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# GENERAL ELECTRIC REVIEW

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A 25-kw. General Electric Gasolene-Electric Generating Set on Caterpillar Trailer Lighting Part of Camp Leonval, France. This set had been moved up near the front in preparation for the great drive that was being planned at the time of the armistice

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The General Electric Company in the Great World War


SILENCE


SPEED


NORMA


PRECISION


SERVICE

# GENERAL ELECTRIC REVIEW

*A MONTHLY MAGAZINE FOR ENGINEERS*

Manager, M. P. RICE     Editor, JOHN R. HEWETT     [illegible]

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FRANCIS C. PRATT

Vice-President General Electric Company

At a meeting of the Board of Directors on May 16, 1919, Mr. Pratt, who has been with the Company for many years as Assistant to the President, was elected a Vice-President

GENERAL ELECTRIC
REVIEW

# PROGRESS

In one of the articles in our present issue Dr. Steinmetz points out that in the development of the Arts and Sciences we sometimes strike barriers which appear to stop progress for a time, and that this is specially true in the industries that have enjoyed such rapid development as electrical engineering. This is an interesting thought at the present time, after we have just passed through the greatest world-wide upheaval of which we have record. Can such a calamity as the great world war ultimately lead to progress? Will it lead to the removal of some of these barriers? This is a useful question for engineers to ask themselves.

We have ample evidence that great progress was made along many lines as the direct result of the necessity that the war imposed. We publish in this issue Part II of the war activities of the General Electric Company, and throughout this story there are recorded developments that were stimulated, and, indeed, some that were originated, by the war. —A new type of Coolidge X-ray tube; a host of radical improvements in wireless telegraphy and telephony; great strides made in the art of electric welding and improvements made in insulating materials; and in subsequent issues we shall show other developments which were products of war-time activities. Indeed, so marked were the developments in searchlights alone that we are planning to devote an issue of the REVIEW to recording these achievements.

Many of the developments stimulated by war are going to find peace-time applications in the arts and industries. Perhaps some of the most notable of the developments that were stimulated by the war, and that are destined to play a large part in human progress in times of peace are to be found in the realms of aviation. The first trip by air across the Atlantic, via the Azores; the first direct flight, both accomplished in heavier than air machines, and the epoch-making voyage of the R-34, followed one another in such rapid succession that it is, perhaps, hard to realize the magnitude of the accomplishments. The fairytale of yesterday has become the reality of today, and where these achievements are to lead us is hard to predict.

The developments that can be traced directly to the war are far-reaching in effect, but the developments that owe their stimulus only indirectly to the war, will be harder to trace, but will, in all probability, be more numerous and more far-reaching in our general scheme of human progress.

The war led to a host of workers dropping their usual pursuits and prosecuting war work on an intensive basis; in short, whole countries were forced *out of the rut* which has been just as destructive to national progress as it is recognized to be in the case of individuals. It is this general stimulus, and the keen competition that The Great Change has brought about, that will lead to a host of new developments. Many of those who dropped their work to pursue war activities have returned to their old, or to new, jobs with quickened brain power, added energy, and stimulated ambition, and will find a more fertile field for their activities in a world that has been so thoroughly shaken *out of the rut*.

In this connection we call attention to Dr. Langmuir's article, the second part of which appears in this issue. We confess this article is not easy reading, but his postulates give a great deal of food for thought in the realms of chemistry and physics; they are an attempt to simplify the laws which govern the structure of atoms and molecules. It is such studies as this that are destined to have such a far-reaching effect on the progress of our knowledge of natural science, and that we may expect to see taken up with added vigor now that peace has been restored.

We hope shortly to record in the REVIEW some of Dr. Hull's work which was interrupted by the war but is now being continued, on the X-ray spectra of crystalline materials, and to show our readers how it is now possible to actually photograph the atom. What these developments may lead to in the realms of both qualitative and quantitative analysis is fascinating to contemplate.

It is not in such spheres of activities alone that we may expect marked developments as a product of the war. We have learned more thoroughly the value of organization, both national and international, and added to this there has been a friendliness built up between the allied nations which will lead to much progress through co-operation in both science and engineering.

In just what direction we are to see most progress for the next decade or two it is hard to prophesy, but we believe that history will repeat itself and that advancements in many directions will follow one another in rapid succession, and we believe that such advancement will not be limited to engineering and scientific progress, but will include political improvements which will be far-reaching in their effect on the future welfare of mankind. The trend of events for the last few years call vividly to mind those prophetic lines of Tennyson in Locksley Hall, written over quarter of a century ago:

"For I dipt into the future, far as human eye could see,
Saw the vision of the world, and all the wonder that would be;

Saw the heavens filled with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales;

Heard the heavens fill with shouting, and there rain'd a ghastly dew,
From the Nations' airy navies grappling in the central blue;

Far along the world-wide whisper of the south-wind rushing warm,
With the standard of the people plunging thro' the thunder storm,

'Til the war-drum throbb'd no longer, and the battle flags were furl'd,
In the Parliament of man, the Federation of the World.

There the common sense of most shall hold a fretful realm in awe,
And the kindly earth shall slumber, lapt in universal law."

This prophecy has surely been partly fulfilled: the ghastly dews have rained from the sky; the war-drums have ceased beating; how far shall the League of Nations fall short of "The Parliament of Man—the Federation of the World?" The great political thought has been sown; we believe it will bear fruit. If it is to bear fruit the engineer must sometime look up from his all-absorbing tasks and take an interest in our political life. Some of the best brains in the country are in the engineering professions. They must now take a broader view of their national and international responsibilities. With the faith and hope we have in the new progress we still recognize that there are great dangers ahead, but we believe that "the common sense of most shall hold a fretful realm in awe." We believe that common sense is the best cure for Bolshevism, and we believe that most people, in all walks of life, have a good share of common sense. Most capitalists are trying to look the situation squarely in the face and be just. And we believe that Labor will have the good sense to discriminate between good and bad leadership—to distinguish between liberty and license, and, we hope, to recognize the fact that he is often the victim of paid propoganda, which is one of the greatest enemies of democracy.

While it is true that "Science moves, but slowly, slowly creeping on from point to point"—and that the same holds good of engineering and political progress, we believe that the great World War will speed up progress in all these directions and that the next quarter of a century is to be the greatest era of progress that the world has seen. This is our one consolation that we can get from the great world tragedy.

J. R. H

# Electric Power Collection

By Charles P. Steinmetz

Consulting Engineer, General Electric Company

Dr. Steinmetz points out that we sometimes meet barriers to further progress [illegible] industries as electrical engineering. The generation of electric power seems to have [illegible] motor is a comparatively small unit compared with our huge modern generator. The [illegible] ating plants has made them more complex, but many of the refinements of controlling and [illegible] nisms might be dispensed with in a power unit no larger than a motor unit. The author pro[illegible] small generator installations with simple switches and fuses to make use of our small water [illegible] conserve our fuel resources.—Editor.

In the development of arts and sciences, and especially in industries which have advanced as rapidly as electrical engineering, we frequently strike barriers which seem to stop further progress in a certain direction and give the impression that the possibilities have been exhausted and the final limit reached in this direction, until some new idea carries us beyond or around the apparently unsurmountable barrier and the beyond shows us a field of development vastly greater even than what had before been considered as the final possibilities. Or more often it is an old idea, which though discarded in the earlier days of development, leads us beyond the barrier which had stopped progress. Thus, when we see development slow down and apparently the limit of progress reached in certain directions, it is advisable to go back to the earlier days and search whether, amongst the ideas then unsuccessfully tried, we may not find some which lead to success under the changed conditions.

A good illustration is given by the history of electric lighting. Metal filaments were tried but found wanting in the early days, before the carbon filament, and for a quarter of a century the latter held sway. But after the first few years of rapid advance, progress slowed down and apparently the ultimate limit had been reached at about three watts per mean spherical candle-power. Then the old idea of the metal filament, backed by the twenty years' advance of chemical engineering, carried us around the barrier and more than quadrupled the efficiency of incandescent lighting.

So power generation by the reciprocating steam engine seemed to approach a limit in size and economy of units, until the development of the oldest type of steam engine, the steam turbine, carried us far beyond the possibilities of the reciprocating steam engine.

So the interpole or the commutating pole had been known for many years, but lay dormant until with the change of conditions of commutating machine design it became the means of advance beyond the barriers which were limiting further progress.

But if ever progress was important, and especially engineering progress, beyond the barriers retarding the advance, it is now, in our present period of the world's reconstruction.

But to progress beyond barriers, we first have to see and realize those barriers, and long familiarity with existing methods of doing things tends to standardize our thoughts and leads us to consider as essential and inherent, features which are only incidental and due to the conditions under which the development has taken place, and disables us, when these conditions change, to see beyond the incidental limitations. Standardization is useful and important, and indeed industrial progress would be impossible in the chaos which would result without standardization, but standardization becomes harmful when extending to our thoughts whether and how things can be accomplished. One of the first ways to realize and overcome this limitation is to review the development and ask ourselves why it has taken place in that particular direction, how far the course of development has been due to temporary conditions and whether with the change of these conditions a different direction of development may lead us beyond the possibilities of our present achievements.

Let us apply this to the development of electrical machinery.

The electric generator and the electric motor are identical. Often the same machine is used as generator or as motor, and where there are differences in construction, they are in details, to accentuate certain characteristics for certain purposes.

Thus in a synchronous machine we may add a squirrel cage winding in the field pole shoes, when used as synchronous motor, to give a better starting torque, while we may omit this winding in the generator; but the turbo-alternator when left in circuit, with the steam cut off the turbine, continues to revolve and is just as good a synchronous motor; in a commutating machine we may add a series field when intended as a generator, to give better voltage regulation, and omit it in the use as motor, since the speed regulation of the shunt motor is sufficiently close, etc.

Looking back over the electrical development of the last quarter of a century, we have seen the size of generators and generating stations steadily increase, due to the higher economy of larger generators and generating stations. The maximum size of motors also has steadily increased up to units of many thousand horse power; but the average size of motors has increased little, if at all, due to the increasing use of individual motors, applied directly to the driven machines.

The average motor is installed with a switch to turn it on, and a fuse to cut it off in case of overload or accident, and then left to itself with practically no attention. In the generator installation, however, we find a very elaborate system of switchboards, instruments, controlling and protective devices, etc., requiring continuous and highly skilled attention. Why is this, if generator and motor are the same type of apparatus? Obviously, it is not due to the use of the machine, in the one case as motor, in the other case as generator, but it is due to the size of the machine. With the huge size of the average generator installation, an elaborate system of control and protection becomes necessary, which is not necessary with the average small motor installation, and indeed, in the installation of very large motors, we find more controlling and protective devices than a switch and a fuse.

Thus, inherently a generator installation is no more complex than a motor installation. The complexity of the modern generator installation is the necessary result of its huge size, and a small generator installation could be as simple, limited to switch and fuse as controlling and protective devices, could be left to run itself with occasional inspection, as a small motor installation.

Thus if the average size of generator installation has steadily increased, while the average size of motor has not, this is not due to the complexity required in the former, but the reverse is the case, the complexity of the generator installation is the result of its huge size.

The difference in the course of development of motor and generator thus must be found in other directions. As an instance, let us consider the application of the electric drive to the cotton mill industry, which is typical of the entire electric motor development.

When the first cotton mill was electrified in 1894, the steam engine was taken out, and a 400-h.p. synchronous motor put into its place, driving by belts and shafts and countershafts the individual machines, that is, the power was generated electrically, but distributed mechanically. But in the new mill of the same plant, a number of 100-h.p. induction motors were installed, each driving a line of shafting to which the individual machines were belted, that is, at least a part of the power distribution was done electrically. I need not to say that even this is antiquated and that experience has long proven that the most economical arrangement is to entirely eliminate mechanical power distribution and distribute all the power electrically, up to the individual driven machine. That is, to have individual motors at every machine. This has long become the standard method of electric motor application. This is the reason why the average size of electric motor is small, corresponding to the power required by the individual machine, and large motors are used only where a large unit of mechanical power is required, as at the rolls of a steel mill, or the propellor of the battle cruiser.

But in electric generation we are still in the first stage, that typified by the huge synchronous motor distributing power mechanically through numerous belts, shafts, and countershafts. We collect the power of a watershed mechanically by elaborate hydraulic works, costing many times more than the most elaborate electric generating station, and then in a big unit convert the hydraulic, that is, mechanical power into electric power in a modern synchronous generating station. Or we burn millions of tons of coal under the steam boilers of our huge steam stations, extract 10 to 15, or possibly 20 per cent of its energy as electric power, and then pay for the condensing water to throw away the 80 odd remaining per cent of the heat energy of the fuel, while in numerous other furnaces we burn millions of tons of coal to produce heat, but waste the potential mechanical and electrical energy of this coal.

This is not a condition to make us proud of our industrial efficiency. But it came about naturally, as the result of historical development.

The first electrical development occurred where hydraulic power was available in concentrated form, at waterfalls such as Niagara, etc., that is, cases corresponding in motor development to the rolling mill or the ship's propellor. The synchronous machine is the proper type of generator for such installation, just as the synchronous motor is today, and always has been, the preferable type of motor for large units of power unless special conditions prevail and demand the induction motor, such as the need of frequent starting under heavy torque.

The same type of hydro-electric development was extended to conditions where water power was available in less concentrated form, and had to be collected by more extensive hydraulic works, gathering together the power of a watershed, and so the modern hydro-electric generating system was developed as the most perfect known method, within its scope and limits, of utilizing water power—mechanical collection of the water power by hydraulic works, and conversion to electric power in a big unit synchronous generating station.

