic that the greatest enthusiasm for automobilism is found among those who prefer the explosion motor vehicle, which at present is much cruder in the quality of its performance than either the electric or the steam vehicle; and it is also notable that some of the best explosion motor vehicles are designed by electrical engineers, some of the best steam vehicles by photographers, and some of the best electric carriages by bicycle manufacturers. Automobile progress depends to such an extent on all of the principal discoveries of the past century, that it is hard to find men in the orthodox M. E. profession who are masters in all the questions involved in automobile construction. Automobilism draws its designers from many vocations. They fumble and grope in the beginning, but learn as they proceed; and when the results accomplished by all of them are exhibited, as they were recently on two successive occasions in New York, the public at large is induced to believe that it may form an approximate idea of the automobile development that has been reached; but, unfortunately, an indoor "show" fails to reveal much that is of the highest interest for judging of the real fitness of the various carriages, under working conditions; and again the public must fall back on what faith they can muster, and such evidence of faith on the part of manufacturers as one may be disposed to find in a gorgeous display, elaborate workmanship, and expensive finish.

A really competent opinion can only be formed by those who are, or might be, automobile engineers themselves, and this qualification can at present only by courtesy be admitted as properly belonging to any one person; automobile engineering not being a small, special branch of mechanical engineering, but, on the contrary, one that comprises all the requirements of all branches of engineering, in their most exacting form; with the additional requirement of experience in the art of carriage building and familiarity with all the changing conditions under which vehicles must be used. Practically, automobile engineers do not exist, but the best automobile results are obtained by co-operation between persons qualified, each in one of the branches of knowledge entering into the construction.

This is the situation especially for the gasoline motor vehicle, less so for the steam vehicle, and in a still smaller degree for the electric carriage. The

three types are therefore reaching toward perfection in the reverse of the order named; but on the other hand, the electric vehicle and the steam phaeton or surrey have limitations that seem unavoidable, while the explosion motor vehicle, once perfected, seems to be adaptable to all kinds of work for which horses and wagons have heretofore been employed.

The electric and steam carriages as known at present are to all intents and purposes new commodities, highly useful in their way, but their value is to be judged from a personal standpoint in each case without any reference to what previously has been done by horses. They are adapted for certain kinds of work in the hands of certain classes of people, and, to paraphrase Lincoln's well-known remark, "if the kind of service they are adapted for is the kind of service a person wants, then such a person is just the kind of person who should buy that kind of a vehicle." The gasoline motor vehicle is more like an unbroken horse; it will not do any work quite satisfactorily, but nothing that we are accustomed to look upon as vehicular work is beyond its scope and possibilities.

As the limitations of the steam carriage are very largely conditioned by the high degree of skill, care, and watchfulness which they exact, and the great bulk of the boilers and tanks; it seems to the writer that the future of the steam system for automobiles would be brighter, and its field larger, if more ingenuity were expended on devising a suitable form of steam horse entirely dissociated from the carriage proper, so as to leave the latter free from the encumbrance of machinery, and frankly acknowledge the motor portion as the delicate engine which it is, wherever it is placed. But nothing has been done in this respect, and nothing will probably be done, unless the need arises for steam vehicles to be used for other than purely pleasure purposes.

What is the present status of automobilism? The question cannot be decided on technical grounds, because nobody's competency to give the decision is admitted. Each constructor is entitled to his opinion. The public can have none, except as it may judge from what the various vehicles prove themselves in practice. The exhibitions give only clues in this respect, but leave a multitude of questions unanswered. They show styles, and workmanship, but fitness only in the meagerest fashion. Still, a few data are beyond controversy, mainly the favorable ones.

Electric carriages of the larger sizes are practically where they were a year ago. The latest development tends toward diminutive electric piano-box runabouts, so small and light that two storage cells, weighing less than two hundred pounds, will propel them as far as three-thousand-pound batteries will propel a five-thousand-pound electric cab. These light electric vehicles are not subject to those troubles with the air tires that form one of the most formidable items of expense in the maintenance of the full-sized electric carriages.

Two of the largest producers of electric carriages, the American Bicycle Company and the Electric Vehicle Company, have this year supplemented their stock with gasoline vehicles of very substantial design, and containing original features in construction. These are both illustrated herewith, and it is perhaps worthy of special notice that the Electric Vehicle Company's gasoline carriage supports the engine, and driving mechanism, entirely on the running gear, leaving the carriage box free for other purposes. The spark shifter is automatically regulated according to the engine speed, by means of a governor, a provision which removes one of the features in the management of gasoline vehicles which troubles beginners most.

It is one of the most decided advancements of the year, that speed regulation, by throttling of the explosive mixture, has been perfected—as in this carriage and several others—so that now all voluntary speed changes of the vehicle may be effected as easily as with a steam-engine, while the variable gears need only be used when the speed of the engine is insufficient to produce the desired speed of the vehicle, or the power insufficient to overcome the resistance from road and wind with the normal gear. Indirectly the throttling system, which is more specially American than any other feature of the gasoline-engine vehicles, contributes to reduction of noise, reduction of the amount of cooling water to be carried, and reduction of the disagreeable shaking of the carriage—three shortcomings which have militated strongly against gasoline vehicles in the past. The value of the throttling system depends principally on the fact that, for nine tenths of the work of a vehicle, the full-sized explosion that may be produced in the cylinders develops much more power than can be utilized, and much more

heat, and vibration, than desirable. The most original and effective throttling system is perhaps exemplified in a radically new motor, which at the Madison Square Garden show was exhibited in a little three-wheeled vehicle. Although capable of as high as five-horse-power, the single cylinder motor of this little carriage worked with perfect regularity at a power development not exceeding three fourths of one-horse-power, and seemed better adapted for light work than any of the other air-cooled motors, mostly of French design, usually employed in motor cycles and very light carriages, in which the power application is regulated chiefly by the spark shifter. In the new American motor referred to, the compression of the explosive charge is variable, but its composition constant, and the spark, while not automatically regulated, except for starting the motor, is fired in the middle of the combustion chamber, in order to reduce the time for flame propagation, but is not retarded or advanced according to the engine speed.

In variable-gear-devices no radical improvements are recorded, and sparkers and vaporizers still leave much to be desired in the majority of vehicles.

The prominence of the water coils, in which the cooling water is exposed to radiation of heat, constitutes one of the esthetic drawbacks to the larger sizes of gasoline vehicles, from which no relief is in sight, but otherwise, it seems to be generally admitted that there is freer scope for artistic, and striking design in this type than in either steam or electric vehicles. It would probably be more correct to say that the necessity for new design in the gasoline vehicle is more pronounced, and that the necessity has caused the radical departures from ordinary carriage lines by which the gasoline vehicle distinguishes itself, sometimes offensively, but oftener in a manner pleasing to the eye and grateful to the natural demand for new contours in new things. Among the illustrations will be noticed one representing a carriage made by the Automobile Company of America, in which this happy boldness of design is well merged in a harmonious *ensemble*.

In the massive Daimler freight wagon is shown one of the first American applications of the explosion motor system to heavy work, but the pattern is almost if not quite identical with Daimler wagons built in Europe for the same class of work.

A number of heavy gasoline touring carriages have been developed, of which the Robinson carriage is a good example. They represent a school of automobile engineering which studiously avoids everything flimsy and untried, in favor of the safety against breakage that may be obtained by the use of heavy material and painstaking workmanship, and it seems to be well established that these heavy carriages can actually travel over bad roads at high speeds; but those who look to automobilism for all-round usefulness, find it difficult to discover the germ of further progress in a system of construction by which two to three thousand pounds of material are required for the transportation of two or four persons. Still the ratio of weight to pay-load is said to be smaller than that between the weight of a Pullman sleeping-coach and its full complement of passengers.

In steam-vehicle construction there is a similar divergence of opinions in the matter of weight. The extremely light steam phaetons of a year ago have practically been discarded. Even those manufacturers who prefer light construction have increased the weight from five hundred to seven hundred and fifty pounds, and the opposite faction, which is more numerous, produces carriages which average about fifteen hundred pounds. The addition of material is partly in the carriage portion, but also largely in the boiler and engine. Boilers and water-tanks are made larger than formerly, and in racing vehicles attain a special size with a view to sustaining high speed for a long time. Engine construction, with all its minor variations, is kept well within the experence of time-honored steam-engine practice, and nothing radically new has cropped out. In fact, there is a marked reaction from the preference for automatic regulation of the operative functions of the engine, which was incorporated in the first successful American steam automobiles. Most builders now lean to the opinion that automatic devices lull the operator's watchfulness unduly, and become a source of danger to the integrity of the engine through failure to operate reliably. By dispensing with the automatic devices, they simplify the mechanism, and throw the burden of correct operation upon the skill and care of the driver. Several builders go so far as to warn prospective customers from purchasing, unless they are willing to take upon themselves all the responsibilities of a locomotive engineer. A notable exception, in this respect, is the Overman Automobile Company, which makes the Victor steam carriages. In this vehicle the principle of

automatic regulation is carried out consistently; to such a point of completeness that an entirely unskilled person may operate it after a few minutes of instruction; but the automatic devices are supplemented by others, that permit the operator to throw them out of action, and regulate the functions of the engine by hand. The carriage body is entirely of metal, and the steam exhaust is made invisible by fine comminution through sixty small apertures in the exhaust tubes.

In all of the steam pleasure-carriages, so far produced, the entire carriage body is filled with machinery, and no space is available for baggage; but a makeshift arrangement is made in some instances, permitting a trunk to be strapped to a shelf bracketed behind the seat. Lately, steam delivery-wagons have been placed in the market, in which the carrying space is obtained by means of an inclosed superstructure over the rear portion, and the chimney is boxed in and extended through the ceiling of this superstructure. Many different patterns of chimney hoods have been tried during the past year, with a view to preventing the wind from blowing into the gasoline burner and interfering with the regularity of the flame and the steam generation. Most troubles in this respect are said to have been overcome.

Krarup, M. C. "The Prospects for Economical Automobiling," *Scientific American Supplement*, 51 (May 11, 1901), 21201–21202

This article is included because it focuses on the problem of producing an inexpensive automobile—the solution of which was Henry Ford's key to success. Observing that there are few "full-fledged automobiles at present," Krarup concludes that developing the engine and fitting it to the body are the keys to success. He further concludes that the gasoline engine offers the best hope for an inexpensive engine, but he notes that "this power is by its explosive nature as poorly adapted for the work of driving a vehicle as imaginable." The author suggests that steam and electric vehicles remain viable alternatives because it is not certain that present progress in developing gasoline engines for automobiles is satisfactory or is evidence of ultimate complete success.

The Prospects for Economical Automobiling

BY M. C. KRARUP

The slump from which the automobile market in France suffered during the latter half of the year 1900 was followed by a material reduction of the selling prices at the beginning of the present year, and now the public demand for automoblies is being quickly revived in that country. Great Britain and Germany are following suit in a measure modified considerably by the lower range of price spreviously prevailing in both these countries. Will something similar take place in America, notwithstanding that our prices from the beginning have been far below the schedules of Europe? And, inquiring further into the future, how long will it be before any person whose economical condition would permit the ownership of horse and vehicle may just as well contemplate the purchase of an automobile?

Commonly these questions take the more definite form: How soon will it be possible to buy a practical, reliable and useful automobile for $500? With this price limit the question refers mainly to pleasure vehicles, from the use of which no pecuniary returns are expected. With reference to business vehicles it may be put a little differently. The American business man does not like a large initial investment in a new venture. He has been accustomed to "turn his capital over" once a year in every enterprise involving risk and personal work. He wants to do the same with business motor vehicles. Spite of all computations of interest and

depreciation tending to show that automobiles at their present prices and cost of operation compare favorably with the capitalized cost of horses and their keep, he will continue to consider them dearer so long as their first cost is much higher than that of the horse equipment which suffices for his work. The possible savings in operation, upkeep and time constitute his business chance. It is an uncertain factor, and reimbursement from future savings must be very sure before he will consider it a suitable compensation for a high and certain immediate disbursement. Perhaps the average business man will consider a 25 per cent higher purchase price the limit of "what is about right." If a team of draft horses and a dray cost him $700, he may be willing to pay $900 for a motor dray, but ordinarily not much more.

How soon will he be able to buy it at that figure?

Probably his expectations may be met long before those others can be gratified who hope to buy a smaller power in a pleasure vehicle for about half as much money, for within the moderate dimensions available for vehicles it is not principally size that enhances first cost of machinery and wagon work, but the quality of reliability of the motor as a power producer and the refinement of its operation. Reliability once attained will be imperatively demanded for a small pleasure vehicle as well as for the dray, and refinement in operation is naturally more important in the former.

These principal factors of cost will continue to apply to all sizes of motor vehicles in nearly equal degrees untill standard patterns shall have been reached and the manufacture reduced to routine processes, and the tendency must therefore be that of maintaining a certain level below which the prices for an acceptable quality in automobiles cannot descend at any given time, almost irrespective of size and the animal horse-power which the automobile is intended to supplant.

Infractions of this rule at the present stage are more apparent than real. High prices are frequently arbitrary and find little response among the buying public, while low prices, such as asked for motor cycles, represent a deliberately reduced standard of utility, a compromise between economy and vehicle qualities. Purchasers of motor cycles are supposed to "put up with" crudities in construction, design and operation that could not be tolerated in vehicles intended for something more substantial than sportive play. There is nothing derogatory to motor cycles in acknowledging their limitations. They occupy an essentially new field, most nearly comparable to that of the road and track sulky, and it remains to be seen if this field will be cultivated after means shall have been found for removing the shortcomings in automobile vehicles which in the motor cycle are now more or less frankly accepted in consideration of the low price.

The lack of a commonly accepted standard of automobile quality or fitness explains other deviations from that level—about $1,500—at which the highest automobile quality of the day is obtainable in combination with vehicle qualities corresponding to those of a buggy or "spring wagon." Above this level should ordinarily be found the comforts and style of a fine carriage. Below it there is usually a sacrifice of vehicle convenience as well as of motor quality or traveling radius.

One feature in the automobile market seems at first to support the hope of cheap gasoline vehicles. It consists in the manufacture and offering for sale of vehicles complete with pneumatic wheels, steering gear, differential gear and driving pinion, for $200 or less. That is to say, the motor is omitted; also the transmission mechanism. But the supposition is that any good mechanic with an ambition for constructing and owning an automobile can fit the motor of his choice, steam or gasoline, at an expense of $200 for a gasoline motor and $400 for a steam engine, boiler, etc.

There is the cheap automobile. But it is the part of wisdom when the makers of these running gears and wagon boxes refuse to shoulder the responsibility of fitting a motor in their product and by this omission escape all blame for the shortcomings of the automobile-to-be. In this form of business it is taken for granted that: 1, a satisfactory motor and power transmission gear can be procured; and, 2, that the problems of a running gear and a vehicle body suitable for any motor and transmission gear have been solved. Both assumptions are of course radically faulty. If they were not so, the ideal motor vehicle would already be among us. The best that may be said for a motor vehicle built according to this system is that it may not turn out much worse than more expensive automobiles bought in the open market, and that it may be adapted for the first experiments of inventors who have new motors to try.

ECONOMY IN FIRST COST

From the public's viewpoint the question of economy in first cost is a different one and implies that the complete vehicle shall be known in advance to operate satisfactorily and to be possessed of a reasonable degree of durability. Apart from these requirements, economy has no sensible meaning. With any of the essential conveniences left out which constitute the reasons for using horse and carriage instead of a bicycle, for example, economy takes on a very much restricted meaning, and this applies to motor cycles, to any automobile without baggage carrying capacity, to any automobile requiring special technical education in the operator or caretaker, and to electric vehicles of very limited traveling radius. These are all new commodities, comparable to nothing that has previously existed. They do a new class of work, each of them, by new means, and the idea of economy as here considered, being relative and only intelligible in comparison with earlier methods of doing the same work, is inapplicable. Their economical worth must be judged by new standards drawn directly from the consideration of the special class of work for which they are fitted.

In order to have a clear case the economy of the automobile must be looked upon solely with reference to such automobiles as are intended and adapted to take the place of a horse and vehicle equipment in all respects. Whether other self-propelled vehicles are worth the money asked for them each individual must decide according to his needs, his fancy and his knowledge of what the vehicle will do. If he has had a saddle horse and wants a change, a bicycle is the nearest substitute. It can be obtained at from $25 to $75, and costs practically nothing to keep, but it is impracticable on muddy roads and under certain other conditions. A motor cycle is still more impracticable on muddy roads, but it will go much further and faster than either bicycle or saddle horse on good dry roads. It can easily be arranged to take an extra passenger. It supplies at present a somewhat troublesome and decidedly disagreeable form of locomotion. What this *ensemble* of attributes is worth is an individual question. Comparisons are idle. The cost—$400 to $600—may be low for a fancier and prohibitory for one who wants to cart goods to market. The convenient little electric runabout of recent production, of which the battery weighs less than 200 pounds and may be easily handled, may be excellent and well worth $500 for taking a man to his office or a woman to the shopping district and back, but it is worthless for many other kinds of work for which a horse and vehicle could be used.

It is the full-fledged automobile which is of prime interest. Automobilism will stand or fall with it, economically and otherwise. When perfected its perfection will be the standard from which no downward deviation will be tolerated in any other class of mechanical vehicle. Its speed, now its chief recommendation, will be a mere incident, to be arranged to suit purchasers—a mere matter of power, gearing and strength of material, involving no special engineering difficulties.

In gathering data for forecasting the future price of the full-fledged automobile, one is first astonished at discovering that there are no full-fledged automobiles at present except delivery wagons, electric cabs and carriages, a few drays and here and there a gasoline vehicle with the motor mechanism suspended between the axles under the wagon box. In all others the ordinary vehicle conveniences for carrying goods in addition to passengers have been sacrificed to the necessity of carrying the power source and to the desire for imitating the horse vehicle's outward appearance. They are mere locomotion machines, but not vehicles in the sense of supplying adequate means for carrying, say, 1,000 pounds of baggage if required, as does the ordinary spring wagon.

To remedy this defect is likely to mean additional cost of construction. In the case of some of the electric pleasure carriages the conveniences are equal or superior to those of ordinary carriages of corresponding types—victorias, broughams, hansoms—but with such an addition of weight, causing tire troubles and high operating cost, that the remedy is less acceptable than the defect. The solution adopted in a few makes of gasoline vehicles of hanging the motor mechanism under the wagon box has few advocates, being unsightly and bunglesome for caretaking, cleaning and repairing. But progress seems open in this direction, though on new lines. For light steam pleasure vehicles no remedy worth the name has been discovered. The shortcoming may be considered trifling so long as there are other shortcomings apparently calling for more engineering skill, which must also be removed, but in the competition with horse traction from an economical viewpoint it is not trifling but fatal, and no remedy is in sight short of a radical redesigning of every automobile intended to be more than a toy. Specialties such

as physicians' automobiles, solely and exclusively meant for transporting one or two persons, may perhaps be excepted. These represent the cheapest possible construction of an automobile, and this construction being the one now generally adopted, an increase in cost may be looked for when the defect here referred to shall have been removed.

