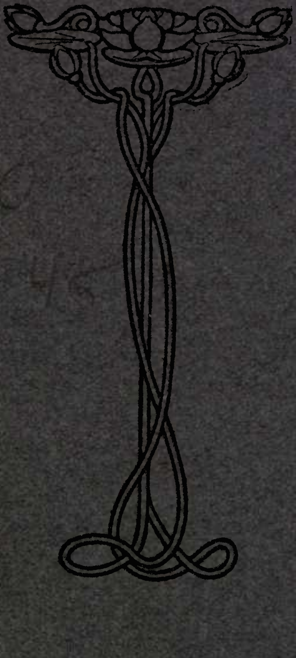
GASOLOGY



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GASOLOGY

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FOREWORD

This little volume is a compilation of the first twenty-seven lessons of the "Gas Engine Course" which has been published as a serial in Gas Review.

When Gas Review first started three years ago it was deemed advisable to offer a complete course in gas and gasoline engineering. One requirement of these lessons was that they were to be written in plain, simple language that anyone could understand. We have followed that idea all the way through and the lessons won the approval of our readers from the start.

There were many calls for back copies of Gas Review from those who subscribed late and who wanted to own a complete copy of the lessons and we concluded to publish them in book form since we were unable to supply back copies of the magazine.

The lessons do not cover the whole subject for the reason that they are not yet completed. However, as far as they have gone they cover the subject quite completely and it is believed will give the reader much valuable information in regard to the best modern practice.

We have drawn freely from many sources in preparing the lessons and make no claims for originality in anything except the phraseology and general arrangement of the subject matter. In these particulars we believe we have succeeded in producing a book that has the great merit of clearness and simplicity. It is a book primarily for the beginner and the actual user.

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CHAPTER I

GAS ENGINE PRINCIPLES

LESSON I.

In presenting this series of lessons on the gas engine, the aim will be to explain as clearly as possible the principles of action of each type considered, the various mechanisms by which the engine is enabled to perform its operations, together with directions in regard to the care and proper method of handling gas engines.

Very little attention will be given to the principles of designing and the computations necessary for the proportioning of the various parts. Neither will much attention be given to the mathematical theory of the gas engine beyond what can be worked out by the simpler rules of arithmetic. The aim of these lessons is to help those who are running gas engines, rather those who are designing them. To this end the lessons will be rather elementary in character.

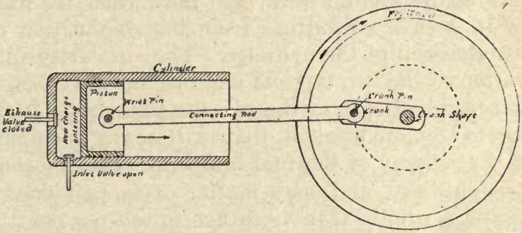


FIG. 1.

The term gas engine is commonly applied to any engine in which the fuel is first turned into a gaseous state and then burned in the engine cylinder. Gasoline engines, kerosene engines, crude oil engines and alcohol engines are all called gas engines, as well as those that run on either city gas or producer gas. A better appellation for such engines and one that is now frequently applied is "internal combustion engines."

The general principles governing both the construction and the operation of a gas engine are nearly the same as in a steam engine. The object in both is to obtain useful work from heat, that is, to transform heat energy into work. In the steam engine fuel is burned in a furnace under a boiler which contains water. The water is heated to the boiling point and steam is formed. This steam is piped to the cylinder of an engine and is there made to push a piston back and forth and rotate a shaft which is connected therewith by suitable connectors. In the steam engine, therefore, there are three distinct parts, the furnace, the boiler and the engine—the two latter may be close together or at a considerable distance from each other and connected by means of a steam pipe. In any event, the source of heat and the moving piston are at a considerable distance apart, with the boiler intervening.

In the case of the gas engine the transformation of heat into work is accomplished in a simpler and more nearly direct manner. The fuel, together with the necessary air for combustion, is introduced directly into the engine cylinder where it is burned. The gases or smoke resulting from this burning of the fuel are raised to a very high temperature, estimated at from two thousand to three thousand degrees Fahrenheit. This high temperature causes the pressure of the gases to rise and provides the motive force for moving the piston.

In both the steam engine and the gas engine heat is the motive force. In both, heat is applied to a gaseous substance in order to raise its pressure and do work. In the former the gas is steam, in the latter it is smoke resulting from the combustion of the charge of fuel introduced into the cylinder. The similarity in the principles of operation of the two types of engines has thus been pointed out, and it is quite evident that of the two the gas engine is the simpler. It ought also to be more efficient, that is, it ought to transform a larger amount of heat energy of the fuel into work than the steam engine because of its simplicity, and, as a matter of fact, it does. The average steam engine can only turn from five to ten per cent of the heat energy of the fuel into work, while an ordinary gas engine utilizes from twelve to twenty-five per cent. Despite the difference in efficiency, however, the steam engine possesses certain advantages in operation that make it a more desirable form of motor for many kinds of work than the gas engine, while for certain other purposes the gas engine is without a rival.

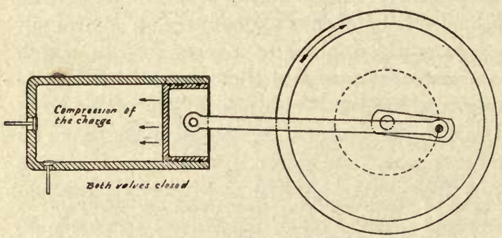


FIG. 2.

Before going further into the matter of efficiencies or advantages of the different types of heat engines, we will first discuss the elementary mechanism of a gas engine.

Every gas engine, no matter whether it uses alcohol, gasoline, kerosene or some other gaseous or liquid fuel, must have certain parts, no matter how different engines may vary in other details. These parts are shown diagramatically in the four accompanying sketches—Figs.

1, 2, 3 and 4, with all the parts named. The type of engine illustrated is called the four-stroke cycle engine or sometimes simply the four cycle engine, since four separate strokes of the piston are necessary to complete its cycle of operation. There is another type of engine which completes its entire cycle in two strokes, or one revolution of the crank shaft, called a two-stroke cycle engine.

Referring to Fig. 1, it will be noticed that the length of the cylinder is considerably greater than the length of the stroke and of the piston combined. When the piston is at the left end of the cylinder there is still left a considerable space between the piston and the cylinder head. This space is sometimes called the clearance, sometimes the compression chamber and sometimes the explosion chamber, since it performs all three of these functions. Both the inlet valve and the exhaust valve are located in this chamber and both open inward. When the piston moves toward the right from its extreme inner position, a charge of fuel and air, which has been first mixed in the proper proportions, is drawn in through the inlet valve, while at the same time the exhaust valve is held shut.

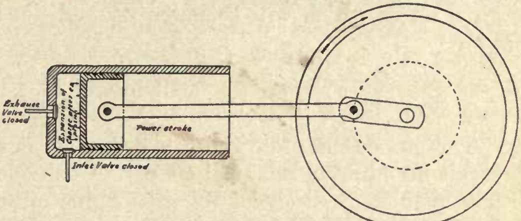


FIG. 3.

On the return stroke of the piston, shown in Fig. 2, both valves remain closed and the charge is forced back and compressed in the compression chamber. The amount of compression varies according to the size of the chamber in the various makes of engines and according to the fuel used, but may be taken roughly as being from fifty to one hundred and fifty pounds per square inch. Just before reaching the inner dead center, the charge is ignited, combustion or explosion takes place, and the piston starts toward the right again, as shown in Fig. 3. During this stroke both valves remain closed until almost at the end of the stroke, when the exhaust valve is forced open and the spent charge is allowed to escape. During the fourth stroke, see Fig. 4, the exhaust valve remains open and the

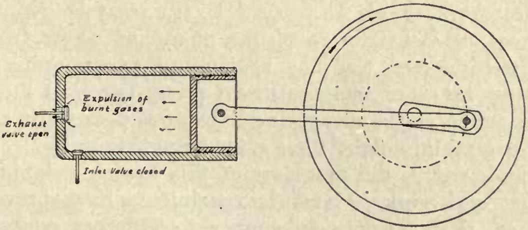


FIG. 4.

burnt gases are forced out of the cylinder by the retreating piston. Just previous to the end of this stroke the exhaust valve snaps shut and on the fifth stroke a new charge is drawn in, thus beginning a new cycle of operations, and subsequently the whole series of operations is repeated indefinitely and automatically as long as the mechanism is in running order.

While the above parts are essential to every gas engine, it will be understood, of course, that an engine so constructed would not run. There are other parts and details necessary to a complete working engine, all of which will be taken up and described in subsequent lessons.

LESSON II.

The gas engine, like the steam engine, is a heat motor. It transforms heat into mechanical energy. Consequently, to be in any measure complete, a study of the gas engine must include a study of the laws of heat.

Heat is not a substance but a condition. It has been defined as a form of energy. When a body is hot all of its particles or molecules are in a rapid state of vibration; the hotter it is the more rapid the vibration. As it cools, the particles move less and less rapidly and through shorter distances, thus causing the body to contract. There is a difference between temperature and quantity of heat. Temperature merely measures the intensity of heat and not the amount. For example, if a small rod of iron be heated red hot and then be plunged into a barrel of water, it will lose its heat to the water without raising have absorbed all the heat of the iron down to its own temperature. the temperature of the water a perceptible amount. Yet the water will

In order to measure quantity of heat, a unit of measurement has been adopted by engineers, called the British Thermal Unit—generally written in engineering work simply B. t. u. A B. t. u. may be defined as the amount of heat necessary to raise one pound of water from sixty-two to sixty-three degrees F. The heating of two pounds of water through the same range of temperature requires two heat units and so on. Water is taken as the measuring substance because it absorbs more heat for a certain weight than almost anything else.

There is, as foreshadowed in the first part of this lesson, a definite relation between heat and work. Careful experiments have proven that a heat unit is equal in mechanical energy to 778 foot pounds. That is, the amount of heat necessary to heat one pound of water one degree is equivalent to raising a weight of 778 pounds one foot high, or, what is the same thing, raising one pound 778 feet high.

The reader may inquire at this point what the above conception of heat has to do with a gas engine. The answer is easily given. A pound of fuel contains a certain number of B. t. u. and since it is the duty of the engine to transform them into work, it follows that if we want to find out just how efficient an engine is we must measure the number of heat units supplied in the form of fuel and then determine how many of these heat units have been turned into useful work at the band wheel. To illustrate, every pound of gasoline contains from 18,000 to 20,000 B. t. u. If on testing an engine we found that for every pound of gasoline used we obtained the value of 4,500 to 5,000 B. t. u. in useful work, then the actual heat efficiency of the engine would be twenty-five per cent. That is, one-quarter of the heat producing power of the gasoline was turned into useful work and three-quarters was lost. That which is lost is carried away, in part by the jacket water, in part by the exhaust gases, while the remainder is lost in overcoming the friction of the engine and through radiation. A complete test of an engine takes account of all these losses and if the engineer who makes the tests understands the laws of heat, he can determine very closely just how much is lost in each of the different ways above mentioned. A complete discussion of the laws of heat will be reserved for a future lesson when directions will be given for making a complete test.

We will now proceed to discuss some of the effects of heat. The general effect of heating a body is to cause it to expand. If a gas, such as air, is heated it expands, or if it is imprisoned so that it cannot expand, it exerts a pressure on the walls of the containing vessel in proportion to its absolute temperature. The absolute temperature, by the way, is measured from absolute zero, that is, a point 461 degrees below zero on the Fahrenheit scale and is the point at which all molecular motion ceases. Above that temperature all the bodies are supposed to contain some heat and their particles are in a state of motion. The expansion or rise in pressure of a gas when heated is the principle that is taken advantage of in a gas engine.

As explained in lesson I, a charge is drawn into the cylinder and there compressed. At the moment when the piston is passing center the charge is ignited and burned, the temperature of the resulting gas is raised to between 2,000 and 3,000 F., and since this gas is imprisoned behind the piston in a small space it exerts a tremendous pressure upon the piston at the beginning of the stroke. The amount of the pressure varies under different conditions of adjustment of the engine and upon the amount of fuel and air admitted to the cylinder and the proportion in which the two are mixed. In ordinary gas engines the pressure often amounts to 350 or 400 pounds per square inch, thus giving a total pressure on an eight-inch piston of somewhere near 20,000 pounds. This pressure, it must be borne in mind, is not in the nature of a blow such as would be struck with a heavy hammer, but to the sudden energy imparted to the gases by the liberation of the heat energy of the fuel they contain when first admitted to the cylinder. As the piston advances on its power stroke the gases expand and this pressure falls rapidly until at the end of the stroke when the exhaust valve opens, the pressure is comparatively small. On account of the very high initial pressure, however, the average pressure for the whole stroke is quite high, as it must be considering the fact that there is only one power stroke in every four strokes of the piston.

Since the motive power of the engine is heat and this heat is generated by the combustion of fuel in the engine cylinder, it follows, naturally, that a knowledge of the principles of combustion is essential to a proper understanding of the working of a gas engine. The lack of understanding of this important subject is responsible for a considerable amount of the difficulty in handling these engines.

Combustion or burning is a chemical process and may, for our purposes, be defined as a combination with oxygen. The oxygen is supplied by the air, which consists of two gases, oxygen and nitrogen, mixed in the proportion of 786 parts of nitrogen and 214 parts of oxygen, by volume. When fuel burns, the oxygen of the air unites with the carbon and hydrogen in the fuel, forming a new chemical compound. This compound is in the form of a gas and is the resulting smoke of combustion. The liquid fuels, such as gasoline, kerosene and alcohol, are composed of carbon and hydrogen in varying proportions, depending upon the fuel used. When they are introduced into an engine cylinder they are mixed with the proper amount of air in a chamber called a carburetor, from which they pass directly to the engine cylinder. When the charge of air and fuel passes into the cylinder the fuel is either in the form of a gas or vapor or else in a very finely divided mist or fog.

Ignition is started by passing a flame through some portion of the charge, as in the case of the electric spark or by means of a heated body. The gas at this place is heated to the ignition point and the resulting flame rapidly propagates itself throughout the mass.

A certain amount of carbon requires a definite quantity of oxygen for complete combustion and the same is true of the hydrogen. Consequently the fuel and air must be mixed in exactly the right proportions to give the best results. If too much fuel is supplied for the amount of air, the mixture will be too rich in fuel and ignition may not take place at all, and if it does the heat generated will not be as great as though the correct proportion were used. Consequently the engine will not develop its maximum power. On the other hand, if there is not enough fuel for the amount of air admitted, the mixture will be lean and ignition may fail or the explosion may be weak.

In the greater number of small engines using liquid fuel, the supply of air cannot be varied and so the correct mixture is obtained by setting the oil valve to admit the right amount of fuel. The correct amount of fuel is determined by the character of the exhaust gases. As much fuel should be admitted as possible without showing a dense smoke at the exhaust.

LESSON III.

It was shown in the last lesson that there must be the correct proportion of fuel and air in order to obtain a mixture that will ignite readily and burn to the best advantage. Such a mixture burns almost instantaneously and is said to be explosive.

Gun powder, dynamite and other such explosives differ from the explosive mixture in a gas engine in this particular. They do not require air to supply the necessary oxygen for their complete combustion because they contain a chemical within themselves which supplies the necessary oxygen in copious quantities. All fire arms are gas engines, nevertheless, because it is the gas formed by the burning of the powder which hurls the missile from the barrel. This gas which is formed almost instantly is highly heated by the process of burning and exerts an enormous pressure in the gun barrel just as the burning of the charge in a gas engine cylinder causes pressure on the piston and drives it forward.

Before any substance, either solid or liquid, can be burned it must be heated to such a temperature that the carbon and hydrogen which it contains are distilled from the surface in a gaseous form. The temperature at which any substance will ignite is called the ignition point, and this temperature is that at which the given substance begins to give off a gas. A lump of coal does not burn as a solid but as a gas. Likewise, kerosene, gasoline and alcohol and other liquids used in gas engines must also be turned into a gas before they will become readily explosive. Gasoline at ordinary temperatures forms a gas and it is therefore easy to start an engine with this fuel except in very cold weather. When the weather is severe heat must be applied at some point in order to start, either to the engine cylinder by filling the jacket with hot water, to the air by heating the air pipe or mixer with a torch or a piece of hot iron, or by heating the gasoline. The latter method is somewhat dangerous and is not recommended. Kerosene and alcohol both form a gas at higher temperatures than gasoline and consequently it is more difficult to start an engine with either of these fuels. After getting the cylinder warmed up by using gasoline to start with, however, kerosene or alcohol can then be used with good success because the heat within the cylinder walls is then sufficient to transform the fine mist or spray of the charge into a gaseous form. While the ordinary gasoline engine may not run as economically on either of these fuels as on gasoline, still it can be made to work quite satisfactorily.

In order that a gas shall begin to combine with oxygen, that is, to burn, it must be set fire to, it must be ignited. There are numerous ways in which this may be accomplished, but the ordinary method is by means of an electric spark. The gas in immediate contact with the spark is heated to a high temperature and a flame is started which travels through the mass with great rapidity, provided that the mixture of gas and air is in the right proportions and thoroughly mixed. If the mixture is not correctly proportioned the flame will travel slowly and combustion may not be complete. That is, some of the gas may not be consumed when the piston reaches the end of its stroke. With the ordinary gas engine these conditions may not obtain either if too much fuel is admitted or if there is not enough. In the first case a dense smoke will appear at the exhaust, in the second, one or more charges may mis-fire and be forced into the muffler, then when a charge is fired the hot gases coming in contact with those remaining in the muffler will cause an explosion at that point. In either the first case or the second the force of the explosion in the cylinder is weak and the engine is not developing the power it should develop.

In the ordinary gasoline engine the size of the air pipe is fixed and can not be changed and consequently the only way to alter the mixture is by adjusting the fuel valve.

The timing of the ignition is an important point in the operation of gas engines. In all cases ignition should occur just before the piston reaches dead center on the compression stroke. The exact point depends upon the character of the gas and the speed of the engine. Ignition should always occur early enough so that the gas will be all burned by the time the piston starts on the power stroke. It is a well known fact that a gas highly compressed, or in the act of being compressed, burns more rapidly than when it is not compressed or when it is expanding. In the case of a gas being compressed the flame cap and the gas are moving toward each other, while if the gas is expanding the flame cap must follow a substance that is rapidly retreating before it. Consequently, if ignition occurs just when the piston is at the end of its compression stroke, or after it has started on its power stroke, ignition must necessarily be much slower and it may even happen that combustion will not be completed when the end of the stroke is reached. It must be borne in mind also that the act of complete combustion is not instantaneous but, on the contrary, takes an appreciable length of time. This makes it necessary to ignite the charge before the piston reaches the end of its compression stroke. In slow speed engines running at say two hundred revolutions per minute, ignition should occur when the crank is from five to ten degrees below center. Engines having a higher speed must be ignited still earlier, until on very high speed engines, those running at speeds above one thousand revolutions per minute, ignition must occur just after the crank passes half stroke or nearly forty-five degrees before the crank reaches center. With rich fuel mixtures combustion is more rapid than with lean mixtures and consequently ignition does not need to occur quite so early.

There is another factor that must be taken into account in the timing of the ignition to get the best results, and that is the temperature of the gas when ignition occurs. If the gas is hot, almost at burning temperature, it burns much more rapidly than when at a lower temperature. In an engine that is working hard, that is, one that misses very few explosions, it may happen that the igniter will be set to give the best results to start with, but after the engine has worked for a considerable length of time the cylinder will become heated so much that each new charge becomes heated almost to the burning point and when the spark is formed combustion will be almost instantaneous, making it necessary to retard the spark somewhat in order to obtain the best results. A heavily loaded engine which works all right for a time and then begins to pound in the cylinder can very likely be cured by retarding the spark.

To sum up, then, if ignition occurs either too early or too late the engine will not work to the best advantage and for the amount of fuel consumed it will not yield the maximum amount of power.

LESSON IV.

In preceding lessons considerable space was devoted to the proper mixtures of fuel and air necessary to obtain the best results. In this connection here is an interesting little experiment anyone can try with the ordinary four-stroke cycle engine. Start the engine in the usual way and after it gets to running nicely close the fuel valve a little at a time quite slowly until explosions begin to occur in the muffler. Now throttle the air supply by holding a piece of cardboard or a piece of board on the end of the air pipe, thus reducing the air supply, and note the effect.

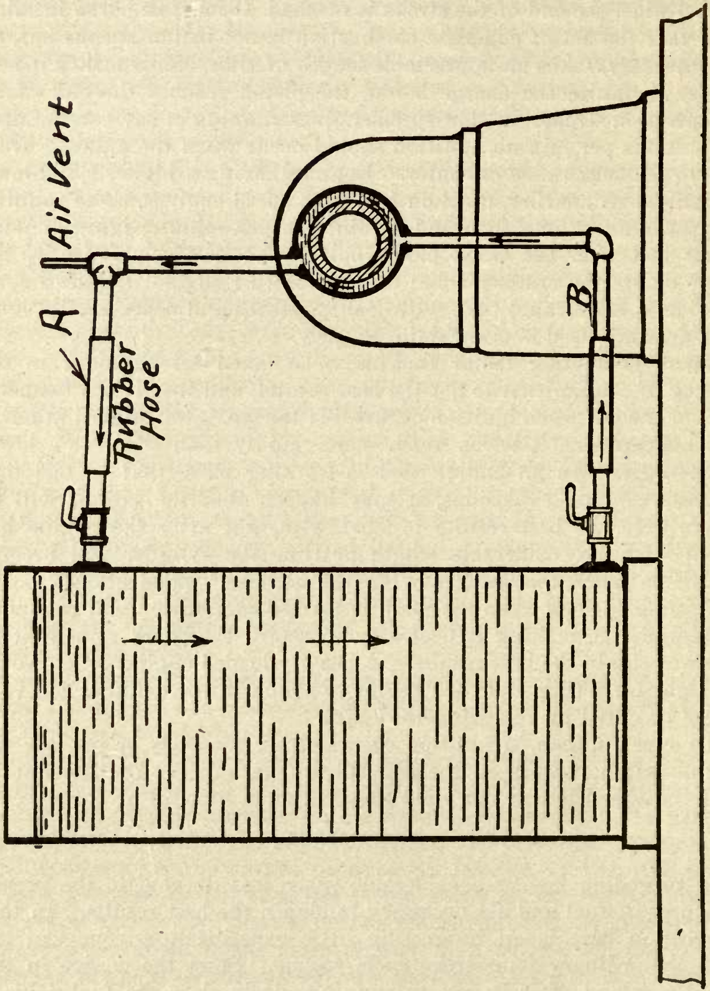


FIG. 5.