But the high cost of the hydraulic work makes such development economically feasible only where large amounts of water power are available in fairly concentrated form, and with the increasing development of such power sites, the number of water power capable of development by our present methods is decreasing, while most of the country's potential water powers can not be developed by our present standard methods of hydro-electric generation, as the cost of the necessary hydraulic development, to collect the water power, is greater than the value of the power which may be collected. The only hope which can be seen for a more complete utilization of our country's hydraulic power, from the abandoned mill sites of New England to the mountain streams of the south and the west, thus lies in applying to the electric generation the same principles which have made the electric motor economically successful, that is, bringing the electric machine to the place of power. That is, just as we place individual motors at every machine where mechanical power is required, and distribute the power to them electrically, so to place individual electric generators wherever along the water course hydraulic power is available, and collect the power of all these generators electrically.

For these relatively small hydraulic generators, required for electric power collection, induction machines would naturally be used just as induction machines are exclusively used for smaller units of motors, however superior the synchronous motor is for larger powers.

Such a small induction generator station then would consist of a standard low 3-phase induction motor connected to some simple and cheap hydraulic turbine, a few hundred feet of pipe, and a low dam across the creek, to cover the intake of the pipe; a step-up transformer connecting the machine into a medium voltage collecting line, low tension switch and fuse to disconnect in case of accident. Hundreds of such small induction generating stations then would feed into the system over collecting lines, just as hundreds of induction motor installations receive power from it over distribution lines, and a large synchronous main station—steam turbine or hydraulic, or possibly even merely a synchronous motor station—would control the voltage and frequency of the system.

In similar manner, a simple and cheap turbine induction generator plant, interposed between the high pressure steam boiler and the steam heating system which it supplies, would abstract the small percentage of fuel energy which is available in conversion to mechanical and electrical power, and turn it into the electrical distribution system, on which the induction generator floats, thus collecting electrical energy from numerous small steam stations and eliminating the present wasteful use of coal.

Now this development of electric power collection is coming, as it is the natural economic development of electric generation, just as the individual motor drive was in electrical power distribution. There are already a number of such hydro-electric induction generator installations throughout the country, some in successful operation for years, and the field thus opened up is very large, larger possibly than all the electrical development which has taken place hitherto, and one of the features of this development is that no new type of apparatus requires to be developed, but the standard induction motor can be used as an induction generator, and has been used successfully for years in some plants.

# Army Electrical Work in the Advance Areas in France

By Oliver F. Allen

Major of Engineers, American Expeditionary Forces

Entered the Service from Power and Mining Department, New York Office General Electric Company

As a nation we are justly proud of the record made by the Engineers of the American Expeditionary Forces. They were almost the first Americans to be heard from in the battle area, when they were caught in the backwash of Byng's big drive at Cambrai in the fall of 1917, throwing down their tools to join the British in the fight to stop the Hun. Their speed in constructing huge docks and terminals and long lines of railroad was a revelation to the French, indeed to the world. The full story of the accomplishments of the Engineers, A.E.F., in the world war has yet to be written; but this article by one of them gives an interesting insight to the nature of the electrical work in the advanced army areas, and the difficulties under which it was performed. The photographs are mostly from small "vest pocket" negatives, finished on the spot.—Editor.

MAJOR OLIVER F. ALLEN

The work performed in Europe by the Corps of Engineers since the first railway regiments came over in 1917 is so vast and so closely intertwined with all the A.E.F. activities that in a short article like this it is impossible to even indicate its ramifications. We will simply try to tell a little of the work in the Advance Areas which had to do with things electrical. The wonderful work of our Signal Corps with telephone and telegraph lines is not touched upon as that corps was not part of the Engineer Establishment.

In 1917 the French and English Engineers told us something of the tremendous growth of their special engineer services to meet the requirements of the Western Front. One of the problems which confronted the office of the Chief of Engineers in Washington in planning similar services was to guess what the American Army would require in the way of shop and electrical equipment which must be purchased in the United States and sent to France. Inevitably some things were bought and shipped across which were never used, and others proved to be failures, but as we look back and realize how little was known about the actual conditions and how those conditions changed, it is amazing how few mistakes were made and what a small percentage of the special engineering material could not be used advantageously.

The program for the special engineer services crystallized in that memorable War Department General Order No. 108, of August 15, 1917, authorizing six regiments and some extra battalions of special and technical engineer troops for each Army and fourteen regiments for the line of communications. These regiments varied from an organization of a regimental headquarters and six companies to one of a regimental headquarters with ten battalions of three companies each and nine service battalions of four companies each. Although we finally had three armies functioning in Europe, we never had the special and technical troops for more than one Army according to the original program. Additional regiments were authorized just before the armistice was signed. The first of these troops to reach France were distributed over what was then called the Line of Communications and afterwards became the Base Sections at the ports, the Intermediate Section sweeping up through the central part of France and the Advance Section immediately behind the Army areas during hostilities and including them after the armistice. These sections were collectively grouped as the Services of Supply (S.O.S.). When American combat troops entered the army areas, i.e., the sectors where actual fighting was going on, they first had only the divisional engineers, or sappers, but as the requirements developed, small detachments consisting of companies, or less, of special troops were sent forward and carried on until larger units were available in the late spring of 1918. Our First Army began to function as a complete army in the latter part of June and it was then that American shop and electrical work really started on a large scale in the sectors where there was actual fighting.

General Order No. 108 included a water supply service of one regiment of six companies, and what was called "an engineer supply service," consisting of a regimental headquarters, one battalion of engineers (supply) and one battalion of engineers (workshop), both of three companies each, with a service battalion of four companies. A great many labor troops were attached to this regiment at various times, but no service battalion was ever definitely part of it. Both of these regiments were army troops. General Order No. 108 also provided "an engineer supply service" for the line of communications. The water supply service became the 26th Engineers; the engineer supply service, Army troops, the 24th Engineers; and the engineer supply service, S.O.S., the 34th Engineers. Soon after the establishment of the Chief Engineer, A.E.F., began to function in France, it was realized that the Americans would also require an electrical and mechanical service, and in the latter part of 1917 the 37th Engineers was organized in the United States for that purpose.

The French Army had two special engineer services which had reached a high degree of efficiency in the fall of 1917, their Service des Eaux, or water service, and their Service Electrique, or electrical service. They had not developed any engineer shop service because their activities were all where they could take full advantage of a large number of civilian factories and shops. The British had developed a water service, an army workshop service and an electrical and mechanical service of the Royal Engineers. The French Service des Eaux installed and operated its own pumping plants, dug its own wells, built its pipe lines and attended to all the mechanics of water supply as well as to the chemical and sanitary features. The French Service Electrique furnished, installed and operated a vast quantity of small isolated electric plants required by the armies, and reinforced, extended and utilized the great high tension civilian electric transmission lines which ran from the Vosges northwest almost parallel to the front lines of 1917 and 1918. The British Electrical and Mechanical service attended to the mechanics of water supply, such as installing and operating machinery, laying long pipe lines, etc., and also installed and operated the electric and power plants; but until the last months of the war very little was done in the British Army areas in the way of high tension transmission, although large central stations with high voltage electric service were built and utilized very extensively by the British Army in the vicinity of their base ports.

The mobilization of the 26th Engineers (water supply) began with the opening of the National Army encampment at Camp [illegible] New Jersey, on the [illegible] 1917, and the writer, as a Captain [illegible] Officers' Reserve Corps, was [illegible] and during the fall [illegible] the first companies, two of which were dispatched for France in the latter part of October. At about the same time Elliott H. Whitlock, the well-known engineer of Cleveland, who had one of the first major's commissions in the Reserve Corps, was in Washington selecting the shop equipment for the 24th Engineers. Just before Christmas [illegible] companies, which had been mobilized as part of the 26th Engineers, were transferred to form a battalion of the 24th Engineers, and when the regiment began to function about the 1st of January, 1918, with Col. James F. Bell of the Regular Army in command, and Whitlock as Lt. Colonel, National Army, under him, the writer, as Major in the Reserve Corps, was given the Battalion, and continued in command of a battalion of the same regiment until the latter part of April, 1919, when it started for home.

American engineers had begun to study the special services of our Allies in the field in the fall of 1917, and our Water Supply Service was one of the first to begin to function. Our Railway Engineers started their shops and certain power plants very early in the game, but the Engineer Shops and Engineer electrical work did not really begin until February, 1918, when machine shops were started almost simultaneously at Gievres (Loir-et-Cher) and at Is-sur-Tille (Cote d'Or). During March and April American engineer officers made a careful study of the electrical, mechanical and shop services of the Army areas of two British Armies and of their lines of communication and principal base ports and also of the Army areas of the two French Armies which were occupying what afterwards became American sectors. The British were doing some very interesting things, such as the pipe line and water supply system running to what was then the front line before Lens, north of Vimy Ridge. The big mines at Bully-Grenay had been destroyed, but pumping plants had been built in the abandoned shafts and a pipe line carried over the hills to the main system of trenches with duplicate pumping plants and other safety precautions. The pumping station nearest the Germans was constantly under shell fire and could be provisioned only at night. Fearing that the pipe line might be demolished, the British decided to dig a well in a

FIG. 1

*Photo by Capt. Edw. Van Winkle, Engineer Officer, 24th Engineers*

Fig. 1 Turbo-generator in Bakery Power House, *Is-Sur-Tille*

*Photo by Capt. Edw. Van Winkle, Engineer Officer, 24th Engineers*

Fig. 2. Boiler Plant, Bakery Power House, *Is-Sur-Tille*. Under construction in July, 1918

FIG. 3

*Photo by Capt. Edw. Van Winkle, Engineer Officer, 24th Engineers*

Fig 3. **Foundation of Turbo-generator, Bakery Power House, *Is-Sur-Tille*. Water level made a basement impossible and the generating unit had to be elevated**

*Photo by Capt. Edw. Van Winkle, Engineer Officer, 24th Engineers*

Fig. 4. **Bakery Power Plant, *Is-Sur-Tille*. Under construction in July, 1918**

section of the front trenches. The nature of the ground required a deep well which had to be dug with a machine having a tall mast to support the pulleys for the ropes used in sinking the tubing. There was no tree in the trenches strong enough to serve as such a mast, but they were able to locate a tree which had large branches and considerable foliage. One night a pole of sufficient strength to serve as a mast was carried in. The next night the camouflage service went in, cut the tree down, trimmed it and set the mast up in its place. They then put all the branches on to the mast, so that in the morning the landscape appeared unaltered. The third night the Royal Engineers went in and fitted the mast with the necessary rigging for well drilling and in the succeeding nights successfully sank the well. The French were doing a great deal of lighting of posts of command, mines, shelters, etc., at the very front in sectors where "No Man's Land" was very narrow and the opposing front trenches were only 25 to 100 yards apart. They were furnished electric power and light for mining operations under these conditions and the precautions taken to protect cables and air lines from the German "minniewerfer" shells and grenades were very interesting. One little drama near Vauquois was particularly interesting. A French isolated plant was operating in a dugout connected with a front line trench, with feeders running back through a communicating trench to the second line trenches. The night before I was there the Germans had made a raid, captured and practically destroyed the French front line trenches. The Boches had been repulsed in the early morning and driven back some, but the French had not recovered their former front line and their old second line became the first line with the demolished trench in "No Man's Land." In the rush of the fight the electric light plant and operator had been forgotten and it was assumed that he had been killed and the plant demolished. Imagine their surprise just before daylight to have current turned on through the feeders coming out of the debris of what had been the communicating trench. Good, steady service was given all the morning, but I never learned what happened to that operator, as I left the sector before noon and up to that time the French had been unable to get out to him.

The installation and operation of pumping plants in all American sectors was generally done by the Water Supply service, but sometimes by the other engineer troops. The electrical installations in the rear of the Army areas were first made by the 24th Engineers and those in the Toul and Verdun sectors were first handled by the 37th Engineers. The 24th Engineers operated the first Engineer shops in both the S O S. and the Army areas. Later both the 24th and 37th Engineers, as well as occasionally some sapper or division engineer regiments, did both electrical and mechanical and shop work.

In the late spring and early summer of 1918, a considerable number of quite large electrical installations were made in hospitals. The Engineer Shops at Gievres and Is-sur-Tille were started and several big plants built, such as the bakery power house at Is-sur-Tille and the refrigerating plant at Gievres. The Gievres engineer shops layout called for over 200 motors, aggregating 860 h.p., and with the yard (which must not be confounded with the Engineer Depot and all the other activities there) required 30 acres, and the Is-sur-Tille Engineer Shops (which were also a small part of the total establishment) were laid out to cover 22 acres and use about 180 motors, aggregating 775 h.p. The Is-sur-Tille bakery, which has a capacity of 800,000 lbs. of bread a day, had a power plant which is typical of the many which the American Engineers built. The turbine illustrated in Fig. 1 came from one place, the condenser from another and the boilers from a third. The illustrations, Figs. 2, 3 and 4, show this plant in process of construction.