THE EXPERIENCE WITH BICYCLES DELUSIVE

The popular hope for cheap automobiles rests mostly on the experience with bicycles. On the other hand, sewing machines and typewriters may be cited as commodities in which cheapness is following only very slowly upon extensive manufacture and large competition. If, however, automobiles are to be cheapened it must be through the standardization of certain types of automobiles and the security for large investments in manufacturing plants which such standardization of types will engender. Until the lines of design and construction shall have become fixed and accepted it is reasonably sure that large capital will shrink from the manufacture, especially with the examples before it which the industry affords now of large but apparently premature and unprofitable investments made with the purpose of rushing the manufacture of heavy electric vehicles and light steam vehicles. Yet until capital is freely supplied to organize automobile manufacture economically no great reduction of selling price is to be expected if a margin over the cost of production is to be reckoned with.

While there can be no reasonable doubt that the production of any highly successful type of automobile—and the success well tested out by the public—will be followed by manufacture on a gigantic scale, it is not by any means certain that this will mean a price reduction to the buyer in less than twenty years after the inception of such manufacture. It will beyond all doubt mean a lessening of the cost of production, but it will depend largely on the breath and validity of patents whether the public will receive the benefit.

In this respect the competition with horse traction is perhaps the only feature which may be relied upon to brighten the horizon and prevent a repetition with automobiles of the scandalous extortions which have been practised in this country with relation to telephone and telegraph service.

AN INCREASE IN AUTOMOBILE PRICES

Most other data point rather to an increase of automobile prices than the reverse. Among such data are the following:

The price of steam pleasure vehicles is now considerably higher than when the light steam vehicle was first put on the market, it having been found necessary to make the construction more substantial. Owing to the absence of basic patents in steam engine construction and the comparative economy in operation of the larger sizes of engines, there seems, however, to be the best chance that steam automobiles for heavy hauling—sufficiently heavy to warrant the employment of an engineer—will reach an economical basis at an early date. Steam pleasure vehicles will probably hover over the average figure of $1,500, where they practically are today, for some length of time, until gasoline vehicles become so perfected that the much lower cost of operating them—not much more than one to five as compared with steam—begins to depress the price of steam pleasure vehicles, and perhaps forces them out of the market.

The electric storage battery vehicle is intrinsically the cheapest of all to manufacture. The cost of raw material plus the cost of labor figures up lower than for any other automobile. When the patents on storage batteries expire, in a few years, it will be quite possible to make and sell an electric vehicle of the kind now in use and selling for $1,000 for, say, $600 or less, but improved batteries have already been patented which promise less weight and greater traveling capacity, interchangeably. Other more radical improvements are, while not probable, by no means inconceivable. Nothing relating to new means for generating or storing electric energy may be pronounced impossible. But whatever progress will be made is likely to be patented and will, if radical enough to compete with the gasoline motor for general vehicle purposes, render the present form of electric vehicle hopelessly antiquated.

THE HYDROCARBON MOTOR

The mainstay of all hopes for cheap automobiles is the hydrocarbon motor, with kerosene, gasoline, alcohol or acetylene as fuel. Almost any of the existing models of gasoline motors might be produced in quantities at a cost of less than

$100 for a single cylinder five horse-power engine, the material in the rough being worth about $40. Not one of the double, triple or quadruple cylinder motors used in automobiles would necessarily cost more than $200 if produced by economical repetition methods. But not one of them is so near perfection that it may even be thought of as approaching finality. The "overhead" expenses in their production are enormous, unless an artificial halt has been made in progressive construction for purely commercial reasons.

About fifty American manufacturers produce somewhat similar motors for use in boats and thousands of gasoline motors are more or less successfully employed to drive machine tools in factories and dynamos in electric light plants. These motors are sold at good profits and yet at prices that do not seem high, but any argument drawn from this condition in favor of cheap gasoline vehicles—of satisfactory construction—would be sadly at fault.

DIFFICULTIES INVOLVED

The hydrocarbon or internal combustion motor is generally known to be the most economical power available and the simplest in construction. Unfortunately, however, this power is by its explosive nature as poorly adapted for the work of driving a vehicle as imaginable, especially where crude roads prevail. To make it available even for unvarying work it is necessary to store it first in the rotary energy of a heavy flywheel and then to take the power wanted from the shaft of the latter. This works very well when the power is uniform or of necessity proportionate to the power developed, as that of turning a propeller wheel in water. Still, when the flywheel is heavy enough to absorb the spasmodic power impulses it does not respond promptly to variations in either the work or the power. It takes some time before an adjustment to slow down the motor can take effect. This would be bad for boats and fatal for automobiles. For this reason alone heavy flywheels cannot be used in boats and automobiles, but their size and weight would also prohibit their use. If, on the other hand, the flywheel is small, its stored energy easily becomes insufficient for the work in hand and the force of each explosion takes effect directly in the work, rendering it highly disagreeable for anybody exposed to the jarring.

If the public would accept a form of transportation in which constant shaking of the vehicle is the unavoidable accompaniment of crude construction, there would be no reason why gasoline automobiles should not be sold very cheaply. But the public, in sober reflection, will do no such thing, as long as there are horses, steam and electricity. The majority still believe in the testimony of their senses and cannot remain persuaded that jarring is pleasant and the odor of partly burned gases a delight.

The cost of gasoline vehicles of the highest quality which the present stage of the art affords is mainly that incurred in making a hundred and one more or less efficacious provisions for minimizing, subduing, smothering and absorbing the evil effects of an explosive power by heavy material, fine workmanship, multicylinder high speed motors, ingenious transmission gears, balancing of rotary parts, etc., and the problems involved are so many sided and difficult that the progress made so far looks like a drop in the bucket from the standpoint of a perfectly unbiased spectator.

If the progress were really satisfactory and conclusive evidence of ultimate complete success, steam vehicles could no more be thought of as in the race, and electric vehicles would be at once abandoned to await some revolutionary invention in applied electrics.

The crude gasoline vehicle is cheap, or ought to be cheap—$500—now. The acceptable gasoline vehicle is not yet made, and the creations which come nearest to the ideal conception of the striving engineer are expensive to make, expensive to sell and none too easy to handle. And yet they are the standard bearers of automobilism. Furthermore, they are growing more complicated rather than less so. Refinement spells complication in the gasoline engine as it did in the formative period of the steam engine. Promising improvements are snapped up by large concerns. The possibilities of unpatentable features have been nearly, if not quite, exhausted. The vista of needed improvements presents a deep and interesting but hazy perspective. Automobilism is yet in its infancy.

Cheapness combined with efficiency is not an immediate prospect, but there is compensation in the thought that when cheapness arrives "to stay," it will come in company with all other good and desirable qualities.

In this thesis several apparent contradictions in a brief and brash analysis of a vast subject may be found harmoniously resolved.—The Iron Age.

Bodman, Walter L. and G. T. Hanchett. "Steam and Gasoline Automobiles," *The Automobile,* (March 1902), 68–69

These discussions, by engineers, of the two prime motive powers result in opposite findings: one that the steam car is practicable and others doubtful, the other that the gasoline car is "without qualification" the car to buy. However, neither engineer finds any particular overriding advantage in his favorite; instead, each plays down the disadvantages and plays up the advantages of his chosen engine. Like many other observers, Hanchett, writing for gasoline engines, believes that the steam engine is nearly perfected while gasoilne is an "undeveloped power." It is interesting how often the imperfections of the gasoline engine were perceived as chances for improvement while the difficulties of the steam engine were seen as fixed.

The Steam Automobile

BY WALTER L. BODMAN

Whilst it is obvious that the consideration of the detailed merits of various systems as advanced by their makers will influence the deciding judgment of an automobile purchaser, the more important stage of settling to his satisfaction the variety of power generation he will use must be passed before reaching such a position.

The broad physical claims that can be made in fabor of steam are:

A. The constant generation of heat over a large area, and its absorption by a body of high specific heat, makes it an elastic source of power for use under the most varying load conditions possible to conceive.

B. The generation can be visibly followed in all its stages, and "faults" be readily detected with care when the vehicle is not in operation, so that the operator is usually himself to blame if his machine breaks down in public.

The result of the former feature is a mechanical construction simpler in form and cheaper in construction and maintenance than can be used on a constant load engine generating heat intermittently. An ability to use grosser fuel, and a pleasanter movement of all the parts, engine, transmission and vehicle itself, are obtained. The writer considers that steam vehicle makers are in error in relying absolutely on the variability of steam to surmount all road and weather conditions and that on every vehicle a second or emergency speed should be provided. Still it is a well-known fact that the running gear of a steam machine can practically provide for all conditions, and thereby not only the mechanical construction be reduced to its lowest point, but nearly all the elements of driving skill be eliminated. Ability to recognize the limits of an explosion motor, and the moment when a change of gear is necessary, is in some hilly districts difficult to acquire; and in addition the changes of gear carelessly made can be extremely destructive.

There is little doubt that the use of gasoline for steam vehicles will soon be a thing of the past, and kerosine, which it is perfectly practicable to use in plate burners properly designed, will take its place.

The fuel cost of running an automobile does not exceed, probably does not reach 30% of the total charge, wear of the transmission being a far heavier one; but it is desirable to make this change of fuel in order to equalize fuel cost in a steam car with the same cost in an explosion engine.

The quickness of movement of a steam vehicle will probably form a principal argument in its adoption for business vehicles which are under the necessity to make constant stops of unknown length, their noise having been a militating factor against explosion motor cars in England for this purpose. Provided, however, that he does not get an excessively high prime cost or running and maintenance cost, all considerations for the automobile purchaser are trivial beside that

of immunity from break-down, and particularly break-down under distressing conditions. And there is not the slightest reason why a properly designed steam car, receiving in the coach house as much careful examination as a fairly good horse would obtain, should ever annoy its owner by failure in work.

A great debt is owing to the original designers of the present light American steam car, for the possibilities they demonstrated; but to our mind the experience of the last two years has shown that the time is ripe to change the general arrangement of the steam car, or it may disappear, owing to the difficulties, the present design places in the way of seeing and regulating the generation of power, the most valuable feature of the system.

The adoption of an arrangement by which the weights are brought considerably nearer the ground, the driver moved back from his position over the steering axle, the engine and boiler placed under a hood in front of the driver and the gauges and control levers in a similar position, and the adoption of a "dead" driving axle with double chain drive to each rear wheel are common sense methods of utilizing the "visibility" of steam generation, that with very ordinary care gives steam an almost absolute immunity from unexpected breakdown.

There is nothing to guess about in steam; given a good fire under the boiler, and water in the boiler, the car will run, provided the mechanism beyond the engine is in good order. In this mechanism again there is nothing to guess at for it need contain no slippery device to allow for and trust to. In such a design as we speak of, atmospheric and temperature conditions are unable to prevent the successful operation of the car as a self-propelled vehicle. Rain, wind and low temperatures will naturally affect all transport, but in the case of steam the limit of efficiency is purely the power of adhesion, and no especial knowledge is required to make the motor itself agreeable to the weather prevailing.

Any system other than steam relies for the generation of its power either on excessive mechanical contrivances, as in explosion engines where the admission of the fuel, the volume of the fuel, the regulation, the time of the explosion, the utilization of the explosion and the exhausting of the waste products are separate mechanical operations, none of which admit of any visible indication at the moment of operation that they are being correctly performed, or on chemical means for transporting and utilizing power, as in an electric vehicle. The bringing together of two delicate powers such as an explosion engine with electric ignition necessitates the maintenance of a mechanical efficiency that can only be assured by costly workmanship and expert attention.

The aim of the designer who has the commercial welfare of the industry at heart is to produce a vehicle that shall be roomy and fairly solid in its construction, as certain in operation as a horse receiving proper attention, that shall be sold at a price fixed somewhat by the present cost of such a horse, vehicle and equipments, and shall not exceed the present horse owner's allowance of about 25% of the prime cost for its year's repair maintenance. This means a well-equipped car devoid of fantastic tubular and other toy-like construction, of complete carriage-like proportion, at a total cost of $800, to be run 7,000 or 8,000 miles for a repair bill of $150 to keep it in condition equal to a new car. Such a cost no user could object to, for it is a substantial saving on any form of transport now in use on road, and with a good steam car it is practicable and certain of attainment. Whether this is so with cars using other means of propulsion the writer greatly questions.

The Gasoline Vehicle

BY GEORGE T. HANCHETT

To intelligently answer the question, "What is the best automobile to purchase?" immediately necessitates asking two others, namely, for what purpose is it intended, and who is to operate and care for it? For work within its traction limits, the electric vehicle gives the least trouble to the passenger, but this ceases to be true if the passenger is at once the operator and caretaker, and it also follows that the owner of such a vehicle must have more money to pay bills than those who use steam or gasoline for automobile work. It is further necessary that the passenger shall be satisfied with the limited radius afforded by the electric vehicle. The operator, however, need not be a man of technical attainments or even have more than ordinary familiarity with the power he is using,

for the condition of things is such that he cannot stray far from home. For city delivery work, where a charging station of considerable dimensions provided with competent attendants can be had, electricity satisfactorily fills another field beside that of ordinary city passenger transportation. The automobile enthusiast, however, who represents at present a very large percentage of the manufacturers custom, must dismiss the electric vehicle at once, and there remains for him only steam or gasoline, or perhaps in some cases a combination of either of these powers with electricity.

The load on an automobile engine is probably the most variable load ever put on a motive device of any kind. The motor which delivers this power must possess reserve torque in enormous excess of its steady operating capacity. The vehicle is likely to encounter positions where a certain torque is required to extricate it. This may be needed only for a moment, but if it is not forthcoming the vehicle is stalled and the trip is at an end until extraordinary means are brought in play. The recourse of the steam vehicle is to wait until the boiler pressure has reached a sufficient amount to develop the torque necessary for the purpose. The pressure is often allowed to run up from 200 to 500 pounds in order to give the vehicle sufficient power to mount a grade or traverse a bad stretch of road. This suggests many things with reference to the working strength of the metal of which the boiler is made or the rating of the working boiler pressure, for the designer may depend upon it that among the many automobilists who may handle his vehicles, there will be found some who will let the pressure run up to almost any amount rather than to get out and push.

The reserve torque of a gasoline vehicle is found in its gear, clutch and flywheel system. A gasoline engine can be unclutched from the vehicle and brought up to high speed, and if judiciously clutched to the vehicle on the low-gearing ratio, the result is a very large torque which will usually serve to move the vehicle a short distance. It is very often the case that a short distance is sufficient. If, however, the distance during which the heavy load continues is long, as in the case of a long stretch of heavy muddy road or steep grade, the engine must have sufficient continuous torque to meet the demand. Therefore, the gasoline vehicle should on its low gearing be able to skid its wheels on ordinary roads, and the same should be true of a steam vehicle operated at a reasonable excess of boiler pressure.

At the high speeds, the steam vehicle is likely to be deceptive, for it can spurt for short distances at speeds which it could never maintain for longer ones, because of its inability to keep up the necessary steam pressure which it is easily able to momentarily acquire. The gasoline vehicle, on the other hand, can continuously maintain the maximum speed of which it is capable under uniform road conditions. The steam vehicle is light, stylish, moderately quiet, and its visible exhaust is not an annoyance to the passenger. In its present form, it is useful for light delivery work or moderately extended touring purposes. It requires more fuel than a gasoline vehicle of equal speed and carrying capacity, and it requires on the part of the operator more expert proficiency than any other vehicle. The gasoline vehicle may refuse to run through ignorance or mismanagement, but it is not so likely to hopelessly injure itself through such causes as its steam-propelled competitor.

The gasoline vehicle requires a peculiar qualification of the part of the operator, namely, an intuitive knowledge of the capabilities of the power. The electric vehicle is simply a case of turn on the power and wait for the results. A steam vehicle is largely so with the single exception that the power can be increased by waiting for the steam pressure to rise, but the gasoline automobile must be operated with a certain intuition which neither of the other vehicles require. The expert gasoline automobilist can tell by the sound of his engine and the condition of the road the exact time to apply the energy and the proper gear to use, and can coax astonishing results out of an equipment where a less experienced man would fail completely.

Like the steam vehicle, the supplies are gasoline, water and lubricating oil, but less gasoline and any supply of water will answer, and concerning the water, it may be said that the supply will last very much longer, as it is used for cooling and not for motive purposes. About the only cases where carelessness can seriously injure the gasoline vehicle are those of allowing water to freeze in the cylinder and crack the castings, or to neglect properly supplying the cylinder with oil. The latter case will effectively stop the engine for a time, but even then will not injure the same so seriously that ordinary repairs will not suffice.

The gasoline engine depends absolutely upon the reliability of its ignition, which is usually electric, and requires a reliable source, a well-insulated line and coils, and a clean plug and contacts, matters which a few hours study should make the novice an expert. It, therefore, reigns supreme in the long distance field, and owing to the fact that it can be built much lighter for equal amounts of continuous torque, other things being equal, it holds and will continue to hold supremacy in long distance racing until a radical departure from existing methods in the design of its competitors is made. It is the noisiest of all the vehicles, but its exhaust is colorless, and if proper combustion is obtained, it is largely carbonic acid gas, which is not unduly offensive.

The state of art is such that it is difficult to compare the three powers, for in few cases are the vehicles built on similar lines. In speed, in rugged reliability and independence of a source of supply, the gasoline vehicle stands first, and those who are content to overlook slightly greater vibration and noise will be well satisfied, especially if they take pains to become familiar with the peculiar art of utilizing the power.

The steam vehicle in its present form is light, speedy, graceful and easy to operate, but it is more dependent on source of supply of lesser radius, and in general less substantial.

The electric vehicle is the level, smooth road vehicle for the rich owner with a coachman operator. The brains necessary to maintain the electric vehicle are in the charging station, and it is perhaps fortunate that its radius is so limited that it cannot stray farther from that most important source of supply.

The electric vehicle is at present at a standstill as far as future development is concerned, and will so remain until an improved form of storage battery appears. The torque and efficiency of electric motors is perhaps better known by designers than the corresponding properties of any other form of motor. Perfection in the motor design is a known quantity, and this has been reached within excedingly small percentages in existing machines.