The explosions will cease in the muffler and the engine will work nicely because the supply of air has been cut down to make the correct mixture with the fuel admitted. By working carefully the fuel valve and air pipe may both be almost closed and yet the explosions will occur regularly and be all right, but will not have much force because only a small amount of fuel is taken into the cylinder at each charge.

If, when the amount of fuel is cut down so low, the air pipe were left with the full opening, the mixture would be so lean that it would not ignite at all and the engine would stop. When an engine runs on a weak or small charge as just explained it will of course not develop much power. This little experiment not only illustrates the effects of fuel and air mixtures, but illustrates also a means for governing a gas engine which is made use of in many engines, as will be more fully explained in a subsequent lesson.

The cylinder of a gas engine is made of a close grained cast iron and when well designed the walls are of practically uniform thickness throughout. This is necessary on account of the intense heat, which would cause unequal expansion and dangerous strains if the metal varied much in thickness. The cylinder is bored as smooth as possible and in the best constructions it is ground to a perfectly smooth finish. Some manufacturers claim that they grind the cylinders slightly tapering, making them two or three thousandths of an inch smaller at the head end than at the crank end. Then when the engine is in operation the greater heat at the head end causes greater expansion and the cylinder sides become exactly parallel. Such refinements in construction are practiced only on the higher priced machines, such as automobile engines and the like. Ordinary gasoline engine cylinders are merely bored out as true as possible on a boring machine.

It has been proven by experiments that there should be no pockets or chambers on the side of the combustion chamber in which a part of the charge may accumulate. It appears that where such is the case that the gases so trapped explode a little later than the main charge and are liable to set up waves of pressure in time or synchronism with the waves of the main explosion. These two waves of force occurring at the same time and meeting are apt to have the effect of a blow on the inside of the cylinder, causing an abnormally high pressure for an instant which strains the entire engine without in any way increasing its power.

The truth of this assertion has been proven by taking indicator cards from an engine having no such pockets, then screwing a short piece of pipe capped on the outer end into the combustion chamber, and taking indicator cards again, the extremely high pressures were clearly shown on the cards. This fact would seem to indicate that the inlet and exhaust valves should both open directly into the clearance space of the cylinder, or if they open into a chamber on the side of the clearance space, ignition should take place in the valve chamber.

Surrounding the cylinder and separated from it by a short space, the exact amount depending upon the size of the cylinder, there is an outside casing or jacket. This casing is usually made of cast iron, although in some instances it is made of copper. When made of cast iron it may be entirely separate from the cylinder or it may be cast with the cylinder and attached thereto at intervals in the process of casting. The space between the cylinder and this outer casing contains the cooling liquid, which may be either water or oil. Water being cheap and easy to obtain, is more commonly used than oil.

Since the temperature of combustion in a gas engine cylinder ranges between two thousand and three thousand degrees, and since cast iron melts at a temperature of about two thousand three hundred degrees it is evident that some means must be provided to carry away the excess heat. This is accomplished generally by means of circulating water or oil around the cylinder. Sometimes, however, in small sized engines ribs or spines of metal are cast on the outside of the cylinder, thus providing a large radiating surface which conducts the heat away from the cylinder to the air. Such engines are known as air cooled engines. This method works very satisfactorily with engines up to about 10-horse power, but in sizes above this the heat can not radiate rapidly enough to keep the cylinder cool.

Where either water cooling or oil cooling is resorted to there are two methods of circulating the liquid around the cylinder, either the gravity method or the pump method.

In the first case advantage is taken of the difference in weight between equal volumes of cold water and hot water, or of cold oil and hot oil if oil is the liquid used. For example, at a temperature of 39 degrees Fahrenheit a cubic foot of water weighs sixty-two and one-half pounds, while at 212 degrees Fahrenheit a cubic foot weighs only fifty-nine and one-half pounds. The hotter the water the less a certain volume of it weighs. If we have, then, a gas engine cylinder connected to a tank as shown in Fig. 5, the water in the engine jacket will become heated, its weight will be less than an equal volume in the tank and consequently the heavier water from the tank will flow in by gravity through pipe *B* and push the lighter water out.

Care must be taken to see that an air vent is placed in the highest point of pipe *A*, otherwise a bubble of air or steam may form at that point and prevent circulation. A case of this kind recently came under the writer's notice. The vent pipe was not placed in the highest part of the pipe and the cylinder became hot enough to burn the paint. The water should be from four to six inches higher in the tank than the end of pipe *A* to insure circulation. If the water falls below the pipe there will be no circulation.

In the second method a pump is used to force the water from the tank through the cylinder. A small rotary pump driven by the engine shaft is generally used. This method insures better circulation. In many cases the water is delivered from the discharge pipe in the form of spray, which falls thence into the main reservoir. By this method radiation of the heat from the water is much more rapid and a smaller quantity of water is required. It is generally conceded that the temperature of the jacket discharge water should be just below the boiling point or in the neighborhood of 180 degrees in order to obtain the best efficiency from the engine. If the jacket water is very much colder the gases in the cylinder lose their heat and consequently their expansive power too rapidly and the engine lacks power.

Oil boils at a higher temperature than water and it is not uncommon in engines cooled with oil to run with the oil in the jacket much hotter than 212 degrees. If the engine is well made this is an advantage rather than a disadvantage because the gases do not lose their heat to the jacket so rapidly and a larger quantity of their heat is available to do work on the piston. The limit of heat in the jacket is reached when lubrication of the piston becomes difficult and it has a tendency, on account of the heat, to expand and stick in the cylinder.

LESSON V.

Another method of cooling which has been proposed, and which is used in an auxiliary way to some extent, is to introduce water directly into the engine cylinder. This may be accomplished in one of two ways; either by introducing it in the form of a fine mist or spray during the aspirating stroke, or else by means of a pump during the power stroke.

If introduced during the aspirating stroke, the compression of the mixture will turn the water into steam which will become further heated after ignition. On account of the high specific heat of water, it requires a large quantity of heat to vaporize it or to raise its temperature after it is vaporized. Since this heat must be absorbed from the heat of combustion of the charge it follows, necessarily, that the temperature of the mixture in the cylinder will be materially reduced. If very much water is introduced it may absorb so much of the heat generated during compression that the gases will not be hot enough to ignite readily. Especially will this be true if the charge is somewhat lean. This accounts for the fact that a leak of water from the jacket to the cylinder makes it difficult to start the engine.

Cooling, in the method just described, cannot be carried out completely. Some writers declare that it is never conducive to good economy in any case because it reduces the temperatures and pressures in the cylinder. The results of tests seem to prove, however, that under certain circumstances it may be advantageous to use. In kerosene engines and in many alcohol engines provision is made to use a water spray, and the result of such use is always a smoother running engine. A heavily loaded kerosene engine will pound heavily after it has run for some time unless a large amount of jacket water or else a spray of water is used. It seems advantageous in some types of engines, both from an economical and mechanical viewpoint, to use a small amount of water in the cylinder in addition to the regulation method of cooling by means of jacket water.

Water cooling is also practiced in some cases as respects the products of combustion, by introducing it into the exhaust pipe. The effect is to absorb heat from the gases and allow them to escape at a lower pressure, thus acting to some extent as a muffler. This practice does not, of course, affect the heat in the cylinder itself.

In very large engines the piston must be cooled as well as the cylinder because the heat in the central part of a large disc of iron, which exposes relatively a small surface to the cool cylinder walls, can not part with its heat rapidly enough to keep the central part at a safe working temperature. Cooling, in such cases, is accomplished by circulating water under pressure within the hollow part of the piston, using either flexible connections or telescoping pipes to convey the water.

It is also necessary to cool the exhaust valve by a water jacket owing to the high degree of heat of the exhaust gases. The admission valve does not need cooling especially, because it is sufficiently cooled by the fresh charge of cold gas and air, although it is customary to bring the water jacket as close around both valves as can be done conveniently.

The volume of the compression space is an important consideration in gas engine design and a knowledge of the part it performs is equally of value to the man who operates an engine. In steam engine practice it is a well recognized fact that the clearance space should be small in order to insure the best economy. What is true in this respect in the steam engine is equally true in the gas engine. The highest economy demands small compression volume. There is a practical limit beyond which high compression can not be carried, and this limit is different for every different kind of fuel used.

In a previous lesson the statement was made that there is an exact relation between heat and work. If work is done upon a gas by compressing it, it becomes heated and, if the gas afterwards expands and does work upon the piston its temperature falls. When the charge in a gas engine is compressed its temperature rises in proportion to the amount it is compressed. If compression is carried too high, its temperature may reach the point at which it will ignite. The vapor of gasoline ignites at comparatively low temperatures, and it has been found by experience that if it is compressed much above eighty-five pounds per square inch pre-ignition will take place. Alcohol vapor, on the other hand, is less volatile and needs a higher temperature in order to burn, consequently it will stand a higher compression, and with higher compression it yields greater power for a given quantity of alcohol consumed. For this reason alcohol engines, designed primarily to use alcohol, have a smaller clearance volume than do gasoline engines. Engines designed to work under varying conditions and different fuels are usually given a clearance volume equal to from twenty to twenty-five per cent of the volume displaced by the piston. There are certain well-known laws which govern the pressure, volume and temperature of gases, which will presently be briefly alluded to. It should be understood, in passing, that the three quantities, pressure, volume and temperature, are inter-dependent, that is, when one changes, the other two also change, unless some means are taken to maintain one of them constant. The principal law connected with pressure and volume is known as "Boyle's Law." It may be stated thus: The pressure of a gas varies inversely as the volume, if the temperature is kept constant, or the volume varies inversely as the pressure with the temperature constant. Stated in plainer words, it means that if a given volume of gas is compressed to one-half its volume, the pressure will be doubled. For example, if a cylinder full of air or any other gas at the pressure of the atmosphere be compressed to half a cylinder full, the pressure will be doubled, provided some means is provided to keep the temperature of the gas from rising. In other words, if air at 14.7 pounds pressure is reduced to half that volume its pressure will be 29.4 pounds absolute pressure or 14.7 pounds, as shown on a steam gauge.

The law relating to temperature and pressure states that the pressure varies directly as the absolute temperature, provided the volume is kept constant, or the volume varies directly as the absolute temperature, provided the pressure is kept constant. This means that if a cylinder full of gas be heated the pressure will rise in direct proportion to the absolute temperature. Consequently, if we simply took the cylinder full of gas and heated it, or if it was an imflammable gas, if we burned it, the increase in heat would cause the pressure to increase in exact proportion to the increase in temperature.

It is upon these two laws that all theoretical calculations in regard to gas engines are worked out. Furthermore, it is upon just such considerations as these that the size of the clearance space is calculated in order to give any compression pressure which we may desire.

An example of heating due to compression is often witnessed in the case of starting a gas engine in cold weather. It may be too cold to start the first few times the engine is turned over, but if it is turned rapidly a few times the cylinder may be sufficiently warmed by the compression of the gas to cause the gasoline to vaporize.

CHAPTER II

IGNITION, PRIMARY BATTERIES

LESSON VI.

There are three methods in common use for igniting the charge in gas engines. They are by means of a hot tube or torch, by compression, and by electricity. The hot tube is one of the oldest methods, but has fallen largely into disuse except as an emergency device. It finds its widest application, at the present time, as an auxiliary device to be used in case something goes wrong with the electric igniter. Igniting by compression is used only on a few types of engines, such as the Hornsby-Akroyd, Diesel, and a few others. Electric ignition in one form or another is the method almost universally adopted. It is the easiest to handle, the most reliable and certain in action, and provides for the closest regulation of the time of ignition, which, by the way, is a very important item in the economical operation of a gas engine.

Let us first consider the hot tube system of ignition. This can be best explained with reference to the accompanying diagram, Fig. 6. A small tube, *T,* closed at the outer end, is screwed into the compression chamber of the engine. Just below this tube there is a gas jet in the form of a Bunsen burner which is supplied with gasoline by a pipe which leads from a reservoir on the top of the engine. Surrounding both the burner and the tube there is a cast iron box with a chimney on the top. This box prevents air currents from striking the flame and at the same time directs the flame upon the tube at the desired point. The chimney is lined with asbestos to prevent radiation of the heat generated by the flame.

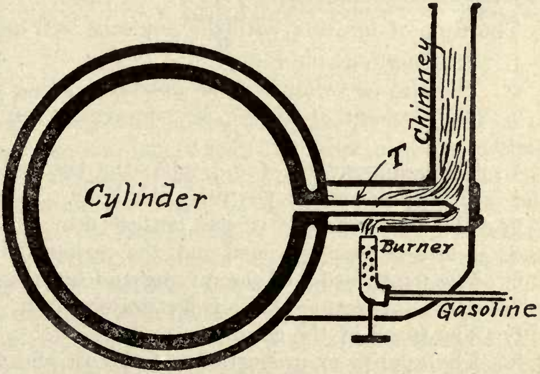


FIG. 6.

In operation, the action of the hot tube is as follows: A few minutes before starting the engine the burner is lighted and the tube is brought up to a red heat, then when the charge is compressed a part of the inflammable gas enters the tube and when it reaches the red portion it becomes ignited. On the exhaust stroke there will be some burnt gases still left in the tube when the new charge enters the cylinder. When this charge is compressed, the burnt gases remaining in the tube from the previous charge must be compressed until the new charge meets the hot portion of the tube before ignition can again take place. Consequently, if the burner heats the tube near where it enters the cylinder, ignition must occur earlier than if the hot portion is further out toward the end of the tube. In some engines the position of the burner is made adjustable in order to vary the time of ignition, in others the burner is fixed in position at a point where it has been found by experience to give the best results.

The life of an ordinary iron tube is very short, being only a few days at most. Nickel, steel or porcelain tubes last much longer, but are more expensive. The uncertainty as to timing of ignition, the bother of starting and the delay caused by the burning out of the tubes makes this form of ignition anything but efficient.

Prof. Hutton in his book, "The Gas Engine," has the following to say about hot tube ignition:

The time of ignition with the hot tube will depend upon:

1. The length of the tube.
2. The size or volume of the passage leading to the tube.
3. The amount or degree of compression of the mixture by the piston.
4. The temperature of the tube; the hotter the tube, the earlier the ignition; the cooler the tube, the later.
5. The fact whether it was hottest near the open or the closed end; if heated near the open end, the earlier the ignition.
6. The temperature of the mixing and igniting chambers.
7. The temperature of the jacket-water outlet.
8. The speed of the engine.
9. The quality or proportions of the air and fuel admitted.
10. The pressure of the intake or suction stroke.
11. The governing action and the system of governing.
12. Leakage; at piston, at exhaust, past valves.
13. The state of the surfaces of the tube, outside and in.
14. The location of the tube with respect to receiving and acting on new or fresh mixtures or mixtures containing burnt gases.

Ignition by Compression.—In the Diesel engine a charge of air is drawn into the cylinder on the aspirating or charging stroke—but no fuel. This air is compressed to a very high pressure, usually above five hundred pounds per square inch. When air is compressed so strongly the work done upon it is transformed into heat and its temperature rises very high. If now, when the piston reaches the end of its stroke, a jet of oil is pumped in, this oil will be ignited by the hot air and no other form of igniter will be needed. A governor attached to the pump regulates the time during the power stroke that the oil jet is admitted, which generally does not exceed one-tenth of the stroke.

Fig. 7 shows the method of igniting the charge in the Hornsby-Akroyd oil engine. The chamber at the left of the cylinder is not water jacketed. It is first heated by an auxiliary burner to a red heat. Then when the piston makes its first outward stroke air is drawn into the cylinder and a thin jet of kerosene is forced into the hot chamber and is instantly vaporized. On the compression stroke the air is forced back through the narrow neck into the vaporizing chamber where it mixes with the fuel. Ignition is caused by the heating effects of compression, friction, and the heat of the vaporizer. At first thought it might be supposed that when the oil first enters the vaporizer it would be ignited, but this can not occur because it has no air to combine with. The air that is entering the cylinder during the charging stroke is moving toward the rear of the cylinder, away from the fuel. On the compression stroke this air is forced into the chamber with the fuel and when the compression stroke is nearly completed the air has mixed with the vaporized fuel sufficiently to cause an explosive mixture and ignition takes place. A governor controls the stroke of the pump and allows the correct amount of oil to be delivered to maintain the speed of the engine. There are no means for changing the time of ignition. This engine is adapted for using kerosene or heavier oils.

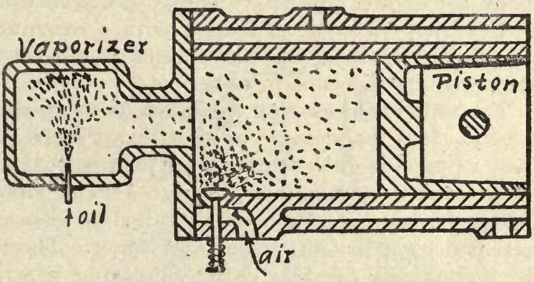


Fig. 7.

Electric ignition, as before stated, is used by nearly all makers of gas engines at the present time. There are many different systems in use, some of which differ from each other in essential particulars and some only in minor details. A complete knowledge of electrical ignition must necessarily include a considerable knowledge of electricity and much more than can be presented in this series of lessons. However, in order to make the subject as plain as possible it will first be necessary to consider some of the fundamental principles of electricity and that we will now proceed to do.

To begin with, electricity is one form of energy, just as heat or motion is a form of energy. Electricity must always be generated by some outside source of power and a given amount of power is always consumed in generating a certain amount of electricity. We know some things electricity can do; we know some of the laws governing its action, and we know something about how to handle it; but we do not know just exactly what electricity is. This need not trouble us, however, because we, as gas engineers, are concerned with the practical application of electricity rather than with its theory.

Electricity may be generated with a machine as in a dynamo, or chemically, as in a cell; the character and properties of the current delivered are the same in either case.

The unit for measuring the intensity of an electric current is called a *volt*. It is the measure of electrical pressure or electro-motive force just as pounds on a steam gauge represent steam pressure, or water pressure if the gauge is attached to a water pipe. The unit for measuring the amount of current is called an *ampere*. This may be represented by gallons in the case of water. The flow of electricity can be represented very easily by comparing it with the flow of water. For example, we may have a low voltage and a large current and consequently a large amount of electricity delivered. In the same way we may have a small pressure and a large stream of water and in a given time a large volume of water will be delivered. Or we may have high voltage and small amperage and a large amount of electricity delivered just as a high pressure of water and a small sized stream will deliver a large volume of water.

Voltage applies only to the pressure of electricity and amperes to the size of the current. We may have a very high voltage and small current or low voltage and large current. These terms will be used again and again in these lessons and the student should try to remember just what they mean.

LESSON VII.

Batteries are of two principal kinds, primary batteries and secondary batteries. A primary battery generates electrical current by means of chemical action. A secondary battery must first be charged by means of some outside source of current. This current sets up chemical action within the cells of the battery which changes the chemical nature of some of the elements in such a way that when the battery is connected up to do work, these elements revert to their original form and electrical current is generated. Ordinary batteries, either of the wet cell or the dry cell variety, such as are used generally for the electrical ignition of gas engines, are familiar examples of primary batteries. Storage batteries are examples of secondary batteries.

Primary batteries are made up of a number of simple voltaic or galvanic cells which are connected together by means of wires. In order to understand the working of a battery, we must first study the construction of a cell and the action which takes place between its parts. Figure 8 is an illustration of a very simple form of cell. It consists of a jar nearly filled with weak suphuric acid, called the electrolyte, in which there is suspended a plate of copper and a plate of zinc. These are marked C and Z, respectively, in the figure. The zinc plate is the positive element in any cell and the other plate the negative element. Curiously enough, however, the binding post attached to the zinc element is known as the negative pole and the other as the positive pole of the cell. If the two poles be connected by means of wires an electrical current will flow, in the direction shown by the arrows, from the copper plate through the connectors to the zinc plate. In some types of cells there is very little local action unless the cell is working on a closed circuit, but in this type of cell the zinc is attacked by the electrolyte whether it is on open or closed circuit, although the action is not so strong when the circuit is open as it is when it is closed. When the two wires *a* and *b* are touched together, chemical action is set up strongly within the

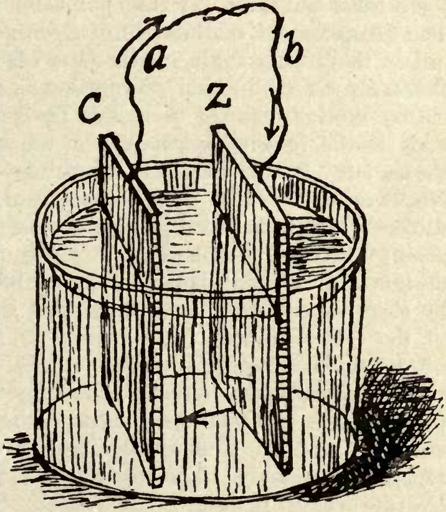


FIG. 8.

cell. A part of the acid of the electrolyte is constantly decomposing and uniting with the zinc, forming a new substance, zinc sulphate, and at the same time an electric current is generated by this chemical action.

The amount of current which is generated is proportional to the amount of zinc consumed or changed into zinc sulphate. There is a similarity between an electrical cell and a furnace. In the latter, coal is burned and heat is generated; in the former, zinc is consumed and electricity is generated. The amount of heat that is generated depends upon the amount of fuel burned, and, in like manner, the amount of electricity that is generated depends upon the quantity of zinc consumed. Both the generation of heat and of electricity are examples of chemical activity.