We were rarely able to get any drawings or foundation templets in advance. We frequently knew that a certain number of car loads of turbines, boilers, gasolene engines, motors, lathes, concrete mixers, or other machinery, were on the way, but had no idea as to the make and rarely any definite information as to the actual capacity. Sometimes we were able to send an officer to inspect the machinery at a base port or main depot, or at the plant in France where it was being built or overhauled, and he would get to its ultimate location with some information about it a few days ahead of the machine itself. In some instances, where duplicates were expected and foundations and connections prepared, the new machines were found, upon being unboxed, to be of another make and radically different dimensions. Perhaps the hardest problem which the electrical and mechanical and shop services had was to piece together parts which did not belong together and make a practical, reliable working whole in the shortest possible time. It is really remarkable how rapidly complete units and even

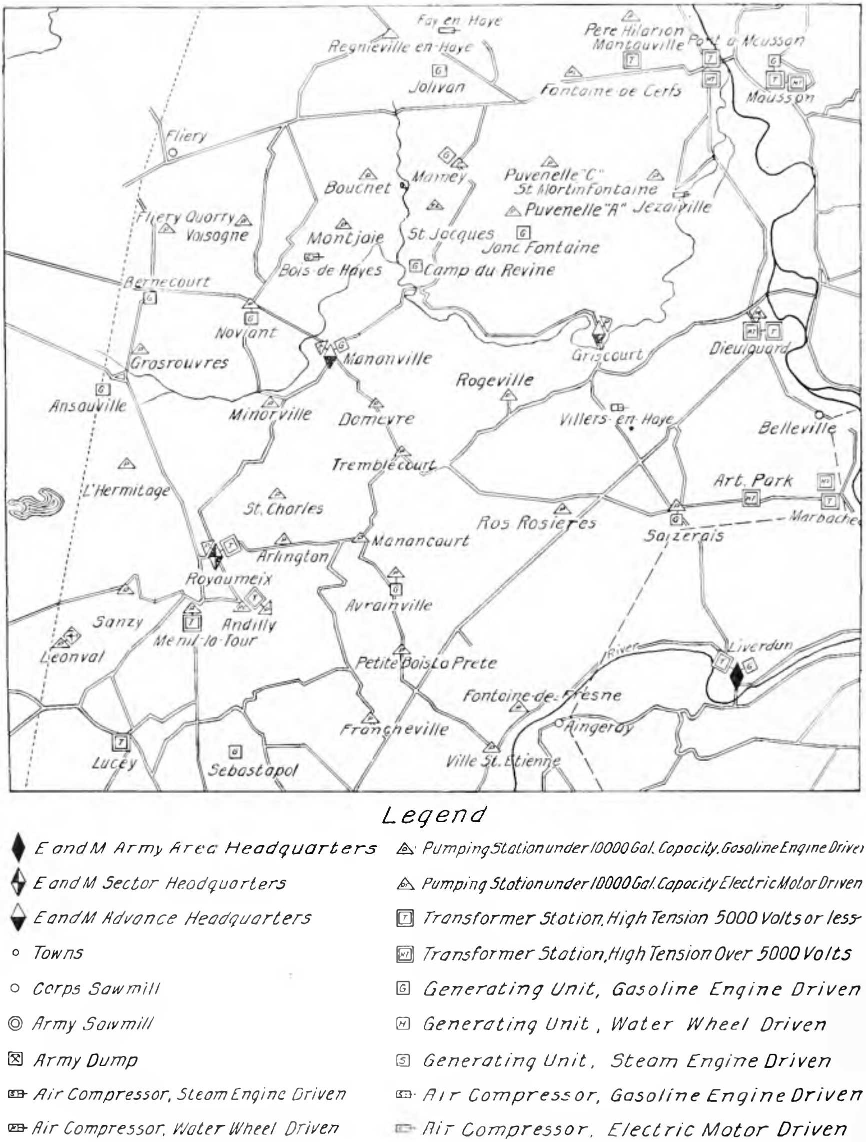

Fig. 5. Section of Map Showing Electrical and Mechanical Installations, Second Army Area, October, 1918.
Map made by 1st Battalion Headquarters, 24th Engineers

large plants were made out of conglomerate masses, frequently a mixture of new American machinery, new French machinery and second-hand French and English machinery, to which was added after the St. Mihiel drive Boche machinery. Frequently the same installation would have American, French and English pipe threads, which were by no means interchangeable, and three or four different kinds of bolt and nut threads. The expedients successfully resorted to by our junior officers, our master engineers and sergeants and our engineer soldiers were remarkable for their ingenuity and practicability.

The majority of the installations in the forward areas were the little isolated plants, most of the electric units being between 1 and 5 kw., with a few of 25 kw.; and occasionally a bigger one, and most of the pumping units 1½ to 10 h.p. These were packed into the Army areas literally by the hundreds. The little piece of the map of electrical and mechanical installations in the Second Army area about the 1st of November, 1918, shown in Fig. 5, covers an area only about 13 miles square and yet it contains 70 plants of various kinds. All parts of the Army areas were not as congested as this particular section, but it is really typical. Each installation had to have an operating crew for continuous operation, and be supplied with rations for the men, as well as fuel and lubricants, with the exception of the transformer stations, which in some cases had only a guard. The plants were divided into small groups with a senior noncommissioned officer in charge. These groups were combined in advance sectors, each under a junior officer with a regularly established headquarters, a detachment of reserve operators, some spare parts, etc., and automobile trucks for the supply of gasolene, rations, electric lamps, etc. The larger sectors, under the supervision of company commanders, generally combined two of the advance sectors, and all the groups in an Army area were, in turn, under the control of the Electrical and Mechanical Officer of the Army as part of the establishment of the Chief Engineer, Army. The photograph, Fig. 6, shows the E & M Advance Headquarters at Griscourt, one of the points indicated on the map extract, Fig. 5. This was a typical Advance Headquarters maintained by one of the Lieutenants of the 24th Engineers. The camp had excellent sleeping quarters for the operators, chauffeurs, administrative force, etc., a fine kitchen, good offices, its own electric and water plants, a small repair shop and a garage. It was about 7 miles from the front line.

Fig. 6. Adrian Barrack at Griscourt, Used as E. & M. Advance Headquarters Detachment of Co. A, 24th Engineers. The hill behind gave some protection from Boche shelling

12. The German drive in the spring of 1918, which involved the Chateau-Thierry show of our Paris Group, left Epernay, on the Marne, in a very precarious position during the first weeks of July. There was an excellent civilian central station there with automatically stoked water tube boilers, steam turbine units, etc., which, strange to say, had been very slightly injured by the German shelling and bombing. The demolishing of the city and surrounding areas made the plant useless there. As both the French and the American Armies were in urgent need of large equipment of this sort, a detachment of the 24th Engineers was sent from the Toul sector the middle of July to dismantle and ship out this machinery, which was divided between the French and the Americans. They were first quartered in cellars of ruined buildings near the plant. While it was very nice to have the German shells dig the potatoes in the garden back of the cellar where they had their mess, the combination of rats and bombs was rather uncomfortable, and the detachment moved to a grove on one of the adjoining hills

where they lived for several weeks in shelter, or "pup" tents, as they are commonly called. The heavy machinery in this plant was taken apart and moved to the railroad under great difficulties. Not only was the town continually shelled and bombed, but the detachment was forced to work with very inadequate tools, had a long trip back and forth to its camp every day, and more or less difficulty in getting its rations. One of the few redeeming features, however, was the abundance of champagne. Good water was almost unobtainable, but the champagne vaults in that neighborhood were well stocked and the few remaining civilians were so generous that these engineers literally drank champagne like water.

instance, was in a large well on a mine property, supported by beams put across the well about twenty feet below the surface. Some were in deep dugouts with ventilating machinery to insure a supply of fresh air. Many were in corners or niches of ruined buildings with all kinds of expedients in the way of shelter for protection against bombing and rain. These were some 75 feet underground in the lowest galleries of forts. In many cases the plant would be in one corner of a room, or shed, the bunks of the operating crew taking up the rest of the space. The men literally lived with their machines, and in some cases had to prepare their own meals in the same place, but generally were able to mess with troops in the neighborhood.

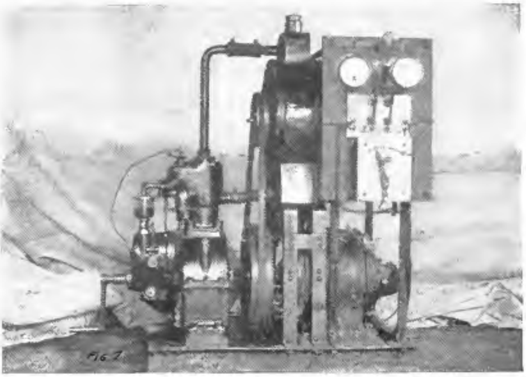

Fig. 7. "Group Electrogene à Essence" French "l'Aster" Engine with 1400-r.p.m., 25-amp., 115-volt, d.c. generator. Note light weight and that magneto ignition makes battery unnecessary even for starting These same engines were used extensively for pumping plants

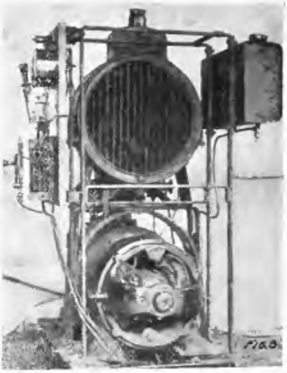

Fig. 8. "Group Électrogene à Essence" End view of "l'Aster" gasolene-electric unit shown in Fig. 7. Note radiator, gasolene tank and switchboard all mounted on same frame

The vast majority of the small generating units used in our First and Second Army areas were French, because we took them over with the areas. They were light weight, efficient and very reliable. They were of several different makes, but the illustrations, Figs. 7, 8 and 9 are typical. They show only the bare units and were taken at an Engineer Depot after the machines had been salvaged, following the armistice. During hostilities the engineers had little opportunity to take photographs, and besides, these little sets were almost invariably in cellars, dugouts, or other dark and inaccessible places, where it was impossible to get satisfactory pictures, even had flashlight powder been available. One, for

As each plant was installed, taken over from an ally or captured from the enemy, a plant record was made out covering all the details of the location, machinery, etc., and a number was assigned to the plant. There were suffixing letters and blocks of numbers were assigned to areas, so a number described the type of plant and gave its general location. As an example 564-G was the 25 kw. generating unit at the very well-known Evacuation Hospital No. 1, at Sebastopol. Part of the same form was a service record blank on which interruptions and repairs were recorded. There was an interruptions-to-service report on which the operator had to report every interruption to service, giving the cause, duration, etc. Each plant submitted a weekly operation report to the Commanding Officer of the sector. This report had sixteen items to be filled out. These not only included a log of operations, but such information as the designations of the units served, the rationing of the crew, the health of the crew, the location of the nearest telephone and of the nearest message center. These reports were consolidated at each E. & M. sector headquarters as a weekly progress report to the Electrical and Mechanical Officer of the Army, with a copy directly to the Supply Section of the Chief Engineer's Office. This consisted first of a log summary, covering the output of units, power purchased at transformer stations, and record of the operators. Also a report of all interruptions to service, covering the date, the time shut down and the cause or authority for the interruption; a summary of the number and capacity of the plants in service under eight different heads, such as electric motors, water wheels, steam engines, pumps and different kinds of electric sets; a summary of supplies used during the week and required for the next week; consolidated reports on repairs and new work; miles of 3-phase transmission lines completed during the week; weekly strength return showing the officers and men, both engineers and labor units on company duty, sick or absent, operating plants, supervising plants making repairs, etc., under separate headings, with the number available for new work; and finally, a report of the transportation in good order and how much of it was available for new work, with separate headings for horses, bicycles, motorcycles, touring cars, light box cars (small delivery trucks), and light and heavy trucks. Another form was the project report, on which new work, extensions, repairs, etc., were reported, described and authorized. These forms are not thought to be of sufficient general interest to take up the required space for their reproduction here on such a scale as would enable them to be read, but they are mentioned as showing how the work was systematized even under the most trying conditions. The reports had to be made out very promptly and forwarded by fast couriers, and frequently anticipated by telephone, but in spite of everything, it is surprising how well the records were kept, and the Office of the Chief Engineer, Army, was always in a position to make an intelligent report on the electrical and mechanical situation to the Staff of the Commanding General. In addition to the forms mentioned, job tickets, stock cards and many of the most efficient forms of civilian practice, modified to meet army conditions, were extensively used.

Fig. 9. "Groupe Électrogène á Essence" French 4-cylinder, 1650-r.p.m. "Ballot" gasolene engine with *Constructions Electriques* 29-amp., 110-volt, d-c. generator. Magneto ignition. Entirely self-contained. A very popular and reliable unit much used by the French Service Electrique

From the time the Engineer troops landed in France until what was left of them embarked for the United States, they were called upon to do almost everything except what they had dreamed about when they were mobilized in the United States. The regiments which had most to do with the electrical work had their share of diversity of employment. When there was something particularly difficult and complicated to do the engineers were asked to do it. In the early days of the big depots at the base ports and in the intermediate and advance sections, these engineers not only built power plants, warehouses and barracks, and assembled, tested and reshipped machinery, including designing and making missing parts, but unloaded and loaded thousands of tons of supplies, quartermaster as well as engineer. There is one organization which will long remember 125 carloads of potatoes which were handled very rapidly in the hope that some more congenial job would follow. Not only did men who held prominent situations in electrical and shop industries at home do the most menial tasks cheerfully, feeling it was all part of the game, but our Master Engineers and Sergeants took hold of whatever job happened to be in front of them and never hesitated to work with their own hands when necessary. The Engineers, like most other American troops, came over with the compelling spirit that it was up to each one of them individually to win the war. The Engineer work was never done, and under the most trying conditions our Engineer soldiers worked night and day, frequently with very little sleep and almost without exception with no leaves until after the armistice. It gets tiresome to work hard all through the daylight hours and then be kept awake most of the night by enemy airplane bombing as our men often were. The Commanding Officer of one of these special Engineer regiments, upon leaving it for other Engineer work here, included the following in his farewell order, which, while particularly true of the regiment to which it was addressed, is also true of other similar organizations: "* * * * I wish to express my appreciation of the high sense of duty that has marked the work of the officers and men of this organization. You have been loyal to your Country and to the officers under whom you have served. The markedly courteous and correct attitude of the enlisted men of this regiment toward their officers has been in itself complete proof that the work of the regiment is efficient. You have worked hard and efficiently and merit your reputation for being able to do anything and being willing to do it. No regiment has done more varied work. * * *" The patriotism, loyalty, co-operation and esprit de corps of these special engineer troops was of the very highest order, and it has been an inspiration as well as an honor and privilege to have served with them.

**Fig. 10.** Army Concrete Factory, *Liverdun*. An Engineering Company just off the train, July 8, 1918. Note the bows and canvas cover of one of the heavy trucks used as a kitchen with the army field range in front

Previous to the armistice the matter of camouflaging night lights was very serious and it required constant vigilance and fertile brains to insure the necessary continuous service to headquarters, etc., where work never stopped, with no protruding rays of light to indicate to enemy airplanes either the places lighted nor the plant itself. Not only was it contrary to orders to allow lights, either army or civilian, to show, but sentries were given considerable latitude and it was not safe to allow any light to escape. On more than one occasion a sentry shot at windows which continued to leak light after being warned.