Steam is also at a standstill as far as developing the motive power is concerned. Improvements in this class of vehicle will be confined to increasing the economy and reliability. Gasoline, on the other hand, is as yet an undeveloped power. It is difficult to predict just what results will be obtained in the future for a given weight of metal. The chances for improvement in all directions are admittedly the best. It is capable of an advancement with which its two competitors cannot keep pace, for it is certain to receive improvements of a radical character.

The fields of steam and electricity for automobile work have been so largely exhausted that future improvement in them seems to be quite remote.

At present the answer to the question without qualification as to which is the best automobile to buy, seems to be gasoline. In the future the outlook seems to be such that we may dismiss the doubt and answer in the same way unequivocally.

Edison, Thomas A. "The Storage Battery and the Motor Car,"
***North American Review*, 175 (July 1902), 1–4**

It was well recognized that the future of the electric car, otherwise so attractive, was limited by its battery's weight and need for frequent recharging. Thus, when Thomas Edison, the doyen of American inventors, announced an imminent breakthrough in batteries, the public must have felt that the viability of this alternative had been reestablished.

The Storage Battery and the Motor Car

BY THOMAS A. EDISON

The final perfection of the storage battery, which I believe has been accomplished, will in my opinion bring about a multitude of changes and improvements in our business and social economy. No one of these will interest the public more just now than the doing away with the chauffeur, the irresponsible instrument, in the public eye at least, of so many recent accidents with automobiles.

Of the new storage battery, which was admirably described in *Harper's Weekly* last December, and about which a great many erroneous and unauthorized statements have since been made, I can now say that it has sustained and overcome the four thorough tests applied to it, and it is now, at this writing, undergoing the fifth, and last, with every prospect of the same result.

These four tests, which I will describe briefly, and this fifth now in progress, point to the new nickel-iron battery as being in fact the only real storage battery known. The attempts to compare its performance with those of the lead storage batteries, so called, now in use in automobiles and elsewhere for lack of something better, make it not improper to declare the facts. A real storage battery must be reversible, like a dynamo, which converts power into electricity and *vice versa*.

A storage battery, to deserve the name, should be a perfectly reversible instrument, receiving and giving out power like a dynamo motor, without any deterioration of the mechanism of conversion. The present lead storage battery in an automobile does not meet this condition. It gradually becomes less and less efficient and in a few months wholly inoperative. The acid environment prevents a proper mechanical construction, its chemical reactions are of the most capricious character; it must be watched and treated with great care—so great care, indeed, as to make it impracticable for general use. It can be made, as far as mere weight is concerned, of sufficient lightness to meet all the wants of commerce and pleasure; but, if made light, it rapidly becomes useless.

On the other hand, the nickel-iron storage cell has an ideal environment. Being in an alkaline solution, none of the ingredients is attacked by the solution in any degree. The chemical reactions are also of the most simple and stable character. The conditions permit of a perfect mechanical construction, and, finally, it remains uninjured under any condition which one could imagine, when in the hands of an inexpert. The weight can be made to meet every exigency of commercial vehicle traction, and up to the present time there are no signs of chemical deterioration, even in a battery which has been charged and discharged over 700 times.

I have been working for a number of years on the problem of a true storage battery. The experiments have been continuous for the past three years. The above may be considered the first stage.

Tests on the battery have been going on for over a year and a half; this was the second stage.

The construction of chemical works and a manufacturing plant for the cells was the third stage.

The manufacture of standard cells from the tools is the fourth stage.

Twenty-one cells made in the factories, weighing 332 pounds, were placed in a Baker automobile, the total weight with two men in the vehicle being 1,075 pounds. The vehicle made a run, on one charge, of sixty-two miles over country roads, containing many grades, some as steep as twelve feet in a hundred. At the end of this run the vehicle was making eighty-three per cent of the original speed. The average speed over the entire distance was 11.2 miles per hour. On a comparatively level country road a little heavy from a recent rain, the same vehicle on one charge came to a stop at the eighty-fifth mile.

In spite of assertions to the contrary, I think the storage battery carriage, by the aid of the new battery, will come ultimately within the reach of the man of moderate means. Driving through the many miles of streets in the suburbs of New York, I have been impressed with the fact that something like eighty per cent of the residences have no carriage houses. The storage battery carriage, with the new battery, should enable the owners of forty per cent of these residences to have a serviceable pleasure vehicle at their beck and call, without hiring a coachman to keep it clean and run it, with no horses to eat their heads off and no oats and hay to buy. With an initial outlay of from $700 and upwards, the storage battery automobile can be used once a week at the cost of a fifty-cent charge, or twice for a dollar, and so on, the cost of use being met as it is incurred and so ceasing to be the bug-bear that fixed charges must always be to the householder of moderate income.

For safe and successful use, the automobile must, in my opinion, be made with heavier running gear, on the lines of the latter French automobiles. Especially should stability be secured in the wheels and frame; the superstructure may be made gauzy. It seems likely that two general types of electric carriage will be developed, a light buggy type and a heavier touring carriage, the battery varying accordingly.

The French types of electric carriages come nearer to my ideas in strength and stability than any other models. This result has been attained, of course, only by experience. At first I was inclined to the opinion that the French machines were abnormally heavy; but when I study out the concussions and strains to which they are subjected, my inclination is to make the touring carriage even heavier still. It is surprising to me that American builders have not more closely followed these French models, since experiments costing millions must have been made to reach the present stage.

We hear of fewer automobile accidents in France and in Europe generally than in our own country, and they are fewer in spite of heavy types of carriages. One reason for this is that in Europe there are wider roads and less traffic; another is that the public have been educated up to the situation. The electric carriage of the future, and of the near future, will in my opinion not only supersede other types of automobiles, but it will be built and run on such practical lines that accidents will soon become things of the past. Horse owners and drivers will educate their animals, as in old times they had to be educated up to the steam engine and later to the trolley car. The electric carriage will be practically noiseless and easily stopped in an emergency. Above all, it will need no irresponsible chauffeur.

The fifth endurance test of the nickel-iron battery, which is demonstrating that the storage battery is indeed an accomplished fact, is now being made with five different models of automobiles, in each of which the new cells have been installed. They are of various weights and construction, and each of them is being run 5,000 miles over country roads, at an average distance of 100 miles per day.

If these tests shall show no loss of capacity and no mechanical defect in the battery, and that it is in all respects exactly the same at the end as at the commencement, we can be reasonably assured that at last we have a real storage battery.

Anon. "Steam Vehicles Can Regain Popular Favor," *Cycle and Automobile Trade Journal*, 7 (April 30, 1903), 21

This editorial contends that the decreasing popularity of steam powered vehicles resulted from their makers' failure to adopt the latest innovations. It points out that most gasoline cars had been improved, but most steam cars had not. Nevertheless, the editorial concludes, steam can regain its popular favor if the industry will innovate, for steam has many intrinsic advantages.

Steam Vehicles Can Regain Popular Favor

If the makers of steam vehicles had not been so slow to adopt improved appliances, if they had met disadvantages under which the steam vehicle labored in competition with gasoline, as they arose and overcome them, steam would never have lost its one-time strong hold on public favor.

In proof of this we point to the White and the Stanley steam cars, which are steadily gaining in popularity.

The first and most important disadvantages urged against steam cars were the necessity of stopping for water and the large fuel consumption. The White steam cars overcame these by the adoption of the condenser and a kerosene burner. Their form of steam generator also overcame the necessity for watching the water glass.

When the low tonneau body and long wheel base construction came into popular favor the White Company adopted it, with the result that the White steam tonneau is one of the most salable vehicles on the market to-day.

The Stanleys have also secured popularity for their vehicles by overcoming some of the disadvantages that were urged against steam vehicles. They provided automatic boiler and fuel feed, doing away with the water glass and air gauge, and insured the user against a burnt boiler by providing fusible plugs, and in other ways reduced the amount of attention necessary by the operator.

On the other hand, many steam vehicle makers are still putting out their latest models without in any way endeavoring to overcome the apparent disadvantages which have prejudiced the public against steam cars.

The gasoline makers have been progressive, they are continually adopting improvements.

The vast majority of gasoline cars have been greatly improved, while the majority of steam cars have not. That is undoubtedly the reason steam has been steadily losing in public favor.

We are thoroughly convinced, however, that steam can regain popular favor if the steam makers will improve their cars by adopting a long low construction, and the addition of such improvements as condensers, kerosene burners, pilot lights and generators, fusible plugs, automatic water feeding devices, etc. thus reducing the fuel consumption and the danger of fire, and doing away with the stopping for water, watching of water glass and gauges and burning of boilers. For the steam car has very apparent advantages in its silent, vibrationless and even running, the ease with which its speed can be regulated and its great hill-climbing powers, and if its apparent disadvantages were remedied these advantages will readily replace it in public favor.

Clough, A. L. "Gasoline and Steam Vehicles Compared," *The Horseless Age*, 12 (July 1903), 29–30, 62–63, 87–88

This is one of the very few item-by-item comparisons of steam and gasoline automobile engines. Several disadvantages of both become evident. Problems with the steam engine included slowness to start, greater fuel consumption, and excessive water consumption. Solutions to these problems were under development, however: the flash boiler eliminated the slow start, kerosine reduced the cost of fuel, and compound cylinders and condensers reduced water usage. Problems with the gasoline engine included vibration, noise, and odor. Solutions included multiple cylinders, better mufflers, and improved carburetion. Overall, the author does not attempt a summing up to decide which is best; and neither engine seems to have a preponderant advantage.

Gasoline and Steam Vehicles Compared

BY A. L. CLOUGH

It is seriously to be doubted whether there is anyone really competent to write an article upon this subject which shall be free from prejudice and entirely fair to the two motive powers. Hardly a person can be found who has personally given steam and gasoline an equally favorable and extended trial or who was free from bias when his use of motor vehicles began, and a writer's view of the subject may be affected by personal experience which is not common to other users. He may have had bad luck with gasoline vehicles and good fortune with steam or the reverse, or he may have been witness to the experiences of others, which are not truly representative but which cast undue discredit upon one or the other of the two powers. Hardly any person's experience has been broad enough to have correctly averaged the advantages and disadvantages of the two systems, and such a writer's view is necessarily somewhat ex parte. The contributor of an article upon this subject can at best merely try to be just and hope that in case he has shown a bias someone else will set his readers right by presenting the other side of the picture in as fair a manner as possible. It must also be borne in mind that one motive power may be particularly applicable to some conditions where the other might prove unsuccessful, and vice versa.

It may be well to divide this comparison into certain definite heads, and first and foremost should be considered the relative safety of the two motive powers. With a large amount of energy confined in a steam boiler at high pressure a cer-

tain danger would seem to be involved, but it is a remarkable fact that the explosion of vehicle boilers is almost unknown. These boilers being very small possess a very large factor of safety and generally leak around the tubes and allow the reduction of the pressure before the shell is endangered. If the boiler becomes dry either a safety plug melts or the boiler burns out and prevents the attainment of explosive pressures upon the introduction of feed water. It can hardly be held that steam vehicle boilers have proved dangerous, and even the possibility of danger from them is practically eliminated when they are of the water tube variety or of the flash type in which the amount of energy stored is very small.

In some steam vehicles the whole gasoline supply is stored under a considerable pressure—as much as 40 pounds in some cases. In others only a comparatively small amount of the fuel is under pressure. The collapse of these tanks, containing large amounts of gasoline, or the development of leaks therein due to road vibrations or other causes, has been the cause of most serious accidents. The inflammable fluid is scattered about under the influence of the pressure and is almost sure to ignite with very lamentable results. If only a little gasoline is under pressure and the remainder simply stored the effects of a leak may not be nearly as serious. The fact remains that in the steam carriage there is constantly burning a more or less exposed flame, and any leak of fuel, whether from tank, piping or burner is almost certain to cause a fire by the liquid or vapor coming in contact therewith. By careful piping the use of the strongest tanks with a minimum amount of fuel under pressure, and by the employment of metal bodies and frames in steam car construction, danger from fire may be minimized, though never, in the nature of the case entirely eliminated.

Possessing a large store of energy the steam carriage is more likely to be involuntarily started than is a gasoline car. Although throttles and reverse levers are intended to be securely locked in the closed position, accidents due to leaky throttles or throttles being inadvertently or maliciously opened, are not uncommon. The action of a steam carriage is so energetic and powerful, the instant the throttle is opened either intentionally or unintentionally, that some damage is very likely to be done whenever the power is thrown on inadvisedly. With a gasoline car the engine must be speeded up and the clutch engaged before a start can be made, and then its movements are much more sedate and gradual. It can always be stopped either by disengaging the clutch or shutting off the spark and it can generally be stalled by the throttle alone.

Since the gasoline car possesses no storage of energy under pressure the explosion question may be disregarded. However, it uses the same fuel as does the steam car, and if it is ignited involuntarily a fire will ensue. Gasoline is never stored under pressure on hydrocarbon cars, and, as they carry no exposed flame, the danger of fire is very small. Gasoline cars have taken fire in rare instances from leaks developing in the piping or tanks or on account of gasoline dripping from flooded carburetors and the vapor becoming ignited by sparks from wiring, or plug connections or from muffler explosions, but the cases are so rare as to be hardly worthy of mention.

The cases of "runaway" gasoline cars, due to the unintentional application of the motive power, are practically unknown, owing to the fact that several acts are necessary to bring this about.

READINESS FOR SERVICE

Assuming everything to be in working order the time required to put into operation the two classes of vehicles is somewhat in favor of the gasoline car. The steam car requires the heating of the vaporizer of the main burner and the raising of steam. The time required for the first operation is about equal in all steam vehicles, but the latter varies in proportion to the water space of the boiler from almost nothing in the case of flash boilers to several minutes in the case of flue boilers of considerable capacity. The starting operations with the gasoline car consist of the closing of the electric switch, the priming of the carburetor and the cranking of the engine. It would be very good practice to start a steam vehicle from cold water in five minutes and very bad practice to fail to start a gasoline vehicle in fifteen seconds.

CONVENIENCE IN DRIVING

The amount of attention required by drivers of cars of the two systems, in normal operation, is worthy of comparison: Neglecting the operations of steering

and braking, a steam carriage operator is concerned with his throttle alone, so far as the application of the power is concerned. This appears to be almost ideally simple, particularly as the control of the lever becomes almost automatic after a little practice. He has, however, to keep his eye upon his water glass quite closely and regulate his feed water to meet the demands of the engine.

Automatic water levels have been devised to obviate this necessity, but none of them have proved perfectly reliable. If the water level is not correctly maintained a flooded engine or a burnt out boiler or blown plug may be the penalty. The water glass is probably the greatest bother about the steam carriage and the flash system of steam generation has an advantage in obviating its use.

The fire in a steam carriage is supposed to be automatically regulated by means of a fuel regulator actuated by the steam pressure. These regulators are fairly effective, but still the steam gauge and the condition of the burner demand some attention. The air pressure gauge is consulted sometimes to determine whether there is sufficient pressure to properly supply the burner with gasoline.

The large water consumption of steam vehicles creates some little anxiety in the mind of the driver as to the condition of his supply tank.

The operator of a gasoline car is, like the steam carriage driver, chiefly concerned with his throttle—the movement of which, as in the steam vehicle, becomes automatic through practice. The control of his spark position is automatically maintained in some machines, but when not so arranged demands a slight amount of attention. He, however, has to shift his gears occasionally when the slowing of the vehicle indicates the necessity, and to shift them back when the necessity ceases. Many miles of good roads may be covered without a change of gear, and gear shifting is hardly necessary save at starting and upon very bad hills if the machine be of ample power and provided with proper sprocket ratio. He has no gauges or other indicators to watch and need have no thought of his water supply while on the road. Although the ideal of "nothing to watch but the road" is seldom actually attained, it is very closely approximated.

The fact is that the operator of a steam car is more busied with the production of his motive power and less occupied with its application than the driver of a gasoline vehicle. The generation of the steam power is not strictly automatic, but requires manual regulation of the water supply, while the production of the power in the gasoline engine is perfectly automatic. On the other hand the application of the steam power to purposes of traction is the simplest imaginable, while the application of the gasoline power is fraught with the occasional throwing of gears; the frequency of the operation being dependent upon road conditions.

The operation of the gasoline vehicle certainly calls for less watchfulness upon the part of the operator, and a failure to handle the motive power correctly can hardly result in any injury to it, as may be the case with steam.

"GROOMING" REQUIRED

To secure the normal operation of either of the motive powers careful inspection in the stable must be performed.

The steam vehicle requires most rigid scrutiny for leaks in steam, water and gasoline piping and tanks, the renewal of packing in pumps and valves, the cleaning of pipes, portions of the vaporizer and burner, where carbon may be deposited, and check valves, and the grinding of throttle and needle valves.

The gasoline car requires frequent attention to batteries, spark plugs and vibrators. The carburetor should be frequently cleaned, valves occasionally ground in and the clutches adjusted. Circulating pumps bear a little watching, as do circulating pipes and radiators. Where cylinder head gaskets are used there is a little replacing to be done once in a while.

It is probable that the motive power of a gasoline car requires somewhat more care in the stable than does the power plant of a steam vehicle. This is increasingly true in case the gasoline vehicle is of the three or four cylinder type.

A gasoline engine requires the exact fulfillment of several easily realized conditions in order that it shall operate. Unless they are properly realized the engine may not run at all. If they are fulfilled the engine is perfectly automatic and capable of doing its full work indefinitely.

The steam engine is somewhat different in this respect. It is not quite so particular as to the conditions. It may be badly out of adjustment and repair, but when the steam reaches it something generally has to turn around. It may operate very badly, indeed, but it will still keep on moving when conditions are most

unfavorable, because it has the boiler as a vis a tergo and although it may leak steam at every possible point, it will most likely not entirely refuse to "mote" as long as nothing breaks. As to reliability of the motive power, hardly any distinction can be made. With equally careful construction, inspection and operation both are dependable in about the same degree. More people have a general knowledge of the working principles of the steam engine than of the gasoline motor (or have had until very recently) and this fact has had its bearing upon the relative performance of the two motive powers in the hands of the general public. It is probably true that a gasoline vehicle engine is more subject to suddent stoppages than a steam engine, but unless in very ignorant hands the difficulty is very easily and quickly remedied. When a steam engine "lies down" there is likely to be something serious the matter. A little special training is necessary to secure the most reliable results with the gasoline motor, on account of electricity being an important factor in its operation. Steam vehicle engines have been given a bad name by being built upon too frail lines and exposed to the dust and mud from the road, while gasoline engines have suffered from miserably inadequate sparking arrangements to an even greater extent. Both steam and gasoline vehicle engines are straightforward engineering propositions and both can be made as reliable as any human mechanism which operates under equally adverse conditions.