Polarization.—When the sulphur and oxygen of the electrolyte unite with the zinc, forming zinc sulphate, hydrogen gas is set free, which appears as small bubbles on the copper plate, unless there is some other substance at that point for the hydrogen to unite with. The formation of the bubbles of hydrogen gas represents lost energy unless they can combine with some other substance, in which event the energy used in their formation is given back and adds to the electro motive force of the cell. Their presence on the copper plate adds to the internal resistance of the cell very greatly and reduces the amount of current which the voltage of the cell can send through any external circuit. The formation of bubbles of hydrogen gas on the copper plate is called *polarization* and the removal of them by any means is called *depolarization.* All cells in commercial use are designed to prevent polarization as far as possible, and generally by chemical means. In this way, not only is the internal resistance of the cell prevented from increasing, but the electro-motive force of the cell is actually increased.

The Edison-Lalande cell is an example of one of the best and most popular cells used for gas engine ignition. Since it is a very efficient type of cell, and is arranged to prevent polarization, it will repay a little study. The electrolyte is either a solution of potassium hydrate (caustic potash) or sodium hydrate (caustic soda), and water. Zinc forms one of the elements and the other is formed by mixing together cupric oxide and magnesium chloride and forcing the mixture into a suitably prepared plate under pressure. This plate is then heated and the mass becomes thoroughly bound together. This composition plate is suspended by means of copper channel strips, in the electrolyte, between two plates of zinc. The terminals of the elements pass up through a cover plate which insulates them from each other. So long as there is no metallic connection between the two terminals, that is, between the zinc plate and the composition plate, there is practically no action in the cell. In other words, the zinc is not attacked unless the circuit is closed. In this respect it differs from the first cell described.

The internal action of this cell is as follows: When the external circuit is closed, some of the solution of potassium hydrate in contact with the zinc plates decomposes and part of it unites with the zinc, forming a new chemical substance, while the hydrogen goes over to the cupric oxide plate and there unites with the oxygen of the plate, thus forming water and setting free metallic copper. The *cupric oxide* is the *depolarizer* since the oxygen it contains is always ready and at hand to combine with the bubbles of hydrogen gas. This cell, when in use, will give an electro-motive force of about .7 volt. When freshly charged it will give a slightly higher voltage. The internal resistance is very low and it gives a good strong current. Since the caustic potash will absorb carbon dioxide gas from the air and thus lose its virtue as an electrolyte, it is necessary to cover the liquid in the cell with a heavy mineral oil.

These cells do not need any attention until they are exhausted, that is, until either the zinc is consumed, the composition plate is red all through (which can be told by digging into it with a pen knife), or the electrolyte is too weak. It is not much trouble to recharge them. If the elements are all right, that is, not completely worn out, all that is necessary to do is to pour out the old electrolyte and make a new one by using caustic potash and water. Care must be taken that the top of the copper oxide plate is at least an inch below the top of the liquid, otherwise the cell will be almost sure to fail.

Arrangement of Cells.—The usual way to arrange a number of cells, to form a battery for ignition purposes, is what is called a series, that is, the zinc from one cell is connected to the carbon of the next one and so on. One cell is arranged directly behind the other in this arrangement and the current is compelled to pass through all of the cells.

Another method of arranging cells in a battery is to connect all of the zincs together and all of the carbons together. This amounts to the same thing as making one large cell having a zinc as large as the sum of all the zincs and a carbon plate whose area is equal to the sum of all the carbons. This method of connecting is called connecting in *parallel*. For some kinds of work the series method of connecting is preferable, while for other kinds of work better results are obtained when the cells are arranged in parallel. A discussion of this phase of the question will be left for some subsequent lesson.

LESSON VIII.

Dry cells are made up in practically the same way as wet cells and with the same active materials. The elements are zinc and carbon. The outer portion or can is made of zinc and surrounds a rod of carbon which does not quite reach the bottom of the can. The electrolyte consists generally of a solution of sal-ammoniac and water mixed with zinc chloride. This occupies the space next to the zinc and is held in position by some absorbent material, like blotting paper, which is completely saturated by the solution. The space between the electrolyte and the carbon rod is filled with some substance such as powdered carbon and manganese dioxide which acts as a depolarizer. The details of construction and the ingredients which are used are not the same in all dry cells, but the description just given will give the reader a good general idea of how they are constructed. The tops of dry cells are covered with hard pitch, which prevents the evaporation of the electrolyte, while the outside of the can is insulated with paper.

The chemical action that takes place in a dry cell is the same as that which occurs in a wet cell, having the same elements and the same electrolyte, but owing to the fact that this action takes place in a paste instead of in a liquid it is not nearly so rapid. A good dry cell when new will show on dead short circuit—that is right across the terminal—about one and one-half volts, sometimes a little more, and a current strength of from twenty to thirty amperes. When a dry cell battery has been in use for a number of hours both the voltage and amperage will decrease—the battery get weaker; but if it is allowed to stand idle for some time it will recover its normal strength. Sometimes when a dry battery is nearly run down it has sufficient strength to give a spark that will ignite every charge for a few minutes and then it will gradually die down and the engine will stop. It often happens that only one or two cells of a battery are worn out, while the others are still in good condition. If these poor cells are taken out and new ones substituted the battery will be in good condition again. It will pay any one who uses dry batteries to have an ammeter and test the cells, each one separately, whenever he suspects that they are not right. A good enough ammeter can be purchased for three or four dollars and directions for using come with the instrument. Any cell that shows less than six amperes is worthless and should be thrown away. It is a good plan to test new cells at the time of purchasing. The writer only last winter got hold of a new battery that, presumably at least, had never been used and yet it was worthless. It was probably old and the electrolyte had slowly evaporated. It is said that a cell will not last much over three years even if not used at all, due to slow evaporation of the moisture that it contains. Such a cell could be made good again by introducing some new electrolyte through a hole in the top or sides. Ordinarily, however, when a dry cell gives out it can not be revived and the only thing to do is to throw it away and get a new one.

For ordinary ignition purposes a battery made up of from four to six cells is sufficient. A larger number of cells will give a hotter flame, but the action is so intense that it will injure the contact points of the igniter, causing them to wear rapidly and become pitted. Large sized cells are more economical than the smaller sizes even if they do cost more than twice as much, but they will last considerably more than twice as long. Of course, if they are accidentally short circuited they will be ruined just as quickly and the loss is greater. It does not take very long for a dry battery to become ruined by short circuiting either; ten or fifteen minutes will ruin any battery absolutely.

Care should be taken in connecting up any battery, either of wet or dry cells, to see that a good grade of insulated wire is used, preferably rubber covered wire, and that the ends of the wire that are attached to the binding posts of the cells are scraped clean and bright. A film of copper oxide sometimes gathers on copper wire that offers a great deal of resistance to the passage of a current of electricity and consequently it is necessary to scrape the surfaces that form contact perfectly clean. Electricians in putting up electrical wiring usually solder the joints together to insure good contact and to make certain that no oxide can form between the parts in contact and prevent the free flow of the current. The nuts on the binding posts should be screwed down tightly. A loose connection will soon become oxidized and prevent electricity from flowing. In fact, a loose connection either in the battery or on the engine is very frequently the cause of an engine's refusing to run.

Batteries should be kept in a clean, dry place and the battery box should be kept covered to prevent any pieces of metal or tools from accidentally finding their way into the box and short circuiting some of the cells.

Wet cells can be recharged by putting in a new solution and new elements. If the elements are carbon and zinc, the zinc is all that needs renewing. The carbon does not wear out. The zinc plate is all right, even if quite thin, until it begins to fall apart. When new zincs are needed it pays to make a new solution. In the case of the Edison-Lalande cell, both the zinc and copper oxide plate will become worn out and both, together with the solution, will need renewing. Directions are usually sent out with the batteries for recharging and if these are followed faithfully there will be no trouble. The chemicals used in recharging cells are inexpensive and the cost of renewal is not very great. The largest cost is for zincs and copper oxide plates.

All zincs used in electrical cells are amalgamated. This is done by first cleaning the zinc plate thoroughly and then rubbing a little mercury over it. The mercury unites with the zinc and protects it from local electrical action, and not only makes the cell give greater current, but prevents the zinc from wearing away so rapidly. Commercial zinc is always impure. It contains particles of iron and other impurities, which would cause electrical action on the neighboring particles of zinc. This is prevented by the coating of mercury and so causes the zinc to last longer and also give better service. Curiously enough, as the zinc is gradually taken into solution by the electrolyte and the plate becomes thinner, the mercury is not affected but retains its place on the surface of the plate to the very last.

CHAPTER III

MAGNETISM AND COILS

LESSON IX.

On the shores of Lake Superior and in various other parts of the world, there is found a peculiar ore which will attract iron. The ore was first found by the ancients in the city of Magnesia in Asia Minor and they called its property of attracting iron magnetism. The ore is an iron ore somewhat similar to the scale that falls from red hot iron on a blacksmith's anvil and is called *magnetite*. Pieces of this ore, when suspended, will always point toward the north. It was in early times used in navigation for a compass, and was hence called a leading stone or *lodestone*. It was subsequently discovered that if a piece of hardened steel be rubbed on a piece of lodestone it also became magnetic, and thus the compass needle was discovered. The former is a natural magnet, the latter artificial.

Artificial magnets when of hard steel retain their magnetism a long time and are called *permanent magnets.* If of soft iron or soft steel, they lose their magnetism quickly, almost instantly, in fact. The ordinary form of permanent magnet is a horseshoe shape, having a soft bar or keeper called an armature across the ends to prevent loss of magnetism.

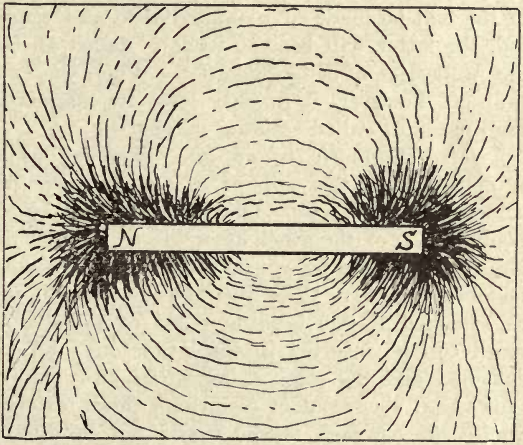


Fig. 9.

Lines of Force.—If a straight bar of hard steel which has first been magnetized be placed in iron filings, the filings will adhere in tufts to each end, but not in the middle of the bar. The two ends of the bar are called the poles, one the north pole, the other the south pole. The north pole of a bar magnet will attract the south pole of a compass needle and repel the north pole. Unlike poles of magnets attract each other and like poles repel. Since the earth is a great magnet whose poles very nearly coincide with the geographical poles, they attract the magnetic needle. If iron filings be placed on a smooth piece of paper that is held above the poles of a magnet, and the paper is shaken to agitate the filings, they will arrange themselves as shown in Fig. 9; and if the paper is held over only one pole the filings will arrange themselves in radial lines. The lines along which the filings arrange themselves are called lines of magnetic force. The actual lines of force are, of course, invisible, but their direction and existence are shown by the filings. The direction of these lines is assumed to be from the north pole to the south pole through the air or surrounding medium.

If a piece of wire be wound into a long spiral and a current of electricity be sent through it, it will have all of the properties of a magnet, with a north pole and a south pole and a neutral region between. If suspended, it will assume a north and south direction. If the coil be made of insulated wire and wound around a soft iron rod, the latter will become what is called an *electromagnet,* with all the properties of a bar magnet. When the current of electricity is shut off, however, it quickly loses its magnetism, all except a very small amount called *residual* magnetism.

Electro Magnetic Induction.—This can be shown experimentally by constructing two coils of wire wound over paper or wooden tubes, using insulated wire. One tube should be small enough to slip easily inside of the other after the winding is done. The ends of the larger coil should be wound several times around a compass and then fastened together. The two ends of wire of the smaller coil should be attached to the binding posts of a galvanic cell. If, now, the small coil be inserted in the larger one, the compass needle will be deflected and the same thing will happen if it is withdrawn. This shows that a current of electricity flows through the larger coil, otherwise the compass needle would not be disturbed. Since this latter coil is not connected to the cell—the source of current—it follows that the current which deflects the needle must be *induced* current. If the inner coil remains stationary the needle is not affected, but if it is moved then deflection occurs. The reason for this induced current may be explained as follows: When a current flows through the smaller coil, a magnetic field with lines of magnetic force traveling from one end of the coil to the other through the air is set up, and completely surrounds the coil. When this coil is dropped inside of the large coil these lines of force are cut by the coils of wire in the larger coil, and a current of electricity is generated therein. When no relative motion occurs between the coils no current is set up in the outer coil. In order for a current to be generated, therefore, *lines of magnetic force must be cut by a moving conductor.* This is the principle upon which all dynamo electrical machines work, and it will be made use of later in these lessons in explaining the operation of magnetos and dynamos used for ignition purposes.

Spark Coils.—An ordinary spark coil used for make and break ignition consists of a single coil of insulated wire wound on a spool, in the center of which there is a core of soft iron wires. This core is insulated from and is not connected electrically with the coil. When a current of electricity from say a battery flows through the coil, the core of soft iron becomes magnetic and it is surrounded by lines of magnetic force. The passage of a current of electricity through this magnetic field sets up a counter electro-motive force that opposes the flow of current and consequently the current does not instantly come up to its full value, but builds up rather slowly. When the current is broken, as when the igniter trips, the lines of force decrease slowly and this induces an electro-motive force which tends to keep the current flowing in the coil. This *self induction,* as it is called, between the loops of the coil, tends to maintain the current after it is broken and the result is a bright spark at the igniter points. The coil acts as a sort of reservoir for the accumulation of a certain amount of electricity to be used when the circuit is broken.

A coil of this kind must always be connected in series with the cells of a battery for the ordinary or hammer break ignition, in order to give a spark of sufficient volume and intensity to ignite the charge. There is nothing about a simple coil of this kind to wear out and if taken care of it should last indefinitely. If water gets in between the turns of wire, a short circuit may take place, or the insulation may be burned through by a heavy current at some time, or possibly a wire may become broken inside of the coil, although this is a rare occurrence. All the care a coil requires is to be kept in a dry place. If it is made with the proper kind of wire, thoroughly well insulated and kept dry, it will continue to give good service indefinitely.

In the next lesson we will discuss the jump spark coil and then take up magnetos and dynamos. The subjects of magnetism and induction presented in this lesson will be found necessary to a clear understanding of the next lesson.

LESSON X

There are two principal methods of electric ignition in common use, one known as the hammer break method, the other as the jump spark. In the former two rods pass through the cylinder walls to the interior of the cylinder, into the clearance space. One rod is carefully insulated. This is called the stationary electrode. The other rod is not insulated and is movable. At the right instant in the stroke some moving part on the outside of the engine, driven from the main shaft, rotates the movable electrode until the two igniter points inside the cylinder come into contact. This completes the electric circuit. Electricity flows from the source of current through the insulated electrode, then through the movable electrode to the points of the the engine frame and back through the other lead wire to its source. In this connection it may be well to note that there must be a complete unbroken circuit for electricity to travel along or it won't travel. At the right instant a tripping mechanism of some sort throws electrodes apart and a spark is formed inside of the cylinder and the charge is ignited.

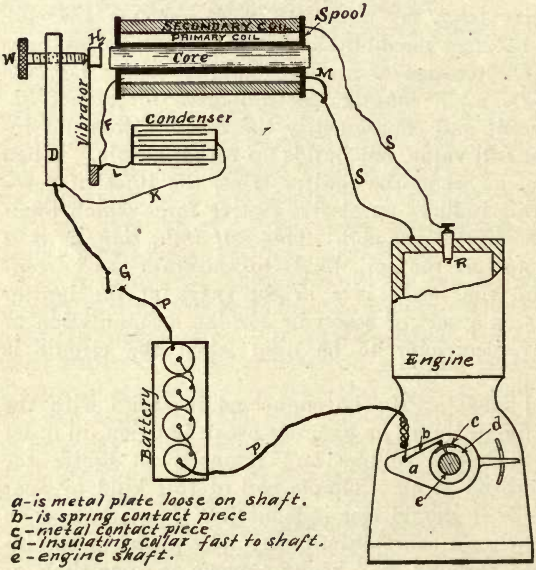


FIG. 10.

In the case of the jump spark there are no moving parts inside of the cylinder. The current which ignites the charge does not have a complete metallic circuit to travel in, but is obliged to jump across a short air gap inside of the cylinder. When electricity has to bridge a gap in this way it forms an arc or spark and it is this that ignites the charge. The current used in the hammer break system could not jump a gap because it has not pressure enough, or voltage enough, to use a more exact term. The same battery would do in either case, but a different spark coil is necessary. This leads us to a consideration of the jump spark coil, or induction coil, as it is often called.

The induction coil, known also as the *Ruhmkorff coil,* is quite different from the simple spark coil described in the last lesson. It consists essentially of a core of very soft, thoroughly annealed, iron wires, bound together and covered with a good insulator of some sort, which forms the core. Outside of this there is a coil consisting of a few turns of rather coarse, well insulated copper wire of about 14 gauge. This wire is connected with the battery, or source of current, and is called the *primary circuit.* Outside of this again, and thoroughly insulated from it, there is another coil of much finer wire, about 28 gauge, called the *secondary coil.* This coil is made up with a great many turns of wire and makes the circuit which ignites the charge. The general arrangement and details of this piece of apparatus are shown in Fig. 10, to which constant reference must be made to complete the description.

At the left end of the coil there is shown a hammer, H, mounted on a flat spring, forming what is called the vibrator. When at rest the spring holds the hammer against the screw, W. When the switch at G is closed, current from the battery can flow through wire P, up through D, to screw W, then down through the vibrator spring, thence through wire F, to the primary coil, and back to the battery through wire M—S—the engine—and wire P to the battery, thus completing the circuit. In practice it should be noted that the primary circuit is closed by the engine at the right instant. When the primary circuit is closed a current flows around the primary coil and the *core* becomes an electro magnet. It immediately attracts the hammer H and the circuit is broken. The core now loses its magnetism and the vibrator spring throws the hammer back and the circuit is again completed. As long as the circuit remains closed the hammer vibrates back and forth very rapidly, in fact, hundreds of times per second, each time opening and closing the primary circuit. The result of this is to induce a current in the secondary coil of very much higher voltage, which has power enough to jump across the gap in the spark plug at R to the engine frame and thence back to the secondary coil.

It must be remembered at this point that there is absolutely no connection electrically between the primary coil and the secondary.

The question then arises, how is a current formed in the secondary coil? Referring to lesson IX, this statement will be found: "In order for a current to be generated, therefore, lines of magnetic force must be cut by a moving conductor." This was made to apply to current generated by mechanical means, not chemically, as in a battery. Now, it might have been stated at the same time that motion is only *relative.* For instance, suppose we wish to get away from a certain object; there are two ways to do it. Either we may move ourselves away or we may have the object removed. So far as we and the object are concerned, the final result, that of mere separation, will be as well accomplished in one way as in the other. Motion, therefore, between two objects is relative. Consequently, we can just as well generate current by moving the magnetic field as by letting it stand still and moving the conductor. Now that is just what actually happens in an induction coil. We showed in the last lesson that if a current of electricity were sent through a coil a magnetic field was instantly set up around the coil. If this current be broken the magnetic field disappears. If now the magnetic field be made to change rapidly from zero to a maximum in intensity, as it does due to the vibrating current in the primary coil, the result is a moving magnetic field and a stationary conductor. Thus, we accomplish the same result as we would obtain with a stationary magnetic field and a moving conductor. Consequently, a current will be induced in the secondary coil, and this current will have a much higher voltage than the voltage in the primary coil. The reason for this increase in voltage is due to the difference between the two coils. If the secondary coil was made up with the same sized wire and the same length of wire as the primary, the voltage would be practically the same, but since it is made up of very much finer wire the voltage or pressure is increased, but the amperage or *amount of current* is decreased. The reason for this may be explained in a rough way by considering water flowing through a pipe. If all the water that flows through a large pipe be made to pass through a much smaller pipe, the *velocity* in the smaller pipe must be very much greater, while the size of the stream or amount of current is proportionately decreased.

The condenser shown in the diagram is placed inside of the box containing the coil and consists of a number of sheets of tin foil piled one on top of the other and insulated from each other. The ends of every alternate sheet are connected at K and the other sheets are connected with wire L. The object of this device is to demagnetize the core instantly between each vibration of the hammer, to prevent an intense spark between the hammer and contact screw W, to increase the rapidity and extent of the changes or vibrations in the primary current, and by changing the magnetism of the core quickly to augment the current in the secondary coil. The manner in which all this is accomplished may be explained thus: When the hammer is in position, shown in the diagram, the condenser is practically inactive, but when the contact with W is broken a spark has a tendency to jump across, but instead, current flows from D through K to the condenser and charges it. The latter, however, immediately reacts just as a spring reacts when struck a sharp blow and sends a small current backward through K—D—G—P, the battery, engine wires S and M, thus opposing the direction of the current in the primary coil and destroying it and demagnetizing the core.

One of the secondary wires S is attached to the spark plug and the other to some part of the engine frame. The outer casing of the spark plug is connected electrically to the cylinder, while the wire that passes through the plug is insulated from the cylinder, but is separated from the metal rim at R by only about 1-32 of an inch. When current flows in the secondary coil it leaps across this small air gap and forms the spark. As long as the vibrator is working a stream of sparks flows across this air gap.

In some types of spark coils the vibrator instead of making a large number of oscillations makes only one, and only one spark is formed inside the cylinder. This, of course, is much easier on the battery as it takes only a fraction as much current.

CHAPTER IV

DYNAMO—ELECTRIC GENERATORS

LESSON XI

The sources of electrical current for gas engine ignition are dry cell batteries, wet cell batteries, storage batteries, dynamos and magnetos. We have already discussed the first two. In this lesson we will turn our attention to dynamos and magnetos, reserving storage batteries for a subsequent lesson.

Batteries generate electrical energy by chemical action. Dynamos and magnetos generate electrical energy by mechanical means. In the case of batteries a definite quantity of certain chemicals is consumed in generating a given amount of electricity. While in the case of a dynamo or a magneto a definite amount of work must be expended to produce a given amount of electricity. Batteries transform chemical energy into electrical energy, while dynamos and magnetos transform mechanical energy into electrical energy. The equivalent electrical energy that is generated in either case will be less than either the chemical energy or the mechanical energy that produces it. In other words, there is always some loss in the transformation process, even under the most favorable conditions.