The illustration, Fig. 10, shows Company "C" of the 24th Engineers upon its arrival at Liverdun, Meurthe-et-Moselle, on the afternoon of the 8th of July, 1918. This company built and operated the Army Concrete Factory, which made several thousand tons of blocks and beams for dugouts, machine gun emplacements, etc., as well as reinforced concrete tiles for culverts, concrete water storage tanks, etc. The right-hand end of the old factory building directly behind the line of troops in the picture was used as power house and sub-station, and the rest as a carpenter shop for building forms, a metal shop for making the reinforcement grids, a tool room, and on the upper floor offices. The power plant started with a 5 kw. French gasolene-electric set. A 25-kw. 110-volt direct current standard General Electric Co. gasolene set was next installed, followed by a high tension line from an abandoned iron furnace in the Moselle valley with a 50-kw., 3-phase, 50-cycle, 6000-volt to 190/110-volt 4-wire, transformer with motor-generator set, etc. There were about a dozen motors driving wood and metal working tools, an electric pumping unit and two electric hoists. There were two large American concrete batch mixers and two stone crushers with screens, all driven by gasolene engines, which would have been changed to electric drive had more power been available. An electric spot welding machine for fastening the parts of reinforcement grids together, in place of using small tie wires like the French and British, was designed and built during the fall, but not tested and shipped until after the signing of the armistice and consequently never used. In addition to power for the plant itself, the electric installation furnished lights for the entire camp, including lounging room and canteen, barber shop, bath house and the motion picture machine. The windows of the shop and barracks were so well screened that work went on at night and cinema shows were given while under observation of German night fliers, and while absolute darkness outside was imperative. The illustration, Fig. 11, shows the mess hall of a pioneer infantry company which worked at this plant.

Fig. 11. *Liverdun*—Adrian Barrack Used as Mess Hall by B Co., 59th Pioneer Infantry, in Fall of 1918. The old mediaeval town on the hill behind.

The original shop program included mobile shops, consisting of a few machines mounted on automobile chassis with a small electric generating unit and individual motors for each tool. A number of such shops were actually built, three styles being machine shops, carpenter shops, and blacksmith shops respectively. They proved, however, to be very heavy and there was always so much demand for the automobiles that, when used, the shops were generally taken off the chassis and set in some shed or other sheltered place. The Ordnance Department had some excellent mobile units of this type which they used as originally planned. The plan also included semi-mobile shops which would consist of groups of motor-driven tools with the necessary power plants on caterpillar trailers, the buildings and tools to be capable of being easily moved from place to place. The theory of these shops was sound, but in the scramble for equipment, with the very limited time and transportation available, the plan was never worked out. The British, the French and the Americans all had hope in [illegible] completely individual motor drive [illegible] were recognized as the best [illegible] conditions; but frequently all three [illegible] compelled to resort to combination [illegible] and motor drive, sometimes with [illegible] power, steam engines and gasolene engines in the same shop. The chief objective was never efficiency in fuel consumption or labor, but ability to produce a maximum output in a minimum time, yet in spite of all the limitations there were many plants which were very efficiently laid out. One large British shop was inspected which was entirely individual motor driven and could be dismantled, moved and set up again within forty-eight hours. It had actually been moved four times and was still in fine operating condition. The first area taken over by American troops was in the Toul sector, with a division headquarters at Menil-la-Tour. The French had an engineer dump there and a wood-working establishment. These were taken over by the Americans. The wood shop was very unimpressive on the outside, being a string of ordinary Adrian barracks, like the ones shown in Figs. 6 and 11, but a closer examination showed a 60 c.m. railroad running through it with the logs going in at one end, moving steadily through and coming out at the other end as finished mine frames, trench boards, etc. There was a 100-kw. transformer furnishing power, and every tool was individual motor-driven and fitted with an ampere meter, not on a starting panel out of sight of the operator, but mounted directly over the table of the tool where the operator could always see what his load was. The full load was marked very plainly and it was up to the operator to push the work through the machine so as to get maximum output at all times, but without overloading. In a light lean-to was a tool room with complete machinery for grinding and repairing saws. With the exception of lack of peace-time safety devices, this mill in these wooden shacks was one of the most efficient that could be designed. It is true that when our Forestry service finally took it over and had to increase the output, they substituted some larger motors and heavier saws with automatic attachments, but that was simply an expansion of the French design. There was another very interesting electrically-driven mill at Marbache, in the Moselle valley just below the junction of the Meurthe and Moselle. One of our American engineer lieutenants operated this mill which turned out bed frames, mine frames, camouflage material, coffins, grave crosses, duck boards, etc., etc. In the Fall of 1918 it was about nine miles from the Boche trenches and subjected to both airplane bombing and long range shelling. Although Americans were killed on the railroad track a few yards away and the artillery dump in the adjoining lot was partially demolished, this plant escaped untouched. The officer in charge lived in a little toy chateau in the center of the depot, with a bomb-proof shelter a few feet away. One of the interesting features of this plant was the employment of French girls to make such things as camouflage screens. There were many factories in this neighborhood before the war and a large number of the workmen's families did not move away. It was desirable to give their women employment, and as there was more work than we had soldier labor for, over a hundred of them worked in this Marbache shop. It was surprising how they went ahead with their work, enthusiastically singing most of the time and paying very little attention to the enemy shells and airplanes.

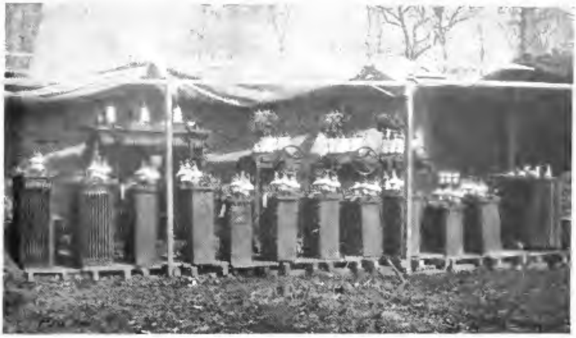

Fig. 12. Group of Boche Transformers and Oil Switches Collected at Leonval Engineer Depot from Captured Territory After the St. Mihiel Drive

An interesting illustration of the conditions controlling the electric lighting is to be found in St. Mihiel. The Germans held the St. Mihiel sector for so long, and felt so confident of retaining it, that they had dug themselves in very thoroughly. To supply light and power they had built a very comprehensive network of 3-phase, 50-cycle, electric transmission lines coming down from behind their main lines. The main transmission system was 17,000 volts, with sub-stations usually of about 100 kw. The secondary system was

Fig. 13. Captured Boche Three-phase Transformer. Rating plate missing. Thought to be about 50-kv-a., 17000 3000 volts

at 3000 volts, with over 60 transformers, mostly 10 kw., but some from 3 kw. to 15 kw., of the usual European 190 110-volt, 3-phase, 4-wire, low tension distribution type. These lines were very well built and the transformer stations equipped with the most modern safety devices. The illustrations, Figs. 12, 13, 14, and 15, show some of these German transformers at one of our engineer dumps where they had been collected from the territory captured in the St. Mihiel drive. Attention is called to the oil reservoir on the top of the transformer shown in Fig. 15. This was pierced by a bullet or piece of shell. Illustrations, Figs. 16 and 17, show one of the oil switches used at the sub-stations. Note that these were equipped with time-limit overload relays on all three phases, that the operating levers were of the indicating type, and that the oil can was raised and lowered by a system of levers, one of the illustrations showing the can up and the other with it down. The entire switch was mounted on trucks so as to be easily moved about. Of course the transmission lines were bare stranded iron wire, generally galvanized, but they were of large capacity and with relatively light load. In evacuating the St. Mihiel sector, the Boche destroyed some of their substations. The illustration, Fig. 18, shows all that was left of their electric motor driven concrete mixing plants and transformer stations used to build the dugouts and other concrete shelters on the Hindenburg Line in front of the Americans in the Toul sector. The transmission lines, substations and transformers were more or less destroyed by artillery. It was not practicable to operate any of the system when we took the sector over, but American engineers laid out a comprehensive system of distribution for this area with the intention of utilizing a water power plant at St. Mihiel and also connecting to the French high tension network a few miles up the Meuse valley, to the South. This reconstruction work was under way when the armistice was signed, but of course never completed.

**Fig. 14.** Captured Boche Transformer. 7.5 kv-a., Three-phase, 50 cycles, 3000-2700 218 volts, four-wire

**Fig. 15.** Captured Siemens-Schuckert Transformer. 15 kv-a., Three-phase, 50 cycles, 3000 volts to 223 129 volts, four-wire. Oil tank on top and insulators injured by shell or rifle fire

Meanwhile, upon the occupation of St. Mihiel by the Americans, it was necessary to have electric current. Before the war there had been water power in the Meuse valley at St. Mihiel with a good sized grist mill on the left bank of the river. An alternating current electric plant was included in this mill with two 3-phase cables running under the river to substations in the heart of the city. The mill had been practically demolished by shell fire and the machinery taken away by the Germans. The illustration, Fig. 19 shows the side of the mill away from the river, and Fig. 20 the river side of the same building just above the railroad track. There had been six or eight water wheels in the mill. It was found that one of these was in operating condition. Necessary bulkheads were put in to hold enough water to meet the demands of the wheel and a 335-ampere, 220-volt, direct current English generator was installed next to one of the walls and belted to a short jack shaft driven by the water wheel. The illustration, Fig. 21, shows this machine with the canvas hood over it to protect it from the rain dripping through the ruins above, and its very temporary switchboard in the rear. Hand manipulation of the water gate by a hand wheel among the debris on the floor above was the only way of controlling speed, and sudden changes in load were troublesome. Ordinary rubber covered cable was run down the outside of the building and through the tail-race under the railroad to the old underground cables near the bank of the river. It was very difficult to find the other end of the cables in the ruins of the town, which was almost completely demolished where the substations had been, but they were finally located and hooked up so as to make a temporary 2-wire lighting system. The next problem was to reconnect what was left of the Boche high and low tension, 3-phase, 4-wire distributing system so as to make it work on 220 volts, 2-wire, direct current. To add to the complications, there were two kinds of sockets, and for weeks only 110-volt lamps were available. It is easy to imagine the complications resulting from such a system of distribution. It took a gang of men chasing all day to keep a few lights running through the night. Before the armistice was signed, however, the distributing system was in fairly good shape and 24-hour service was given with very few interruptions. A great deal more current was demanded than it was possible for this little plant to produce. One of the mobile plants which had been assembled at a main depot was shipped into the freight yard at St. Mihiel and is shown in the illustration, Fig. 22. It was in a standard American box car with fittings to conform to French railroad practice, of which there are so many thousands in use in France by the American Army. Inside the car was a 80-h.p., 50-kw., 250-volt, direct current gasolene-electric generating unit. The machine was complete with self starter, storage tanks, cooling device, searchlight, flood lights, coils of flexible cable for transmission, and racks of lamps and other supplies. This plant was used to supplement the water power plant, and continued to operate until the Corps Headquarters moved away.

Fig. 16. Portable Oil Switch Captured from Germans. No name plates could be found. Were used on 17,000-volt lines. Are three-pole with 3-6-amp. trip coils having time limit relays mounted on one set of insulators. One set of terminals were from the relay coils and the other set from the other three insulators. Oil can is shown closed

One of the most serious problems at places like St. Mihiel was to keep the number of lights down to the capacity of the generator and the supply of bulks available for replacement. Officially only headquarters offices, work rooms, officers' quarters and dining rooms, and men's mess halls and recreation rooms were entitled to lights, but there were always auxiliary uses which had some grounds of legitimacy, such as churches, ministers' houses, public offices, etc. Actually, as billets changed, civilians would continue to use lights after officers had moved out, and it was a never-ending job to cut off the unauthorized customers. In one place the situation became so bad that the Commanding General issued preemptory orders that no light should be connected by any one except on authority of a designated officer, and that any one found using an unauthorized light should be summarily dealt with. The first one caught adding additional lamps was the General's personal orderly, who was trying to make his own quarters more comfortable.

It is interesting to note in connection with the German high tension transmission system just mentioned, that the Boche dismantled many high tension lines as well as took away a vast amount of machinery which the French had used before the war. From the time the French drove the Germans out of the forts around Verdun in 1916, until the armistice, the French in front of Verdun and the Germans in front of Etain watched each other over the entrenchments in the intervening valleys. Etain had a covered water reservoir built on the high ground to the east of the city and apparently fitted with an electrically-driven pumping plant of considerable capacity. High tension lines came across the open country to this reservoir. Without in any way changing the contour of the embankments [illegible] the reservoir, or otherwise affecting [illegible] so as to change aerial photographs, the Boche cleaned it out, built bomb proofs inside, and made what seems to have been a telephone central and comfortable living quarters. At the top, on the western corners, they constructed two ideal observation posts. These observation posts were very completely fitted, even having plate glass protection in front, hoods for screening the sunlight and comfortably backed benches for the observers to sit at, with many telephones and other signal apparatus right at hand. The illustration, Fig. 23, shows the northwest observation post with a part of the entrance to what had been the pumping plant and a transmission line pole with all the wire taken off of it.

Fig. 17. Boche Portable Oil Switch. This is the same switch as in Fig. 16, but with the oil can dropped. Note the system of levers for lifting the oil can, the frame with wheels and the handwheel, which has indicating device with colored disk

Fig. 18. Boche Concrete Mixing Plant, Slip-ring Motor Driven with Transformer Station. This was near Charey, on the Hindenburg Line, in the Toul Sector. The Germans had several of their plants on hills with extensive narrow-gauge railroads running down to the massive monolithic concrete dugouts on the Hindenburg Line

While on the subject of high tension lines, a few of the ridiculous happenings may be mentioned, such as one case where a repair crew connected in a loop so as to make an ideal short circuit, but as the conductors were iron the short circuit only seriously dimmed the lamps, and was not of low enough resistance to burn itself off with the power available, and several hours were consumed in trying to find out why the lights were so dull. In another case, at an 11,000-volt transformer station, an attendant who had more zeal than knowledge of such things, had some high tension fuses blow out. He opened his disconnecting switches, substituted copper wire for the fuses, closed the disconnecting switches and then closed his oil switch. The oil switch was of the non-automatic type, and so did not open, but his copper fuses burned up. He kept on replacing them until a very mad and tired courier reached him with a message relayed from the 65,000-volt central station 75 miles away, ordering him to stop, as he was repeatedly throwing out the circuit breakers on the entire system feeding current to three French and two American Armies.