ECONOMY OF OPERATION

The fuel consumption of a gasoline vehicle is small in comparison with that of a steam car of the same class, and this is due to the direct manner in which the energy of the fuel is applied in the former vehicle. The gasoline which is burnt to raise steam in the steam vehicle gives a large part of its heat to the surrounding air through the chimney gases and radiation from the boiler, and the conversion of the heat into mechanical power by the small steam vehicle engines is very wasteful.

The average gasoline motor, despite its large loss of heat to the cooling water and in the exhaust, is capable of doing more than twice the work with the same quantity of gasoline than could be accomplished by the average steam vehicle engine and boiler. Those gasoline engines of liberal stroke and bore, which operate with high compression, a fairly high degree of expansion and moderate speed, are remarkably economical of gasoline, while the small, short stroke motors of very high speed are in general decidedly less efficient.

It is not uncommon to find gasoline cars of 2,000 pounds weight which will travel decidedly further on each gallon of gasoline than a light steam runabout of less than half the above weight.

The use of highly superheated steam, the prevention of radiation from the boilers, piping and engines of steam cars, and the furnishing of warmer feed water by the application of feed water heaters or the return of the exhaust water from air condensers have lately much increased the economy of operation of steam vehicles, but the fact still remains that the fuel consumption of a large gasoline touring car is generally found to be less than that of a light steam runabout for the same service.

The successful use of kerosene for steam raising is much more imminent than is its application to internal combustion motors, and when its use in vehicle burners is fully accepted its economic superiority over gasoline will at least reduce the present discrepancy in the cost of operation of the two motive powers.

The cost of ignition batteries is an item in connection with gasoline vehicle operation which goes very far toward offsetting the inferior fuel economy of the steam car. This item is largest in cases where high speed multi-cylinder motors are employed, and least in instances where single cylinder moderate speed motors are used. If mechanical spark generators are employed the expense of ignition current is practically nil.

As a rule, somewhat more cylinder oil will be required for the lubrication of a gasoline motor than a steam engine, as the cylinder area is larger for the same service. The multi-cylinder gasoline engines which are now very popular consume a good deal of cylinder oil, and gas engine oil is somewhat more expensive than oil only intended to withstand steam temperatures. The cost of lubrication will generally prove somewhat greater in the case of the gasoline than that of the steam car.

DURABILITY

Since so large a proportion of all the steam vehicles in use has been constructed upon altogether too light lines for successful general use, and since the

liberal use of material has been such a general rule in the construction of the engines and running gears of gasoline vehicles, a comparison of the average representatives of the two motive powers is most unsatisfactory. There are plenty of exceptions to the above statement, and recently steam carriage builders have put out vehicles which, for durability, should certainly not be inferior to those operated by the other motive power. It may, however, be said with truth that in the past at least steam cars in general have not shown the durability of the gasoline rigs, owing to the very high speeds of their engines, the scant wearing surfaces, the questionable use of ball bearings and their entire lack of protection from road dirt.

The majority of gasoline engines have, on the contrary, always enjoyed the advantage of liberal plain bearings, lower speeds, stronger parts and enclosure from dust. Some of the large slow speed American gasoline engines constructed four and five years ago are frequently found to have a good deal of service in them even now, after continuous use, for they are simple and liberal in design. It might prove difficult to find any such "veterans" among steam vehicle engines.

I believe, however, that there should be no inherent difference whatever in point of durability between the two motive powers. Steam engines will be, and indeed have been, designed which must enjoy at least an equal durability with internal combustion vehicle motors. Indeed, it would be quite natural to assume, from theoretical reasons, that the impulsive action of the explosion engine ought to result in wear which must always, by the nature of the case, be more extensive than that occasioned by the more constant force exercised by steam pressure. It can hardly be said that this view is warranted by experience, but rather that, so far as the past is concerned, steam vehicle engines have suffered in comparison with gasoline motors when relative durability is considered.

It is to be remembered that gasoline cars possess clutches with frictional surfaces and gears, which are in use a part of the time, and that all these parts are subjected to stresses which are somewhat impulsive. On the other hand, steamers possess burners maintained at high temperatures, boilers subject to the action of all kinds of waters and the direct action of flame and quite an intricate system of pumps, piping and valves. Super-heated steam, too, is capable of doing a deal of "cutting" wherever it is applied.

In point of fact, we know very little of the relative durability of the vehicles of the two motive powers as yet. Styles and systems have been so rapidly changing that very few vehicles have been allowed to wear out, but have been rebuilt or retired for other reasons than general depreciation. It will be a matter of some years before this point is set at rest.

WATER CONSUMPTION

While much improvement has been effected in the water economy of steam vehicles of late, the frequent stops on the road for the purpose of refilling the tank and the constant watchfulness required to "make" watering points before the supply is exhausted constitute great objections to the use of this motive power. I have a friend who operates one of the very best steam vehicles, and who tells me that he makes it a rule to stop every six miles to fill his tank, for fear that he may be caught in some district where water is inaccessible and run short. This is an extreme case. His supply would probably carry him over 15 miles, but he wishes to be on the safe side.

On hard country roads the average steam vehicle user may be expected to renew his supply about every 15 miles. Of course, this figure is not exact, and it should be said that the vehicles using superheated steam and air condensers make very creditable distances with the large tank capacities now supplied. Vehicles not provided with these modern improvements demand very frequent refillings. However, in most settled parts of the country good soft water, free from much organic matter, is generally obtainable at very frequent points along the road, and by means of the ejector and hose which modern steam vehicles generally carry the tank may be refilled without undue inconvenience.

The replenishment of cooling water on the road is something which should not become necessary in the operation of a first class gasoline car. The supply will not be diminished by evaporation in any single day's run, unless the cooling system is of most antiquated design. Some gasoline vehicles may still be found which employ gravity circulation, and which have insufficient radiating surface or tanks placed where they receive none of the cool breeze. These vehicles will oc-

casionally have to stop for cooling water, and some of them may have to renew their supply as frequently as a steamer, although the amount of water needed is quite small. When circulating pumps are used, with plenty of flanged radiators, and tanks fanned by the breeze of the vehicle, the cooling water will last indefinitely.

The rapid rise of the air cooled internal combustion motor has demonstrated the practicability of entirely eliminating the use of water in the operation of gasoline cars of moderate power.

SMOOTHNESS OF OPERATION

To secure a rapid forward motion, free from any periodic increase and decrease in its rate, free from any up and down tendency and devoid of any vibration of the vehicle body, is the ideal which is aimed at in the design of motor pleasure vehicles. The steam vehicle realizes this ideal with sufficient closeness, owing to the comparative lightness of the reciprocating parts and the very slight variation in angular velocity of the engine.

It cannot be claimed that the gasoline car is nearly as perfect in this respect. In a single cylinder slow speed horizontal engine, even when provided with a liberal balance wheel, there is a considerable variation in angular velocity at different points of the cycle, enough, indeed, to produce, when the engine is running at quite low speeds, a perceptible forward jerk of the car at each explosion stroke of the motor. When, however, the engine is speeded up, this defect becomes barely perceptible.

A high speed vertical engine when unduly slowed down produces a decided up and down motion in the vehicle, and when speeded high communicates very rapid vibrations to the carriage body which are said to "put one's foot to sleep." The double cylinder twin type of motor is somewhat less of an offender in this regard, and the double opposed cylinder engine can hardly be said to be at all objectionable in point of unsteady running. The three cylinder motor furnishes a sufficiently close approximation to uniformity of angular velocity and balance of reciprocating parts, and when the four cylinder type is reached the smoothness of the torque and the balance attained by the several pistons and connecting rods are so perfect as to leave nothing to be desired.

Perfect steadiness of running is thus only attained in gasoline engines by the multiplying of the cylinders and necessarily at the sacrifice of simplicity. The expected advent of the two cycle engine into general automobile practice may result in much greater smoothness of operation with a minimum increase in engine complication—perhaps with an actual decrease.

A word should be said in commendation of the steadiness of operation of the single cylinder horizontal engine which has large flywheel capacity, well proportioned balance weights, not too high compression and an automatic spark governor. American designers have attained about all the steadiness of which the type is capable.

A steam car can be started from rest with rather less vibration than the same operation involves in a gasoline car, for the reason that the boiler reserve is drawn upon and immediately produces a steady torque. In order to furnish the considerable amount of energy necessary to accelerate a gasoline car the motor must be speeded up to furnish power at the requisite rate (since it possesses no reserve), and then a slip allowed in the clutch to render the acceleration sufficiently gradual to be comfortable.

All these questions of vibration appear more serious on paper than they do in practice, and to anyone not unusually finical they are of hardly more than academic importance in comparison with more vital considerations.

QUIETNESS OF OPERATION

The steady pressure of the steam as applied to the piston, the relatively light weight of the reciprocating parts, the character of the valve mechanism and the absence of a transmission mechanism, including gears, render the steam car almost ideal in regard to noiselessness of operation. In fact this is its most valuable characteristic, so far as its appeal for popularity to the general public is concerned. It, however, is being rather less considered as people become more accustomed to the characteristic sounds of motor vehicles in general.

The presence of a visible exhaust from steam vehicles has been brought forward by some as a partial offset to their noiselessness. In crowded traffic, on cold

wet days, this certainly is an inconvenience, but the use of highly superheated steam and air condensers has minimized this objection except when hard work is being performed or when the air is already saturated with moisture.

The impulsive character of the working pressure as applied to the piston, the comparatively great weight of the reciprocating parts, the relatively high exhaust pressure, the use of clattering poppet valves, the employment of gears in the transmission device and other considerations have given the gasoline vehicle a reputation for noisy operation which has often been deserved.

A great deal of effort has been expended in eliminating this disagreeable accompaniment of the operation of hydrocarbon cars. Mufflers have been greatly improved and, if of sufficient size and proper construction, can silence the exhaust to little more than a gentle hiss without the production of a serious back pressure. The reciprocating parts of gasoline engines have been carefully balanced, and the increased use of multi-cylinder construction has resulted in a uniformity of torque and a smoothness of operation that are highly satisfactory.

More perfect ignition methods have obviated the noise of missed explosions; the employment of spark governors, and a better understanding as to the proper time of ignition upon the part of users of manual spark timers have resulted in smoother operation, and the provision of more perfect methods of correcting wear in the bearings of the moving parts has made it possible to keep engines in quiet running order.

Better carburation and some other improvements have resulted in the ability to run gasoline engines at extremely low speeds when the vehicle is at rest, with a consequent reduction of noise; and better throttling devices have enabled operators to run very slowly on the high gear, which is generally the quietest.

The greatest improvement in the direction of noiselessness has resulted from the elimination of gears upon the most used speed—generally the high. The best practice now calls for direct connection between the engine and the driving wheels when the customary "driving" speed is in use, and for the resort to gears only for hill climbing or for negotiating very bad road conditions.

Complete enclosure of the speed reducing gears in an oil case has greatly reduced their noise when they have to be employed, but the securing of noiselessness at the sacrifice of reliability by the employment of fibre gears is a very doubtful expedient event in very small cars.

Modern gasoline cars operated by multi-cylinder balanced motors, properly muffled, with gearless operation on the "speed" which is intended for customary use, cannot be called objectionable as regards noise. Nevertheless, steam vehicles are inherently more quiet in their operation and give satisfaction in this regard naturally and without the precautions necessary to be observed with gasoline cars.

ODOR

The combustion of gasoline in the burner of a steam vehicle gives rise to a slight though characteristic odor. Little objection can be made to it, however. As the gasoline vapor is burned in an excess of air its combustion is likely to be very perfect.

The combustion of gasoline in an internal combustion motor produces a decidedly different and more objectionable odor, which is compounded of gasoline, often somewhat imperfectly consumed, and of violatilized or chemically altered, cylinder oil, which escapes from the hot cylinder walls with the exhaust. The occupants of a motor vehicle themselves are seldom troubled by this odor, but, in the interest of the general public, it should be reduced to the lowest practicable point.

By the employment of carburetors which furnish a perfectly combustible and uniform mixture under all conditions of demand, by the attainment of perfectly regular and complete ignition and by the use of cylinder oil of exceedingly high temperature test and in an amount just sufficient to insure proper lubrication without excess, the odor arising from the operation of a gasoline automobile may be minimized to such an extent as to become practically unobjectionable.

CONTROLLABILITY

In this regard I consider the cars operated by the two motive powers to stand upon an almost perfect equality. They may truthfully be said to be perfectly controllable; infinitely more controllable than animal drawn vehicles. The aspersions

as to the controllability of motor cars cast by the would be "funny papers" are so grossly untrue that they have already ceased to amuse even the most ardent motorphobes.

There is an impression current that steam cars are more controllable than gasoline vehicles, but I think that this has arisen from the greater agility in maneuvering which they possess, due to their boiler reserves. When the throttle of a steamer is opened the car leaps forward instantaneously, and if the reverse is thrown it will leap back with equal energy, in a manner decidedly in contrast with the more sluggish, though none the less accurate movements of the gasoline car. This performance strikes the superficial observer as a great display of controllability, but to one who considers it appeals not as an advantage, but rather as a danger. There are generally more control levers on a gasoline car than on a steam vehicle and there is somewhat more for the operator to learn in order to achieve facility in maneuvering than with a steam car. The fact that the matter of brakes has generally received more careful attention from the manufacturers of gasoline vehicles than from the steam car builders, and the fact that the power may be instantly cut off either by releasing the clutch of the gasoline car or by shutting off the spark are decidedly favorable considerations.

As to the relative effectiveness of vehicles of the two motive powers in hill climbing and encountering sand there is something to be said. The steamer is equipped with an engine which is capable of carrying a large overload and with a boiler in which is stored a large amount of energy (except in those of the flash type). The capacity of the engine to use steam is very generally greater than that of the boiler to produce it. This boiler reserve and large overload capacity of the engine endow the steamer with remarkable powers of momentary exertion, such, for instance, as the horse possesses. A short steep hill may be climbed by a steamer at a speed that is truly impressive, at the expense of the reserve energy in the boiler. If, however, the hill is too long and too great speed has been attempted, the pressure may fall very greatly, owing to the demands of the engine being in excess of the powers of the boiler to supply. If the steam falls to the stalling point and good brakes have been provided, the car may be held and the attainment of the requisite steam pressure awaited, when the ascent of the hill may be completed. A steamer will free itself from a very bad "hole" by "bottling up" steam and then making a supreme effort. Often the power momentarily developed may be in excess of the capacity of the tires to transmit to the road surface, in which case the wheels will slip.

I think it will be admitted to be very uncommon to find a steamer permanently "stuck" upon a hill or in sand. Upon roads which are exceedingly bad for long distances and which demand an amount of power equal to or in excess of the continuous capacity of the boiler, the progress of a steam vehicle is likely to be somewhat slow and very different from its boulevard operation. There is likely to be much recourse to auxiliary water pumps, and some little exercise obtained. However, it is a fact that even the steam runabouts will travel almost any road, however bad, if enough water and gasoline can be secured. The pace may be decidedly slow.

It should be said right here that one is likely to fall into error in making this comparison of the two motive powers in respect to traveling capacity over bad roads, for the simple reason that one is likely, almost unconsciously, to compare steam runabouts with gasoline touring cars—two classes of vehicles intended for very different purposes. There have been so few steam touring cars constructed in comparison with the gasoline vehicles built for that use that the steam vehicle is represented in the minds of most people by the familiar runabout type. It should be remembered that some steam cars of avowed touring capabilities are being built which doubtless possess boilers of sufficient capacity to steadily meet the maximum demands of the engine and power pumps capable of maintaining the water level under the most trying conditions. Such cars may be expected to make sufficiently high speeds to meet rational touring requirements, even over the worst roads. Their actual fitness for touring bad roads has yet to be demonstrated.

The gasoline engine has very different characteristics as to power production from the steam engine. If it is receiving an unthrottled cylinder charge of perfect mixture, with the spark in its most advantageous position, it is doing its utmost. There is no boiler upon which it can draw, and if the amount of power demanded by the vehicle is ever in excess of the rate of its generation, the vehicle will stall. On the other hand, the gasoline motor will keep on developing its full power until its fuel is exhausted. With a low gear, sufficiently low, there is no

limit to the road resistance that a gasoline vehicle can overcome except the adhesive power of the tires. If this gear is so figured as to give the vehicle sufficient tractive effort to overcome the worst hills or sand to be met with in practice, then it can successfully negotiate the most unfavorable road conditions and do so indefinitely. The highest gear should be so chosen that full advantage may be taken of level stretches or slight inclines, and the intermediate speed or speeds so proportioned as to take care of all hills or sand stretches usually met with. The low gear should, I believe, be just capable of sliding the driving wheels on good footing with the front wheels blocked.

Makers have been charged with the mistake of not furnishing intermediate gears, and of thus being tempted to make their low gears too high, so as not to make the vehicle too slow on moderate grades where the high speed just fails to carry. Certain builders of low powered runabouts in the Middle West have shown great wisdom in making the lowest of their two speeds exceedingly low, as they have thus earned the very just reputation for their vehicles of being able to travel anywhere.

In the opinion of the writer, at least three speeds are most desirable, and this requirement is realized with very little increased complication where a sliding gear transmission is employed and without an excessive increase in parts where the separate clutch system is adopted.

The fact that modern gasoline touring cars are equipped with a "first" or low gear practically fulfilling the above specification, and the further fact that their motive power is capable of maintaining its full output indefinitely, when desired, without attention, have led to their present practical monopoly of the touring field. If a gasoline car will climb a few hundred feet of a certain per cent grade on a certain gear it will do so until its gasoline tank is empty. There is no anxiety about the water supply and the operator has only to wait until the grade decreases, when he can immediately "pick up" a higher gear and take full advantage of its greater traveling capacity.

There is something truly impressive in the dogged persistency and "stick-to-itiveness" of the gasoline motor, as it cheerfully delivers its full power continuously until its tank runs low. It will "lie down" instantly if you demand any more power, but up to its limit it is tireless. The steam engine is no "quitter," but quite the reverse. Its ambition is likely to exceed the powers of its source—the boiler—and when slowed down for long periods under extremely heavy duty it is too often unable to pump the water which it voraciously demands.

Chambers, T. G. "The Future of the Electric Automobile," *The Horseless Age*, 15 (April 12, 1905), 433–435

This review of the electric automobile concludes that the electric car will be used in the city, the gasoline car in the country. He sees the city delivery van, the ambulance, and the "single horse brougham" all being powered by electricity.

The Future of the Electric Automobile

BY T. G. CHAMBERS

PAST AND PRESENT

The electric vehicle holds a peculiar, and, in some minds, a not altogether satisfactory place in the automobile family. It is rather in the position of the clever boy, who, in spite of great early promise, has signally failed, on reaching maturity, to realize the hopes of his parents.