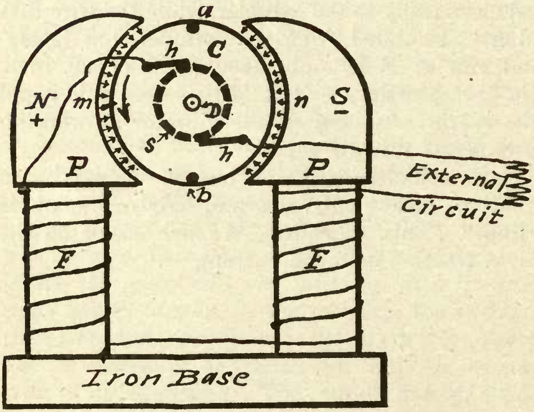


Fig. 12

When a coil of wire is moved across a magnetic field in such a way as to cut the lines of force at right angles, an electric current is set up in the coil. This is the fundamental principle of operation of both dynamos and magnetos.

Figure 12 is a diagram which illustrates the method by which this principle is applied in a practical way. *P P* are the pole pieces; *C* is the armature, which is keyed to a shaft *D* and which rotates between the pole pieces. The core of the armature is made up of a large number of thin iron punchings (see Fig. 14) having slots on the circumference to carry the coils of wire. The completed armature is shown in Fig. 13. The loops of wire are wound lengthwise around the armature and the ends are soldered to copper segments, S. One end of the loop of wire is soldered to a segment on one side of the cylinder and the other end to a segment on the other side. These copper segments are insulated from each other with strips of mica, and from the shaft by a mica sleeve. All of these copper strips taken together are called the commutator. *F F* are the field pieces. They are soft iron columns around which there is wound a continuous coil of insulated copper wire. One end of this coil is connected to one of the brushes *h*, the other is connected to the outside circuit and through that to the other brush. The brushes collect the current from the armature, pass it through the field coils, and the external circuit and back again to the other brush, thus completing the circuit through the armature coil that the two brushes happen to be in contact with at the given instant. The above description applies to what is known as a direct current series wound dynamo.

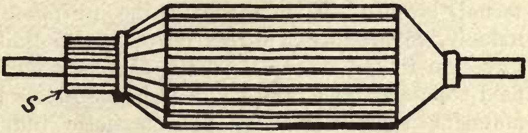


Fig. 13.

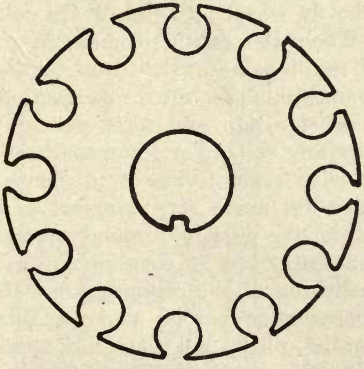


Fig. 14

The little arrows pointing toward the center of the armature represent the lines of magnetic force which are supposed to be constantly passing between the pole faces *P P*. We will call the left pole the positive or north pole *N*, and the other the south pole *S*. If the armature is rotated, a coil such as *a b* cuts all the lines of force and a current of electricity will be induced in it. While the conductor is passing the neutral region, at the gap between the pole faces, no current will be generated. Current is generated only when lines of force are cut, and will be greatest at the points *m* and *n*. When the coil passes the north pole, revolving in the direction shown by the large arrow, the current is flowing toward the segment under the top brush, but when it cuts the lines of force opposite the south pole the direction of current is reversed. By placing the brushes just at the point where the current reverses in direction a continuous current, flowing always in the same direction, will be produced in the external circuit. This, then, is the purpose of the commutator; namely, to produce a direct current, one that does not change its direction in the external circuit. When a current flows through the field coils around *F*, the fields and pole pieces become strong electro-magnets, thus increasing the magnetic induction, or number of lines of force, and consequently a stronger current is generated in the armature coils. The larger the current flowing through the field coils, therefore, the greater will be the strength of the magnetic field until what is known as the *saturation* point is reached, or the point at which no more lines of force are possible. The faster a dynamo is run the greater the current that will be generated. In order to protect the dynamos used in gas engine ignition from too heavy currents they are provided with a governor that will not allow them to run much faster than about 1,400 revolutions per minute. At this speed they will generate about eight or ten amperes with a voltage of about ten. Since it is hardly possible to make them run fast enough by turning the fly wheel by hand, a dry cell battery is required for starting. When the engine comes up to speed this may be switched off and the dynamo switched on to the ignition circuit. Some of these dynamos must be run in connection with a spark coil for make and break ignition and some generate a current strong enough not to require any coil. For jump spark ignition the coil is necessary, except with some forms of magnetos.

These little direct current dynamos are made very compact and some of them are entirely enclosed from the dust by a metal casing. They do not require very much attention except an occasional turning of the brushes with a file and polishing of the commutator with a bit of fine sand paper. Emery paper must not be used for this purpose. The commutator must not be oiled. All the lubrication that is needed is a little on the armature shaft bearings. For ignition purposes on stationary gas engines they are quite satisfactory. Where they are used on road engines, difficulty may arise through some of the wire connections becoming loose. This must be guarded against by frequent inspection.

LESSON XII.

MAGNETOS.

The fields of a magneto are made of permanent magnets. Those of a dynamo, such as we described in the last lesson, are electro-magnets. This, then, is the essential difference between these two types of generators. The dynamo is provided with a field winding, that is, a coil of wire which surrounds the field pieces and either all or a part of the current generated flows through this winding. This is what generates the magnetic field between the pole pieces. In the magneto there is no winding around the field pieces. These, instead of being made of soft iron, are made of hardened steel and permanently magnetized. The armature is also made differently. It consists of an H-shaped piece of soft iron around which a single continuous coil of wire is wound parallel with the axis. Figure 15 shows the simplest style of magneto armature, and Fig. 16 shows an end view of the complete machine assembled.

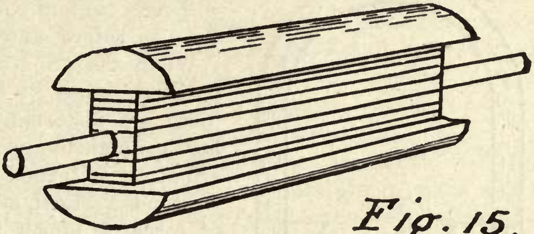


Fig. 15.

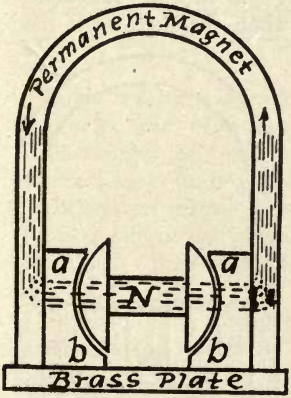


Fig. 16

The armature fits very closely between the pole pieces, having a clearance of only about one one-hundredth of an inch. The pole pieces *P* are made of soft iron and the lines of force pass from the positive pole to the negative through the soft iron *H* of the armature. The manner in which the current is generated will now be described.

When the armature is in the position shown in Fig. 16, the lines of force pass from one pole piece to the other through the soft iron neck of the armature, since that is the only path they can travel. The brass plate at the bottom is not a conductor of magnetism and no lines of magnetism can pass from one pole to the other through it. The armature acts just like the *keeper* or flat piece of iron that is laid across the ends of a horse-shoe magnet. When the armature is not in position the lines of force will pass through the air along the lines of least resistance, through *a-a* or *b-b*. But the greater number will pass between the points *b-b* since these are the nearest together. When the armature is in the position shown in Fig. 16, all of them will pass through the neck of the armature, as before stated.

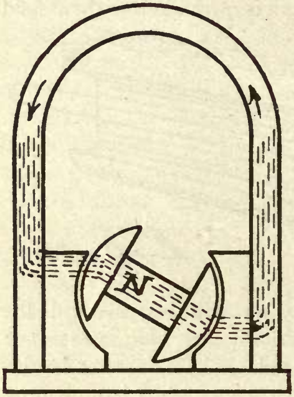


Fig. 17.

When the armature is turned to the position shown in Fig. 17, the lines of force are distorted, as shown, but still flow through the neck *N*. But when the armature is turned still farther so that *N* stands vertical, as in Fig. 18, the lines of force no longer flow through *N*, but take two paths, one across *a-a*, the other *b-b*, since these are the paths of least resistance.

When the lines of force are flowing through the neck *N*, as in Fig. 16, the soft iron core is strongly magnetized; but when the armature revolves to the position of Fig. 18, *N* is demagnetized. In this way the magnetism of the armature varies from a maximum, when the neck *N* is horizontal, to almost nothing when it is vertical. As the armature revolves, therefore, there are rapid changes in the magnetic field through which the armature coil is passing. We have, then, *a variable magnetic* field, just as we have in an induction coil, and the result is that a current of electricity is induced in the armature coil. Since the greatest change in magnetism occurs when the neck *N* is vertical, it follows that the strongest current will be induced each time *N* stands in a vertical position, and the weakest when *N* is horizontal. Twice in each revolution of the armature the current will be a maximum, and twice it will be a minimum.

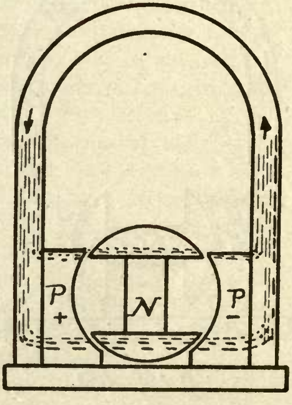


Fig. 18.

Since the current is variable, it follows that ignition must be made to occur when armature stands with its neck in a vertical position. This is the only position in which current is strong enough to produce a sufficiently strong spark.

It is perfectly clear in view of the above explanation that the magneto must be in exact step with the engine in order to ignite the charge at the right time. It must, therefore, be driven by the crank shaft of the engine by some positive means. If it were driven by a friction pulley or by a belt in the manner that the dynamo described in the last lesson was driven, it would soon be out of time with the crank shaft on account of slippage between the friction surfaces. The only way to drive the armature of a magneto, where it makes a complete revolution, is by means of toothed gearing.

A consideration of the principles of action of a magneto will show the reader that it is not necessary for the armature to make a complete revolution. If it is made to turn from a vertical position to a horizontal position and then is whirled swiftly back to the vertical, say by means of strong springs, a sufficient current will be set up to ignite the charge. Some magnetos are built on this principle and a push rod operated by a cam on the crank shaft or on an auxiliary shaft, if it is a four-cycle engine, will oscillate the armature of the magneto at the right time.

There are two types of magnetos, one known as the low tension type and the other as the high tension. The one just described is a low tension magneto used for make and break ignition. A magneto of this type is wound to deliver current at from 100 to 150 volts.

High tension magnetos, strictly speaking, are provided with two windings, one of a few turns of coarse wire and the other of a large number of turns of fine wire. Magnetos of this type generate current at a high voltage, ranging from 10,000 to 20,000. Such high tension magnetos are used only for jump spark ignition. Low tension magnetos, in conjunction with a spark coil, are used more frequently than the high tension magnetos for jump spark ignition.

In the simple magneto just described, one end of the coil wire is grounded on the metal of the armature and the other end is attached to a metal rod passing through the armature shaft. This rod is insulated from the shaft by a hard rubber bushing. There is, therefore, only one terminal, and if this is connected to the insulated electrode, the current can pass back to the armature of the magneto through the engine frame when the igniter points are in contact, since the magneto itself is connected directly to the metal frame work of the engine.

LESSON XIII.

The general principles of magneto ignition were outlined in the last lesson. A little study will show the reader that a magneto of the kind therein illustrated is a very simple machine. There are comparatively few parts, there is only one winding, that on the armature, and there are few wire connections to work loose. In fact, there are only two connections, one to the armature shaft and the other to a ring or bushing which is insulated from the shaft. The current is taken off by means of a brush or metal contact point from this bushing.

On account of the simplicity of magnetos, and their general reliability in case of rough, hard service, they are used quite extensively on automobiles. Two types are in general use, one the low tension magneto which works through a make and break igniter, or in conjunction with a spark coil for jump spark ignition. The other type of magneto is known as a high tension magneto. In this machine the armature is provided with two windings, one consisting of a few turns of coarse wire, the other of many turns of fine wire. This secondary winding is identical with the secondary winding on an induction coil, and like it, is insulated from the primary winding. Magnetos of this type are expensive and are used only on automobiles.

The higher the speed at which a magneto is run, the higher will be the voltage and the hotter the spark. At slow speeds the spark will be quite thin and weak, while at high speed it will be almost a flame. This is particularly desirable because at high speeds ignition and combustion must be rapid in order to be completed at the instant the piston passes its dead center position. When a battery is used, the spark must be advanced greatly at high speeds. While it is true that the spark of the magneto must also be advanced, it need not be advanced so much as a battery spark on account of its greater intensity.

Magneto Troubles.—Like all other mechanical devices, the magneto is liable at times to give trouble. If ignition fails the first thing to do is to test the magneto and see if it gives a current. An easy way to do this, though some may find it a trifle severe, is to disconnect the magneto from the ignition system, then connect a piece of wire to its terminal and hold the free end with the bare fingers of one hand while the other hand, also bare, is in contact with some bright metallic part of the engine. Now have an assistant turn the magneto quickly by turning the fly wheel of the engine. If the magneto is in good shape a shock will be felt. By holding the free end of the wire against a toothed wheel while some one turns the fly wheel around quickly, a spark will be formed as the contact is broken between the teeth at some point in the stroke, if the magneto is working right. This method of testing is just as satisfactory as the first method and a little less severe on the operator. If no current is being generated, it shows that something is wrong with the magneto. Perhaps some oil or dirt has accummulated under the brush or spring that leads the current from the armature. Or, it may be that the armature wire is broken. This does not often occur and if it does, the break will be found where it connects to the insulated rod passing through the shaft. A drop of solder will repair the mischief at this point.

Care should be taken in making any repairs on a magneto where the magneto has to be taken apart. A little carelessness or ignorance may easily spoil a valuable machine. The armature acts the same as a keeper on a toy horseshoe magnet. It provides an easy path for the lines of magnetic force. If this is taken away, the lines of force pass through the air and since they meet considerable resistance some are lost and the magneto becomes permanently weakened. On the other hand, if the armature is always in place, a magnet will retain its magnetism indefinitely unless abused in some other way, such as being heated to a high temperature. The armature of a magneto also acts as a path for the lines of magnetic force. If it is removed either the space between the pole pieces must be filled with a piece of soft iron or a heavy piece of soft iron must be laid across the pole pieces under the arch of the magneto to provide a path for the lines of force. Unless a man is well informed about magnetos he had better not take them apart or try to make extensive repairs. In cases where the difficulty is not easy to detect, or where considerable repairing must be done, it is better for the ordinary unskilled individual to turn the job over to a good electrician.

If, after the test of the magneto, it has been found to be in good condition, the trouble will be found in some of the connections, probably in the spark plug. The most prevalent cause of trouble at this point is due to the fouling of the igniter points. A deposit of carbon, or of oil, often forms on the points which will prevent the passage of a spark. Poor lubricating oil, which has a flashing point somewhat too low, causes trouble since some of it will be consumed while a part will merely char and form a deposit of carbon. Too much lubricating oil, even of good quality, will produce as bad results. A plug with oil dripping from the points will not give a spark. When a plug is found to be in this condition, or covered with a deposit of soot or carbon, it should be washed with gasoline. The gasoline dissolves the carbon and loosens it so that it can readily be wiped off. The distance between the points of a spark plug should not exceed one thirty-second of an inch, and, in general, should be only about one-half this amount. It frequently happens that the points become bent so that they either touch or else are too far apart. An inspection of the plug, of course, will show if either one of these things causes the trouble, and the remedy is evident. A crack in the insulation of the plug often causes trouble. Moisture is apt to gather in the crack, thus making an easy path for the passage of the current to the engine frame instead of arching or sparking across the gap and producing a spark as it should. The obvious remedy, of course, is to put in a new plug. One of the best ways to test a plug is to put in a new one and try it. If it works all right, and the old one does not, it shows the old one is not in good condition. When jump spark ignition is used, the man in charge should see to it that there are one or two new plugs on hand in case of trouble with the one in use.

Where a magneto is used for hammer break ignition, as it frequently is, it may fail to act if the igniter points are in poor condition. A deposit of soot on the points will cause failure; also if the movable electrode sticks in contact with the stationary electrode, or if the insulation of the stationary electrode is broken down. A short circuit, due to any cause, such, for example, as the wearing of the insulation from the wire that leads to the stationary electrode at the point where it crosses the engine frame, will cause failure of ignition.

Sometimes an engine fitted with a magneto will run well at low speed and never miss a charge, but when the speed is increased it will begin to miss. The reason for this is generally a break in the insulation of the stationary electrode, which is not serious enough to cause a leak of current when the voltage is low, as it is when the magneto runs slowly, but which allows the current to pass through the break to the engine frame when the voltage is high. The obvious remedy in this case, of course, is to either repair the insulation or get a new igniter block. When several cylinders are fired from the same magneto, it may happen that only one of the igniter blocks is out of order, in which case all the cylinders will fire at slow speed, and this one will miss when the speed is high. The manner of testing to determine which one is at fault is to disconnect the ignition system from all cylinders and try to run at high speed first with one cylinder and then with another until the faulty igniter is located.

CHAPTER V

STORAGE BATTERIES

LESSON XIV.

It has already been pointed out in these lessons that the sources of current for electrical ignition may be classed under two heads; *chemical* and *mechanical*. Chemical generators are again subdivided into two classes; *primary* batteries, made up with either wet cells or dry cells, and *secondary* batteries, called *storage* batteries or *accummulators*. Mechanical generators may be either dynamos or magnetos.

Glancing back over previous lessons in which primary cells have been described, we will find that a primary cell consists of two elements submerged in a liquid or paste called the *electrolyte*. The elements are usually carbon and zinc, but very often they are copper oxide and zinc. Either dry cells or wet cells may be made up with either of these pairs of elements.

The electrolyte for the first named elements is generally a solution of sal-ammoniac and water. For the last named elements caustic soda and water are used.

In all primary cells that we have considered, electricity is generated by the destruction of the zinc element and the quantity of current generated in a given time is proportional to the amount of zinc consumed.

When zinc is acted upon by the electrolyte, bubbles of hydrogen gas form on the other element. The formation of these bubbles is called *polarization* and the effect is to weaken the voltage and current output of the cell. In all well constructed cells some means are used to prevent polarization. In dry cells manganese dioxide is placed in contact with the carbon element to prevent polarization, but it is only partially successful. It is in consequence of polarization that dry batteries become weaker with continuous use. If they are allowed to rest for a time the bubbles of hydrogen unite with the oxygen of the manganese dioxide, the cell is depolarized and it is quite fresh and strong again.

It is quite evident in view of the tendency of the dry cell to polarize that it is not adapted to continuous service or for ignition purposes for a high speed four cylinder engine such as is used in many automobiles.

In the Edison cell polarization is largely prevented by putting a depolarizing agent such as manganese dioxide in the copper oxide plate. Since the chemical action in a liquid is more rapid than in a paste it follows that the liquid cell is better adapted to continuous service, or nearly continuous service, than is the dry cell, because depolarization takes place more rapidly.

Briefly, we have considered the action of primary cells and are now ready to look into the construction and operation of secondary cells.

The storage cell consists of two elements, as in the case of a primary cell, dipped into an electrolyte. Unlike the primary cell it can not give off electrical energy in its original state when the circuit is closed. The storage cell must first be charged with electrical energy from some source of current like a dynamo before it in turn can be used as a source of current. The charging of a storage battery sets up chemical action in the elements and in the electrolyte which causes changes in the material of which they are formed. The electrical energy of the charging current is thus changed into chemical energy which in turn works certain changes in the electrolyte and in the elements. If now the newly charged storage battery be put on a closed circuit, that is, connected up to deliver current, chemical action will again take place, but in a reverse direction. The electrolyte and elements will be changed back to their original condition and nearly as much electricity will be delivered from the battery as was put into it in the first place. The current produced by the battery will flow in the opposite direction to the charging current.

A storage battery may be charged and discharged a great many times, and if properly cared for will last for a number of years. In this respect it differs from primary batteries which can not be recharged ordinarily, but must be renewed when run down.

There are several substances that can be used for the electrodes and electrolytes of a storage battery, but practically all that are now on the market use some compound of lead for the former and sulphuric acid and water for the latter. One electrode is composed of sponge lead and the other of lead peroxide. The former is the negative plate, the latter the positive plate since it is from this plate the current flows out.

Since lead is the only cheap metal that will withstand sulphuric acid, it is used to form the support for the electrodes. The surface of the cast lead plates is filled with grooves and a paste of lead oxides is forced in under pressure and then treated to form either sponge lead or lead peroxide as the occasion demands.

A number of the plates after being prepared in the way above described are placed side by side in a glass jar, or, if the battery is to be used for automobile ignition, the containing vessel may be made of hard rubber, or of wood lined with rubber or sheet lead. The electrodes are carefully insulated from each other and from the bottom of the containing vessel to prevent any possibility of short circuiting either by contact with each other or by dipping into the sediment which may form in the bottom of the vessel. The top of the vessel, if it be an automobile cell, is covered with a hard rubber cover which is sealed in place with hard pitch. A small vent hole in the cover allows the gas to escape, but is too small to allow much of the electrolyte to spill even if the cell is turned bottom side up. The two terminals come up through the cover and a suitable opening is provided through which the electrolyte may be introduced. This opening is stopped with a rubber cork.

Each side of each positive plate should face a negative plate, thus making it necessary, generally, to have one more of the latter than of the former. Automobile ignition batteries consist, generally, of two cells. When this form of current generator is used it is customary to have two batteries connected to the engine through a double point switch so that either one may be connected in as the operator desires. Since a storage battery does not recover by standing idle, like a primary battery, one battery should be used until the engine begins to miss, when it should be cut out and the other battery put in service.