Fig. 19. Part of the Main Building of the Before-the-war Large Grist Mill and Electric Control Station on the Left (west) Bank of the Meuse River at St. Mihiel. The Army electrical plant was on the ground floor of this ruin and the control of speed was by a handwheel among the debris on the floor above. Most of the floors were gone as well as the roof and windows

Another time some soldiers, anxious to have a little target practice, made a crude target and nailed it to what they thought was a telephone pole. Their marksmanship proved rather good and the pole came crashing down with something over fifty bullets through it. They were surprised at the accompanying fireworks and to find that they had cut the 11,000-volt transmission line supplying almost the whole of the Verdun sector. It is also sad to note that 65,000-volt insulators, to say nothing about many more for 11,000 volts, were such attractive targets that they were frequently successfully fired at by passing troops with consequent interruptions to service.

The main power house of the 65,000-volt, 3-phase line, just referred to, lies south of Toul and Nancy. The main distributing stations are substantial brick buildings, very well designed and completely equipped. The one just north of Void, which furnished the current used by the American Army in and around Commercy, is illustrated in Fig. 24.

The French Army developed an excellent portable transformer house consisting of a wooden shack just small enough to be transported on a large automobile truck. Concrete or masonry foundation was built and the little house tilted off the truck on to it. Inside was the transformer, sitting on the masonry foundation. Fuses and disconnecting switches were on a frame above. A door was arranged so that with insulated hook the disconnecting switches could be pulled before the operator entered the building. The primary was universally 3 phase, 50 cycle, varying in voltage from 3000 to 18,000 according to the source of supply. The transformers were always 3 phase with 190 110-volt, 4-wire, low tension distribution. Illustration, Fig. 25, shows one of these installed by the 37th Engineers on a transmission line which they built from near Toul to an aviation field at Gondreville. Fig. 26 shows another, also installed by the Americans, which was part of the electric lines for the great British and French aviation fields near Azelot and Burthecourt. Another illustration, Fig. 27, shows one of the expedients resorted to. For the last mentioned high tension line it was possible to utilize some of the steel poles of a French before-the-war line, which had been dismantled to use the insulators and cables elsewhere. It was necessary to make a branch

Fig. 20. Part of the East Face of the Old Mill at St. Mihiel, shown in Fig. 19. The Army 220-volt supply cables can be seen coming out of a window and running down the wall into the tailrace, in which they went under the railroad tracks

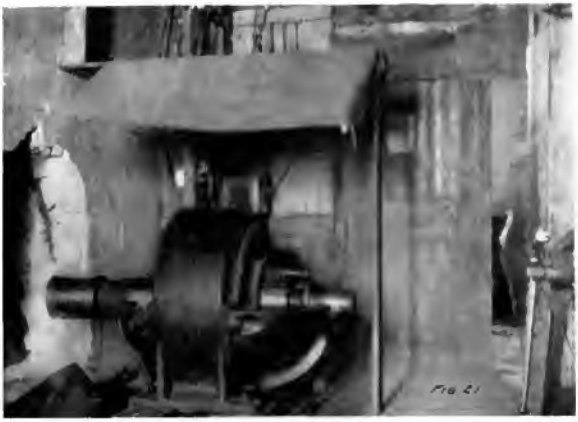

Fig. 21. St. Mihiel Electric Plant. The generator in the building shown in Figs. 19 and 20. Note wooden frame switchboard behind the generator and the hood over it to deflect dripping rain

and desirable to have disconnecting switches. The illustration shows the standard type of French air-brake sectionalizing switch mounted on two wooden poles between two of the steel poles of the former transmission line.

Fig. 22. 50-kw. Gasolene Engine Electric Plant in American Box Car in Freight Yard at St. Mihiel. This is the type of freight car in which hundreds of thousands of American soldiers rode back and forth across France and which was also used to supply them with rations, clothing, etc.

The latter part of October the American General Headquarters were still all at Chaumont, the headquarters of our First Army at Souilly, southwest of Verdun, which had been for a long time the headquarters of the Second French Army, and the headquarters of the Second American Army was at Toul. As part of the plan for the tremendous drive which would have been made against the Germans had they failed to sign the armistice, the 1st Echelon of General Headquarters, which finally went to Treves, in Germany, in connection with the Army of Occupation, was to move to Toul, and the headquarters of the Second Army was to leave Toul for a point nearer the front so as to be in the midst of their troops. A little hamlet called Hamonville, about 10 miles north of Toul, was selected because of its position, and rush orders were given to make it ready for an Army Headquarters. This involved the transport there of several hundred truck loads of barracks, and their erection and completion all within 36 hours; the establishment of a large telephone central station and all the other complicated minutiae of a great business organization which must function fully and freely within a few minutes after its arrival. About 9:30 o'clock Saturday night, final instructions were given. Headquarters would move Monday afternoon. At least 250 electric lights must be available that afternoon, mostly in buildings which would not even be on the ground until Sunday afternoon and not put up until some time Monday. Ample water pumping capacity must also be provided. The roads leading there were in atrocious condition and blocked with transport of troops. There was practically nothing available in the town. It was decided that the most feasible proposition was to erect a 24-kw.

Fig. 23. Boche Observation Station in Former City Water Works. The Germans held this point until the armistice. They watched the French forts before Verdun from here. Note how little the ground is changed as seen from above by an airplane, by the addition of this post. The slot in front was faced with heavy plate glass and shielded from sunlight by a metal hood covered with earth

American gasolene-electric generating set on a caterpillar trailer, and send it up across country with a tractor. Fortunately, at the large Engineer Depot at Leonval there were two such units actually running in the Engineer Shops. A large caterpillar trailer was backed into the shop and with a few timbers to reinforce the platform, one of these units, with its radiator and fan, its switchboard, and a gasolene drum as supply tank, was bolted on. A light frame was thrown up to support a canvas cover. The work was started just before noon, Sunday, the unit was actually running during the early part of the night and was pulled out by the tractor about 1:00 a. m., work continuing on the trip. It was towed through the mud, in the dark the rest of the night, and was pushed into a shed at Hamonville ready to be connected and operated before 9:30, Monday morning. A few hours before work was started on this unit, a detachment from the Griscourt camp, referred to above, started out with motor trucks and three days' hard rations to salvage sufficient poles, cross arms and insulators from the captured Boche transmission lines, for the outside lines over the town and the fields taken for barrack buildings. They came rolling in with the salvage before daylight Monday morning. Meanwhile other trucks brought men, supplies and tools, Saturday night and Sunday. A small plant had been set up for temporary and breakdown service and by the middle of the night lights were available in the Commanding General's quarters and offices and soon after daylight the next morning in all the barracks and quarters which were completed. It happened, however, that that next morning was the 11th of November, and the installation was never completed. The caterpillar trailer with its 25-kw. set was drawn back to Camp Leonval and used for lighting a large number of barracks, a gymnasium and a theater, and the cover illustration shows it there where it stood for several months. The following extract from a letter from the writer to a friend at home, written three days later, November 14th, tells so clearly some of the story of that day that it is quoted here. It starts with the work just before noon on Sunday:

Fig. 24. 2000-kw., 65,000 11,000 volts, Three-phase, 50-cycle Substation of the Compagnie Lorraine d'Electricite Between Void and Commercy, in operation throughout the war. It supplied several large American units with electric current. The main 65,000-volt line passing through this station fed the extensive army lines in the Verdun sector from a similar substation at Bar-le-Duc

"Next I went to the site of the new P.C. with the Captain who was to do the job there and personally laid it out with him. The first truck loads of barrack parts were being unloaded then. Labor troops were pouring in on all the roads. Water supply, bath houses, telephones, latrines, and all the great minutiae required for the central control post for the several hundred thousand men that make up an army, were all under way. My electrical show was only a very small part of it, but so interlaced with it all that we had to know about all that was going on.

"Then I went way up into the Northwestern part of our Front, where we had pushed ahead from one to seven kilometers the night before. Hospitals were coming in which must have light and current for other purposes.

"I started a connecting link between good French transmission lines and Boche lines which they had not had time to destroy, except in spots. I put one of my Lieuts. who built Western high tension lines before the War, at the cleaning up of the German lines, the reconnecting of transformers from 17,000 to 11,000 volts, and the establishment of a 3000-volt secondary network.

"It was after dark by that time, and about the nastiest fog I ever was in. We could not see any distance in front of us. Fortunately I had a good driver. (I have two of them, both of whom are fine, careful, night drivers. In times of stress I use one one day and the other the next.) The roads were crowded with trains of all sorts. It had been raining, and was very muddy and slippery. Automobiles were getting ditched. Trucks were stalled more or less, and horse-drawn outfits were having a hard time of it. It was slow, nasty work getting around. We went over 100 miles in the dark.

Fig. 25. French Army Transformer Station. Wooden building which can be moved complete with switches, insulators, choke coils, lightning arresters, etc., on auto truck without dismantling. A great many were used in all the French and American Army areas. 6000-volt line shown above and regular 190 110-volt, four-wire distributing lines below.

Fig. 26. French Army Transformer Station. Of the same type as shown in Fig. 25, but with the door open showing transformer sitting on masonry foundation and insulated stool for operator to stand on. 6000-volt, three-phase incoming line shown on pole behind the house. Aviation field barracks in rear.

"By midnight I had inspected the new plant being finished for the Army P.C. and gone over the ground again. The wiring of the quarters and offices of the Lieut. General was ahead of the painters and everything was going good. I still had to visit another sector headquarters. I reached my own quarters a little after 3 a. m., as I had to go to my office and attend to a lot of correspondence and dictate some orders after 2 a. m.

"At 6:45 I had finished breakfast and was off again. I checked up on some work and then reported to Army headquarters, to my Chief's office at 8 a. m. I found that there were some supplies needed at various point that morning, which could only be got forward in a fast car. Some of them were very special, and not in our stocks. I took a Frenchman attached to our service and beat it for Nancy.

Fig. 27. Abandoned High Voltage Line Steel Poles Used for Military Line to Aviation Field. Branch line taken off with French three-pole air-brake switch mounted between the tops of two wooden poles with operating lever down alongside one of them. This Army line was for 6000 volts, three-phase, with three transformer stations

"At just before 11 o'clock I was in the office of the Cie. General Electrique at Nancy, getting some special high voltage insulating material for one of the salvaged Boche transformers, when the whistle began to blow and the bells to ring. We soon found that the armistice had been signed and was to go into effect in a few minutes. I could not wait to see the fun, as there were no orders to let up on anything except to stop actual fighting. In fact, they did not stop until the exact hour. Not far from here a whole platoon of infantry with two machine guns and their crews went out at 10:30 to do a little consolidating work. At 10:45 the Germans put down a horrible barrage and at ten minutes before 11 captured the whole lot, or what was left of them.

"I stopped just long enough to read the official notice, to buy two French and two American flags for my automobile and to finish loading the things we had bought. As I came away the town was turning out. Shops, stores, schools, everything was closing. I saw more smiles that day than I had seen in all France in the past nine months.

"It was surprising how the news had spread. I passed through only one or two camps which did not know of it.

"By the middle of the afternoon I had readjusted things and celebrated by taking about an hour's rest. That night I got a pretty fair sleep, with the very strange experience of having the camouflaged shutters open.

"Tuesday morning I was off again early for another very long day, getting things adjusted to the new conditions. I went through Nancy late that night, i. e., about 11 o'clock, and it seemed so strange to see streets lighted, shutters open, and people in the cafes and on the streets at that time of night. It was equally strange to be able to use head lights, side lights and tail lights on our autos."

Fig. 30. Wreck of German 17000 3000-volt Transformer Substation Just Outside of Vigneulles, showing the condition in which the Boche abandoned it. One 17,000-volt line ran from here toward Montsec and another toward St. Mihiel. Four 3000-volt lines went out of this station to about ten transformer stations of 10 and 15 kv-a. The oil switches and iron framework are completely destroyed

# The Arrangement of Electrons in Atoms and Molecules

## PART II

By Irving Langmuir

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In Part I, published in our last issue, the author discussed the fundamental postulates and applied these to explain the periodic properties of the elements. In the present issue he deals with the mechanism of chemical action and the structure and properties of compounds. After pointing out the uncertainties attached to the ordinary text book conceptions of valency, the author suggests a much extended theory of valence. This theory is then applied in elucidating the structure of a large number of organic and inorganic compounds, for some of which it has been impossible to postulate any structure in accordance with the ordinary valence theory.—Editor.

### The Mechanism of Chemical Action and the Structure and Properties of Compounds

The preceding theory of structure of the atoms in the two short periods is nearly the same as that postulated by Lewis. Lewis has discussed how a theory of valence may be derived from this structure. He considers the nature of the single, double and triple bonds, the structure of the ammonium ion, iodine and oxygen molecules, ions such as the sulfate, perchlorate, etc., the tetrahedral arrangement of the electrons around the nucleus in the carbon atoms, etc. In this way he has fully demonstrated the general value and applicability of the theory. Unfortunately Lewis' treatment of this subject was rather brief and perhaps for this reason it does not seem to have met with the general acceptance which it deserves.

It therefore seems desirable to consider in some detail how this theory may be applied to the prediction of the properties of the first 18 elements and their compounds. In doing so we shall considerably extend Lewis' theory and because of the more definite conceptions of atomic structure which we have developed we will be able to apply a somewhat different viewpoint. In particular we shall attempt to explain the "physical" as well as the "chemical" properties of compounds. The prediction of these properties depends mainly on Postulates 8, 9, 10 and 11 given below. Following Lewis' practice we will refer to the outside electrons forming an uncompleted shell or layer as "the shell" of the atom; while the whole inner portion, consisting of shells and layers each containing its full quota of electrons, will be called the kernel.