It is true that this disappointment is partly due to the fact that too much was expected of it, but it is also largely owing to the injudicious attempts on the part of its advocates to force the utilization of its services in fields for which it was clearly never intended by nature.

The elasticity of the electric motor and its ease of control, together with silence and absence of smell and vibration, made the electric carriage very attractive

at an early date. The inherent disadvantages of the deadload of accumulators and the necessary limit to the available supply of power which could be carried, were not so apparent in the days when automobiles of all descriptions were of comparatively slow speed, and when a day's journey of 100 miles without a hitch was a rare occurrence.

Experiments with carriages propelled by the power available from primary cells carried in the vehicle date from 1832, but it was not until the year 1881 that a carriage was designed to carry secondary batteries. In that year electric tricycles were constructed both in London and Paris, and the modern electric car has been developed during the twenty-five years that have elapsed since that date. The progress between 1881 and 1886 was not very notable. The first electric hackney cab appears to have been built in this country in 1886. It weighed 1¼ tons, and ran at a speed of 8 miles an hour.

To no country in particular can the credit of progress be assigned. In England, France and the United States we find improvements of a similar nature appearing at the same dates. The period was purely one of experiment.

In 1895 we have the first evidence of a mistaken policy on the part of electric carriage constructors. Instead of developing the vehicle upon its own independent lines, as a purely town carriage with a limited range, they strove to emulate the petrol car, and to compete with it in speed and long distance contests.

In this year a vehicle was entered in the Paris-Bordeaux race. This carriage weighed 3¼ tons, and carried a battery consisting of thirty-eight Fulmen cells of an aggregate capacity of 300 ampere hours. Relays of batteries were arranged at Chatelleraut and Bordeaux, necessitating six railway wagons for their transport. The carriage carried six persons. It covered the first half of the race after encountering various accidents, and finally accomplished a distance of 370 miles in 100 hours.

Many other examples of futile effort might be given to indicate the mistaken efforts which had an adverse influence on electromobilism from the commercial point of view. We have such in the construction, both in Paris and the United States, of gigantic cigar shaped vehicles carrying huge loads of accumulators which were driven over measured distances at furious speeds, exhausting in the effort the whole available power of the battery. By such means record speeds and considerable advertisement were obtained, but the results had little technical and no commercial value. This kind of folly culminated in the United States in the running amuck of one of these terrible contrivances, which left the track and ran into the crowd of onlookers.

With the passing of the Locomotives on Highways Act of 1896, the commercial history of the electromobile may be said to have begun in this country. Here again we find certain mistakes were made which had an injurious effect upon the industry. Directly the automobile was let loose by act of Parliament, electric omnibus companies and electric cab companies sprang into existence, and considerable sums of money were embarked upon schemes based on insufficient data and too limited experience.

The story is the same whether we turn to Paris, New York or London. The electric carriage, on account of its attractive outward appearance, lent itself to the promotion of enterprise on a scale too large to be wise in such early days. In Paris and New York some of these early companies were fortunately supported by financial houses of sufficient strength and tenacity to assist them through their early troubles and enable them to benefit by the experience gained by their mistakes. The result has been that those cities are, in respect, at least, to the number of carriages operating, considerably ahead of this country.

In London the liquidation of the Electric Cab Company had a sobering effect, and acted for many years as an example to deter the capitalist from similar enterprise. This company was started under good auspices. As recent developments have proved, it was nearer technical success than was supposed at the time it failed, and had the necessary financial support been forthcoming to enable it to weather the storm it might today have been among the successful electric carriage companies of Europe. They made the mistake of launching out upon a large scale with insufficient technical experience, and with no data as to the costs of operating the carriages.

We cannot, however, put down the lack of success of the cab company in London entirely to technical mistakes. The company made a bid for success in the most difficult field of all, that of the hackney carriage. In this service the receipts are practically limited by act of Parliament, and increased payment for increased

luxury cannot be enforced. The promotion of a cab company at that date was, in its very conception, a commercial error. The years from 1897 to 1900 were again not encouraging.

In this country, as well as in France, constructors continued to vie with one another in producing carriages which would travel great distances on one charge of the batteries, and accumulator makers assisted in hindering the developing of the electric carriage in the right direction. In this country the claims of electric vehicle makers to compete with touring cars led the Automobile Club to hold some very severe trials of electric carriages. These trials, which took place at Chislehurst, were admittedly designed to question these claims. Whether this attitude was altogether a fair one to the electric car or to the supporters of the trials is an open question. It is, however, certain that neither before nor since have tests ever been held which were merely calculated to emphasize what could not be done rather than what could be done. The undoubted merits of the electric carriage were certainly not brought to light, and the trials constituted another serious check to the industrial advancement of the electromobile in this country. In the meantime, both in Paris and New York, the electric carriage was beginning to find its own sphere.

The development of the garage system on an extensive scale in New York, and to a lesser extent in Paris, gave at last the impetus which was required to promote business.

The electric carriage, more than any other type of self propelled vehicle, lends itself to the housing and manipulation of large numbers in a depot. The relief and security which the maintenance and care of the carriage by the maker gave to the owner was a considerable advantage, and this was gradually made use of to its fullest extent.

In this country the electric carriage had to some extent fallen into disrepute, owing to the circumstances I have pointed out, and it was not until the business was taken up in London by a wealthy man, and placed upon a firm basis upon the lines which had been adopted in New York, that it at length came to be considered seriously.

The first large electromobile garage was opened in London in 1901 by the City and Suburban Electric Carriage Company, and the electromobile industry in this country owes much in this respect to the enterprise of a well known member of this club, Paris Singer.

The four years that have elapsed since that date have seen very rapid progress in a similar direction, and today we have, under the auspices of various companies, in London alone six or seven large electric garages operating an aggregate number of between 400 and 500 carriages. When it is remembered that these have all been placed in service within four years the progress may be considered remarkable.

The success of the electric carriage upon finding its proper sphere was due, not to fashion or favor, but to its essentially practical advantages. It is unnecessary to emphasize all its merits. I would rather in a few words deal with the less obvious reasons for the popularity of the electric carriage, since these, to my mind, have an important bearing upon future developments.

The electric carriage is as nearly proof against mishap as any machine can be. An ordinarily intelligent man can be taught its manipulation in two or three lessons. Consequently, any driver who understands traffic conditions can be safely placed in charge. No mechanical knowledge or training is requisite, or, indeed, altogether desirable. As a result, there is no "driver" difficulty such as exists in dealing with almost every other type of automobile.

Moreover, the carriage is extremely reliable, and there is an almost entire immunity from involuntary stoppage and breakdown. Taking the last six months' working of the Electromobile Company's Curzon street garage, I find the total involuntary stops, excepting those due to power exhaustion, with which I shall deal later, to have been sixty-one in 159,258 carriage miles. Of these stops fourteen were due to a mechanical defect in the contact breaker, the possibility of which has since been entirely eliminated by an improved mechanism; nine were due to tire trouble; thirteen were due to the blowing of the main fuse, a matter immediately repairable by the driver, an operation taking less than one minute. This leaves only twenty-five stops in about 160,000 carriage miles necessitating the attention of a mechanic, or, on an average, one stop in every 6,400 miles.

When it is remembered that at least half these carriages are in the hands of comparatively raw drivers, and practically all of them are in the hands of men

without mechanical training, the reliability may be considered very great indeed.

When limitations of the accumulators are understood and recognized little or no difficulty arises from power exhaustion. With an effective range of from 25 to 35 miles upon one charge, and with the adoption of interchangeable batteries, a carriage may be run all day, if only time be allowed for its return to a depot to take up a new battery, an operation which takes from two to three minutes.

The far reaching importance of this system of rapidly exchanging an exhausted battery for a fully charged one cannot be too much insisted upon. It will probably have a material effect upon the future of the electric carriage.

The garage system, to which the electric carriage is so peculiarly adapted, lends itself to the convenience of owners in many ways. Large stocks of spare parts can be kept, and renewals can be effected without delay. Spare carriages and spare drivers can be placed at the disposal of owners in the event of accident. The driver's services can be utilized for a large number of hours in each day, since the carriage is taken out of his hands, and he is at liberty immediately the carriage returns to the depot.

Many of these are trivial points in themselves, but they all tend to the comfort of the owner, and provide him with a luxury on a level with the requirements of the day, while the constant expert supervision which is available in a large garage has a very material effect upon that important question affecting cost, namely, the life of the carriage.

I do not wish to enlarge upon this question of cost in detail. The subject is a difficult one, and figures may be misleading.

With regard to the electric carriage, it is only necessary to say that even with a garage in the most expensive and central position of London the total costs per year are considerably less than they would be in the case of a horse drawn carriage giving a similar degree of luxury. When the electric carriage is used to its full extent the costs are very considerably less. In certain individual cases I might name owners have effected an economy of as much as from £200 to £300 a year by exchanging their horse carriages for electric vehicles, and in no case am I aware that they are spending more than they did with their horses.

As compared with other types of automobile, I am of opinion that on the absolute bedrock of cost per carriage mile under similar conditions the electromobile will show an advantage.

Accumulator renewals have been reduced by organization and careful treatment to a figure equal to, if not below, that of the cost of tire renewals, and in other respects the mileage costs of the electromobile will compare favorably.

With regard to future cost one may confidently predict that the tendency will be downward both as regards power and battery renewals. At the present time the most favorable contracts that can be obtained in London for power supply do not bring the cost per Board of Trade unit below 1½d. There is no reason why this should not be reduced to a penny. The cost of renewals of battery plates will be very largely reduced as the output of plates is increased by the demands of the growing business. This will be more marked if an agreement as to the use of a standard plate can be come to by the principal makers of electric vehicles.

The relative financial importance of the cost of labor in a schedule of the total costs of running an automobile is hardly sufficiently appreciated, and it is in the labor items that the costs incidental to the running and upkeep of an electric carriage show to most advantage.

The electric carriage can be relied upon to start instantly without adjustment and run without a hitch in unskilled hands, and from a practical commercial point of view, convenience and reliability, though not to be measured in pence per mile, have nevertheless a far reaching influence.

FUTURE

We may now turn to the main object of this paper, the consideration of the commercial future of the electric carriage. It is upon this aspect of the subject that discussion will in all probability centre itself.

Dealing first with the touring car, I will at once suggest that the electric carriage will not be the touring car of the future. Nothing short of the discovery of some new element will provide us with a battery that would provide us with the electric touring car. The lead accumulator will not give it to us even if improved 50 per cent, and if the country be studded with charging stations.

I do not think the nickel battery will give it to us, whatever may be its possible practical and commercial advantages in other directions. The electric car with a featherweight battery would still have certain disadvantages as compared with the explosion engine carriage. The batteries would have to be charged. The charging station with the right voltage would have to be reached, and there would remain the risk of battery exhaustion through accidental increase of power consumption on account of bad roads, hilly country, faulty lubrication, and a hundred other causes.

Again in touring conditions in the open country the advantages of the electric carriage are insignificant. The modern gasoline car when once started travels as silently and as smoothly as may be desired on country roads, and I think that in this field it will certainly maintain its complete supremacy.

Turning to commercial vehicles, the question of the required range of action is the dominant factor. Given a limited distance and suitable roads, I see no reason why the electric carriage should not have a very considerable future in this field. Heavy electric vehicles for the delivery of goods have been apparently used for some years with considerable success, and on a large scale in New York; but it is to my mind questionable whether these vehicles have been retained on purely economical grounds, or for the benefit of a certain kind of advertisement attending their use.

I see no reason why the light delivery van for town use should not be accumulator driven. Here the conditions are very suitable. Ability to start at once, noiselessness, reliability in the hands of an unskilled driver, the small amount of overhauling required, and the moderate amortization fund necessary for renewals, are all arguments in favor of the electric carriage. The light electric delivery van is already a success in other countries. With regard to price, the time is not far distance when such a van can be sold at a very moderate price, say from £300 to £350, without tires or batteries, and the tendency will probably be toward the sale of such carriages outright to users, the sale being coupled with a contract for maintenance together with the use of tires and batteries upon loan; such a system will appeal to the user, as the capital outlay will be small, and he will have the security of the maintenance contract against unknown expenditure on upkeep. The question of the driver has an important effect in this connection. In many cases the drivers of the existing horse drawn vans have acquired a considerable special knowledge of the business of the firms who employ them. It is extremely undesirable that these employees should be thrown out to make room for a special motor driver, and it is equally undesirable on financial grounds that two men should have to be carried on each van. There is no reason why the existing van driver should not learn to drive and manage an electric automobile. In many cases, indeed, where two men now have to be carried, one to drive the horse and the other to deliver the goods, one may be dispensed with if an electric vehicle is adopted, and the driver himself can deliver the goods. He can leave the carriage unattended in a perfectly safe condition, while he delivers the goods himself.

The omnibus of the future will not, in my opinion, be electrically driven. The conditions are by no means those in which the accumulator car is likely to be successful. The constant and erratic stopping and starting, often upon hills, and the heavy weight of body and passengers are quite against it. If the accumulator passenger tramcar running upon rails has been unsuccessful in the past, it is only reasonable to conclude, having regard to the expense of tires and the increased consumption of energy, that it will be even less successful on the common roads.

The hackney cab constitutes another very difficult problem, and I think it will still be a long time before any self propelled carriage will be commercially successful in this field. Any discussion on this subject is bound to centre itself on the question of costs, and I do not believe that sufficient experience has been gained in the practical operation of automobile cabs for a sound opinion to be forthcoming.

Town ambulance work is so essentially the province of the electric car that I may be forgiven the mention of such a limited field. In this case every advantage of the electric carriage plays an important part, while its disadvantages have little or no effect. The only necessity is a proper organization to deal with the carriages, and this may already be said to exist in its best form in connection with the fire brigades which have reached such a high pitch of excellence in most of our cities. There would be no difficulty in rendering every fireman and every police constable an efficient driver.

It is unnecessary to say much with regard to the automobile of the future which is to take the place of the smart horse drawn carriage. In my opinion this will, without doubt, remain electrically driven.

It is probable that, in cases where only one carriage can be afforded, the gasoline care of the enclosed Limousine or of the Landaulette type will always be in demand; but I think it is now universally recognized that the type of gasoline care which is most advantageous for touring purposes—that is to say, fitted with an engine of high horse power and having a long wheel base and roomy body—is least adapted for London streets and traffic conditions.

When two automobiles can be kept, it is more than probable that the electric carriage will be universally adopted for purely town use. The gasoline car, as it becomes more perfect, does not become simpler in construction, and I think it will be admitted that, however perfectly it runs when once started and clear of the town, it is not at present, or very likely to become, the carriage for shopping, calling, theatre or night use. It is very attractive to imagine the ideal car which can be used with comfort all the week in London and which provides the means of a country excursion from Friday to Monday; but is the gasoline car built especially to suit town conditions ever going to be at the same time a good touring car?

There remains to be considered one very important field of the future. What automobile is to take the place of the single horse brougham? The doctor's carriage may be taken as the typical private one horse carriage, the expenses of the running of which have to be kept as low as possible.

The average medical man cannot afford to pay more than £250 to £300 a year for the use of a carriage, including the driver. I do not think that any automobile of today which the smart doctor leaves standing outside the door of his fashionable patients could be let out to him at this figure.

I can foresee the electric brougham in a few years' time, when the cost of production is lowered by building in large quantities, and when standing costs are reduced by the number of carriages garaged, let out at about £250 pounds a year without driver. Assuming that an efficient driver may in time be procurable at £75 a year, we have a figure of £325 a year as the lowest inclusive cost which would be remunerative to the company supplying the carriages. Is this a prohibitive figure, considering the advantages which a business man would receive by the increased speed of his carriage, and, as a consequence, the larger amount of time he could give to his professional work?

White, Thomas L. "The Ultimate Internal Combustion Motor and Its Probable Fuel," *The Iron Age* (January 7, 1909), 16–17

By 1909 the internal combustion engine was the engine of choice for the automobile. Adequate sources of fuel were, however, a critical problem. White notes that development of the automobile had by this time proceeded to the point where the engine was set and the fuel had become the element to be experimented with. Observing that the engine had evolved "along the lines set by economic necessity," White contends that "from a business standpoint the introduction of a new fuel for use with the current equipment is a vastly better proposition than the introduction of a new type of motor to burn a new kind of fuel, no matter how good the latter may be."

The Ultimate Internal Combustion Motor and Its Probable Fuel

BY THOMAS L. WHITE

Perhaps the truest thing that can be said by way of a review of present practice in the design of automobile motors is that we are drawing to the close of a period of empirical construction and entering upon a period of systematic research. The principal need of the designer at the present time is for the kind

of information which the steam engineer derives from his steam tables, and, speaking of the well defined field covered by the power equipment of the self-propelled vehicle, the indications are that in the present state of our knowledge no structural changes of a radical character are probable, or even possible, even in the event of a failure of the gasoline supply, and that further gains in thermal efficiency can only result from a more thorough study of the physical and chemical changes which occur in the working fluid from the moment that it enters the carburetor to the moment when it leaves the exhaust.

There is no intention in putting forward these propositions to claim finality of design for the existing type of motor nor to minimize the importance of the fuel issue. They simply represent the facts. It is significant, for instance, that although the high compression alcohol motor has a thermal efficiency of over 30 per cent, and alcohol is cheaper on the Continent than gasoline, there has been practically no attempt in France or in Germany to install this type of power plant in the automobile. It is equally significant that the Automobile Club of France is now offering a prize of 40,000 francs, not for a suitable equipment to burn alcohol, but for a "cheap fuel for general use and for a suitable device for its gasification, which must both be adaptable to all motor systems."

LIMITATIONS TO CHANGE IN ENGINE DESIGN

The fact of the matter is that the present type of automobile motor is the outcome of a number of determining conditions of which the necessity of using gasoline was only one, and the current impression that it is the low preignition temperature of gasoline and air mixtures that has prevented the use of high compressions is only partially correct. There are other reasons which are just as cogent. One of them is that the high pressure motor is not suited for lay use. In inexperienced hands the compression is apt to be lost, owing to the piston rings and valves giving out through want of attention. Another is that the high pressure motor is a violation of the accepted canon of automobile design that power must be sought in the direction of speed and not in the direction of weight. Still another objection, and, perhaps, the most important of all, is that it is difficult to the verge of impossibility to control the ignition of a high speed motor under conditions of varying load, unless the quality of the mixture can be depended on to be absolutely the same at all speeds. Where the fuel is vaporized by the ingoing air this condition is rarely attainable. The same trouble is experienced with the high compression suction producer engine. Here it is the percentage of free hydrogen in the producer gas which varies with the speed of the motor, and the opinion is held by many engineers that the presence of this hydrogen, in spite of its great fuel value, is a positive disadvantage.