The chemical reactions in a storage battery are not yet thoroughly understood, but it is generally agreed that when the cell is being charged, lead peroxide is formed on the positive plate and metallic lead on the negative plate. During discharge, lead sulphate is formed on both plates. Lead sulphate is a white substance and has no electrical conductivity. If the cell is allowed to discharge too much, an excessive amount of this substance is formed and the cell can not be easily recharged again. Care must be taken not to allow the voltage of a dry cell to run down too low or it may be ruined. When the voltage of a cell falls to 1.8 volts on discharge, it is time to put it out of commission until it can be recharged.

Another reason why the voltage must not be allowed to run down below 1.8 is that the formation of lead sulphate causes an increase of volume which causes the plates to buckle and the paste to crack and fall out of the grooves in the plate.

Charging a Storage Battery.—Direct current must be used to charge a storage battery. Alternating current can not be used except in connection with a rectifier which changes the alternating current to direct. The voltage of the charging current used for charging a single cell must not exceed 2.5 volts. A two cell battery would require a current strength of 5 volts. The positive wire of the charging line must be connected with the positive pole of the battery. If the charging current is passed the wrong way into the cell, the cell will be ruined. The positive and negative terminals can be determined by means of a voltmeter. If this is not at hand, draw off some of the electrolyte and place in a glass vessel. Connect two strips of lead to the terminals of the battery and insert them in the liquid, taking care they do not touch. The strip that turns brown is connected to the positive terminal.

In charging a battery remove the vent plug from each cell to allow the gas which forms to escape. This gas is hydrogen gas and is highly inflammable and care must be taken not to bring a naked flame near the cells while being charged. The completion of the charge will be indicated by the boiling or *gasing* of the electrolyte, and the charging current should be shut off about twenty minutes after this begins. At this time the voltage of each cell will be about 2.5 volts. A slight overcharge will not hurt a cell, but if charging is carried too far lead sulphate will form and the cell may be injured or even ruined.

LESSON XV.

The electrolyte is made up with sulphuric acid and water, using one part of chemically pure acid to three or four parts of distilled water or clean rain water. The acid should be added to the water slowly, at the same time stirring the mixture vigorously. The addition of sulphuric acid to water generates heat and care must be taken not to pour water into the acid, because heat would be generated so rapidly that steam would be formed and both water and acid would be thrown violently out of the vessel, burning whatever it came in contact with.

In order to mix the water and acid in exactly the right proportions an instrument called a *hydrometer* is used. This consists of a glass tube weighted with mercury at the lower end, and having graduations marked on the stem. This instrument indicates the weight or density of a liquid as compared with pure water. It is used by allowing it to float in the liquid to be tested. If floated in rain water at a temperature of 4° C, it will sink, to a point marked 1.000 on the stem. If floated in a liquid heavier than water it will not sink so far and the mark on the stem will be greater than unity.

In making up the electrolyte for storage batteries the acid should be added until the density shows 1.200. If the density of the electrolyte drawn from a cell tests less than 1.200 acid should be added, if more, then add water. An electrolyte of higher density will make the cell more active, but it will cause the cell to deteriorate more rapidly. The electrolyte should be tested frequently.

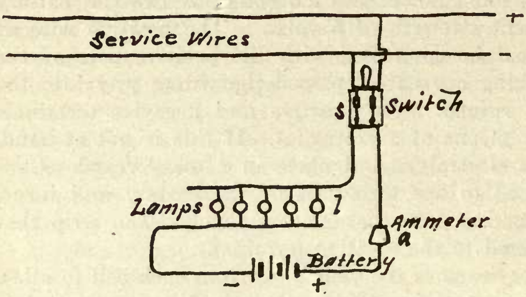


FIG. 19.

A storage battery may be tested by testing each cell separately with a voltmeter. An ammeter is of no use in testing storage battery cells, although it is the correct instrument to use for testing either dry or wet primary cells. When the voltage of the storage battery cells drops to 1.8 volts per cell it is time to recharge.

The electrolyte should cover the plates to a depth of about one-fourth inch. If some of the electrolyte is spilled add some of the fresh solution, which may be kept at hand in a bottle for this purpose. If some of the liquid is lost through evaporation add rain water or distilled water.

The Rating of Storage Batteries.—The capacity of a storage battery is rated in ampere hours. For example, a ten ampere hour battery is capable of delivering a current of ten amperes for one hour, or one ampere for ten hours. The rate of discharge is thus seen to be variable, depending upon the work the battery is called upon to do. A storage battery is able to supply a heavy current for a short time or a smaller current for a longer time.

In considering storage batteries for electric lighting, it is customary to multiply the ampere hour capacity by two to find the number of 16-candle power lamps that the battery is able to carry for one hour. Each carbon filament 16-candle power lamp requires about one-half an ampere of current, so that one ampere per hour is sufficient for two lamps. A ten ampere hour battery, therefore, will run twenty lamps one hour or four lamps for five hours.

Charging from a Lighting Circuit.—A convenient means of charging storage batteries is found in the ordinary incandescent lighting circuits. If the current is alternating, a rectifier must be used which will change it to direct current, for only direct current can be used in charging the battery. Where direct current at 110 or 220 volts is available, lamps may be used for resistance if a suitable rheostat is not at hand.

Figure 19 shows the method of wiring where lamps are used.

A bank of lamps *l*, connected in parallel, is connected in series with the battery. A double pole switch *s*, connects the battery with the service wires and an ammeter is placed in the line at *a*. This instrument is not absolutely essential, but it is well to have it in order to be certain of the strength of the charging current. The number of lamps used will depend upon how much current they require and the charging rate of the battery. This latter quantity may be determined by dividing the ampere hour capacity of the battery by eight. For example, if the battery is rated at forty ampere hours, it will take a five ampere current to charge it. If the line pressure is from 110 to 120 volts, then five 32-candle power lamps, each requiring a current of one ampere must be used. If 16-candle power lamps at one-half ampere each are used, it will require ten lamps. Fewer lamps can be used, but it will require a longer time to charge the battery.

Laying up a Battery.—If a battery is not to be used for some time it may be kept in condition by giving it a small freshening charge occasionally, say once in two weeks. This charge should be given at a very slow rate. Where the battery must lie idle for an extended period, as it frequently does in many summer or winter resorts, it should be put in dry storage. To do this proceed as follows: — First charge the battery at normal rate until it is completely charged, then syphon out the electrolyte and place in clean bottles for use when the battery is to be recharged. As each cell is emptied, refill it immediately with pure cold water. After all the cells have been treated in this manner, connect up the battery and discharge it until the voltage falls to one volt per cell. When this point has been reached the water should be drawn off. If the battery gets hot during discharge add cold water to take up the excess heat. After being emptied of water the battery may stand for an indefinite period without suffering any injury.

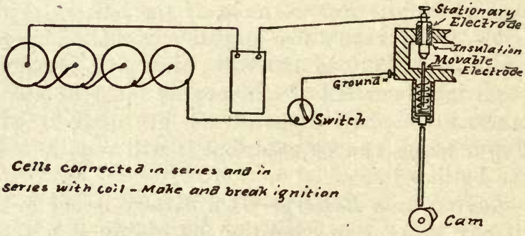
CHAPTER VI

WIRING AN ENGINE

LESSON XVI.

This is a subject that gives probably as much trouble as any other feature of gas engine operation, and it is proposed in this and succeeding lessons to present a few wiring diagrams with the purpose in view of acquainting our readers with the principles, at least, of this subject.

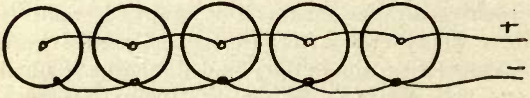
All wire used should be preferably rubber insulated. Cotton insulated wire is not nearly as satisfactory, first, because the insulation soon becomes worn in service; and second, because the cotton absorbs more or less moisture. Wire of proper size should be used since very small wire presents too much resistance to the flow of current, especially if the external circuit be long.



Cells connected in series and in series with coil - Make and break ignition

FIG. 20.

All joints should be scraped clean and all binding, nuts and screws should be set up tightly with a pair of pliers. Wherever there is a loose connection there will form an oxide of copper, which is a good insulator, and even if current does pass through it will be weaker on account of the resistance at that point. All wires should be supported and not be allowed to hang or flop. A loose wire is apt to rub against some metal part of the engine and cause a short circuit at that part, thus stopping the engine and perhaps ruining the battery.

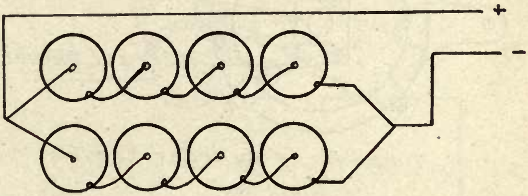


Cells connected in multiple

FIG. 21.

The simplest style of wiring is for a single cylinder engine fitted with make and break igniter. This is illustrated in figure 20. The battery consisting of four cells is connected in series, that is, one cell behind the other with the carbon of one cell joined to the zinc of the next, and so on. When the cam, which revolves at half the engine shaft speed, forces the movable electrode into contact with the stationary electrode, the circuit is completed and current flows from one electrode to the other. When the cam passes the movable electrode the current is broken and a spark is formed at the break. No more current can be used until the electrodes are again in contact.

Where from four to six cells are used in one battery they are always connected in series since this arrangement gives the greatest voltage. For other kinds of work other styles of connection are sometimes adopted, as shown in figures 21 and 22. The former represents what is called connecting cells in *multiple* and the latter *multiple series.* The voltage and amperage differ in the different styles of connections. For example: If N represents the number of cells; V, the voltage of one cell; and A, the am- will be N times V; perage of one cell, then the voltage of a battery in series if connected in multiple, V; and in multiple series S times V, where S represents the number of series units. The amperage will be for series connection A, for multiple N times A, and for multiple series S times A. To illustrate: If the amperage of each cell shown is 20 and its voltage 1, then in figure 20 the battery will show four volts and twenty amperes. In figure 21 there will be one volt and one hundred amperes, while figure 22 will record two volts and forty amperes. In other words, we will obtain the largest flow of current from figure 21 and the least current, but greatest voltage from figure 20.

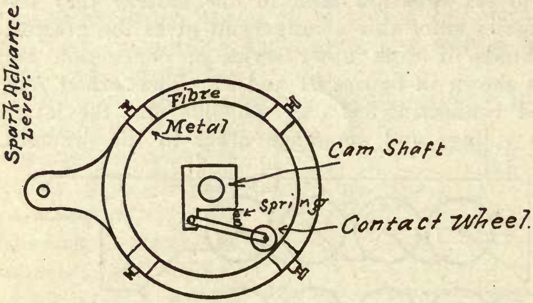


Multiple—Series

FIG. 22.

Series connection adds all the voltages together, while multiple connection adds the amperage of each cell. It has the effect of forming a single cell whose carbons are the sum of all the carbons and its zinc the sum of all the zincs in the individual cells. In this discussion no account has been taken of resistances of either the internal or external circuits.

The Timer.—Where there are two or more cylinders to be ignited from a single battery or other source of current, it is necessary to provide what is called a *timer* or *commutator,* which will connect the battery first to one cylinder and then to another in the proper order of their ignition. Such a device is nothing more than a revolving switch actuated by the engine itself from gearing attached to the crank shaft. A crude form of timer illustrating the principle of all timers appears in figure 23. It consists of a fibre ring, usually enclosed in a metal case having a cam shaft passing up through its center. This shaft carries a block with an arm on the end of which is a contact wheel. The wheel is pressed outward by a compression spring. As the shaft revolves, it carries the contact wheel around and makes contact with the various binding posts through the metal segments whose inner faces are flush with the fibre ring. Whenever the contact wheel touches one of these metal contact pieces, current can flow through the contact wheel, the arm that carries it and the cam shaft to the engine frame from which it can pass back through the grounded connection to its source.



Timer for 4-cylinder Engine

FIG. 23.

In this connection it may be well to state that a ground connection means a connection to the engine frame, but not necessarily to the earth. The timer housing is provided with a lever connection whereby it may be rotated several degrees and thus change the time of contact with reference to the engine shaft while the engine is running. Timers are made with one, two, three, four, or more binding posts for engines having a like number of cylinders.

In all problems of wiring there is one fundamental fact that must be borne in mind continually, and that is, *each circuit must be complete* in order to get a current through. Here is where a lot of people have trouble. They do not make certain that each circuit is complete before taking up the next. If they did they would have less difficulty in laying their wires. This is not as simple as it might seem when one has several separate sources of current with multiple switches and perhaps jump spark ignition.

Since jump spark ignition presents some difficulty to many people we have prepared a diagram, figure 24, to illustrate one of the fundamental features of this form of ignition. The point we wanted to illustrate is the one just mentioned, that is, that the various circuits must be complete. In this diagram there are two circuits, the primary marked P, and the secondary marked S. There are only three wires to the engine from the coil, and this is what causes trouble.

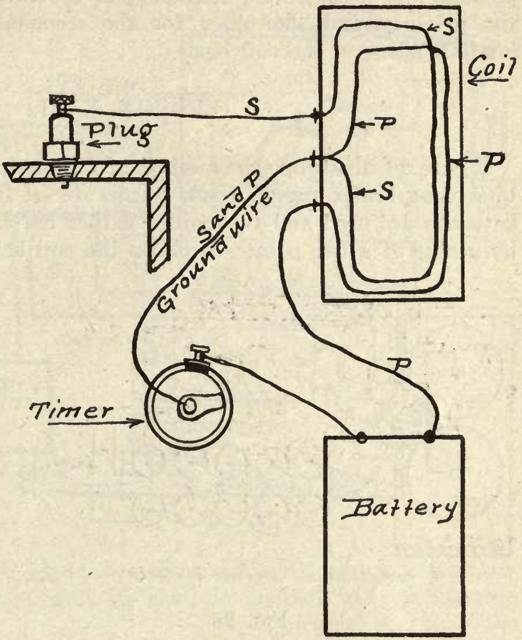


FIG. 24.

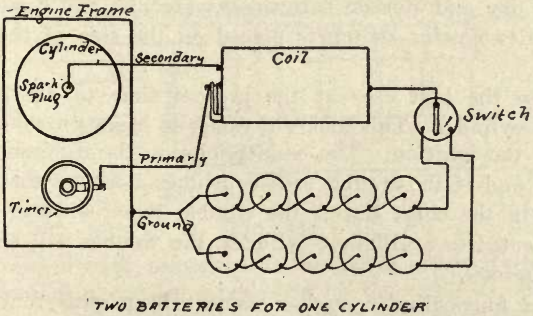
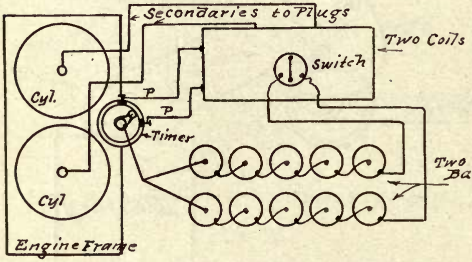


FIG. 25.

There are two distinct circuits in the coil—the primary from the battery, consisting of coarse wire, and outside of this and insulated from it a fine coil of wire called the secondary. When the current flows through the primary, an induced current flows through the secondary and jumps the gap in the spark plug. By referring to the diagram it will be seen that the timer closes the primary circuit, using the engine as a part of the circuit. When this occurs the secondary current flows through the spark plug, jumps to the engine frame and goes back to the coil through the common ground wire and thus completes the circuit. It would be possible and perhaps less confusing to use two ground wires, one for the primary and the other for the secondary—thus making four binding posts on the coil box.

LESSON XVII.

Figure 26 illustrates the method of connecting jump spark ignition to a two-cylinder engine whose cranks are set 180 degrees apart. Two batteries are used and two coils. Either battery may be switched in by means of a two point switch on the coil box. The secondary circuit is completed through the engine frame, the vertical shaft of the timer, and the primary connection back to the spark coil where connection is made to the secondary winding after the manner shown in figure 24 in the preceding lesson.



TWO CYLINDERS – CRANKS 180° APART

FIG. 26.

In figure 27 a method is shown for connecting both dry batteries and storage batteries so that either may be used as desired. The same ground wire is used for both the dry and storage batteries as are also the same coil and timer. The two point switch is placed on the side of the coil box.

It is customary on the best cars at the present time to use a separate coil for each cylinder. This makes it easier to locate trouble, when it occurs, with the ignition. The connections on the different coils can be changed and if the trouble still continues it shows that the difficulty is not in the coils, but if the trouble remains at the same coil when connected to a different cylinder, the trouble will be generally found in the coil.

Figure 28 shows a four-cylinder engine connected up with four coils, the current being supplied by a battery. In wiring a multi-cylinder engine each circuit should be completed and tested before another one is started. In this way all danger of confusing the circuits is obviated. The primary wire should first be laid from its coil unit to the appropriate timer contact. When the switch is closed the vibrator of the coil will buzz when the timer contact piece makes connection with the segment to which the wire is attached. A buzzing of the vibrator when the switch is open indicates a short circuit somewhere. The secondary wire should now be put down before attempting the next primary circuit. This should be tested by noting if a spark appears at the spark plug, which latter may be unscrewed and placed with its shell in contact with the engine frame so that the spark may be observed. When the spark lever is fully retarded the spark should appear when the piston reaches the dead center on its compression stroke.

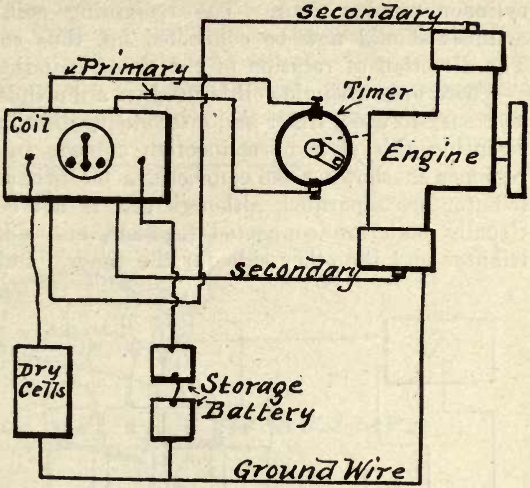


FIG. 27.

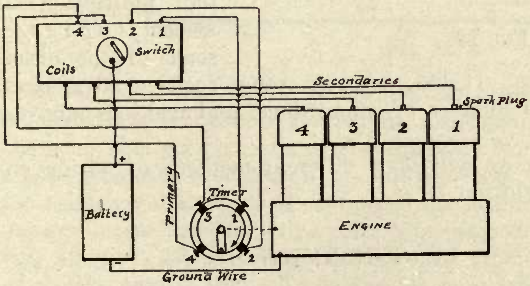


FIG. 28.

The timer contacts for a four-cylinder engine must be arranged with reference to the firing order of the different cylinders, which in turn is established by the order of opening of the exhaust valves. Suppose this order is 1, 2, 4, 3, as in figure 28. After the first cylinder is connected up in the manner just described, the next one to be wired is number two, and the primary wire should be connected to the next timer contact in the direction of rotation of the timer. The primary of coil number four should be attached to the next binding post of the timer and the corresponding secondary run to cylinder number four. The remaining coil, timer contact, and cylinder should now be connected up, thus completing the wiring. The direction of rotation of the timer is indicated by the arrow.

Where only a single coil is used on a multiple cylinder engine it is necessary to use a timer and a secondary distributor. A diagram representing this style of connection appears in figure 29. For convenience in showing the connections the primary timer and the distributor are separated, although this is not customary in practice. Usually both are connected together, one side being for the distributor and the other side for the timer. Only one source of current is shown in the drawing, but there is nothing to prevent wiring in such a way as to be able to use two or more sources of current. This style of ignition is not used as much as it has been in former years. The advantages of the multiple coil system indicate some of the disadvantages of this type. It has, however, some positive advantages, such as reducing the number of connections, and making only one coil to adjust.

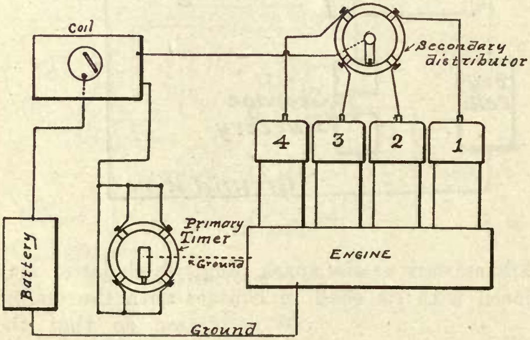


FIG. 29.

In our next lesson we will show different methods of wiring engines for magneto ignition.

LESSON XVIII.

There are two principal methods by which ignition in a gas engine cylinder may be accomplished, using a magneto. The first is with a low tension magneto adapted to the make and break system of ignition, and the second with a high tension magneto adapted to the jump spark system. There are many modifications of the latter system, some of which will be discussed in succeeding lessons. In this lesson we will consider first the low tension system using make and break ignition. In this type of ignition the igniter is just the same as for battery ignition. There is one stationary electrode and one movable. The movable electrode is brought into contact with the stationary or insulated electrode at the proper time in the stroke by the action of a cam acting on a tappet. The current from the magneto flows from the magneto through the contact points, thence to the engine frame and then to the magneto, completing the circuit.

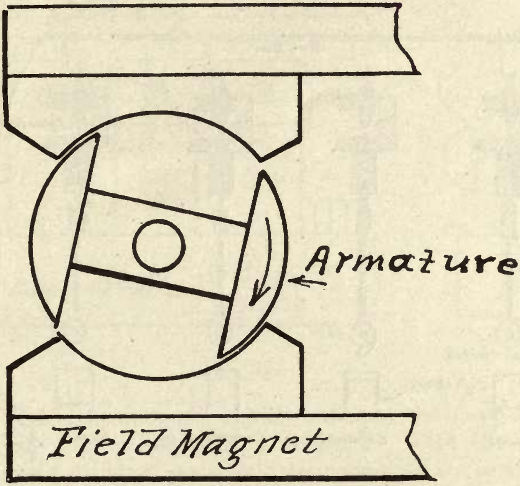


FIG 30.

At the right time in the stroke the two contact points are quickly separated and an arc is formed in consequence, thus igniting the charge. This action is in nowise different from what obtains when a battery is used except that it is not necessary to use a spark coil, as the voltage and strength of current of the magneto are sufficient without any intensification with a coil. The method of wiring is therefore very simple. All that is needed is a wire from the magneto grounded on the engine frame by having its base attached thereto so that the circuit is complete when the two contact points are together.