*Postulate 8.* The very stable arrangements of electrons corresponding to those of the inert gases are characterized by strong internal but unusually weak external fields of force. The magnetic and electrostatic forces are each very nearly internally balanced. The smaller the atomic number of the element the weaker are these external fields.

*Postulate 9.* The pair of electrons in the helium atom represents the most stable possible arrangement. A stable pair of this kind forms only under the direct influence of positive charges.

The positive charges producing the stable pair may be:

(*a*) The nucleus of any element.
(*b*) Two hydrogen nuclei.
(*c*) A hydrogen nucleus together with the kernel of an atom.
(*d*) Two atomic kernels.

These are listed in the order of their stability.

As we have seen from the previous discussion on atomic structure, the tendency to form a pair of electrons about the nucleus of any atom overpowers the tendency to form other arrangements so that the stable pair constitutes the first shell of all the elements except hydrogen. The tendency for the pair to form around two atomic kernels (Case d) is weak and thus only in exceptional cases, under some outside compelling influence does this combination occur.

*Postulate 10.* After the very stable pairs (Postulate 9) the next most stable arrangement of electrons is the group of eight such as forms the outside layer in atoms of neon and argon. We shall call this stable group of eight electrons the "octet." Any atom up to argon having more than two positive charges on its kernel tends to take up electrons to form an octet. The greater the charge on the kernel the stronger is this tendency. In exceptional cases, the octet can form about a complex kernel, that is, about a structure containing the kernels of two atoms bound together by a pair of electrons (Postulate 9d).

*Postulate 11, Electrons Held in Common.* Two octets may hold one, two or sometimes even three pairs of electrons in common. A stable pair and an octet may hold a pair of electrons in common. An octet may share an even number of its electrons with one, two, three or four other octets. No electron can form parts of more than two octets.

The fact that only an even number of electrons can be held in common probably signifies that the tendency to form stable pairs between the two kernels, according to Postulate 9, is a vital factor in the sharing of electrons between octets.

When octets combine together by sharing their electrons fewer electrons are required than if the octets remain separate. Thus when two octets containing a total of 16 electrons combine so as to hold a pair in common two electrons are set free. Two octets held together by one, two or three pairs of electrons thus contain 14, 12 or 10 electrons respectively. When we consider that the shells of all atoms except those of the inert gases are unsaturated, we see how necessary it is for the atoms to share their electrons with each other if the stable pairs and octets are to be formed.

Lewis discusses two possible arrangements of the electrons in the octet. They may be placed at the eight corners of a cube or they may be located in pairs at the four corners of a regular tetrahedron. In view of Postulates 5 and 11 it would seem that the electrons in the octet are normally arranged in positions corresponding to the corners of a cube but that the electrons which are held in common between two octets or an octet and a stable pair, are drawn together by magnetic forces to form pairs. Thus we look upon electrons in the atoms as able to move from their normal positions under the influence of magnetic and electrostatic forces. This view does not conflict with that of Postulate 3 according to which the electrons are in cellular spaces. Thus we might assume when there are eight outside cells that these are in the form of octants of a sphere. In the atom of neon, or the kernel of sodium, or in the chlorine ion the eight electrons would be arranged neraly at the centers of the octants, but in compounds where pairs of electrons are shared by other atoms, the two electrons forming the pairs are displaced over near the boundaries of the octants and are thus able to come sufficiently close together for the magnetic forces to cause them to form stable pairs.

We are now in a position to apply the theory to explain the properties of the elements and their compounds.

*Hydrogen* $N = 1$; $E$[*] $= 1$. Hydrogen atoms are very active chemically because they tend to combine with any other atoms capable of supplying electrons by which the stable pairs can be formed. We should expect a hydrogen atom to constitute a doublet of high moment which would tend to attract all other bodies. Thus atomic hydrogen is very strongly absorbed on surfaces.[†] When two hydrogen atoms come in contact their two electrons form a stable pair (Postulate 9b) under the influence of the two nuclei so that a molecule $H_2$ is produced. This molecule has an unusually weak external field (Postulate 8) and therefore hydrogen has a very low boiling point[‡] and is relatively inert chemically except in so far as it can be made to split up into atoms.

*Helium* $N = 2$; $E = 0$. In the helium atom the stable pair already exists. Since this is the most stable arrangement of electrons and has the weakest stray field (Postulate 8), helium forms no chemical compounds and has the lowest boiling point and highest ionizing potential of any known substance. Hydrogen has a higher boiling point and lower ionizing potential than helium because the mutual repulsion of the two nuclei forces these apart and increases the strength of the external field.

### First Short Period

*Lithium* $N = 3$; $E = 1$. Two of the electrons form a stable pair which completes the first shell. The extra electron just as that of the hydrogen atom tends to make the atom very active chemically. Lithium atoms are electric doublets and therefore attract one another. There is, however, now little or no tendency to form stable pairs of electrons (Postulate 9) since the kernels of the lithium atoms are

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[*] We will use $E$ to denote the number of electrons in the shell of the atom as given in Table I

[†] Langmuir. Jour Amer Chem Soc., *34*, 1310 (1912)

[‡] According to the theory which I have advanced, Jour. Amer Chem. Soc., *38*, 2221 (1916), *39*, 1848 (1917), the so-called physical properties such as boiling point, melting point, surface tension, etc., are manifestations of typical chemical forces, sometimes primary valence, other times secondary valence forces.

not simple nuclei as were those of hydrogen. Thus after one lithium atom has drawn another one to it there is still just as great a force tending to draw in a third. The electrostatic forces involved are like those holding together a crystal of sodium chloride. The positively charged lithium kernels and the free electrons will therefore arrange themselves in space in a continuous lattice in a manner quite analogous to that of sodium and chlorine atoms in crystals of sodium chloride. Lithium atoms when allowed to come into contact with each other do not form molecules but form a crystalline solid containing free electrons as part of the lattice structure which is therefore a metallic conductor of electricity. When lithium is melted the structure is not essentially changed except in regard to the regularity of the lattice. The free electrons still occur between the lithium kernels and the metallic conduction persists. The strong forces exerted by the positively and negatively charged particles on each other makes it difficult to separate the atoms. The great difference between the boiling points of lithium and those of hydrogen and helium is understandable.

When lithium is heated to a sufficiently high temperature, the thermal agitation is able to overcome in some degree even these strong forces so that the lithium evaporates. It is easy to see, however, that the vapor is monatomic. The energy necessary to separate two atoms of lithium from the surface is about twice that required to separate one, but the kinetic energy of a molecule of two atoms is the same as that of one, so that the momentum is only $\sqrt{2}$ times that of a single atom. Or to look at the problem another way, suppose that a diatomic molecule of lithium $Li_2$ does evaporate from the surface, the kinetic energy of agitation of these atoms with respect to each other is the same as when the atoms formed part of the surface. But the forces holding the atoms together in space are in general much less than those which originally held the atoms to the surface. Thus if we assume that the space lattice is like that of sodium chloride each charged particle in the interior has six oppositely charged particles around it. A particle in the surface usually has two or three neighboring oppositely charged particles. For these reasons even if some diatomic lithium molecules should leave the surface they would dissociate into atoms at a rate large compared to that at which they evaporate from the surface. The resultant vapor is monatomic.

The attractive forces between the electron and the lithium kernel prevent ionization and hence lithium vapor is mostly a non-conductor of electricity.

If lithium atoms and hydrogen atoms are brought together the extra electron of the lithium atom and the electron of the hydrogen atom combine together to form a stable pair with the hydrogen nucleus at its center (Postulate 5a). The lithium kernels thus become lithium ions $Li^+$, while the hydrogen nuclei surrounded by the pair of electrons are negatively charged hydrogen ions $H^-$. These charged particles would be attracted to each other but since there is no tendency for negative *ions* to form pairs about positive kernels there would be no tendency to form molecules. The lithium and hydrogen ions form a crystalline solid having the composition of $LiH$. Since there are no free electrons, the solid body is a non-conductor of electricity. If melted, however, the positively and negatively charged particles should be able to move under the influence of an electric field so that molten $LiH$ should be an electrolyte (as Lewis has pointed out) in which hydrogen should appear at the anode. The comparative ease with which an electron can be taken from a lithium atom by an electronegative element makes univalent lithium ions stable in water solutions.

The theory thus not only accounts for the chemical activity and valency of hydrogen and lithium as compared to helium, but explains the ordinary properties, such as boiling point, electric conductivity, ionizing potential, etc.

*Beryllium* $N = 4$; $E = 2$. The first two electrons form the stable pair, leaving two electrons in the second shell. Since the atom can give up two electrons easily it forms a divalent ion.

*Boron* $N = 5$; $E = 3$. The three electrons in the outer shell give this element its tervalent character. The small volume of the atom makes it incapable of forming a tervalent cation. Boron has, therefore, a more electronegative character than the previously considered elements.

*Carbon* $N = 6$, $E = 4$; *Nitrogen* $N = 7$, $E = 5$; *Oxygen* $N = 8$, $E = 6$. We shall consider these three elements together because the application of the theory is best illustrated by the compounds they form with each other and with hydrogen. The properties of the atoms up to this point have been determined by their ability to give up one or more electrons. With carbon and the elements which follow it there is less tendency to part with electrons, and more tendency to take up electrons to form a new octet. This opens up new possibilities in the formation of compounds and as a result we find a remarkable contrast between the properties of oxygen and nitrogen and those of lithium and beryllium. The ordinary theory of valency has nowhere been more strikingly useful than in the chemistry of carbon compounds. Among compounds of carbon with hydrogen and oxygen the valency almost without exception can be taken as four for carbon, two for oxygen and one for hydrogen. This simple theory makes it possible to predict with certainty the existence of great numbers of compounds and the non-existence of others.

When nitrogen is introduced into organic compounds there is often much more uncertainty in using this theory of valence. But among the compounds of nitrogen with oxygen the same theory is almost useless. Who, for example, would ever have been able to predict the existence of such compounds as $N_2O$, $NO$, $NO_2$, $N_2O_4$, $N_2O_3$ and $N_2O_5$ or $HNO$, $HNO_2$, $HNO_3$, etc., by applying the valency theory that has been so successful in organic chemistry? But because of its great success in its special field this theory has been nearly universally used even for inorganic compounds. To explain the existence of the above oxides of nitrogen it has thus been assumed that the valency of nitrogen may be one, two, three, four or five. It is obvious that such a theory must predict the existence of an unlimited number of compounds which do not exist at all. For example, we should have such compounds as $NH_1$ $NH_2$, $NH_4$ or $NCl$, $NCl_2$, $NCl_4$ and $NCl_5$.

The degree to which any given theory of atomic structure is able to explain the success of the ordinary valency theory for carbon compounds and its failure for nitrogen compounds should serve as a measure of the value of the theory and should afford information as to whether the theory corresponds to the actual structure of the atoms.

With the exception of compounds like lithium hydride and some compounds of elements having atomic numbers greater than 20, nearly all "primary valence" compounds involve the formation of octets. Let us examine more closely the theory of valence which results from the application of Postulates 9, 10 and 11.

### Octet Theory of Valence

Let $e$ be the total number of *available electrons* in the shells of the atoms forming a given molecule. Let $n$ be the number of octets formed by their combination and let $p$ be the number of pairs of electrons held in common by the *octets*. For every pair of electrons held in common there is a saving of $2\ p$ in the number of electrons needed to form the octets. Thus we have

$$(1)\qquad e = 8n - 2p$$

For most purposes it is more convenient to use this equation in the form

$$(2)\qquad p = \tfrac{1}{2}\,(8n - e)$$

When a hydrogen nucleus holds a pair of electrons in common with an octet, this pair should not be counted in determining the value of $p$, since it does not result in any saving in the numbers of electrons required to form the octets.

To determine $e$ we add together the numbers of available electrons in the outside shells of all the constituent atoms. Thus for every hydrogen we add one, for lithium one, for beryllium two, for carbon four, nitrogen five and oxygen six.

Equation 2 gives definite information as to the ways in which the octets in a given molecule can be arranged. This equation applies to all "*octet compounds*," that is, to all compounds whose atoms are held together either because their octets share electrons or because electrons have passed from one atom to another in order to complete the octets.

Let us now apply Equation 2 to determine the structure of various molecules.

*Water* ($H_2O$). The hydrogen nuclei always tend to hold pairs of electrons, never octets.

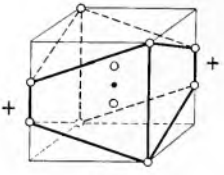


Fig. 2.

Diagram of the Water Molecule

We thus place $n = 1$, $e = 8$ (six for the oxygen and one for each hydrogen). Whence by equation (2) $p = 0$. This means that no electrons are held in common between octets which must obviously be the case for any molecule containing only one octet. The fact that we found $p=0$ thus shows that the compound $H_2O$ can exist. The two hydrogen nuclei attach themselves to two pairs of electrons forming the octet. The arrangement is presumably as illustrated in Fig. 2. The hydrogen nuclei are represented by the + signs and the electrons in the octet by the small circles while the nucleus of the oxygen atom is shown as a black circle. In figures after this one the kernels of the atoms will not be shown.

We see from this structure that water forms molecules which are quite thoroughly saturated. The two hydrogen nuclei are held firmly by the pairs of electrons very much as they are in gaseous hydrogen. All the electrons form an octet and hence (Postulate 8) should have a rather weak stray field of force. Water therefore should be a substance easily volatile as $H_2O$ molecules and should not be a good conductor of electricity in the liquid state. Because of the lack of symmetry of the molecule as compared to the neon atom, water molecules should have a larger external field than neon atoms so that the boiling point should be much higher.