Engineering progress is not as a rule along the lines which are technically the most desirable, but along the lines which have been set by economic necessity, and as a reason, though not a technical one, for the conservation of the present type of motor must be reckoned the natural inertia of the existing order. This is inimical to revolutionary policies. From a business standpoint the introduction of a new fuel for use with the current equipment is a vastly better proposition than the introduction of a new type of motor to burn a new kind of fuel, no matter how good the latter may be. Also it must be remembered that gasoline will for many years be an alternative fuel. In fact, in some localities it will continue to be the only fuel obtainable, and as the automobile in its capacity as a long distance vehicle has no fixed base of supplies, it will be necessary for it to be able to get along on gasoline on occasion, at any rate until the coming fuel is so widely used that a supply of it can always be depended on.

NEW LINES OF RESEARCH

If, as seems to be the case, the long supremacy of gasoline, and other causes of a less ephemeral character, have left a permanent stamp on the design of the automobile motor, then it is to the chemist that we must come not only for aid in the fuel question, but also for information about the phenomena of combustion, to enable us to use the type of heat engine which we have to the best advantage. The time has come when physical and chemical research must supplement a too narrow devotion to the purely mechanical side of motor engineering. To quote Prof. Vivian B. Lewes in this connection, "The engineer relies upon his indicator diagrams and tests of horsepower for information which could be much more easily obtained by analysis of the exhaust gases, and if

this method of investigation were employed important advances would very soon follow. Analyses of the exhaust gases from motor engines are remarkably scarce. Indeed, I do not know of any in this country. But Mr. Sorel, in 1903, published in France some results in which he showed that with a motor running at 1061 rev. per min. and using 382 g. of gasoline per brake-horsepower-hour, the products contained unburned compounds which represented 82 per cent of the hydrogen and 42 per cent of the carbon present in the original fuel, thus reducing the heat value of the gasoline used in the cylinder from 11,278 to 5085 calories."

Almost identically the same contention is urged by Dr. Warschauer in a recent address presented to the Association of German Chemists of Berlin. "Until now the design of vaporizers for different kinds of fuels has been determined entirely by empirical methods. Right here the assistance of the chemist is required by the automobile engineer. By systematic qualitative and quantitative gas analysis data of great value can be derived regarding the character of the combustion of fuels. To take an illustration from the field of illumination, I will quote one of the most important propositions from Stepenoff's 'Theory of the Kerosene Lamp.' It is as follows: 'The efficiency of the lamp is best determined by the analysis of the gases given off.' The same truth with a suitable change in the wording can also be applied to the explosion motor."

The analysis of the exhaust gases from the explosion motor, important though it may be, is, however, only a step. It reveals the last stage of the complicated reactions which have occurred during the expansion stroke, but it affords little information as to the actual nature of these reactions or of the heat changes which accompany them. If carbon be slowly oxydized in the open air, as in the decay of wood, or almost instantly consumed behind the piston of an engine, the amount of heat liberated and the final product are the same. The difference is not in the process, but in the conditions under which it is conducted, and the final goal of the work of the chemical engineer is the determination of the how, why and when of those factors, which in the case of the decaying wood and of the burning fuel are so widely divergent.

ACTION IN EXPLOSIVE MIXTURES

Some of the results which are coming to light in connection with the study of the energy transformations which occur in the motor are sufficiently starting. Thus it appears that carbon monoxide is absolutely inflammable in the absence of water, and, further, the velocity with which an explosion in a mixture of this gas with air is transmitted depends on the amount of aqueous vapor present. Again, there are reasons for believing that the propagation of the flame in the cylinder of a gas engine is not by direct inflammation, but by the compression to preignition point of successive layers of the mixture. It also seems that the old belief that carbon will burn to carbon dioxide in the presence of an excess of oxygen is not altogether well founded. Under certain conditions the lower oxide is just as likely to be formed as the higher.

The fact is that the idea that during the expansion stroke of an explosion motor the carbon and hydrogen of the fuel simply burn up more or less quickly must be abandoned. What really happens is infinitely more complex. Thus every reaction which can occur in the cylinder is reversible within the temperature, pressure and concentration limits of the cycle. Moreover, it is probable that the combustion of the mixture is far from being of a uniform character throughout its mass at any given moment. There is reason for believing that different reactions may occur simultaneously at different points of the working fluid. It is possible, for instance, that water is being formed and decomposed at the same moment during the same explosion.

Speaking of the investigations which are actually being made at the present, the determination of the rate of heat flow through the cylinder walls and the estimation of the specific heat of carbon dioxide at combustion temperatures are the subjects of recent monographs. The latter quantity is important in connection with the phenomenon of suppressed heat and in the determination of the proportion of a given quantity of hydrogen or carbon which can be oxydized under given conditions.

MIXED FUELS

As there seems to be little doubt that the fuel which will take the place of gasoline will be a blend with an alcohol base, it is becoming important to be able

to trace the effect of each individual ingredient in a mixed fuel. It may be pointed out that the properties of a blend are far from being a mere statistical average of the properties of its constituents, for each admixture has a functional as well as a quantitative effect on the behavior of the whole in the motor. Thus the addition of acetylene to alcohol by accelerating its combustion in the motor increases its efficiency. Lastly, it may be mentioned that the increase of the calorific value of a fuel by blending has no effect on the specific power of the motor in which it is burned. The maximum power of a given motor is independent of the calorific value of the fuel which is used in it, the popular belief to the contrary notwithstanding.

Midgley, Thomas, Jr. "Some Fundamental Relations Among the Elements and Compounds as Regards the Suppression of Gaseous Detonation," *Industrial and Engineering Chemistry*, April 1923: 421–423

The White article identified fuel as the critical element in further development and expansion of the automobile industry. Midgley's article reports on the most important step in solving the fuel problem, the development of anti-knock compounds. This article reveals the sophisticated understanding of the spark ignition engine which had been reached by the early 1920's, and described the development permitting achievement of improved power and performance of gasoline engines.

Some Fundamental Relations Among the Elements and Compounds as Regards the Suppression of Gaseous Detonation

Under certain conditions the combustion of gases is characterized by detonation. In the case of the combustion of a mixture of any given fuel in the internal-combustion engine the development of detonation is controlled primarily by the pressure to which the unburned portion of the mixture is subjected during combustion. In view of the fact that both the power output and the efficiency of the internal-combustion engine are functions of its compression, this factor has a large significance. Economical utilization shall be as high as is compatible with proper performance from a mechanical standpoint. Since the motor fuel available is practically of fixed composition, the factor that now limits the compression of automotive engines is the tendency of this fuel to detonate.

It has been found that the presence of very small amounts of certain materials in a fuel-air mixture influences its combustion in such a way that detonation is prevented. This detonation-influencing property is a function of certain compounds of a considerable number of the elements.

RECENT RESULTS OBTAINED IN THE STUDY OF GASEOUS DETONATION

Two things have recently been added to our knowledge of the mechanism of gaseous detonation. First, it has been demonstrated that even in nondetonating, or normal, combustion a higher pressure must exist ahead of the flame front than behind it. It has been shown, further, that the pressure immediately in advance of the flame front is controlled by the reaction velocity of combustion. If the reaction velocity is expressed by the equation $W=KD^nT^m$, a mathematical expression can be derived for the pressure differences existing in the flame front at different total pressures. In this equation W is the reaction velocity expressed in pounds of gas entering the reaction per second, K is a constant whose value must be determined experimentally, T is the absolute temperature immediately in front of the flame, D is the density or concentration, and n and m are exponents whose values must be determined experimentally.

The expression derived on this basis predicts a critical pressure above which the combustion reaction proceeding through the gas must travel at the velocity

of sound. When the transmission of chemical activity reaches this velocity, a condition that we call "detonation" is produced.[1]

These developments may be considered as being based upon the physical chemistry involved in gaseous detonation. But they shed no light on the ultimate nature or mechanism of the chemical reactions involved. They merely apply the known laws of physics and chemistry to the analysis of the progressive combustion of a gaseous mixture.

WHAT ANTIKNOCK MATERIALS DO

Those compounds which, when present in combustible mixtures in very small amounts, have the effect of entirely removing the disturbances that characterize detonating combustion are called for convenience "antiknock" materials. Their effect appears to be that of increasing the critical pressure at which detonation occurs. Thus, if a mixture of acetylene and air of proper proportions contained in an open tube is ignited at one end a detonation wave is set up after the flame has traveled a short distance along the tube, as is shown by the high luminosity and by the loud and sharp "crack" that is produced. If the experiment is conducted in a strong glass tube, the intensity of the pressure wave resulting from the detonation is often such that a few inches of the tube at the end opposite the point of ignition are shattered into small pieces. But when a very small percentage of an antiknock material such as diethyl selenide is present in the acetylene-air mixture, the burn is very quiet and it lacks the high degree of luminosity that characterizes detonating combustion.[2]

The effect of antiknock materials upon internal combustion is even more striking. If, for example, an airplane engine, which has a compression ratio of about 5.3 :1, is run on the commercial motor gasoline of to-day, a violent detonation or knock is produced. Even in the absence of instrumentation for detecting and measuring it, the detonation manifests itself by a loud hammering sound of a metallic quality and by a reduction in power from what should be the normal output of the engine. When a small amount of the vapor of diethyl selenide is admitted with the intake air, the detonation is entirely eliminated and a noticeable increase in the power of the engine is apparent. In a similar way, if a very small amount of tetraethyl lead, about 0.1 per cent by volume, is added to the fuel, the detonation entirely disappears, the engine runs with perfect smoothness, and its power rises to normal or to the value that it should have in the absence of detonation. Computation shows that quantitatively this result is produced by virtue of the presence of only 1 molecule of tetraethyl lead in over 80,000 molecules of fuel-air mixture.

In distinction from these materials whose effect is to eliminate detonation, there is another class of substances that induce detonation. This is in addition to those materials that are neutral as far as effect on detonation is concerned. The knock-inducing property characterizes to a small degree the ethyl compounds of bromine, oxygen, and sulfur. These elements also show this negative characteristic in the elemental form.

But the simple alkyl compounds of these elements exhibit a relatively small detonation-inducing effect. When oxygen is bonded into compounds such as alkyl nitrates or nitrites and phenyl nitro compounds, its effect for inducing detonation becomes very marked. Thus, if an engine is run on a fuel such as a benzene-gasoline mixture that does not produce any knock, a violent detonation can be produced by the admission of a very small amount of some volatile organic nitrate or nitrite along with the fuel-air mixture. This detonation-inducing material is equally effective whether it is admitted as a vapor with the intake air or whether it is dissolved in the fuel. Quantitatively 1 gram molecule of isopropyl nitrite has a detonation-inducing effect that is equal to the inverse of about 0.1 gram molecule of tetraethyl lead.[2,3] (The detonation-inducing elements are considered as possessing the negative of the antiknock property.)

The mechanism by which these materials control the reaction velocity of combustion is not understood. It is inconceivable that their effect can be due to a simple thermal effect, such as an absorption of heat with a consequent cooling of the flame. The amount of the antiknock material present in the burning gas is too minute for such to be the case. As has previously been shown,[2] the presence

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[1] Midgley, *J. Soc. Automotive Eng.*, 10 (1922), 357 : Midgley and Janeway, "Laws Governing Gaseous Detonation," to be published in an early issue of *J. Soc. Automotive Eng.*

[2] Midgley and Boyd, This Journal 14 (1922), 894.

[3] *Ibid.*, 14 (1922), 849.

of as little as 1 molecule of tetraethyl lead in over 200,000 molecules of a combustible mixture of kerosene and air exerts an effect in the supression of detonation that is equivalent to the blending of 25 per cent of benzene by volume with the kerosene. Benzene is a fuel that does not detonate even when burned at compressions in excess of 200 lbs. per sq. in.; and, when it is blended with kerosene, the resulting mixture partakes of the nondetonating property of benzene to the extent to which benzene is present.[4] It has previously been suggested that, in view of the small amounts of some of these materials needed to exert a large effect on the character of combustion, their action bears some analogy to that of catalytic agents.

An adaptation of the Perrin radiation theory has been proposed as an explanation for the behavior of knock-suppressing and knock-inducing materials. The presence of a small amount of one of these materials during the combustion of a highly compressed mixture of gases is conceived as presenting a screen which absorbs some radiation and thereby controls the velocity of flame movement. The application of the principles of this theory to the explanation of the behavior of such materials would appear to be profitable field for research on this subject. With the exception of this one suggestion, which is not as yet borne out by any experimental evidence, no adequate explanation of the action of these materials has been advanced.

PHYSICAL CHEMISTRY OF THE DETONATION-INFLUENCING PROPERTY

But whatever the mechanism by which these materials influence combustion, quantitative measurements of their effects may be obtained by the application of proper instrumentation to the internal-combustion engine. Thus, in a given motor, when operating on a given kerosene, the constants in the equation $W = KVT^nT^m$ (see above) were found to have the following values.[5]

$$K = 3.25 \times 10^{-7}$$
$$n = 0.9$$
$$m = 3.22$$

After 2 cc. of tetraethyl lead per gallon had been added to the kerosene, the values obtained in the same way were

$$K = 3.075 \times 10^{-7}$$
$$n = 0.9$$
$$m = 3.22$$

The following data show how K varies with a number of concentrations of tetraethyl lead in the kerosene used as fuel:

Concentration $PbEt_4$ Cc./Gal.	K
0	3.25×10^{-7}
1	3.17×10^{-7}
2	3.075×10^{-7}
4	2.97×10^{-7}
8	2.86×10^{-7}
16	2.76×10^{-7}

From these figures it is obvious that the effect of the presence of tetraethyl lead in a detonating fuel is to change the value of K in the equation. The results of a number of determinations show the relationship between the concentration of tetraethyl lead and the constant K to be as follows:

$$K = K_0 - 0.173 \times 10^{-7} \log_e (C + 1)$$

where K_0 is the reaction-velocity constant of the original fuel, C is the concentration of tetraethyl lead in cubic centimeters per gallon, and 0.173×10^{-7} is a constant.

The form of this equation is suggestive of a selective radiation absorption, but by itself it must, of course, be considered as inconclusive. Nevertheless, it does make a material addition to the data tending to substantiate the applicability of the Perrin radiation theory to these cases.

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[4] *Ibid.*, 14 (1922), 589.
[5] See Footnote 1, Midgley and Janeway.

These figures should not be considered as expressing the relationship of all antiknock materials to the constant K, because the values for aromatic amines are known to differ from those of tetraethyl lead. It will be some time before complete data of this character on the different types of antiknock materials can be obtained and the true relationships existing between them definitely ascertained.

The amount of work necessary to determine the values of antiknock materials in a comparative way may be materially reduced by determining simply the concentration of any given compound required to produce an effect on detonation that is equal to some standard. Thus, 1 per cent of aniline by volume may be used as the standard. The values so obtained are only relative, because in some cases the relationship changes with concentration. This should, therefore, be considered as an approximate rather than an absolute method of comparison. However, for comparing the antiknock effect of one compound with that of another this method is a satisfactory one.

Detonation-Influencing Property Primarily in the Atom

The magnitude of the detonation-influencing effect is primarily a function of one atom in the molecule, but it is modified to a great extent by the radicals or groups attached to that atom. The relative antiknock effects of the ethyl and phenyl compounds of four elements are given in Table I. By comparing the values for the ethyl compounds of iodine, selenium, and tellurium with those for their corresponding phenyl compounds, it is observed that they are of the same order of magnitude for each element, the alkyl compounds being somewhat more effective than the aryl compounds. The reverse is true with oxygen, diethyl ether being a slight inducer of detonation, while diphenyl ether is a weak antiknock material. From the table it may be observed further that the antiknock value changes enormously with the element, while it is merely modified by the change in grouping. Thus, diethyl telluride is about twenty-five times as effective molecularly as ethyl iodide, and the same relation holds for the phenyl compounds of these elements. It seems reasonable to conclude, therefore, that the antiknock property is primarily a function of the element rather than of the groups attached to it.

TABLE I.—COMPARISON OF RELATIVE EFFECTS EXERTED UPON DETONATION BY ETHYL AND PHENYL COMPOUNDS OF 4 ELEMENTS

Element	Reciprocal of number of gram-molecules required to give antiknock effect equivalent to 1 gram-molecule of aniline[1]	
	Ethyl compound	Phenyl compound
Iodine	1.09	0.88
Selenium	6.9	5.2
Tellurium	26.8	22.0
Oxygen	[2].036	.122

[1] Based on concentrations of aniline up to 3 percent by volume in kerosene.
[2] Induces detonation.

Bryant, Lynwood. "The Origin of the Automobile Engine," *Scientific American,* (March 1967) 102–110, 112

This article reviews the development of the gasoline engine, particularly with respect to its use in automobiles. The major portion of the article is devoted to the work of Nicolaus Otto, whose innovations made the spark ignition engine viable. It is interesting to note that he also worked on the idea of stratified charge to improve the combustion process.

The Origin of the Automobile Engine

(BY LYNWOOD BRYANT)

The first internal-combustion engine to operate successfully on the four-stroke cycle was built in 1876 by Nicolaus August Otto. His "Silent Otto" was a good machine with a poor theory.

The modern automobile is driven by a heat engine whose basic principle was first demonstrated 91 years ago. The principle is the Otto cycle, named after Nicolaus August Otto, a self-taught German engineer who stumbled on a way to burn a compressed mixture of gas and air in the cylinder of an engine without producing destructive explosions. The "Silent Otto," as the engine was somewhat extravagantly called, employed a scheme in which the piston required four strokes to complete one cycle: an inward (toward the crankshaft) fuel-and-air-intake stroke, an outward (away from the crankshaft) compression stroke, an inward power stroke and an outward exhaust stroke.

The term "Otto cycle" is sometimes used loosely to denote this four-stroke mode of operation, but actually an engine of the Otto type can be either two-stroke or four-stroke (or for that matter six-stroke, as some of the early ones were). The four functions of intake, compression, expansion and exhaust must be performed in any Otto engine, but they do not have to be performed in four distinct strokes. Strictly speaking, what distinguishes the Otto cycle from other cycles that can be used in piston engines is that an engine of the Otto type takes in a controlled mixture of fuel and air, compresses it to a moderate pressure and ignites it by some kind of ignition device, nowadays a spark plug.

The original Otto engine achieved an efficiency three or four times greater than the steam engines of the day, with the result that Otto's factory near Cologne became a world-famous source of stationary power plants. Two of his associates in this enterprise were Gottlieb Daimler, who later became a pioneer in the automobile business, and Wilhelm Maybach, who designed most of the early Daimler automobiles and went on to make excellent engines for aircraft.