When several cylinders are fired with the same magneto it is customary to use what is called a bus bar, that is, a common wire from the magneto, to which all the individual wires are attached.

When it is desired to stop the engine the magneto is short circuited on itself by means of a switch between the bus bar and the engine frame. This causes the current to go back through the engine frame to the magneto. It would be possible to stop the engine by simply opening the switch leading to the various cylinders and not causing the current to go back to the magneto, but this might result in injury to the magneto, since the current which it would continue to generate would have no outlet and might break through the insulation of its own windings, causing permanent injury.

It must be remembered in considering magneto ignition that the armature of the magneto must occupy a certain position with reference to the field magnets at the instant ignition occurs (see figure 30), as the current generated by the magneto when in any other position is very feeble. For a magneto whose armature rotates, it is necessary, therefore, that it revolve at a certain speed, relative to that of the crank shaft, so that it will occupy the position shown in the figure when ignition occurs. It is furthermore necessary that the time of ignition be fixed absolutely with reference to the speed of the engine and this makes some sort of positive drive necessary. The usual method of obtaining this is by means of a gear on the crank shaft driving one having the requisite number of teeth on the armature shaft. A belt or friction drive is not suitable because of slippage and the consequent getting out of time of the magneto.

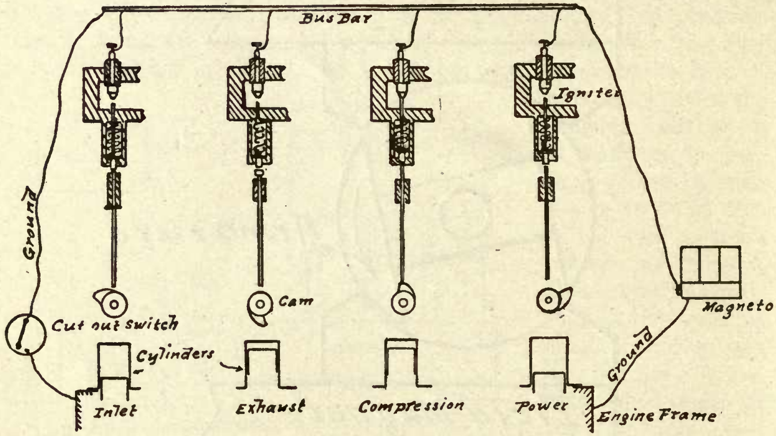


FIG. 31.

The correct time for ignition to occur is during the compression stroke, shortly before the piston reaches dead center. On most automobiles; and, in fact, other engines as well, the piston is given a lead of about one-half an inch, that is, ignition occurs when the piston is from one-half to three-quarters of an inch from the end of the stroke. The correct timing of the ignition, therefore, consists in causing it to occur at this point. This may be accomplished by measuring down from the top of the cylinder to the piston and then adjusting the gears so as to bring the armature into the position shown in figure 30 at that time.

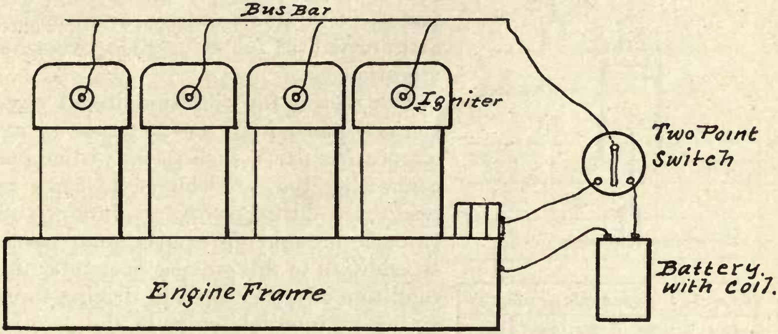


FIG. 32.

Figure 31 is a diagrammatic sketch showing the method of wiring switches, etc., for a low tension magneto. With the above description no other explanation should be needed to make the system perfectly plain.

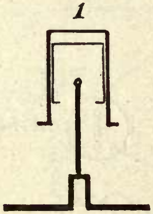
Figure 32 shows how an engine may be connected up with a low tension magneto using a dry battery and coil to start with. After the engine comes up to speed the two point switch may be thrown over, cutting out the battery and cutting in the magneto. This is the common method of connecting a system of this kind, as it is necessary to bring the magneto of this type up to a higher speed than can conveniently be done by hand cranking, in order for it to generate sufficient current for ignition.

CHAPTER VII

ENGINE BALANCE

LESSON XIX.

One of the difficulties encountered in designing and constructing all reciprocating engines, whether they be driven by steam or gas power, is to secure steady, even motion and prevent, so far as possible, excessive vibration.

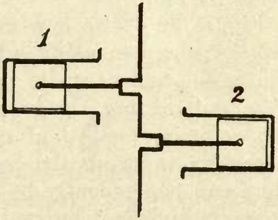


NO. OF CYL.	ORDER OF STROKES			
1	P	E	S	C

FIG. 33.

The reason for vibration in all such engines arises from the fact that all reciprocating parts, such as the piston and connecting rod, are obliged to come to rest twice during every revolution, and twice be brought up to maximum speed. In addition to this we also encounter the condition of a very variable driving force acting at intervals only, in the case of the gas engine. This complicates the problem considerably and has required the exercise of the very best engineering skill to overcome. Even with all the thought and study and skill with which this problem has been approached it is not completely solved and never can be, owing to the variable and intermittent nature of the forces involved. However, much progress has been made in the past few years, thanks to the severe demands made by the automobile trade, and at the present time engines are built in which vibration has been reduced to a point which is not particularly objectionable. Some of the means through which this has been accomplished will be explained in this lesson.

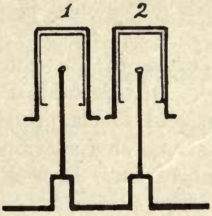
Engines having only one cylinder may be balanced to some extent by the judicious use of counter weights placed either directly opposite to the crank, or else placed opposite to the crank in the fly wheels.



NO. OF CYL'S	ORDER OF STROKES			
1	P	E	S	C
2 OR	S	C	P	E
	E	S	C	P

FIG. 34.

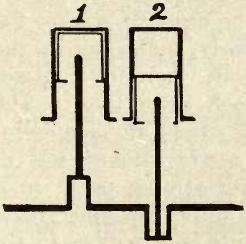
The effect of these counter weights is to set up an oppositely acting force which attains its maximum value at the instant the piston and connecting rod come to rest. Thus one force acting in one direction is made to offset another and presumably equal force acting in the opposite direction. The result is a nullification of both forces and consequent lack of vibration of the engine frame. To this condition is added the steadying effect of very heavy fly wheels, which serve to absorb energy during the power stroke and deliver it to the crank shaft during the idle strokes of the engine. A perfect or, in fact, a near approach to perfect absorption of vibration by this means would require the engine to run at constant speed, since a change in speed changes the intensity of the centrifugal forces set up by the revolving weights in a different ratio from the way in which the forces due to the reciprocating forces change. Consequently, an engine of this type can be balanced correctly for only one speed, and will vibrate more and more as the speed varies from the standard.



CRANKS ON SAME SIDE

NO. OF CYL'S	ORDER OF STROKES			
1	P	E	S	C
2	S	C	P	E

FIG. 35.



NO. OF CYL'S	ORDER OF STROKES			
1	P	E	S	C
2 OR	C	P	E	S
	E	S	C	P

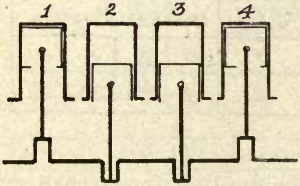
FIG. 36.

The difficulty inherent in the single cylinder engine has led to the general adoption of engines having two or more cylinders. In multiple cylinder engines, as they are called, the pistons and reciprocating parts can be so arranged that they move in opposite directions, and, if care is taken to make these parts of equal weight, they will counterbalance each other at any speed and thus reduce vibration to a very small amount.

This is the plan adopted in all double opposed engines of the horizontal type, and is found to be quite satisfactory for all low powered engines. The pistons are placed horizontally on each side of the crank shaft, with their open ends opposite each other. The cranks are placed 180 degrees apart, or, in other words, on exactly opposite sides of the crank shaft. Thus both pistons reach the head ends of their respective cylinders at the same instant, but travel in *opposite directions* to do so. Thus the shock occasioned by bringing one piston to rest is offset by the other.

The order of the different events of the strokes is tabulated in Fig. 34. In this table P represents the power stroke; E exhaust; S suction and C compression. An outward stroke must be either a power stroke or a suction stroke, and an inward stroke either exhaust or compression. It will be observed that with this arrangement of cylinders a power stroke can be made to occur during each revolution, if the valves and cams are set right. The upper set of events opposite 2 in the figure shows the correct arrangement, while the lower set of events shows a faulty arrangement, since it brings both power strokes in the same revolution.

Two-cylinder engines are often placed side by side, as indicated in Figs. 35 and 36. Two arrangements of the cranks are possible with this construction. They may be placed opposite, or 180 degrees apart, or on the same side of the shaft, in which case they are said to be 360 degrees apart. The order of strokes for both cases is clearly indicated in the figures. In Fig. 35, there is a power stroke once in each revolution. The table shows an idle stroke in each cylinder between the power strokes, but in Fig. 36 both power strokes occur in a single revolution, while the other revolution is idle during both strokes in the two cylinders.



NO. OF CYL'S	ORDER OF STROKES			
1	P	E	S	C
2	E	S	C	P
3	C	P	E	S
4	S	C	P	E

FIG. 37.

In the arrangement shown in Fig. 35, the reciprocating forces are not balanced, while in Fig. 36 they are. However, of the two, the former is preferable, since it gives a steadier motion to the crank shaft and counter weights may be used to offset the unbalanced forces due to the reciprocating parts.

Of the three arrangements of the two cylinders, the horizontal double opposed possesses greater advantages and is the preferable one to use.

In Fig. 37 there is shown a sketch of a four-cylinder vertical engine such as is generally used. The two end cranks point in one direction and the two middle ones in the opposite direction, being thus arranged in pairs 180 degrees apart. The table shows the order of the strokes in each cylinder. An inspection of the figure will show that the order of firing is 1, 3, 4, 2. Nearly all engines of this type are timed to fire in this way.

A further discussion of the four-cylinder engine will be taken up in the next lesson.

LESSON XX.

Some of the difficulties of securing a perfectly balanced engine were pointed out in the last lesson and will be considered at greater length in the present lesson.

There are two classes of forces that produce vibration; those due to reciprocating masses and those due to rotating masses. The former may be perfectly balanced by similar masses acting in the opposite direction at exactly the same instant and in the same line of action. For example, the forces set up by the piston and other reciprocating parts of one cylinder of a double opposed engine may be exactly balanced by similar parts of the other engine, provided both cylinders are exactly opposite; that is, if the same center line passes through both cylinders. If this condition does not exist there will be what is called a force couple acting which will tend to rotate the cylinder in a horizontal plane if they are placed horizontally.

The only way to have the cylinders exactly opposite is to make the connecting rods with interlocking ends, both acting on the same crank pin. This, however, is rarely done in the case of gas engines, since the construction of the double opposed engine is such that the distance between cranks is only about one-half the length of the crank pin and the lever arm of the couple is thus quite short. Where vertical two-cylinder engines are used this lever arm is much longer, being about one and one-half times the length of the crank pin, owing to the double cylinder walls and double water jacket between cylinders.

A four-cylinder engine having the two outer cylinders arranged as a pair and opposed to the two inner ones, is perfectly balanced so far as the reciprocating forces only are concerned. One pair of pistons moves in one direction and the other pair moves in the opposite direction. If care is taken to make all the pistons and connecting rods of equal weight, very good results may be obtained. In the best automobile factories great care is taken in this particular, it being the practice to reduce all reciprocating parts of the various cylinders to the same weight within a fraction of an ounce. This practice results in the minimum of vibration and is necessary for high speed automobile engines and boat engines.

There are, however, some unbalanced forces even if the weights of reciprocating parts are exactly the same. These arise from the rotation of the crank and the oscillation of the free end of the connecting rod. These forces cause some vibration, but they can not be perfectly balanced unless use is made of other rotating parts of equal weight and similarly placed, revolving in an opposite direction. This remedy would lead to a complication of parts and the benefits to be derived being small, at best, it is not generally thought wise to make use of it.

In four-cylinder engines, it was shown in the last lesson, the order of firing of the cylinders might be 1, 2, 4, 3; or 1, 3, 4, 2. The first engines built were all arranged to fire in the order first given, but a little consideration will show that the latter order will give better results, since the force of the explosion is distributed over the engine to better advantage. This is the order that is being generally adopted at the present time.

Three-cylinder engines are arranged with the cranks set 120 degrees apart instead of 180 degrees, as is the case with double opposed or four-cylinder engines. This arrangement results in excellent balance of the reciprocating parts and in excellent turning effort at the crank shaft.

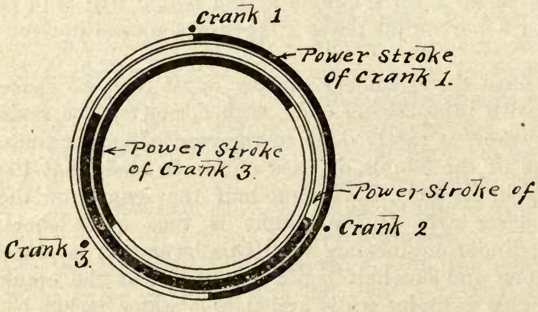


Fig. 35

FIG. 38.

The stresses due to the explosion of the charge are very evenly distributed since there are two power strokes during two revolutions of the crank. While the crank is making two complete turns, or 720 degrees of rotation, power is applied through three half revolutions, or a total of 540 degrees. The longest period, with this arrangement, between the end of one power stroke and the beginning of the next, is while the crank is passing through an angle of 60 degrees. This fact is clearly brought out in the accompanying drawing, Fig. 38. Six-cylinder engines have crank shafts of similar construction to three-cylinder engines, with the cranks arranged in pairs. This arrangement gives six power strokes in two revolutions and provides the best torque and best balance obtainable without using an excessive number of cylinders. In fact, very little additional benefit would be obtained by using as high as twelve cylinders; while the complication of parts and difficulty in keeping in repair would be enormously increased.

It would, therefore, appear from the foregoing discussion that for small runabouts and light powered machines, especially those of the high-wheeled type, the double opposed motor has many advantages. It is cheap, easy to take care of, is not complicated, and has fairly good torque and good balance. The four-cylinder vertical engine is better than the double-opposed, but is more complicated, costs more, and is particularly adapted to high grade cars, especially touring cars and cars of large power. The six-cylinder motor represents about the highest grade of present day gas engine construction, but it is expensive, complicated and difficult for the ordinary, unskilled individual to manage. It is adapted, therefore, to the expensive, high grade cars, managed by skilled attendants. It probably will never be used to any extent, if at all, for farm engine purposes. The one, two and four-cylinder engines are used extensively for farm work at the present time; the one-cylinder motor for all light work, such as sawing, grinding, pumping, etc.; the two-cylinder and four-cylinder motors for automobiles and farm tractors. There are also some quite successful farm tractors of the one-cylinder type.

All single cylinder engines depend upon a heavy fly wheel to preserve steady motion and to a certain extent prevent vibration. In general, it may be said that the heavier the fly wheel the less the speed of the engine will vary. Consequently, gas engines used to run electric dynamos must be fitted with very heavy fly wheels or the speed of the engine will vary enough to make the lights flicker badly. An engine designed for pumping and light farm work will in general vary too much in speed to be used to run a dynamo. If, however, it be fitted with an extra heavy fly wheel it will usually prove quite satisfactory.

CHAPTER VIII

CARBURETORS

LESSON XXI.

Neither pure liquid gasoline nor pure gasoline vapor will burn in a closed vessel. An engine charged with gasoline vapor only would not run. In order to make gasoline vapor inflammable it must be mixed with the right amount of air in order to obtain sufficient oxygen for combustion.

The mixing of the air and gasoline vapor is called *carburetion.* That is, the air is carburetted or charged with the carbonaceous fuel. The apparatus or device in which this act is accomplished is called a *carburetor* or sometimes a *mixer.* The former name is now used almost exclusively and is the name that will be adhered to in these lessons.

In searching the literature of gas engines very little data was found pertaining to mixtures of air and gasoline and apparently there is little exact information available. It is known that a proper mixture will explode readily and do its work with the accompaniment of very little smoke at the exhaust or the clogging of the valves with a deposit of tar. If the mixture is not right both of these things may occur and trouble will be experienced in running the engine.

Experience indicates that only very slight variations are permissible in the mixture in order even to make the engine work at all. If the maximum fuel efficiency is desired the variations in the mixture must be very slight indeed. Stoddard is authority for the statement that one volume of gasoline to 8,400 volumes of air at atmospheric pressure, is a good mixture; and that one volume of gasoline to 10,000 volumes of air ceases to be explosive. If less than 8,400 volumes of air are used per volume of gasoline, some of the gasoline will emerge unburned at the exhaust. Consequently, it would appear that the mixture even under ordinary working conditions must vary only slightly in composition in order to obtain satisfactory results. The quality of the fuel may also have some effect upon the character of the mixture.

Gasoline as it appears on the market varies somewhat in composition. The gasoline sold generally at the present time will show a test for specific gravity of from sixty-eight to seventy degrees Baume, although some is found testing even lower than this. The boiling point of gasoline is also a variable quantity, ranging from one hundred five degrees Fahrenheit to one hundred thirty-five degrees. The lighter and more volatile oils show a higher specific gravity and lower boiling point. To illustrate this matter of the gravity test I might mention the fact that kerosene tests about forty-eight degrees, Baume, while the gasoline best adapted to gas machine work tests eighty-eight degrees. These figures represent the relative weights of a unit volume of the liquid in comparison with pure water, all at sixty degrees temperature.

In most, if not all, of the states the quality of both the gasoline and kerosene is regulated by state law and all oils offered in the market are inspected by the state oil inspector or his deputies. The high gravity test gasolines are more volatile than the low test, that is, they will vaporize more readily and at a lower temperature. Consequently, for a high speed engine like an automobile engine the high test oils give somewhat better results. They are, however, expensive, owing to the fact that only a comparatively small quantity can be obtained from a given amount of crude petroleum. Petroleum is a very complex substance chemically consisting of a large number of oils of different densities. These are separated from the crude petroleum by the process of distillation. This process consists of heating the crude oil to a certain temperature for a given length of time until all that will be vaporized at that temperature has been driven off. The resulting vapors are condensed in suitable condensors, purified, and placed on the market as gasoline, naphtha, kerosene, lubricating oils, etc. After each group or class of oils has been separated, the temperature is raised and the next class is vaporized. Each one of these classes is also a complex structure since the range of temperature used in the separation of each class causes several oils of different densities to be vaporized. This becomes evident at once to any one who has had much experience in running gasoline engines. Stale gasoline is simply gasoline that has lost its more volatile constituents by standing for a long time exposed to the air. It resembles kerosene in its characteristics and does not vaporize and carburete readily and consequently it is difficult to get an engine started unless new gasoline is placed in the tank, that is, if the engine has stood idle for a considerable period.

The vaporizing of gasoline, kerosene or alcohol is accomplished with heat, just as steam is formed in the boiling of water. Since the boiling point of the three first named liquids is much lower than that of water, they, of course, do not require as much heat as an equal quantity of water. Nevertheless, a considerable quantity of heat is required and nearly all high speed engines are equipped with carburetors that are provided with an auxiliary air intake which draws hot air from around the cylinders of the engine. In cold weather this is essential because there is not heat enough in the air to vaporize the fuel.

A considerable amount of trouble is often experienced in cold weather by the freezing of the carburetor. An engine will run for a time and then stop. In a few minutes it can be started again and will run for a considerable time before the carburetor becomes clogged with ice a second time. The freezing of the carburetor is caused by the moisture from the air congealing on its cold surfaces. Air always contains a certain amount of moisture and even if the outside air is nowhere near the freezing point, freezing of the carburetor may occur with a high speed engine. The rapid absorption of heat by the gasoline vapor on its way through the carburetor may lower its temperature away below the freezing point. We have here, on a small scale, the same principle exemplified as in the ammonia refrigerating machine. In this the liquid ammonia is vaporized with the rapid absorption of heat from the surrounding surfaces and their consequent lowering of temperature.

LESSON XXII.

CARBURETORS.

The proper mixing of the fuel takes place in the carburetor, This is, as indicated in the last lesson, a rather delicate process. The variation in the quality of the mixture must be very slight if anything like good results are to be obtained in the engine. A correct proportion of air and gasoline produces a gas whose combustion is rapid; an excess of air makes a slow burning mixture, while an excess of gasoline causes not only slow burning but incomplete burning of the charge. All the difficulties of back firing, popping in the muffler, smoky exhaust, etc., are mostly due to faulty carburetion. Back firing is generally caused by a lean mixture, which is so slow burning that it is not completely consumed at the end of the power stroke, but keeps on burning in the compression space until the inlet valve opens on the suction stroke. Then the flame flashes back through the carburetor and causes the phenomenon known as back firing. This may become exceedingly dangerous if there is a leak of gasoline around the tank or at any of the points in the gasoline piping. Many automobiles have taken fire and not a few have been completely burned through just this cause. A slow burning charge, due to an over-rich mixture, sometimes acts in a similar way, but it always causes a smoky exhaust with sooting of the spark plugs and the inside of the cylinder; all of which causes much loss of time and annoyance to the owner of the engine.

If the same kind of fuel is to be used always and the speed of the engine can be kept constant it is not difficult to construct a carburetor which will give a practically constant mixture, or at least, one whose variations are si slight as to be negligible; but when engine speed, fuel, temperature of the air, and everything is variable, it makes the problem of designing a carburetor which will successfully meet all these conditions exceedingly difficult. There are some very good carburetors on the market, and some that give excellent results, but there is still much to be desired, much that has not yet been accomplished –perhaps is impossible of accomplishment—in the design of carburetors. Any of the so-called automatic carburetors will work almost perfectly for any given speed when adjusted to that speed. They will, also, on account of their automatic principle, give fair results at quite widely varying speeds, but there is no carburetor made that will, without having to be adjusted, give equally good results at all speeds.