*Lithium Oxide* $Li_2O$. As before we place $n=1$, $e=8$ and find $p=0$. The oxygen atoms have completed their octets by taking the two electrons from the two lithium atoms. The lithium kernels, however, already have their pairs of electrons and therefore cannot form pairs with those of the oxygen octet. Therefore, lithium oxide consists of oxygen atoms carrying a double negative charge and of lithium kernels with single positive charge. This substance thus tends to form a solid space lattice structure having low vapor pressure, which is an electrolytic conductor when melted.

*Lithium Hydroxide*, $LiOH$, $n=1$, $e=8$, $p=0$. The hydrogen nucleus is held by a pair of electrons in the oxygen octet but the lithium kernel does not share electrons with the oxygen atom. This substance should thus form a solid body showing electrolytic conductivity when molten and capable of dissolving in water as an electrolyte giving ions of $Li^+$ and $OH^-$. We should expect lithium hydroxide to be easily soluble in water because the $OH^-$ ion so much resembles water in its structure and the high dielectric constant of water makes it easy for the necessary separation of the positive and negative particles to take place.

*Carbon Dioxide* $CO_2$. Here each atom forms an octet. We place $n=3$; $e=4+2\times 6=16$, whence by equation (2) $p=4$. Thus four pairs of electrons must be held [illegible] three octets. This leads [illegible] that shown diagrammatically [illegible] probably better by Fig. 4 [illegible] of electrons held in common [illegible] together. This places [illegible]

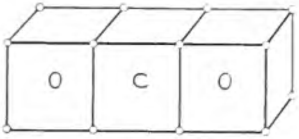


Fig. 3.

Diagram of Carbon Dioxide Molecule

trons forming the octet of the carbon atom at the four corners of a regular tetrahedron. The lines connecting the electrons in these figures are used merely to give a better perspective of the arrangement of the electrons and of course should not be taken as representing the boundaries of the atoms. In the remainder of the figures no attempt will be made to show the probable closer approach of the electrons forming the pairs, that is, we will use only diagrammatic figures like Fig. 3.

We can readily see that carbon dioxide is a thoroughly saturated non-polar substance which should be a non-conductor of electricity, be very readily volatile and rather inert chemically. The structure of carbon dioxide given by our theory is in full accord with that given by the ordinary valence theory $O=C=O$. By Fig. 3 we see that each pair of electrons held in common is the equivalent of the bond of the ordinary theory. The same was true of the structure found for water. But for lithium oxide and hydroxide there are no electrons held in common; the number of electrons transferred from one atom to the other corresponds to the ordinary valence.

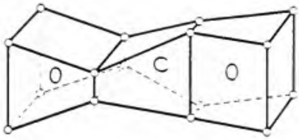


Fig. 4.

Diagram of Carbon Dioxide Molecule

*Methane* $CH_4$. We place $n=1$, $c=8$, hence $p=o$. The four hydrogen atoms supply four electrons to complete the octet of the carbon atom. Each hydrogen nucleus is held by one of the four pairs of electrons forming the octet. The final arrangement is that the four hydrogen atoms are located at the corners of a tetrahedron, each nucleus held by a stable pair just as it is in the hydrogen molecule. This arrangement is very much more symmetrical than that of the water molecule and should have a much weaker external field. Methane should thus be non-polar to an unusual degree; it should be a gas with a fairly low boiling point, and should be a non-conductor even when liquid.

*Organic Compounds.* It will be found that Equation 2 leads to results identical with those of the ordinary theory of valence for all organic compounds of carbon, oxygen and hydrogen. In every case each pair of electrons held in common corresponds to a bond. Two and three pairs held between two octets correspond to the double and triple bonds respectively.

To show how this theory applies to hydrocarbons let us attempt to find according to the octet theory what substances of the general formula $C_xH_y$ can exist.

From Equation 2, it is evident that in al octet compounds there must be an even number of electrons $e$, otherwise $p$, the number of pairs of electrons held in common, would be a fractional number. Therefore in all hydrocarbons there must be an even number of hydrogen atoms since each of these atoms has a single electron. We may therefore confine our attention to hydrocarbons of the general formula $C_xH_{2y}$. In Table II, a series of compounds of this type is analyzed by the octet theory. The first column gives the empirical formula of the hypothetical compound. The values of $n$ and $e$ are in the next two columns while $p$ calculated by Equation 2 is in the fourth. For $CH_2$, $p$ is found to be 1. Since a single octet cannot share any electrons with itself it is impossible to form a compound $CH_2$. In the case of $CH_4$ we find $p=o$ which is easily realized since

TABLE II

OCTET THEORY APPLIED TO HYDROCARBONS

| | $n$ | $e$ | $p$ | Constitution |
|---|---|---|---|---|
| $CH_2$ | 1 | 6 | 1 | Impossible |
| $CH_4$ | 1 | 8 | 0 | $CH_4$ |
| $CH_6$ | 1 | 10 | −1 | Impossible |
| $C_2H_2$ | 2 | 10 | 3 | $HC \equiv CH$ |
| $C_2H_4$ | 2 | 12 | 2 | $H_2C = CH_2$ |
| $C_2H_6$ | 2 | 14 | 1 | $H_3C - CH_3$ |
| $C_2H_8$ | 2 | 16 | 0 | $CH_4 + CH_4$ |
| $C_3H_2$ | 3 | 14 | 5 | Possible only in ring |
| $C_3H_4$ | 3 | 16 | 4 | $H_2C = C = CH_2$ |
| $C_3H_6$ | 3 | 18 | 3 | $H_3C - CH = CH_2$ or as ring |
| $C_3H_8$ | 3 | 20 | 2 | $H_3C - CH_2 - CH_3$ |
| $C_3H_{10}$ | 3 | 22 | 1 | $H_3C - CH_3 + CH_4$ |
| $C_4H_2$ | 4 | 18 | 7 | $HC \equiv C - C \equiv CH$ |
| $C_4H_4$ | 4 | 20 | 6 | $H_2C = C = C = CH_2$ or as ring |

TABLE III

STRUCTURE OF NITROGEN OXIDES

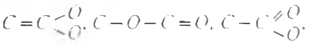
| | | $n$ | $e$ | $p$ | Structural Formulas |
|---|---|---|---|---|---|
| 1 | $N_2O$ | 3 | 16 | 4 | $N = O = N$ or $N = N = O$ |
| 2 | $N_2O_2$ | 4 | 22 | 5 | $O = N - N = O$ |
| 3 | $N_2O_3$ | 5 | 28 | 6 | $O = N - O - N = O$ or $O = \overset{O}{N} - N = O$ |
| 4 | $N_2O_4$ | 6 | 34 | 7 | $O = \overset{O}{N} - \overset{O}{N} = O$ |
| 5 | $N_2O_5$ | 7 | 40 | 8 | $O = \overset{O}{N} - O - \overset{O}{N} = O$ |
| 6 | $N_2O_6$ | 8 | 46 | 9 | Impossible |
| 7 | $N_2O_7$ | 9 | 52 | 10 | Impossible |

there is only one carbon atom. Therefore the compound $CH_4$ should exist. The compound $CH_6$ is obviously impossible since for this the theory gives $p=-1$. For $C_2H_2$ the equation gives $p=3$. The carbon atoms must therefore have three pairs of electrons in common. If we represent each pair by the line used to indicate a valence bond the carbon atoms are represented by $C\equiv C$. There is no question as to where the hydrogen atoms must go. It is impossible to have $C\equiv CH_2$ because such a structure would require *five* pairs of electrons around one carbon atom. The formula therefore must be $HC\equiv CH$. In a similar manner we arrive at each of the other formulas. The only cases where the pairs of electrons can be shared between the octets of the carbon atoms in more than one way are the cases where isomers should exist according to the ordinary valence theory. Once having decided where the pairs of electrons are located, there is never any possibility of arranging the hydrogen atoms in any other than one way. The theory applies exactly as well to ring compounds as to chains.

The Equation 2 is thus a complete mathematical statement of the valency laws for hydrocarbons.

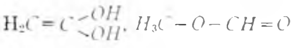
For carbon-oxygen-hydrogen compounds the theory works out in about the same way. All the structures given by the ordinary theory can be found by the octet theory and in every case each bond corresponds to a pair of electrons. An illustration of a compound of this type will help to make this clear.

*Acetic Acid* $C_2H_4O_2$. Here $n=4$, $e=2\times4+4+2\times6=24$; whence $p=4$. The four pairs of electrons may be distributed in several ways such as

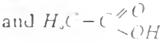


$$C=C\genfrac{}{}{0pt}{}{\diagup O}{\diagdown O},\ C-O-C=O,\ C-C\genfrac{}{}{0pt}{}{/\!\!/ O}{\diagdown O}$$

etc.* These correspond to the compounds



$$H_2C=C\genfrac{}{}{0pt}{}{\diagup OH}{\diagdown OH},\ H_3C-O-CH=O$$



$$\text{and } H_3C-C\genfrac{}{}{0pt}{}{/\!\!/ O}{\diagdown OH}$$

the last one being acetic acid.

Thus if we apply the octet [illegible] compound $C_2H_4O_2$ we find [illegible] that we would be led to [illegible] valence theory. The ordinary [illegible] sometimes indicates the poss[illegible] pounds which we have never be[illegible] prepare as for instance $C(OH)_4$ [illegible] compounds the octet theory will be [illegible] than the ordinary valence theory [illegible] respect the results will always be [illegible]. But we shall see that this identity disap[illegible] in the case of inorganic compounds.

*Oxides of Nitrogen.* There is hardly a [illegible] where the ordinary valence theory fails [illegible] completely as when it is applied to the oxides of nitrogen. Let us try to deduce by the octet theory what oxides of nitrogen might be capable of existence and what the structure of their molecules must be. In the first place from Equation 2 we see that the total number of available electrons in the molecule must be even. Since nitrogen has five electrons in its shell and oxygen has six, there will always be an odd number of electrons, unless the number of nitrogen atoms is even. We will therefore apply our theory to investigate the structure of the series of oxides represented by $N_2O_x$ as given in Table III.

The values of $p$ calculated from Equation 2 are given in the fifth column. The most probable structural formulas based on these values of $p$ are given in the last column. In these formulas, as throughout the rest of this paper, each dash represents a pair of electrons held in common between adjacent atoms just as in the formulas of organic compounds.

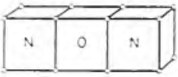


Fig. 5.

Diagram of Molecules of the Oxides of Nitrogen

When $x=1$ we find that our theory indicates that such a compound has the formula $N=O=N$ or $N=N=O$. Because of its simplicity and symmetry we should expect such a compound to exist. The actual arrangement of the electrons is shown diagrammatically in Fig. 5.† According to the octet theory there is no difficulty at all in explaining the existence and properties of this substance. Its structure is exactly like that of carbon dioxide (Fig. 3). We should thus expect it to be a gas having about the same boiling point as carbon dioxide. Its oxidizing properties at high temperatures are due to its

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* As far as the application of Equation 2 is concerned we might also arrange the pairs of electrons thus $O-C=O-C$ corresponding to a compound. $O-CH=O-CH_3$. It is only by taking into account the fact, to be discussed later, that oxygen has a tendency to share either one or two pairs of electrons and only rarely shares three pairs, that we can predict that a compound of the above type does not exist. With sulphur, compounds of this general type frequently do exist.

† There is good evidence that nitrous oxide has the structure $N=N=O$ rather than that shown in Fig. 5. The arrangement of electrons however remains the same.

decomposition into oxygen and nitrogen which is made an irreversible process by the great and unusual stability of the nitrogen molecule.

Let us proceed with the other oxides of nitrogen. When $x=2$ (Table III) we find that a possible arrangement is $O=N-N=O$.

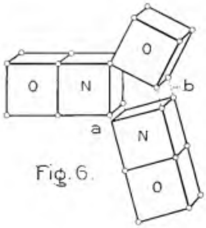


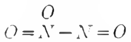
Fig. 6.

Diagram of Molecules of the Oxides of Nitrogen

This formula is identical to that which we obtain by the ordinary theory if nitrogen is taken as tervalent. The fact that this compound does not exist as a gas, but presumably dissociates into $NO$ is not explained by the octet theory but neither is it by the ordinary theory.

According to the octet theory $N_2O_3$ may have at least three different structures

$$O=N-O-N=O,\ O-N=O=N-O \text{ or}$$



$$O=\overset{O}{N}-N=O$$

whereas by the ordinary theory with tervalent nitrogen only the first should be possible. In view of the ease with which $N_2O_3$ breaks down to $NO$ and $NO_2$ and by comparison with the formula for $N_2O_2$ which breaks down into $NO$ it seems that the third of the above formulas is the most probable structure. The deep blue color of liquid $N_2O_3$ indicates the presence of very loosely held electrons. This suggests tautomerism between the first and third forms as shown in Fig. 6. If a pair of electrons is held in common at $a$ we have the third formula while if it is held at $b$ the structure is as given by the first formula. This tautomerism involves the shifting of two electrons between the positions $a$ and $b$.

The structure of $N_2O_4$ derived by the octet theory as given in Table III is as shown in Fig. 7. By comparing this with Fig. 6 we see that the extra oxygen atom has made the molecule incapable of tautomerism like that between the two forms of $N_2O_3$. On the other hand, the molecule still tends to dissociate into two parts ($NO_2$) as shown by the dotted line. The stability of the electrons in $N_2O_4$ causes this to be a colorless compound.

The octet theory also explains the existence of $N_2O_5$ and leads to the structure shown in Fig. 8. There are no unstable electrons so this compound is colorless. It tends to decompose as indicated by dotted lines into $NO_2$ and oxygen, although not nearly so readily as does $N_2O_4$.