Otto's engine would be important if only because it was the ancestor of the automobile power plant. It has a special appeal for the historian of technology because it was a good machine built on a bad theory. In the early days of the gas engine (and it was gas, not gasoline) the central problem was how to get a smooth flow of power out of a series of explosions. Otto solved the problem—or thought he did—by mixing fuel and air in a special way that yielded what he described as a stratified charge. This was supposed to cushion the shock of the explosions. Otto was wrong in attributing the success of his engine to the distribution of the gases in the cylinder, but his error led him to a mode of operation that is still employed in more than 10 million new engines a year.

The Silent Otto looks more like a steam engine than an automobile engine. This is not surprising, because it was the steam engine that provided the theory, the experience and even the hardware used by early workers on gas engines. The cylinder in Otto's single-cylinder engine was in fact a converted steam engine cylinder. It incorporated a slide valve like the valve of a steam engine, except that it had a more complicated system of passages because it had to control three fluids—fuel, air and the ignition flame—rather than steam alone. The Silent Otto developed about three horsepower at 180 revolutions per minute.

The Otto engine, demonstrated in 1876, was the first to use the four-stroke cycle. To observers brought up on the steam engine this must have seemed a wasteful way to run an engine because it yielded only one power stroke for every two revolutions of the crankshaft. The steam engine not only had a two-stroke cycle but also was usually double-acting; this meant the piston was pushed by steam in both directions, so that there were two power strokes for each revolution of the crankshaft—four times as many as in the single-acting four-stroke gas engine. Otto seems to have adopted this mode of operation reluctantly and temporarily for lack of a better way to compress the charge. Such a drastic reduction in the frequency of power strokes must have seemed a high price to pay for the advantages of compression. Otto claimed the four-stroke cycle in his patent, but only incidentally. He promptly set to work to improve his engine by developing a two-stroke process, and so did a dozen other inventors. He was

never able to improve on the four-stroke process, nor has anyone else been able to for engines of a size appropriate to automobiles.

Otto's fuel was illuminating gas. Although gasoline was known, it was regarded as being extremely dangerous. The problem of mixing gasoline vapor and air in the exact proportions required by an engine proved to be an intractable one that was not solved until the carburetor was devised in its present form in the 1890's. Gas, on the other hand, was a convenient and reliable fuel that was already in wide use for lighting. Usually produced by heating coal in the absence of air, it consisted chiefly of hydrogen, methane and carbon monoxide. Gas technology has been evolving for some 50 years, and whenever a city installed a gas system someone was likely to get the idea that this new source of energy could be used for power as well as light.

Early inventors therefore envisioned a small gas engine the user could turn on whenever he needed power (as we now plug in an electric motor) and turn off when he was through. They hoped that such an engine might compete with the steam engine, particularly in small sizes, because of its convenience and adaptability to intermittent use. The more enthusiastic promoters dreamed of supplanting the steam engine entirely but to a more realistic goal was to provide stationary power plans for small enterprises—pumping stations, breweries, printing shops and the like—that could not afford a steam engine or did not use power continuously.

Otto and others naturally considered using a gas engine to drive a vehicle, but that was not a practical objective in the 1870's. The Silent Otto and the first generation of its rivals were much too heavy (they weighed about a ton per horsepower) and they were tied to a stationary gas system. Nonetheless, Otto's engine of 1876 embodied the essential concepts that later made the automobile engine possible, after much refinement of detail, chiefly reduction of weight and adaptation to liquid fuel.

The concept of internal combustion—that is, the notion of burning the fuel inside the working cylinder of an engine and dispensing with firebox and boiler—was an attractive one in Otto's time, and scores of inventors were working on it. Practical engineers knew little thermodynamics in those days, but some knew enough to measure the thermal efficiency of the steam engine. They found it scandalously low, usually well under 5 percent. The internal-combustion approach seemed a promising one because it offered an opportunity to avoid the heat losses, not to mention the weight and expense, associated with firebox, smokestack and boiler. The heat would be generated at the face of the piston, so that it could immediately be converted into work without losses in transmission and storage.

At the time engineers also talked about another kind of economy: the saving of latent heat. The trouble with the steam engine, they said, is that much energy has to be spent in converting water into steam before any work is done, and that this investment in "latent" heat is not recovered if the exhaust steam is discharged into the atmosphere, as it usually is. The key advantage they saw in the internal-combustion process was that it utilized the products of combustion to drive the piston directly, without wasting energy in generating an intermediate working fluid such as steam. Actually the essential advantage, as more sophisticated engineers eventually learned, was that the internal-combustion engine was able to operate through a wider range of temperatures than the steam engine could; the nature of the working fluid made no essential difference.

Otto was not the first to try internal combustion. His most famous predecessor was Étienne Lenoir of France, who like Otto had no technical training. In 1860 Lenoir built a two-stroke engine much like a steam engine. It drew in a mixture of gas and air for the first half of each intake stroke and then ignited it with an electric spark. The second half of the stroke was used for expansion, and there was no compression of charge. The engine was double-acting: it used both sides of the piston like a steam engine.

The Lenoir engine created a flurry of excitement in the early 1860's. *Scientific American* quoted French journals as saying that it marked the end of the age of steam. "Watt and Fulton will soon be forgotten," the article said. "This is the way they do such things in France." Then professional engineers who knew some thermodynamics ran tests on the engine and published discouraging reports. It used large quantities of oil and cooling water, it overheated badly and it was hardly better than a steam engine in efficiency. Several hundred Lenoir engines were made, but within a few years they were mostly scrapped or converted to steam.

One of the suggestions offered for improving the efficiency of the Lenoir engine was to try compressing the charge. The idea of compression is a simple and obvious one that came up frequently in the 15 years before the Silent Otto. A commonsense engineer would see compression as a way of increasing the power of an engine by packing in more fuel, or as a way of reducing the size of the engine by simply packing the same amount of fuel into a smaller volume. One of the advantages of gas as an engine fuel is that the designer can choose a convenient density.

Otto discovered the value of compression as he was experimenting with a model of the Lenoir engine. While working as a traveling salesman for a wholesale grocer in the Rhineland he read about Lenoir in a newspaper and had a mechanic build the model engine for him according to the newspaper description so that he could try it out. Once in the course of testing various mixtures and sizes of charge and times of ignition he drew in a full cylinder of gas and air and then compressed it on the next stroke of the piston. (Indeed, one could scarcely do anything else with a full charge.) When he set off the compressed charge, he got a surprisingly violent explosion that drove the flywheel through several revolutions. He later said that this was the starting point of the four-stroke cycle.

Otto probably did not follow up this discovery at the time because a violent explosion was the last thing he wanted. His problem was to reduce the violence of the explosions. He was not looking for ways to increase the power of his engine but rather for ways of controlling the power he had. A worker on gas engines in the 1860's had two models to use in his thinking. One was the steam engine, in which the steam delivered an easy, steady pressure to the cylinder that could be turned on and off at will and also could be easily transferred to the other side of the piston. This was the ideal to be achieved in a gas engine.

The other model was the gun, which provided experience with the behavior of explosions in cylinders. The gun was the first internal-combustion engine, and it delivered energy in spectacular bursts. The problem of developing a practical gas engine was like the problem of getting useful work out of a gun. One objective is to generate a series of explosions—to make it a machine gun. The other, the critical objective for Otto, was somehow to convert the series of explosive impulses into a smooth flow of power. A flywheel would obviously smooth out the impulses, but Otto still had the problem, or thought he did, of moderating or cushioning the explosions so that they would not destroy the engine.

Otto tried three different solutions to this problem. This first was to use an extra free piston in the cylinder that would act as a spring to absorb the shock of the explosion. Otto later said he had tried such an arrangement in 1862. It was incorporated in a four-cylinder engine (very surprising for 1862) that compressed the charge and was said to employ the four-stroke cycle. The drawing was prepared from memory by a mechanic in 1885 in the course of patent litigation to support Otto's doubtful contention that he had used the four-stroke cycle in 1862; its purpose here is only to illustrate Otto's first solution to the shock problem. Each cylinder had a working piston connected to the crankshaft in the usual way, and between this main piston and the end of the cylinder was a free piston mounted on a plunger that was free to move back and forth in a hollow passage in the connecting rod of the main piston. The free piston would act as a shock absorber; when the explosion came, it would be driven back against the main piston, and the air trapped between the two pistons and the air in the hollow passage of the connecting rod would cushion the shock. The main piston would therefore be driven back more smoothly and gradually than the free piston.

This double-piston arrangement had another function: it helped to drive out the exhaust gases. In an ordinary four-stroke engine the piston does not reach the end of the cylinder because it has to leave room for the compressed charge to be burned. Thus the space occupied by the charge at the end of the compression stroke is still there at the end of the exhaust stroke, and it contains unexpelled gases that remain to contaminate the next charge. At first engineers were concerned about this contamination. Nowadays they do not have to worry so much about it because they work with much higher compression ratios, say 10 to 1 (a tenfold increase in pressure). This means that the space not swept out by the piston is much smaller than it was, for example, in the Silent Otto, which had a compression ratio of 2.5 to 1. The free piston shown in Otto's 1862 arrangement would have been gradually forced back against the main piston by the increasing pressure of the charge being compressed, thereby leaving room for

the charge at the end of the stroke. On the exhaust stroke the compressed air that had cushioned the explosion would have driven the free piston to the end wall of the cylinder and so have pushed out the exhaust completely.

It is doubtful that Otto actually ran such an engine, but he did try the idea of a shock-absorbing device. So did a number of others, including Lenoir. In 1893 Frank Duryea used a free piston like Otto's in the first American horseless-carriage engine. These engines were all failures. At that time engineers worried too much about expelling exhaust and not enough about properly timing the ignition of the charge. In a free-piston engine of this kind the instant of ignition could not be precisely fixed in relation to the instant of maximum compression. One could never tell from the outside where the free piston was at any given time, and it was the free piston that determined the instant of maximum compression. Premature explosions must have been common. Otto said that this engine was ruined by destructive shocks and that he despaired of ever getting a gas engine to work on the direct-acting principle, that is, with the expanding gases driving the output shaft directly.

Otto now turned to a second kind of solution to the shock problem. He gave up trying to moderate or absorb the shock of the explosion and instead disconnected the piston from the output shaft during the explosion. He had found in his early work on the Lenoir engine that the hot gases in a cylinder would cool quickly and form a partial vacuum, so that atmospheric pressure would drive the piston back. In the "atmospheric engine" he developed over the next five years the explosion drove a heavy free piston up a vertical cylinder as far as it would go. The gases then cooled and contracted to form a partial vacuum, and atmospheric pressure, assisted by the weight of the piston, did the work on the way down. A clutch allowed the piston to rise freely but caused it to engage the output shaft on the way down.

The atmospheric engine was an ingenious and perfectly workable solution to the problem of getting useful power from a series of explosions. To someone accustomed to steam engines it was noisy and queer-looking, but it was more efficient than Lenoir's imitation steam engine (chiefly because it allowed more expansion of the hot gases). The principle of the atmospheric engine was not new, although Otto said he had got the idea from his own experience. The Newcomen steam engine, known for 150 years, created a vacuum by causing steam to condense and letting atmospheric pressure do the useful work, and the same principle had been applied to the gas engine in the 1850's. Otto's engine, however, went beyond earlier atmospheric engines in efficiency and reliability; it was the first genuinely successful internal-combustion engine. It was also the foundation of a successful business in which the guiding spirit was Eugen Langen, whose name appears with Otto's on the name-plate of the engine. Langen made the same kind of contribution to Otto's progress that Matthew Boulton made to James Watt's.

About 5,000 of these engines were built in various countries, but the Otto & Langen turned out to be a dead-end branch in the evolution of the internal-combustion engine. The reason was that atmospheric pressure placed a ceiling on its performance. The Otto & Langen came at a time of increasing demand for more powerful engines, and it seemed impractical to make an engine of more than about three horsepower. Since the working pressure could not be increased, the only way to increase the power was to enlarge the cylinder, and it was already so large that in the three-horsepower size it needed about 12 feet of headroom. Otto and his associates tried all kinds of ideas for improving the atmospheric engine, but the basic design proved to be inflexible and not easily adapted to further development. Nevertheless, they learned much from the engine. It was a good experimental tool for Otto's continuing work on combustion because it gave him an easy way to estimate the explosive force of different fuels and mixtures: he could see how far the piston was driven up by different charges. Otto continued to study combustion in cylinders, to test competing engines and to try various ideas for new types of engines, including at least one involving compression.

In 1876, with sales of the Otto & Langen dropping, the need for some kind of radical improvement became urgent. At this time Otto suddenly thought of a third solution to his key problem: cushioning the shock of the gas explosions. It sent him back to the direct-acting gas engine he had abandoned as being hopeless in 1862, and persuaded him to try a compressed charge without the shock-absorbing piston. Guided by this idea, he quickly built the Silent Otto of 1876

and worked out the details of the four-stroke cycle as a way of compressing the charge in the working cylinder. The engine was a great success, and it proved to be a flexible design that could be used for many purposes and was susceptible to evolution into a wide variety of forms.

The idea that led Otto to his third solution was the concept of stratified charge—the concept that the gases inside the cylinder could themselves perform the shock-absorbing function if they were mixed properly. The idea came to him, Otto said, as he was idly watching smoke rise from a factory smokestack and thinking about combustion problems. The smoke billowed and swirled into the air and then gradually disappeared. A combustible mixture might enter a cylinder in the same fashion, he thought, and then it occurred to him that if a combustible mixture spread itself out into an inert medium like smoke rising in air, the inert medium might somehow slow down the burning or moderate the explosion.

Otto had been studying combustion for 15 years. Back in 1860 his work on the Lenoir engine had taught him that the ratio of fuel to air was critically important. If a mixture of illuminating gas and air was too rich or too lean, he found, it would not burn at all. Within the rather narrow range of combustibility a mixture too rich would ignite easily, but the shock of the explosion would be too strong for the engine; a mixture too lean would burn more gently, but ignition was difficult. Accordingly Otto's problem in the 1860's was how to get both reliable ignition and slow burning. The idea suggested by the smokestack episode was that he could have both if he controlled the intake of the gas and air in such a way that he had a mixture rich enough near the point of ignition for the ignition to occur reliably, and lean enough near the piston for the combustion to occur slowly. On this basis the exhaust gases from the last cycle, which would not burn at all, suddenly became a positive good; they might remain in a layer near the piston and help to protect it from shocks. The extra free piston shown in Otto's 1862 plan would no longer be required to absorb the shock, nor would it be needed to expel the exhaust.

To produce this special kind of charge Otto used a slide valve that was driven back and forth across the entrance to the cylinder by a half-speed control shaft. The valve was a brass block with an elaborate system of passages that admitted plain air for the first half of the intake stroke and a fuel-air mixture of increasing richness for the second half of the stroke. To ignite the stratified charge at the end of the compression stroke the slide valve picked up a bit of burning gas from an external standing flame and inserted it in the combustion chamber at just the right moment. This was quite a trick, because the pressure inside was higher than it was outside. What Otto thought he had in his combustion chamber at the time of ignition was a layer of old exhaust gases nearest the piston, then a layer of air, then layers of a fuel-air mixture of increasing richness, with the richest mixture nearest the point of ignition.

Otto got into trouble with the concept of the stratified charge. In fact, he lost his patent protection in some countries when his opponents were able to persuade the courts that the charge in Otto's engine was not stratified and that an engine with a homogeneous charge would also run smoothly. Otto continued to insist that no compression engine could run smoothly unless the charge was stratified in some sense. He did not really mean, he said later, that different kinds of gas had to be in sharply defined layers. They could be in irregular swirls, like the smoke from the smokestack, but the fuel-air particles would still have to be distributed in such a way that the combustion was propagated from one fuel-air particle to another through an inert medium that did not participate in the combustion and had the function of softening the shock or slowing the burning.

In those days nobody could tell exactly what was happening inside the cylinder. Even in a slow engine such as Otto's a complete four-stroke cycle took less than a second. There was plenty of room for argument, and there *was* plenty of argument. One instrument used at that time to measure the performance of an engine and diagnose its ills was the indicator mechanism designed by James Watt for the steam engine; it recorded pressures within the cylinder as the piston went back and forth, in the form of a pressure-volume diagram.

Such an indicator diagram gives the engineer information he can use in the way the physician uses the pulse rate as evidence of what is happening inside the body. There was one important item of information, however, that in those days could only be inferred: temperature. Here the uncertainties were so large that the most respectable experts could differ widely about what was going on

in an engine. The oscillations in the expansion curve of the Lenoir diagram reflect the kind of shock waves Otto professed to find in competing engines without stratified charge, and the smoothly declining pressure in the expansion curves of the diagrams of his own engines indicates the special kind of burning due to the structure of the gases that Otto claimed as the essence of his invention.

Otto never abandoned his theory of the stratified charge, but by the time of his death most experts had turned against it. It was generally agreed that the fuel-air mixture in an engine should be as homogeneous and as free of exhaust gases as possible, and that smooth running was achieved by the proper mixture and the timing of ignition. Still, not everyone was convinced, and it is curious to see how the concept of the stratified charge, or something very much like it, keeps reappearing in the history of the internal-combustion engine. Harry Ricardo, for example, reinvented the stratified charge in 1922 as a means of achieving fuel economy through improved combustion. He proposed igniting a particularly rich mixture in a small antechamber so that a hot flame would shoot out into the main combustion chamber and set fire to a mixture so lean that it ordinarily would not burn at all. (A contemporary version of the same concept appeared in a British automobile magazine as recently as last November.) Although Otto had begun by thinking of the stratified charge as a shock-absorbing device, he also saw in it a means of achieving more complete combustion. In 1877 he patented a modified shape of the combustion chamber of the Silent Otto that would concentrate the richest mixture in a narrow channel so that a hot flame would shoot out into the main charge and ignite its leanest parts.

The possibility of greater fuel economy makes such an idea interesting to automobile and oil companies today. Public awareness of air pollution has also helped to revive interest in the stratified charge as a potential way to get cleaner automobile exhaust through more complete combustion. A number of experimental programs have been launched in the past 15 years in the U.S. and abroad for the purpose of trying new shapes of combustion chambers and changes in fuel injection and ignition, all involving some kind of separation of rich and lean mixtures with the rich mixture near the point of ignition. These programs usually reflect an interest in turbulence within the cylinder that brings to mind Otto's original concept of a combustible mixture swirling about like smoke from a smokestack. One variation of the stratified charge, the Texaco Combustion Process, is said to eliminate knock, which would have been very interesting to Otto. Knock is the premature detonation of a part of the charge that is heard when low-octane gasoline is used in a high-compression engine. It was a different kind of shock that troubled Otto; he probably never tried a high enough compression to detect combustion knock as we know it. Nonetheless, he felt the same need to control combustion within his cylinder, and he tried to control it in the same way: by concentrating a rich mixture in the region of ignition.