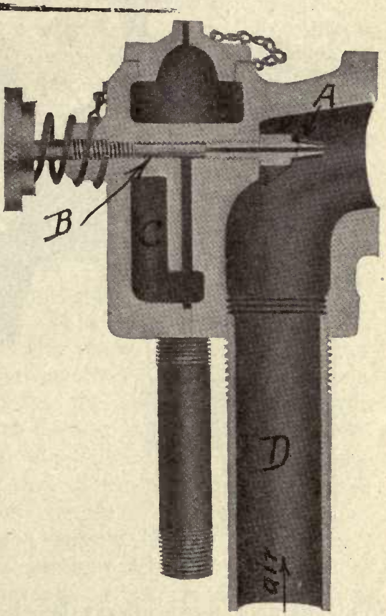


FIG. 39.

In order to make some of the above statements clear we will proceed in this and succeeding lessons to describe various types and styles of carburetors.

One of the simplest carburetors in mechanical construction is the *spray carburetor,* illustrated in Figs. 39 and 40. It consists of a conical nozzle A whose opening may be regulated by the needle valve B. The level of gasoline in the reservoir C is maintained about a half inch below the level of the needle valve by means of a pump which pumps the gasoline from the main supply tank.

The gasoline nozzle projects into the upper end of the air intake pipe a short distance, but enough so that all the air passing to the cylinder will be charged with the vapor of gasoline.

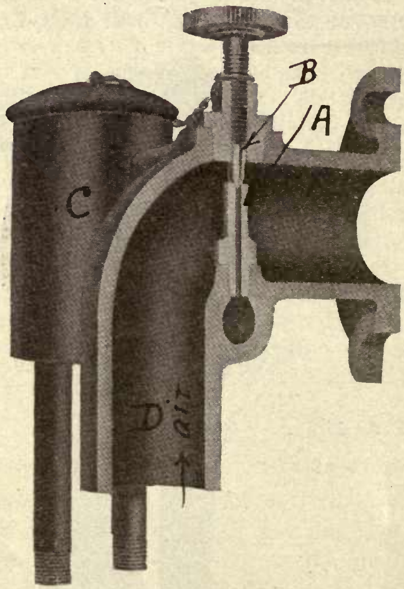


FIG. 40.

When the engine piston moves outward on its suction stroke, it causes a partial vacuum in the cylinder. Atmospheric pressure causes air to rush up through the air pipe D and overcome the tension of the inlet valve spring and enter the cylinder. All the air which enters the cylinder must pass through the pipe D and since it is small compared with the bore of the cylinder, the velocity of the air must be quite high. Indeed, it is this very air velocity that it depended upon to lift the gasoline from reservoir C to the nozzle A, where it shoots out into the moving column of air in a fine mist or spray. The higher the velocity of the current of air past the nozzle the greater will be the pumping effect and the larger will be the amount of gasoline pumped. This, then, is the reason why, with a carburetor of this kind, a damper, or air throttle, is placed in the air-pipe D. This damper must always be closed when the engine is started by hand in order to reduce the size of the air pipe enough to make the velocity of the air sufficient to pump gasoline through the supply nozzle. The reason for this increase in velocity, due to throttling, will become at once apparent when one considers that the cylinder must be completely filled with air at practically atmospheric pressure on each suction stroke. If the piston moves slowly and the air pipe is large the air will move slowly through the pipe, but if, on the contrary, the size of the air pipe is greatly reduced by an air throttle or damper, the velocity of air must be greatly increased in order to fill the cylinder. If the air throttle were left closed after the engine came up to speed, the increased pumping effect would be so great that the charge would be too rich, even though the cylinder were filled at practically atmospheric pressure.

Again, let us suppose that the needle valve of a carburetor similar to the one illustrated were adjusted for a speed of say 400 revolutions per minute and the engine was running satisfactorily at that speed. If we should increase the speed of the engine to 800 or 900 revolutions we would find the mixture too rich because of the greater pumping effect and it would be necessary to partly close the fuel valve in order to get the same mixture as before.

In stationary engine practice there is little or no trouble with the carburetor on account of variations in engine speed because the governor may be depended upon to keep the speed of the engine constant, but in the case of automobiles, motor boat engines, and engines of a similar class, it is necessary to fit them with a carburetor which will automatically take care of the variations in speed.

LESSON XXIII.

In the last lesson attention was called to the pumping effect at the nozzle of the carburetor, caused by the high velocity of the air rushing into the cylinder. This, however, is only one of the forces impelling the gasoline. The other is atmospheric pressure. When the piston moves outward on its suction stroke a partial vacuum is created behind the piston, the admission valve opens under the influence of the weight of the atmosphere, and air rushes into the cylinder. The pressure in the cylinder during the charging stroke is at all times less than that of the atmosphere and consequently there is some rarification, or reduction in pressure of the air below that of the atmosphere, around the end of the gasoline nozzle, while full atmospheric pressure exists on the top of the fuel in the reservoir. This difference in the *pressure head,* due to the rarification or reduction of pressure in the cylinder, plus the *velocity head,* or the reduction of pressure at the nozzle, caused by the *velocity of the air,* are the two forces which serve to project the fuel out of the nozzle. The intensity of these two forces depends upon a number of conditions, as will presently be shown.

These forces at best are small and a very slight change in conditions is apt to affect the results materially. For example, a slight change in the height of the fuel in the reservoir will reduce the pressure head, while any change in the velocity of the air current passing through the carburetor, due to change in the piston speed, will affect the velocity head and consequently the amount of fuel used. These are perhaps the two principal factors governing the operation of spray carburetors of whatever class. Other factors, such as the density of air, the amount of moisture it contains and its temperature, all have an influence on carburetor performance and serve as evidence of the truth of the statement in the last lesson, that it is very difficult, if not impossible, to make a carburetor self adjusting to all conditions of load, engine speed and weather.

In the carburetor shown in the last lesson the height of fuel is kept practically constant by being pumped into a reservoir which is fitted with an overflow pipe into which it discharges on reaching a certain level. This matter of a uniform level from which the gasoline flows, is, as was said before, very important, because if the level is kept constant the pressure head will be constant.

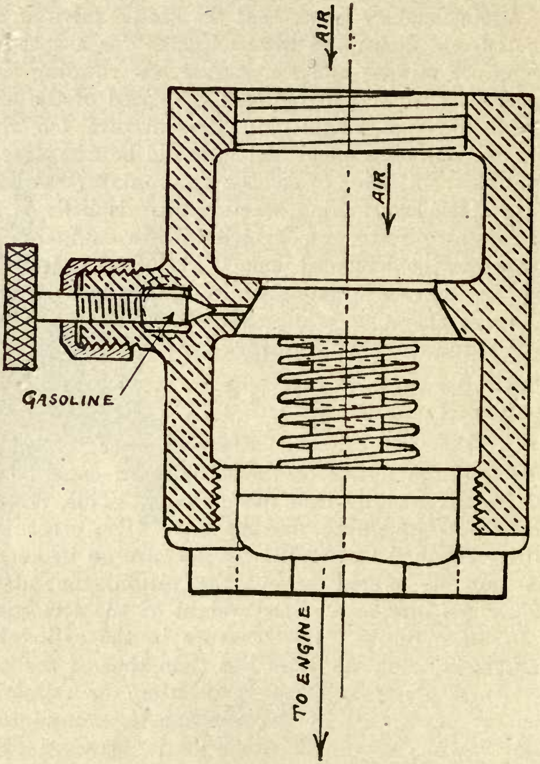


FIG. 41.

In looking into the history of carburetors we find three different types; the *surface* carburetor, *bubbling* or *filtering* carburetor, and the *spray carburetor* or *vaporizer,* a simple form of which we have just discussed. The surface carburetor was arranged so that the air on its way to the engine passed across the surface of the fuel and became saturated with the fuel vapor. The objection to this form of carburetor lay in the fact that only the lighter portions of the fuel became volatilized, the heavier portion never being used at all.

In the bubbling type, the air was caused to bubble up through the fuel. Here the same objection was encountered as in the surface carburetor; the volatile portion only of the fuel was used, while the heavier portion remained behind. The spray carburetor or atomizer has the advantage of utilizing all of the fuel by projecting the whole mass into the air where it is either entirely vaporized or broken up into a fine mist and carried directly to the cylinder. Practically all gasoline carburetors at the present time belong to the last named class. There are, however, many modifications in design with a view of adapting them to different conditions or to making them automatic, which we will proceed to discuss in this and subsequent lessons.

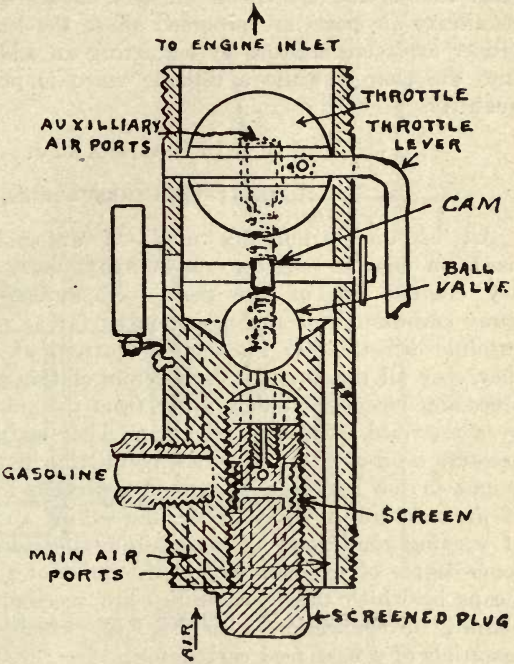


FIG. 42.

Figure 41 is an example of a very simple form of mixing valve or carburetor. It consists of a straight brass casting provided with a valve which is held in position by a light helical spring whose tension is such that it readily opens by suction when the piston starts on its charging stroke. Gasoline is fed in through the needle valve, either under pressure or by gravity. The amount delivered to the engine is regulated in the usual way with the milled head needle valve. If this is opened a certain amount, gasoline will flow in as far as the valve seat, where it is stopped by the main valve. Then, when air rushes through the carburetor on its way to the engine, it opens the main valve and picks up a certain amount of gasoline. This carburetor valve is particularly well adapted to a gravity feed, Another style of mixing valve of somewhat similar nature is shown in Fig. 42 in which a ball valve is used instead of a cone seated valve. Gasoline is fed in below the ball. When air passes up through the main air ports the ball revolves, and a fine spray of gasoline comes up around it. The lift of the ball can be regulated by means of a cam attached to the cross shaft just above it. A milled head thumb nut, shown on the left, makes the proper adjustment. Auxiliary air ports are provided above the ball valve to obtain the proper explosive mixture by admitting an additional amount of air into the charge, while a throttle valve is provided to control the quantity.

LESSON XXIV.

FLOAT FEED CARBURETORS.

All of the carburetors used on automobiles, most of those used on marine engines, and many that are used on stationary engines are of the float feed automatic type. They are spray carburetors or vaporizers, in so far as projecting the mass of gasoline directly into the ingoing current of air is concerned, and they obey all the laws for carburetors of this class laid down in the preceding lessons, but they differ from the simple carburetors which were described, in these particulars. They maintain a fairly uniform pressure head of gasoline by not permitting it to rise above a certain height in the reservoir, and they undertake to regulate the quality of the mixture at all speeds of the engine and under a wide range of varying conditions by maintaining the same, or practically the same degree of vacuum around the point of the spray nozzle. The means by which these two things are accomplished can best be explained in connection with Fig. 43, which represents the main essentials of a float feed carburetor.

Gasoline is delivered to the float chamber by gravity from a tank placed a little above the cylinder of the engine. The float consists of a thin copper vessel closed on all sides with all joints carefully soldered to prevent any liquid from reaching its interior.

Sometimes instead of using a metal float, a cork float is used. If cork is used it must be well shellaced to prevent it from becoming saturated with gasoline and losing its buoyancy. When so treated, however, it is very serviceable and will remain in good condition a long time. The metal float is a very good float as long as it remains tight. It may be good for years and it may develop a leak in a few weeks. A very small leak is much more troublesome, being harder to find than a large one. In every case the function of the float is to operate a valve which admits gasoline into the float chamber. This may be accomplished in one of several ways. In Fig. 43, the valve stem passes easily through the float. A grooved collar is secured near its upper end which affords a means of connection for a couple of weighted levers pivoted at P. When the gasoline falls in the float chamber the float also falls, allowing the weights on the ends of the levers to drop and lift the valve V, thus admitting more gasoline. When the float rises it pushes up on the weights and forces the valve to its seat.

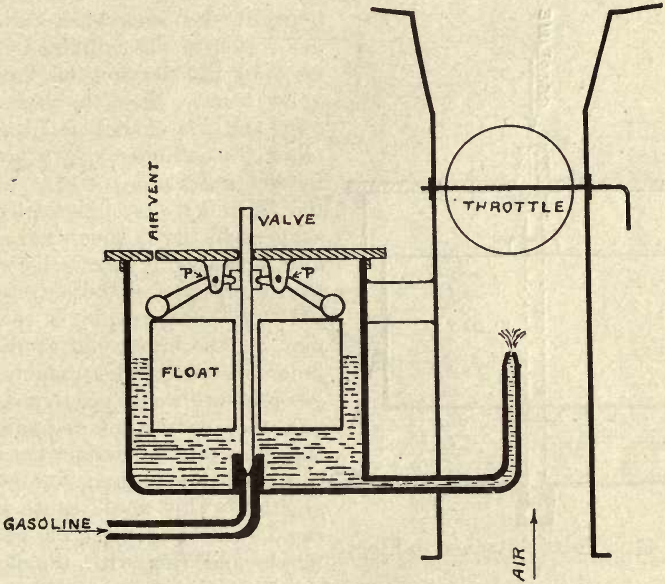


FIG. 43. Elements of a Float Feed Carburetor.

Two other methods of arranging the float and valve appear in Figs. 44 and 45. The arrangement of the float and its valve is so obvious in Fig. 44 that no detailed explanation seems necessary.

In the case of Fig. 45, we have a cork float arranged in the form of a horse shoe, surrounding the central air tube or mixing chamber.

In many carburetors there is some device to provide for raising or lowering the level of the liquid in the float chamber by raising or lowering the float.

In Fig. 43 the grooved collar may be shifted, in Fig. 44 the float itself can be set at the required height by shifting the nuts on the threaded valve stem, but in Fig. 45 there is no way provided to change the position of the float.

When the piston moves from the head end of the cylinder, the pressure of the gas behind it drops somewhat below atmospheric pressure. When it moves far enough so that the difference in pressure between the atmosphere and the gas inside of the cylinder is greater than the tension of the inlet valve spring, then the latter will open and the charge will begin to enter the cylinder. The pressure in the inlet pipe, right close to the cylinder, is practically the same as in the cylinder and gradually increases to practically atmospheric pressure at the entrance.

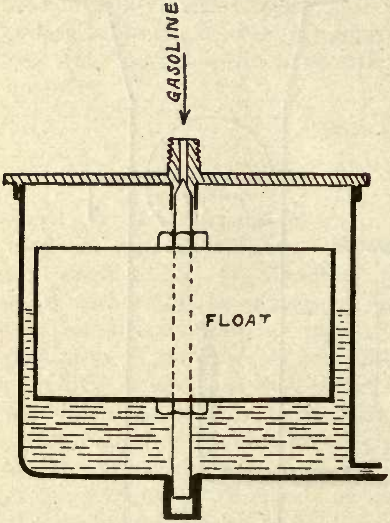


FIG. 44. Valve Attached to Float.

If the piston could be made to move to the crank end of the cylinder instantly, the reduction in gas pressure would occur instantly, and the amount of reduction in the inlet pipe or carburetor would be much greater than it ever is in practice. This would cause a very rapid rush of air past the gasoline nozzle and this with the help of atmospheric pressure on top of the gasoline in the reservoir would cause a more than usual flow of gasoline for the given quantity of air. In other words the mixture would be very rich. This, of course, is the limiting condition in that direction, but, it is easy to see that as we approach this condition in actual practice, by means of high speed we must find some way to bring the mixture back to its proper working composition. This is accomplished by means of what is called an automatic air valve as shown in Fig. 43, which is held to its seat by means of a light spring. This spring is given a certain amount of tension and holds the valve shut until the pressure above the spray nozzle falls to a point where the tension of the spring is not sufficient to hold the valve shut. When this point is reached, air rushes through the auxiliary air port and to a certain extent at least corrects the quality of the mixture, first by diluting it with fresh air, and second by preventing too great a reduction of pressure in the mixing chamber.

That certain defects exist in this method of controlling the quality, is freely admitted by every one who is at all acquainted with the working of carburetors. There is no exactitude in the process of mixing the air and the gasoline. The mixture is first made over-rich and then it is diluted a certain amount. At slow speeds the auxiliary valve does not open, consequently, from that point up to the point where it does work, the mixture is incorrect — not very much wrong, of course— but yet not quite right. Then at still higher speeds the mixture is made so very rich that enough air can not pass through the auxiliary air port. To be sure, the carburetor can be adjusted for this higher speed all right enough, but the point I wish to make is that it is only automatic within a certain range, and through only a small portion of that is it able to qualify with any great degree of exactness.

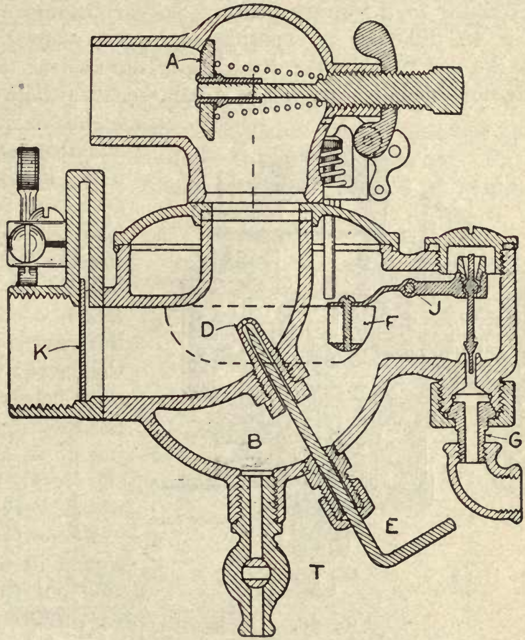


FIG. 45. One style of Automatic Carburetor.

The density of the air, its humidity and its temperature, all of these things have an important bearing on the operation of the carburetor and all taken together, make it difficult to construct one that is able to adjust itself to all conditions, automatically, and produce a uniform mixture.

LESSON XXV.

If you will refer to lesson XXIII, you will find in Fig. 43 that the gasoline reservoir is placed at one side of the spray chamber, while in Fig. 44 surrounds that chamber.

In some of the preceding lessons it was pointed out that it was very essential to maintain a constant level of gasoline in the float chamber, and especially that this level should remain constant with reference to the spray nozzle. In carburetors of the type shown in Fig. 43, difficulty is experienced in this respect whenever one wheel of the car runs in the ditch along the side of the road, or when the car moves along the side of a hill, because there is a distance of two inches or more between the float chamber and the spray nozzle. The carburetor shown in Fig. 45 is the result of an effort to overcome this difficulty by making the float surround the spray nozzle. In this construction the latter occupies the center of the reservoir, a position where the level of the liquid remains most nearly constant, and where the rocking of a boat or the tilting of an automobile will affect the level of gasoline at the nozzle very little.

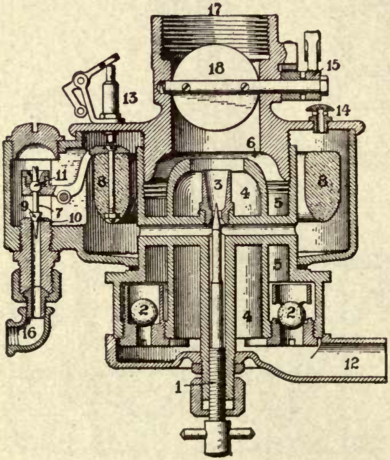


FIG. 46.

The automatic principle mentioned in the last lesson is carried out in a different manner in different carburetors; for example, in Fig. 45, the air at slow engine speed has low velocity and cannot overcome the tension of the spring holding the auxiliary valve to its seat.

Under these conditions enough air can enter through the open space below the auxiliary valve. When the speed of the engine increases and the vacuum in the spray chamber becomes greater, the rush of air through the air intake opens the auxiliary valve and allows the entrance of a larger volume of air. The effect of the high vacuum in the spray chamber, together with the rapid inrush of air is sufficient to produce a mixture that would be too rich to be explosive, hence the necessity of reducing the richness by the admixture of fresh air, either in the manner above specified or in some other manner.

There has been placed on the market quite recently, a carburetor in which the air passes through different sized openings normally closed by ball valves. The larger balls, exposing the greater area in proportion to their mass, will lift first, and, as the speed of the engine increases, thus causing a higher vacuum, the other smaller balls open and more air is admitted. Here, as in Fig. 45, the air all passes through the spray chamber. A sectional view, showing principles of the above described carburetor, appears in Fig. 46.

Fig. 47 represents another style of automatic carburetor, in which the auxiliary air supply is admitted at some distance beyond the spray nozzle. In order to facilitate and insure proper mixing, the auxiliary air is admitted at right angles to the main current. This sets up eddy currents, and the whole mass is supposed to become thoroughly mixed.

There are two other features in this carburetor that deserve more than passing notice. The first is the shape of the chamber around the spray nozzle. The air which enters around the cup below passes through a chamber shaped in such a way that the greatest velocity of the air will be just beyond the end of the gasoline nozzle. This construction tends also to cause all of the air to be saturated with the spray of gasoline, which spreads out in canopy form from the top of the nozzle.

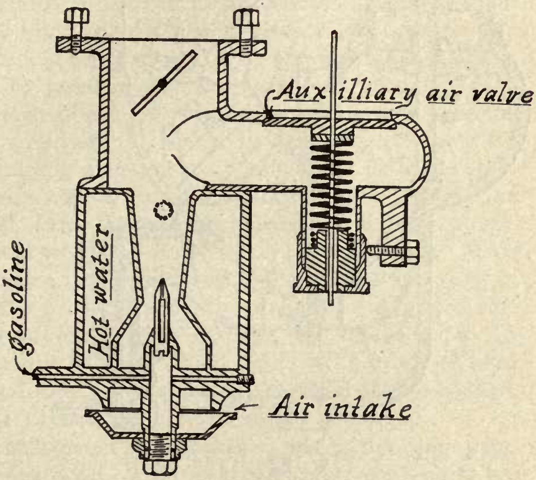


FIG. 47.

The other feature to which we referred is the annular hot water chamber surrounding the spray chamber. This is arranged to be connected to the cylinder jacket and keeps the carburetor hot in cold weather. This aids in vaporizing the fuel and makes the use of the ordinary sixty-eight degrees gasoline effective on high speed cars in moderately cold weather. As stated in a previous lesson, the vaporization of any liquid necessitates using a considerable quantity of heat which must be abstracted either from the incoming air or else from some other source. When the out-of-doors temperature is well below freezing there is very little heat in the air with which to effect vaporization, and some other source is imperative, especially for high speed engines.

In the case of most carburetors the piping is so arranged that the air can be taken from around the hot cylinders in cold weather, or by means of a by-pass valve the hot air supply can be cut off and cold air substituted, thus making the carburetor suitable for either summer or winter use.

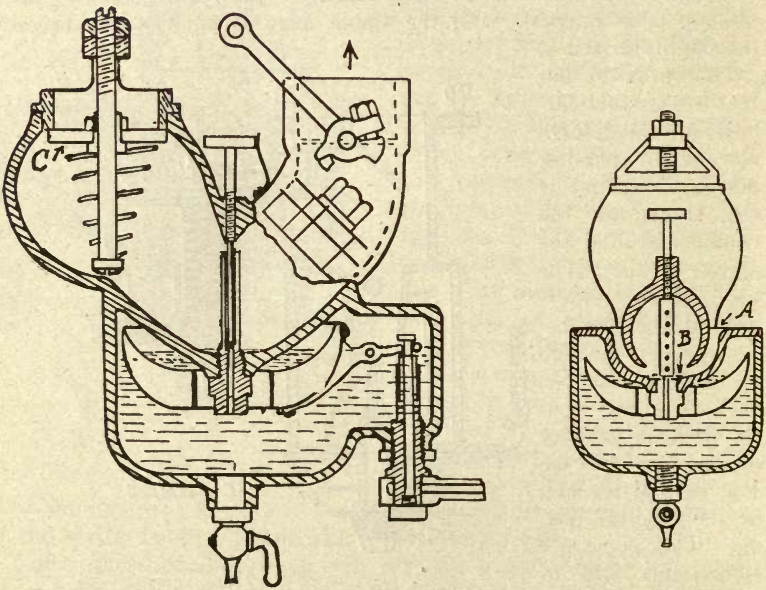


Fig. 48.

It is true that a large weight of mixture will be taken into the cylinder when the air is quite cool, but even with air that is heated to above one hundred degrees, there is no question but that the vaporization of the gasoline cools it down close to the freezing point.

When such low temperatures are encountered, there doubtless is considerable gasoline taken into the cylinder in the shape of minute globules. These must be vaporized inside of the cylinder and there is no certainty that there is sufficient air to effect their complete combustion. It is much better, therefore, where a carburetor is used at all, to have the vaporization completed therein and to supply the engine cylinder with a dry gas. A carburetor meeting these specifications will prove most economical in the use of gasoline.

In one of the earlier lessons of these series we pointed out that practically all of the carburetors in use at the present time are spray carburetors, and that the earlier forms of surface and bubbling carburetors had been displaced and the reason therefor pointed out. There are, however, a few carburetors now on the market, which have come into some prominence quite recently, in which advantage is taken of the principles of the surface carburetor. While these principles are made use of, they are modified in such a way as to obviate the inherent difficulties of the older type of machine.

The carburetor illustrated in Fig. 48 is an example of one of these carburetors. At slow engine speeds it is a surface carburetor. Air enters through the primary air ports at A in the right hand figure, and becomes enriched by passing over the puddle of gasoline at B. When the throttle is opened and the engine comes up to speed, the auxiliary air valve C is opened, air rushes through the auxiliary air intake and causes a pumping effect at the nozzle which lifts the level of gasoline in the spray nozzle, causing numerous fine jets of the liquid to be projected into the rapidly moving column of air. The higher the engine speed, the higher the gasoline rises. This puts more jets in operation, with the result that a larger quantity of gasoline is used, but the proportion is supposed to be adjusted correctly to the quantity of air flowing through the intake pipe. A float maintains the gasoline at any desired level, while a milled head screw in the center adjusts the gasoline for high engine speeds, while the automatic air valve takes care of slower speeds.

There is another carburetor on the market in which the same principle is applied in another way. This is a carburetor used quite extensively for marine engines where it is said to give good service. A float valve maintains a constant level of gasoline, but instead of using a nozzle to supply gasoline to the air, a very narrow annular opening in the bottom of the hole, said to be only one five thousandths of an inch wide, is made use of. When the engine is standing idle, gasoline accumulates in a puddle in the bottom of the bowl. When the engine starts, the air passing through the intake pipe with considerable velocity impinges upon the gasoline with considerable force, as it must do in order to change its direction completely and pass through the supply pipe to the engine.

This operation produces a rich mixture which is necessary for starting or running at slow speeds. When the engine comes up to speed, the puddle is all evaporated and a fine jet or curtain of gasoline is projected into the air.

Economizers.—In connection with any discussion of carburetors the story is not all told until economizers are considered. These are devices whose office it is to prevent excessive fluctuations in the pumping effect at the spray nozzle under wide variations of speed. This is accomplished by partially equalizing the pressures at the three points; just above the spray nozzle, between the throttle and the engine, and the space above the fuel in the gasoline reservoir. The economizer is screwed into the cap of the gasoline reservoir and two pipes are led out, one to a point below the throttle and the other to a point above. Any sudden movement of the throttle, therefore, will not affect to any great extent the quantity of gasoline delivered at the spray nozzle, because a partial vacuum exists above the gasoline, which prevents a flood of gasoline being delivered.

CHAPTER IX

HORSE POWER FORMULAS

LESSON XXVI.

Horse power and work and what an engine can pull are three things that are hard to explain in simple language which non-technical people can understand, but we are going to try it. Every mail brings us requests for information about how to estimate the horse power of an engine, and in every case all we can do is to make the estimate without going into explanations. That is why we are taking this opportunity to present a lesson on the subject. We can go into the subject much more fully and show some of the reasons why we make certain computations.

Almost everyone knows that a horse power is equivalent to doing thirty-three thousand foot pounds of work in one minute, but there are many people who apparently fail to take account of the factor *time*. Furthermore, everyone may not know the meaning of the term *foot pounds*. Consequently, we will start our discussion with the statement that a foot pound is equal to overcoming a resistance of one pound through a distance of one foot. Work is merely the overcoming of resistance through distance, therefore the foot pound is the measure of the amount of work done, since it takes into account the amount of resistance as well as the distance. A horse power not only takes into account the work done in foot pounds, but the time it takes in which to accomplish the work. A horse power, therefore, is a measure of the rate at which work is done. In fact, whenever we talk about power in any form, we are taking into account the factor time or the rate at which work can be done. That, then, is the significance of the term horse power, a *measure of the rate of doing work*. The man or the machine that can do work the fastest has the most power. The amount of work ultimately accomplished is no measure of the power applied unless the factor *time* is taken into account. A machine that can do twice as much work in the same time must have twice as much power.

Let us now consider more in detail the meaning of the term work. According to the definition just given, it consists of two factors, force and distance. Force is expressed in pounds, distance in feet, and work in foot pounds. We could, if we wanted, express force in tons and distance in miles and the work would be expressed in ton miles, but for our purpose in the discussion of horse power we will confine ourselves to pounds and feet. In order to find out how much work is accomplished in any given operation all that is necessary to do is to multiply force by the distance through which this force is exerted; for example, suppose it takes a force of two hundred pounds to move a wagon on a level road, and that the distance moved is twenty-four feet; how much work will be done? The result is obtained by multiplying the two factors together; thus: 200x24= 4,800 foot pounds of work. Again, suppose a man weighing one hundred and sixty pounds climbs a ladder twelve feet high; how much work does he do? Here again we multiply the force by the distance through which it acts and find that the man accomplishes 1,920 foot pounds of work. These examples should suffice to explain the meaning of the term work.

Now, let us turn our attention to power for a moment and try to obtain a clear conception of what it signifies by taking some concrete examples. Take for example the case of the man going up the ladder. If he went up in one minute he would, as before, do 1,920 foot pounds of work, no more and no less. If he went up in one-half minute he would still do the same amount of work, but it would require twice as much power in the second case as in the first because the time is only half as much. Power, therefore, depends upon speed. This can be further illustrated in this way; suppose a man has a ton of wheat put up in one hundred pound sacks which he must place upon a table three feet high. The amount of work to be done is six thousand foot pounds. If he lifts all of them up in one minute, it will require the expenditure of a certain amount of power. If he lifts them all up in one-half minute it will require twice as much power, but no more work is done in one case than in the other. It will require a stronger man, however, to do the work more rapidly, or, even if a weaker man can accomplish the same work he will feel the effects of the strain much more.

A horse power has already been defined as 33,000 foot pounds of work in one minute. Any engine that can accomplish this amount of work in one minute is doing one horse power of work. If the same work can be done in one-tenth of a minute it will require a 10-horse power engine to do the work. Time, then, is the all important consideration in all matters concerning power.

This same factor, *time,* enters into all considerations of the tractive force or pulling power of an engine. The question oftens comes up: How much will an engine pull on the road? This depends upon a number of variable factors, such as the horse power of the engine, the condition of the road bed, the power lost in transmission, the weight of the machine, the grip the wheels have on the road, and the speed of the engine. This latter factor is the one that proves to be a stumbling block for a great many people. Many people do not realize that the hauling capacity of an engine decreases in exact proportion to its speed. That is why in going up a steep hill it is necessary to run an automobile on low gear. It does not have any more power when so run, but the work of lifting itself up the hill is done in a longer *time,* and consequently less power is required. Likewise a traction engine can haul a larger load if the road speed is slower. Other things being equal, an engine ought to be able to pull five times as much at one mile an hour as it can at five miles an hour. In either case, the same number of foot pounds of work will be done, as we can easily prove. Suppose the engine is capable of pulling one ton at five miles an hour; the work done is five ton miles. At one mile per hour, the engine should be able to haul five tons and here again work done is five ton miles per hour, just as in the former case. Slow speeds on an engine enable it to haul a heavier load and fast speeds a lighter load, but in either case the same number of foot pounds or ton miles of work will be accomplished.

Now let us consider some of the formulas for horse power. The first one to attract our attention is the old steam engine formula for indicated horse power with which every one is familiar, and which reads as follows:

$$1.\quad \frac{2 \times P \times L \times A \times N}{33{,}000} = \text{H. P.}$$

In which P represents the average force acting on the piston in pounds; L, is the length of the stroke in feet; A, is the area of the piston, and N is the number of revolutions of the engine per minute. The factor 2 is used to change revolutions into strokes when a double acting engine is used. If the engine were single acting, that is, had force applied only on one side of the piston, this factor would not enter. In this formula PxLxA represents the work done in foot pounds during one stroke of the piston. This multiplied by 2xN gives us the work done in foot pounds in one minute. If this product is then divided by 33,000 we will evidently obtain the number of horse power the engine is capable of developing. This is a strictly mathematical unit, and is invariable. By its use we can calculate the power of any reciprocating engine, whether it be a gas engine or a steam engine, provided we can find the value of the factor P. This is not always easy, however. We can, it is true, use an indicator and estimate the average pressure from the diagram it traces, but even this is not always reliable, especially in the case of a gas engine. When the power is obtained in this way we have a measure of the power developed in the cylinder of the engine, but not the power which the engine will develop at the band wheel. That will always be somewhat less, on account of the internal friction of the engine. The only way to obtain the power the engine is able to develop to do actual work is by means of a brake.

Now let us see what we can find out about calculating gas engine horse power. The formula for the indicated horse power of a gas engine is

$$\frac{P \times L \times A \times E}{33{,}000} = \text{H. P.}$$

The formula is almost the same as for the steam engine, except instead of engine strokes we use E, which represents explosions in the cylinder. Just as in steam engine practice, the value of P must be determined by the use of an indicator.

After you have taken your indicator cards, measured them and made all the proper allowances, and have made an estimate of the mean effective pressure, you are at liberty to use the formula and find out how much work is done on the piston. If you want to find out how much work the engine will actually do at the fly wheel, you must take seventy-five or eighty per cent of the above result, because anywhere from twenty to twenty-five per cent of the work done on the piston is required to overcome the friction of the engine itself, even if it is a good gas engine; and if it isn't, there is no way of telling except after you have found the indicated power, to put on a brake and take the brake horse power. The difference between the brake power and the indicated power will be the amount of work consumed in friction. This is never less than fifteen per cent of the total power developed in the cylinder and often as high as thirty per cent.

There is another way of getting at the mean effective pressure by the use of what is known as Grover's formula. It reads thus:

$$2.\quad 2C - .01C^2 = \text{M. E. P.}$$

In this formula C represents the compression pressure in pounds above the atmosphere. After you have found this value you are at liberty to use it in formula 2 in place of P. After you have done the necessary figuring, you are in a position to make a fairly close estimate of the power of the engine. Of course, this formula is not exact, and it is criticised a good deal, and with good reason, but it has some merit even if not very scientific.

All of this leads up to another class of formulas known as empirical formulas, that is, formulas that give results that are pretty close, but which do not admit of any scientific explanation, or rather not a very rigid one at any rate.

These formulas are divided into two classes, those applicable to four-cycle engines and those applicable to two-cycle. We will consider the four-cycle formulas first. In all of these formulas the symbols have the same value and are as follows:

D equals the diameter of the cylinder in inches; L, the stroke of piston in inches; R, the revolutions of the crank shaft per minute; N, the number of cylinders. Using these symbols, Roberts offers the following formula for gasoline engines:

$$3.\quad \frac{D^2 \times L \times R \times N}{18{,}000} = \text{H. P.}$$

The Royal Automobile Club uses this formula:

$$4.\quad \frac{(D+L)^2 \times N}{9.92} = \text{H. P.}$$

The American Licensed Automobile Manufacturers have adopted a slightly different formula, which reads as follows, and is based on a piston speed of 1,000 feet per minute.

$$5.\quad \frac{D^2 \times N}{2.5} = \text{H. P.}$$

The American Power Boat Association formula for motors of less than six inches stroke is like the last one just given except that the length of stroke is taken into account.

$$6.\quad \frac{D^2 \times L \times N}{15.2} = \text{H. P.}$$

The last two formulas are for motors used in boats rated as automobile boats. For all other marine motors two-thirds of the above results are to be taken. Now let us apply these formulas to an engine with a four-inch bore and five-inch stroke, running at 1,200 revolutions per minute.

Applying formula 3 we have

$$\frac{4\times4\times5\times1200}{18,000}=5\ 1/3\text{ H. P.}$$

By formula 4 we have $\frac{9\times9}{9.92}=8.2$

By formula 5 we have $\frac{4\times4}{2.5}=6.4$

By formula 6 we have $\frac{4\times5}{15.2}=5.2$

An inspection of the above results does not show very close agreement. As a matter of fact, they are principally valuable in determining handicaps in a race and for purposes of comparison rather than to give results that have a definite meaning.

Two-cycle formulas.

7. Roberts'. $\frac{D^2\times L\times R\times N}{13,600}=\text{H. P.}$

8. A. P. B. A. $\frac{D^2\times N}{2.1008}=\text{H. P.}$ for engine having six inch stroke or greater.

9. A. P. B. A. $\frac{D^2\times L\times N}{12.987}$

The above A. P. B. A. formulas are for racing boat motors. All other marine motors use the same formula and take two-thirds of the results above obtained.

Applying these formulas to the same size of motor as in the four-cycle class, we obtain the results herewith shown.

By formula 7, 7.11 H. P.; by formula 9, 6.15. These two formulas do not appear to yield much closer results than the four-cycle formulas just discussed. As a matter of fact, Roberts' two formulas are probably as close as we can come to expressing the actual horse power of a gasoline engine by means of a formula. They do not amount to much more than a fair estimate and are so understood by all engineers who have to do with problems of this kind.

LESSON XXVII.

The indicated horse power of an internal combustion engine is a measure of the actual horse power developed in the engine cylinder. It is, in other words, the power that is expended upon the piston and is always considerably greater than what can be obtained from the engine in useful work at the fly wheel. When the fuel and its proper proportion of air is introduced into the engine cylinder and burned it produces a very high temperature of the gas behind the piston. In accordance, therefore, with the laws of heat this gas, which is at the given instant enclosed in a small space, exerts tremendous pressure upon the walls of the cylinder and upon the head of the piston. In the case of ordinary gasoline engines this pressure, at the moment the piston is started forward on its power stroke, may amount to from 250 to 300 pounds per square inch.

The exact amount of the initial pressure is dependent upon a number of things, among which may be mentioned the degree of compression of the charge, the temperature of the gas at the moment of ignition, the degree of completeness of the combustion before the piston starts forward on its power stroke, and the quality of the mixture.

If the gas is first compressed to 60 or 70 pounds and the fuel is capable of raising the pressure 200 pounds, the total initial pressure will be the sum of the two. Consequently, the higher the compression pressure with any given fuel, the higher will be the initial pressure; and, within certain limits, the greater the power of the engine. It has been stated in nearly every book treating of the gas engine that its efficiency depends very largely upon the degree of compression. It can be proved theoretically that the higher the degree of compression in the case of any engine working on the Otto cycle, the greater the efficiency. This means that with the expenditure of a given quantity of fuel the greatest amount of work can be obtained when the compression is carried to the highest point possible. This is true, regardless of the kind of fuel used. Practically, the kind of fuel exerts a marked influence because of the fact that compression cannot be carried as high with some kinds of fuel as with others. For example, gasoline vapor is highly inflammable and will ignite at lower temperature than some other gas, such as blast furnace gas or producer gas.

In ordinary medium speed gasoline engines a compression pressure of 70 pounds is about as much as can be obtained without causing pre-ignition. If the engine is of the slow speed type, compression pressures as high as 80 or 85 pounds are often carried out successfully, while with the high speed automobile engines a compression of 60 pounds is customary. It requires, therefore, no stretch of the imagination to realize that an engine suitable for one kind of fuel may not be suitable for another. Furthermore, an engine that will produce a given amount of power with one kind of fuel may be very inefficient and lack a great deal of coming up to its power specifications when another kind of fuel is substituted. This can be explained easily when we take into consideration the heat values of some of the different fuels.

Gasoline vapor has a heat value of about 650 heat units per cubic foot; producer gas from 90 to 125; city gas, 750 to 900; and natural gas from 1,000 to 1,100. An engine, therefore, which uses a gas of high heat value, such as natural gas, will yield considerably more in horse power than the same engine using producer gas, for the simple reason that the gas containing the larger number of heat units contains the greater amount of energy which may be set free for the doing of useful work.

The degree of completeness of combustion before the piston starts forward on its power stroke has much to do with the initial pressure. To be most effective, the fuel should all be consumed before the piston has advanced an appreciable amount on its power stroke. When this condition obtains, the initial pressure will be the maximum for the given charge of fuel, and the piston will be driven forward by the expansion of the gas solely and not by the addition of more pressure due to what is known as after-burning. It can also be shown theoretically and it has been proven practically that the best results are obtained when the fuel is all burnt at the beginning of the stroke and the expansion is adiabatic. That is, when no heat is either supplied or taken away during the stroke. It naturally follows from the construction of the engine and its method of operation that a true adiabatic expansion cannot be obtained. There will be some transfer of heat from the gas to the cylinder walls at the beginning of the stroke and toward the end of the stroke there may be a flow of heat in the opposite direction, all of which has a tendency to reduce the thermal efficiency of the engine.

The quality of the mixture is another matter of importance in connection with the efficiency and power of a gas engine. If the mixture is rich in fuel gases, that is, if it contains a large quantity of heat units it cannot be compressed as high as a leaner mixture, and consequently its efficiency will be reduced. Almost any gas, no matter how lean, if compressed high enough, can be ignited, and, in view of the statement that efficiency depends upon the degree of compression, it would thus appear that lean mixtures yield the higher efficiencies. This appears to be true theoretically and has been worked out and verified practically.

We made the statement that the power which might be obtained at the fly wheel is always less than that expended upon the piston. This is true in the case of the steam engine, but more particularly true of the gas engine. The difference between the power supplied to the engine and that which may be obtained from it, is used up in internal friction. In the case of the steam engine, there is the friction of all the working parts which may amount to anywhere from five to twenty per cent of the power supplied. In the case of the gas engine the friction is considerably higher, due to the fact that for every four strokes of the engine there is only one power stroke. There must be supplied by the fuel a certain extra amount of power to overcome the friction of the three idle strokes, thus making the difference between the indicated and brake power much larger than in the case of the steam engine. The very highest efficiency obtained from gas engines shows a loss of at least fifteen per cent in friction, while losses of twenty and twenty-five per cent are common and represent current practice.

The mechanical efficiency of an engine is represented by the ratio between the brake horse power and indicated horse power; for example, if an engine indicates 5-horse power and it shows 4-horse power by brake test at the fly wheel, its mechanical efficiency is four-fifths or eighty per cent.

The thermal or heat efficiency, however, is a different thing and represents the proportion of the heat energy which is transformed into mechanical energy. This is always low and for ordinary medium sized gas engines is in the neighborhood of fifteen per cent. In a few cases thermal efficiencies as high as twenty-five per cent have been obtained for gasoline engines, while the very highest efficiencies have amounted to about thirty per cent. Where the thermal efficiency is twenty-five per cent it means that the heat value of one hundred pounds of fuel is utilized or expended in the engine to obtain the useful effect of only twenty-five pounds. There is, then, a loss of three-fourths of the heat energy supplied to our best gasoline engines in transforming the fuel into useful energy.