Otto's idea of the stratified charge may not be technically respectable, but it guided him to the most important single step in the evolution of the automobile engine, and it continues to have a powerful fascination for engine designers in many countries.

Wherry, Joseph H. *Automobiles of the World* (Philadelphia: Chilton Book Company, 1968), pp. 79–96

This is one of many books describing the early days of the automobile. The portion reproduced here is particularly interesting because of the author's focus on the entrepreneurial aspects of the decline of the steam powered automobile. Wherry contends that technically the steam autos could have competed with gasoline powered cars, but that the managers of the steam auto companies did not incorporate new innovations as rapidly and did not market their products as effectively as did the managers of the companies producing gasoline powered automobiles.

The Locomobile people had moved from Newton, Massachusetts, to Bridgeport, Connecticut, very early in 1900 where they increased production of their 1899–1900 model. The Stanley twins soon wished they had not sold out. The photo-

graphic plate business was gone and automobiles were by now so thoroughly in their blood that even their violin making sideline could not assuage the anguish they felt when steam cars started selling like hot-cakes.

Their original steamer, now a Locomobile, was being copied left and right, and most of them ran like sewing machines. In fact, word drifted to their ears that out in Cleveland, Ohio, the White Sewing Machine Company was going to bring out a steam car shortly. The Stanleys had only a brief wait.

In 1901, the White Steamer was on the market—and the resemblance to the brisk selling '98 and '99 Stanley models was startling. What's more—Grout, Henrietta, Houghton, Keene, Kraft, New England, Milwaukee, Mobile, Squire and other makes—were so much like the Locomobile that it was more than the twins could bear. So they hired some help, and late in 1901 were back in business in Newton turning out Stanley Steamers faster than before.

At about this time, the White Steamer was using an improved flash boiler invented by Rollin White late in 1899. The White was able to get up steam in about half the 15 to 20 minutes required by the Stanley; but the Stanleys, never ones to fiddle around, made several improvements and, relying on their established reputation, proceeded to outsell the White within a year after reentering the game.

Naturally, the Locomobile management hauled the Stanleys into court to face a new kind of music for the twins—infringing on their original patents which Locomobile had purchased. But the twins were sharp—they got out of trouble quite easily. Rather than fighting in court, they switched. In the original Stanley—and in the proliferating copies—the engines were under the seat and drove the rear axle by chain and sprockets. The Stanleys moved the engine back and geared it directly to the rear axle.

The changed location of the engine eliminated some power loss, brought the noise level even lower, and made a better steamer than they'd had before—better than the several dozen makes with which their new 1901 Stanley was competing.

It would seem that everybody with any sort of shop simultaneously decided to build a steam car. Out in Ann Arbor, even a student at the University of Michigan, Howard Coffin, made his own steam carriage, and it was as good as most of the "store-bought" ones—looked about like them, too.

In all fairness, some of the competing steamers had different features. The Geneva, for example, was powered by a small marine-type, 2-cylinder engine and developed a 6 HP. The throttle and reverse levers were combined and were located, along with the steering post, in the center allowing either passenger to drive. The Stanleys and most others had the operating controls at the right side of the seat. The Locomobile had a hinged lever on top of the far right steering column. Mobile, the White "Stanhope" and a few others employed a centrally mounted steering tiller which allowed either occupant to steer, but the boiler burner and the other controls were at the right for the driver only.

While the Locomobile people in Bridgeport were indulging in a management fight, most of the other steam car makers indulged themselves by quietly adopting the patented Locomobile chain drive system. Most of Locomobile's competitors modified the chain drive in slight details in order to have a potential defense should Locomobile send a summons.

As things developed, the troubles at Locomobile became so critical that promotion of the product became secondary to the game of management musical chairs. Locomobiles weren't selling well because the Stanleys and others were beating them to the customers, and this made the corporate struggle all the worse.

By 1903, the Stanley was the best selling steamer in the U.S.A., and the brothers, shrewd as always, offered financial assistance to Locomobile in the form of an offer to buy all their original patents for a dime on the dollar. Locomobile management finally agreed on something and accepted the Stanleys' offer.

In 1904, the Locomobile Steamer vanished from the market, a casualty of bad judgment by management more than of any other single factor. Locomobile switched to gasoline rather than fight the other steamers.

This was a notable year for another reason—a few engineers were building experimental automobiles in Japan and one of the first cars there was a steamer. A Mr. Torao Yamaba built the car, a chain-drive machine with a 2-cylinder, 25-HP, condensing-type steam engine. The Yamaba family was large so this automobile was 15 feet long, 4½ feet wide, and could seat ten people. Yamaba equipped this extremely early Japanese car with wire wheels and solid rubber tires. Little,

unfortunately, is known about the Yamaba Steamer's performance or whether more were built.

In 1906, Grout stopped production after selling about 3,000 fairly good steamers. So the Stanleys had things pretty much their own way until 1906, even exporting a number of cars to Canada and England. Then White ran advertisements in the papers and began to cut a larger piece of the sales pie. Rollin White had hit the market with a condenser that gave his cars four times the range of the Stanley and the lesser competitors. The White condenser, adopted from the French-built Serpolet, saved the exhausted steam and routed the water back to the boiler so it was used over and over again rather than wasted. White relocated the engine beneath the hood and, with the condenser looking like a radiator, the White looked like a gasoline car. By this time, gasoline cars were becoming more refined and less offensive; they looked better and were selling well.

Instead of installing condensers—as they finally did in 1914—the Stanley brothers resorted to a familiar course of action: they made some sensational news! They stuffed a 2-cylinder engine with a bore of 4½ inches and a stroke of 6½ inches, making a displacement of 263.25 cubic inches (roughly five times that of their standard engine), into a specially built Stanley racer.

The brothers Stanley then hired Fred Marriott, a famous driver, and headed for Daytona Beach. On January 26, 1906, Marriott flashed the Stanley's boiler up and sizzled across the smooth Daytona sand at a timed 127.659 MPH to set a new world's record!

There wasn't an airplane or any other man-carrying object that could come close to that mark.

The speed record helped, but not enough and by 1907 the White was giving the Stanley a bad time where it counted—in the salesrooms. People liked steam cars, but they also liked gasoline cars—they looked better for one thing. Moreover, any gas cars, and the White Steamer, could pass up several filling stations. The Stanley always seemed too thirsty. Other than White or Stanley models, there weren't many available steamers anymore, either.

The Stanley solution to the continuing sales problem in 1907? Rap out another record—and they did. Along with driver Marriott, the twins hustled back to Daytona and Marriott put his foot through the Special's floor. He drove that Stanley Special 197 miles per hour!

Still gaining speed, Marriott would have passed the 200 MPH mark easily if the steamer had stayed on the ground. It became air-borne because of speed and the flat bottom, took off, flipped, and was totally destroyed. Marriott recovered but not until after a long stay in a hospital.

The records disclose that the 197 MPH Stanley was carrying boiler pressure of 1,200 pounds per square inch. Though rated a mere 30 HP that steamer had covered the ground at a rate beyond the capability of all but a few specials even today.

White brought out a more popularly priced model, the "00," in 1909. This excellent type was the last of the line and future White cars were gasoline-powered. The White Steamer could, in all probability, have outlasted the Stanley for by this date the White had a two-stage, double-acting compound engine of excellent design.

Compound steam engines, later brought to a high point of efficiency by Doble, have a double set of cylinders, one set with a smaller bore than the other. Initial admission of steam is into the larger cylinder but the exhausted steam, instead of returning to the condenser immediately, is then admitted to the smaller cylinder where, even at reduced temperature, it exerts nearly as much thrust as it did in the big bore because of acting on a smaller piston area. The stroke is the same in each set of bores.

Thus, while Stanley stuck to the relatively simple but considerably less efficient two cylinders, the rest of the steam field nearly ran away with the ball, and Stanley, though remaining the only important steam car maker, quickly started to lose ground to gasoline cars which were taking the country by storm after a bad first decade.

Stanley had had the coffin-nose styling for several years and, despite decreased sales, was not going to change it. The high mark for their cut of the market was 1910. Their entry that year was a 4–5 seater with a runabout body, boiler beneath the hood, no condenser, and engine still bolted to the rear axle. The Stanleys held the runabout's price to a very competitive $850.

A glance at the accompanying roster of steam cars shows that all the significant competition had fallen by the wayside. The Stanleys now had the steam

car field to themselves, nor would any effective competitor challenge them. Only a handful of these steam cars achieved success, and that was fleeting. The exceptions were Stanley, Lane, and White in that order.

ROSTER OF AMERICAN STEAM CARS*

Coats 1921–22
Coffin 1901 (Exp.)
Cunningham 1900–07
Delling 1924–27
Detrick 1957 (Exp.)
Detroit 1922
Doble 1921–32
Dodge 1913–24
Eclipse 1901–02
Electronomic 1901 only
Elite 1901 only
Endurance 1922–23
Essex 1906–08
Federal 1905–?
Foster 1898–1904–or–05
Gaeth 1902–06
Gearless 1920 only
Geneva 1901–09
Grout 1899–1906
Hartley 1898–?
Henrietta 1901 only
Hess 1902–03
Hoffman 1902 only
Houghton 1900 only
House 1901–10
Hudson 1901 only
Jaxon 1903 only
Johnson 1905–08
Keene 1900–01
Kellogg 1903 only
Kensington 1899–1903
Keystone 1909 only
Kraft 1901 only
Lane 1899–1910
Larchmont 1900 only
Locomobile 1899–1904
Lozier 1901–02
Lutz 1917 only
MacDonald 1923 only
Malden 1914 only
Marlboro 1900–02
Mason 1898–?
McKay 1900–02
Meteor 1902–08
Milwaukee 1900–02
Mobile 1899–1902
New England 1899–1900
Olds 1886**
Ormond 1904–05
Overman 1899–1900
Pawtucker 1901–02
Philion 1892 (Exp.)
Porter 1899–1900
Prescott 1900–05
Puritan 1902 only
Randall 1905 only
Reading 1900–02
Remal-Vincent 1923 (only)
Riley & Cowley 1902 only
Rochester 1901 (only)
Rogers 1899 only
Roper 1864–70
Ross 1905–09
Scott-Newcomb 1901 only
Skene 1900 only
Spencer 1901 only
Squire 1899–?
Stammobile 1905 only
Standard 1900 only
Stanley 1896–1925
Steamobile 1901–02
Stearns 1898 only
Stringer 1901 only
Taunton 1901–04
Toledo 1900–03
Trinity 1900 only
Victor 1900–02
White 1900–09
Whitney 1899–?

*Doubtless, there were other steam cars, which makers intended, or tried, to market commercially. However, those listed have more substantial records. Some of the lesser known makes were very few in number.

**One only, a 3-wheeler; rebuilt in 1893 as 4-wheeler and exported on order to Bombay, India. First exported American automobile.

The Lane, built in Poughkeepsie, New York, got off to a slow start in 1899 and lasted one year more than White. A quality car priced at a basic $1,500 for the final 1910 model, the Lane used a relatively simple 2-cylinder, double-acting engine as did the Stanley. The Lane, however, employed a condenser mounted in front like a radiator. Styling was comparable to the gasoline cars of the period including full-length running boards, attractive tool chests, and well-fitted interiors, although not as lavish as the much more expensive White. Another victim of the steamers' slow warm-up time, Lane was marketed in rather limited quantities primarily in the East.

Finally, by 1914, the Stanleys realized that a condenser was the obvious solution to public reaction against the too frequent stops for water. The additional steam and water lines leaked badly at first, but worse, the modified boilers leaked due to engine lubricating oil leaking into the tube joints. This oil solidified in the tubes and caused formations of carbon to accumulate that seriously affected heating efficiency. The Stanleys never licked this problem although they tried many types of filters. Gradually they were losing out but the Massachusetts brothers refused to give up as dozens of steam car makers had been forced to do.

The Stanleys eventually turned out some better styled models as the First World War came along. Getting rid of the famed coffin nose by 1918, the Stanley car had taken on the appearance of its gasoline powered competitors. By 1923, the twins finally realized they were in serious trouble and built their last steamer, the Model 740. Then a new name came into a short-lived existence, the Delling Company, and the Stanley twins again sold out. Delling, without any changes, produced the 1924 Stanley steamer and then closed out the line in 1925 with the "750" and "252" models. These still took up to 20 minutes to get up operating steam.

Delling unsuccessfully tried to market a much improved car under their own name until 1927, but despite excellent styling and a 3-cylinder, double-acting engine, it was too little and too late. The Delling could, however, develop 62 HP and travel some 250 miles non-stop due to the large 22-gallon fuel tank and an equally large water tank. The Delling also had 4-wheel Lockheed hydraulic brakes ('25) and, for a large comfortable car with a 132-inch wheelbase, was a comparatively good buy at prices from $2,500 to $3,200. The boiler had no welded seams and was guaranteed not to explode—something Stanleys were unfairly blamed for.

The Delling had styling equal to that of its gasoline contemporaries and the interiors were almost elegant. The boiler and engine were hidden beneath a long hood nosed off by an attractive shell around the condenser. An improved flash boiler allowed operation one minute after turning up the burner, and a small pilot flame prevented freezing in winter. This final 1927 Delling had the then new Ross cam and lever steering, a heater, a choice of disc or spoke wheels, and custom-built aluminum bodies.

Dellings were so rare that photographs of them are virtually non-existent. One of the very best, the Delling failed primarily because of lack of financial resources. Also the times dictated a jump-in-and-go time of considerably less than the '27 Delling's.

The finest of all the steamers, and a classic in its own right, was the magnificent Doble. Built to the most exacting standards of the time, this $10,000-and-up beauty was for the person of means who could afford the best and knew it when he saw it. Emeryville, California, an enclave in Oakland, was Doble's home base. In his fastidiously run plant, Adam Doble turned out just forty cars between 1921 and 1932. Doble's engine had 4 cylinders cast in pairs and was of the compound type with two high-pressure and two low-pressure bores of 4.5 and 2.67 inches respectively. The stroke was 5.00 inches. The engine was integral with the rear axle and the crankshaft geared directly to it. The huge boiler had 575.75 feet of cold-drawn seamless steel tubing that, when coiled and installed, had a diameter of 22 inches and a height of 13 inches. Doble tested his boilers to 7,000 psi. Beneath the toe boards on the right side was the auxiliary unit which incorporated the water and oil pumps, vacuum pump, the Bosch electric generator, the air pump for the fuel pressure, and the speedometer drive.

The Doble's condenser was a standard type radiator through which cool air was drawn by a 24-inch-diameter fan that turned 3,200 rpm at 60 miles an hour. At this speed the mighty car was merely loafing. The chassis alone weighed a bit over 3,000 pounds and, when the custom coachwork was added, the road weight was upwards of 4,000 pounds. Some fine Doble limousines are said to have weighed as much as 5,000 pounds dry. At 750 pounds steam pressure and a temperature of 750 degrees F., the Doble cruised effortlessly at 75 MPH. Maximum speeds exceeded 100 MPH by a comfortable margin and getting under way after a cold start usually took less than 30 seconds. Frank Thomas, a well-known steam engineer in the '30s, recalls driving Dobles that could get under way in as little as 15 seconds from cold.

Doble, a perfectionist, insisted on excellent roadability and good braking. He made the brake drums of 50-point carbon steel. They were 16 inches in diameter and 5 inches wide, and were externally reinforced by fins which also aided cooling. The shoes were aluminum for lightness and to dissipate heat; the highest priced lining material available was ground to a precise fit with the drum after assembly of the shoes. Chrome vanadium steel was used for the rear axle shafts. The steering was worm and wheel and, despite a standard wheelbase of 142 inches and a tread of 57, this huge car turned in a circle of just 42 feet diameter. The steering wheel, like the car's other finely executed details had a cast and polished German silver spider with a rim of hand-rubbed African ebony.

If there was ever a near perfect steam car, the Doble was that car. Doble's warranty was for 100,000 miles.

The crash of '29 pulled down many of this country's fine cars and Doble was forced in 1932 to cease production of one of the finest of any type. Doble, however, licensed the Henschel Acktiengesellschaft in Germany during the early '30s. Henschel, later to become great in World War II as an aircraft and engine producer, adapted the Doble engines, in varying horsepowers of 120 to 200, to a new line of heavy-duty trucks and buses. These Doble-powered vehicles were produced in the early years of the war and did yeoman service. The Sentinel Steam Vehicle Company of Great Britain also used some of the Doble's features in trucks

that made a great reputation for themselves in such difficult places as the jungles of Burma.

So many references to the various types of generators, or boilers, for steam cars requires an explanation of the characteristics of the three principal boiler types.

Flash boiler (Doble) : very rapid heat exchange was possible by exposing to heat small amounts of water distributed over a large area. Doble had 575.75 feet of tubing. An extremely long steel tube was coiled so that flame played over the entire tube. The Doble could move off from a cold start in 15 seconds and after 80 seconds could maintain a continuous 60 MPH. Pressures exceeded 500 psi.

Water tube boiler (Stanley, Mobile, Locomobile) : separate, short lengths of tubes were connected at the feed water end and at the opposite end by the header tank. The water capacity was greater because the tubes were of considerably greater diameter. The disadvantage was that flame played over only the lower tubes (if horizontal) and/or lower ends of a vertical boiler. Thus, it took much longer to get up steam. Even the last Stanleys (1924) took upward of 12 minutes to get up sufficient steam pressure to cope with traffic. Pressures were generally 250 to 400 psi.

Water level boiler (mostly used by home built types and specials) : a simple tank was used as the boiler with flame at the bottom. The only advantage was a greater water capacity. The disadvantage: upward of 50 minutes to get up steam for adequate speeds. The pressure was usually 250 psi.

The end, though, is not yet, for the fans across the country will keep their steamers going for many years. In Newton, Massachusetts, the home of the Stanley Steamers, the American Steam Automobile Company is reportedly still able to supply some parts from the factory which, as late as 1942, was able to accept orders for complete steam cars before wartime restrictions prevented it. The last engine development from this firm was a single-acting V–4 engine which was used in a number of wartime civilian conversions, the engine being mounted under the hood with the fuel oil or coal-fired boilers in the trunk.

The old Doble factory in Emeryville, California, is now called The Bessler Company and they're supposed to be tinkering with some ultra-modern steam car ideas not yet ready for airing.

The late Forrest R. Detrick, an attorney, long-time steam car expert William Mehrling, and steam engineer Lee Gaeke were preparing some years ago to market, on order, engines and parts for enthusiasts. The unfortunate death of Detrick apparently ended this project.

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