When we apply the octet theory to the case that $x=6$, or 7 we find (see Table III) that the value of $p$ becomes so large that there are not enough electrons in the atoms to form the pairs, except by forming chains of oxygen atoms or a ring structure. Even on the ordinary theory we could account for any numbers of oxygen atoms if we could string them out in chains as for example

$$O=N-O-O-N=O.$$

We see that such a structure as

$$\begin{matrix} & O & & O & \\ O & N & O & N & O \\ & O & & O & \end{matrix}$$

is impossible since by Table III we would have $p=10$ and this would require more electrons in the shell of the nitrogen atom than there actually are. The octet theory thus explains without difficulty the existence and properties of $N_2O$, $N_2O_3$, $N_2O_4$ and $N_2O_5$, although the ordinary theory fails to do so.

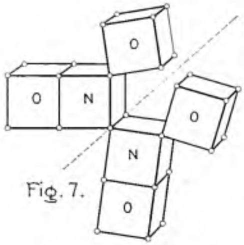


Fig. 7.

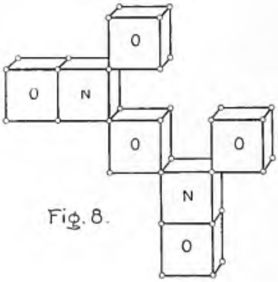


Fig. 8.

Diagrams of Molecules of the Oxides of Nitrogen

Both theories fail to explain the existence of $NO$ and $NO_2$. We shall see, however, that these compounds may be explained by a modification of the octet which we shall consider later.

*Nitrogen Acids.* The structures of the three acids $HNO$, $HNO_2$ and $HNO_3$ are given by the octet theory without the necessity of assuming variable valence. Thus for $HNO$, $n=2$, $e=12$ and $p=2$. This gives a structure represented by $HN=O$ or $HO=N$ and shown in Fig. 9. In a similar way we obtain the structures for $HNO_2$ and $HNO_3$ as given in Fig. 9. It should be noted that the group $O=\overset{|}{N}-O$ which occurs in $HNO_3$ is the same as in the formulas for $N_2O_3$, $N_2O_4$ and $N_2O_5$. The group $O=N-O-$ in $HNO_2$ was previously found in the *b* form of $N_2O_3$ shown in Fig. 6. We see that although $HNO$, $HNO_2$, $HNO_3$ can exist, $HNO_4$ cannot exist, for in this last case $p=5$ which would require ten electrons around the nitrogen kernel.

*Nitrogen-Hydrogen Compounds.* The octet theory indicates that $NH_3$ and $H_2N-NH_2$ should exist and have the properties they do. The compounds $NH$, $NH_2$, $NH_4$ and $NH_5$ cannot exist since in these cases we find $p=1$, $\frac{1}{2}$, $-\frac{1}{2}$ and $-1$ respectively, whereas $p$ must be equal to zero for a single octet. The theory thus automatically shows the radical difference between the number of oxygen and hydrogen compounds that may be formed.

For the ammonium ion $NH_4^+$ we find $n=1$, $e=8$, $p=0$. The structure of this ion is thus exactly like that of the methane molecule. The positive charge is the cause of its resemblance to the potassium ion.

Hydronitric acid, $HN_3$, gives $n=3$; $e=16$ and therefore $p=4$. This leads to the formula $HN=N=N$ as the most probable structure.

*Peroxides.* In the oxides of nitrogen and in the nitrogen acids we have seen how oxygen atoms can attach themselves to any octet in which two or more of the electrons are not already held as stable pairs. Thus in Fig. 9, $HNO_3$ is obtained merely by adding an oxygen atom to the only remaining free pair of electrons belonging to the nitrogen atom of $HNO_2$. Since oxygen atoms have six electrons, they can form an octet by sharing two electrons with some atom which already has an octet. In the case of the nitrogen acids this process could go on until all of the electrons of the nitrogen octet were shared with oxygen atoms. This is quite analogous to the addition in organic molecules of $CH_2$ groups which also have stable pairs of electrons.

We shall see that oxygen atoms can add themselves not only to nitrogen atoms but to chlorine, bromine, iodine, phosphorus, sulphur, and other atoms. They can also add themselves to some extent to each other. Thus if we apply the octet theory to hydrogen peroxide, we find $p=1$. This leads either to the structure $HO-OH$, or equally well to the structure $H_2O-O$ as shown in Fig. 10.

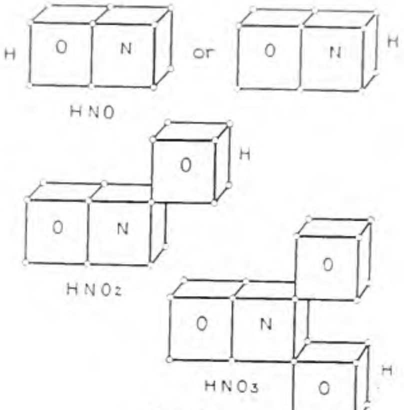


Fig. 9.

**Diagrams of Molecules of Nitrogen Oxy-acids**

As a matter of fact, the hydrogen nuclei are probably very mobile and readily shift from one pair of electrons in an octet to another. It may well be that the ease with which this shift occurs is the cause of the high dielectric constant of such substances as $H_2O$, $NH_3$, etc. Such an effect does not exist in the case of the hydrogen in hydrocarbons, for all the electrons in the carbon octets are held as stable pairs so that the hydrogen nuclei cannot shift positions. The structure given in Fig. 10b for $H_2O_2$ agrees well with most of its properties. According to the ordinary theory this structure implies a quadrivalent oxygen atom. But the octet theory requires nothing at all unusual in the properties of the oxygen atom.

In a similar way for ozone we find $p=3$ which leads to the formula $O=O-O$ as shown in Fig. 11a. For the oxygen molecule, however, we find $p=2$ so the structure is $O=O$ as shown in Fig. 11b. This structure for ozone brings out its relationship to the peroxides much better than the ring structure suggested by the ordinary valence theory. The structure and symmetry of the oxygen molecule account for its stability and the low boiling point of liquid oxygen.

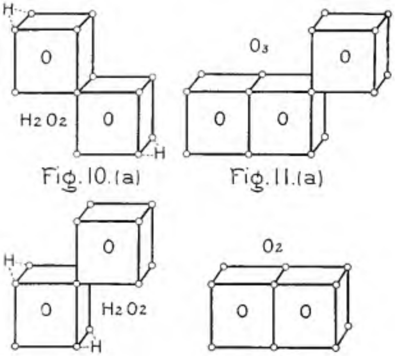


Fig. 10. (a) Fig. 11. (a) Fig. 10. (b) Fig. 11. (b)

Diagrams of Molecules of Hydrogen Peroxide and Ozone

### The Structure of the Nitrogen Molecule

The properties of elementary nitrogen are in many ways extraordinary. The contrast between the properties of carbon and nitrogen, elements adjacent to each other in the Periodic Table, could hardly be more striking. Carbon does not melt even at 3700 deg. C., while nitrogen has a lower boiling point than any substance except hydrogen, helium and neon. Nitrogen, although many compounds with oxygen exist, combines with oxygen only at exceedingly high temperatures and even then only to a small degree. Carbon, notwithstanding the great affinity of its atoms for each other as shown by its low vapor pressure, combines readily with oxygen at moderate temperatures. Even at the temperature of melting tungsten (about 3600 deg. K.) there is evidence that nitrogen is not appreciably dissociated into atoms.*

This stability of the nitrogen molecule, which is so much greater than that of a compound such as carbon dioxide, must be due to some unusual kind of structure.

If we apply the octet theory to the nitrogen molecule by placing $n=2$; $e=10$ we find $p=3$. We are thus led to the formula $N\equiv N$ for the nitrogen molecule. Now in acetylene we have an illustration of two atoms holding three pairs of electrons in common. Such a substance is endothermic, forms addition products easily, and even by itself is relatively unstable. A structure of this kind could not possibly account for the properties of nitrogen.

In its boiling point and in fact in most of its properties elementary nitrogen resembles argon. The boiling points of gases on the absolute scale being approximately proportional to the molecular heats of evaporation, serve as a measure of the external field of force of the molecules. By examination of a large number of organic compounds it appears that the freezing point is dependent to a marked degree on the symmetry of the molecule—the more symmetrical the molecule, the higher is the freezing point. The following table gives the freezing points and boiling points of oxygen, nitrogen and argon on the absolute scale.

| | $O_2$ | $N_2$ | $Ar.$ |
|---|---|---|---|
| Freezing point . . . | 38° K. | 63° | 85° |
| Boiling point . . . . | 90 | 77 | 87 |
| Difference. . . . . . . | 52 | 14 | 2 |

Judging from these boiling points the nitrogen molecule must have a weaker external field of force than either that of oxygen or argon. The differences between the freezing points and boiling points indicate that the nitrogen molecule is very much more symmetrical than that of oxygen and approaches that of argon. The outside layer of electrons in the argon atom consists of a single octet. The evidence given above suggests that the nitrogen molecule also has an outer shell consisting of a single octet. Is such an arrangement possible?

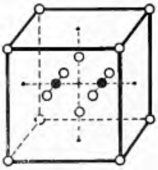


Fig. 12.

Diagram of Nitrogen Molecule

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* Langmuir, Jour. Amer. Chem. Soc., 34, 876 (1912).

The two nitrogen atoms in a molecule have a total of 14 electrons. We may assume that each nucleus binds two electrons to form a stable pair according to Postulate 9. The two nitrogen kernels each with five positive charges, are then surrounded by a total of ten electrons. There are thus two electrons more than are needed to form the octet. In view of the stability of the octet (Postulate 10) and the relatively large charges on the two kernels, it seems reasonable that the pair of extra electrons should be imprisoned within the octet and be held by the two nitrogen kernels (Postulate 9d) as shown in Fig. 12.

Structures of this kind are not usual but it is evident that in this case there are a number of exceptional factors operating to bring about just this result. The original nitrogen atoms are thoroughly unsaturated and very unsymmetrical and thus have large external fields of force. The number of electrons (5) in each shell is such that two atoms cannot form a molecule by forming two octets unless three pairs are held in common, something which seldom occurs with nitrogen atoms. Three nitrogen atoms cannot combine to form a single molecule for this would give an odd number of electrons. Finally it so happens that there are only two electrons too many to form a complete single octet, and that there are two kernels of small volume but with large positive charges, to bind this extra pair.

This structure of the nitrogen molecule explains in a perfectly satisfactory way all the remarkable properties of elementary nitrogen previously mentioned. The high heat of formation of nitrogen molecules from the atoms accounts for the great number of endothermic and explosive nitrogen compounds. It is also evident why elementary nitrogen is so unusually inert, while in its compounds it is one of the most active of the elements.

*Carbon Monoxide.* The structure of the molecule of this gas has long been a puzzling problem. According to the ordinary valence theory, carbon in this compound must be divalent, and hence should be very much unsaturated. Yet carbon monoxide is a relatively inert substance. Its very low boiling point proves that its molecules have very little external field of force. Its small solubility in water, and the difficulty of finding chemical substances which combine with it at room temperature, do not fit in well with the theory of the divalent carbon atom, for such an atom should show much more active properties—logically its properties should resemble those of atomic hydrogen.

As a matter of fact carbon monoxide resembles nitrogen to an extraordinary degree, as shown by Table IV which indicates that the physical properties of these two gases are identical almost within the probable limits of experimental error.

TABLE IV
PHYSICAL PROPERTIES OF GASES

| | CO | $N_2$ | A | $O_2$ | NO |
|---|---|---|---|---|---|
| Freezing point °K | 66 | 63 | 85 | 38 | 106 |
| Boiling point °K | 83 | 78 | 87 | 90 | 120 |
| Critical temp. °K | 122 | 127 | 156 | 155 | 180 |
| Critical pressure Atm. | 35 | 33 | 53 | 50 | 71 |
| Critical volume | 5.05 | 5.17 | 4.04 | 4.26 | 3.3 |
| Solubility in water, 0°C. (%) | 3.5 | 2.4 | 5.8 | 4.9 | 7.4 |
| Density of liquid at boiling point | 0.793 | 0.796 | | | |
| Viscosity $\eta \times 10_6$ at 0° C. | 163 | 166 | 210 | 187 | 165 |

This evidence alone should be sufficient to prove that the structure of the shell of the carbon monoxide and the nitrogen molecule must be nearly identical.

However, the case is still stronger when we consider that the total number of electrons in the molecule is the same in both gases. Thus in one case we have two nitrogen atoms with seven electrons each, while in the other we have carbon with six, and oxygen with eight. Evidently the reasons which led us to assume that the nitrogen molecule has an outside shell consisting of a single octet apply with the same force to the carbon monoxide molecule.

In the carbon monoxide molecule there is then an imprisoned pair of electrons within the octet held as a stable pair by the carbon and the oxygen kernels having charges of four and six respectively.

This theory explains why nitrogen and carbon monoxide are alike in all properties in which a separation of the kernels is not involved. The fact that the two kernels in carbon monoxide have unequal charges makes it much easier for this structure to break down. Thus while nitrogen shows no signs of dissociating at temperature of a couple of thousands of degrees, carbon monoxide enters into a few reactions even at room temperature and many reactions at temperature of a few hundreds of degrees. Its reaction velocity is, however, usually very slow indicating that only a small fraction of the molecules is in a form in which the kernels can be separated.

Once the kernels have been separated the carbon monoxide behaves like a very much unsaturated body. It seems probable that at higher temperatures, the carbon monoxide exists in two tautomeric forms—one in which the outer shell is a single octet, and the second in which there are two octets. According to the octet theory the formula of this second form would be $C \equiv O$. This would immediately react with oxygen to form $O=C=O$.

*Nitric Oxide.* Lewis has pointed out that among the compounds of the first 20 elements there are only about a half dozen cases in which there is an odd number of electrons in a molecule. With the exception of nitric oxide, these are all substances which by their color or their intense chemical activity act as though they might have a free electron either in the outside shell or close to it. Nitric oxide, however, is colorless and very stable even at high temperatures. Although it reacts with oxygen to form $NO_2$, this reaction takes place rather slowly, so that the claim can hardly be made that the substance has remarkable chemical activity. Compared to the other oxides of nitrogen it is characterized by its very low boiling point.

The molecule of this substance contains 15 electrons—just one more than the molecules of nitrogen or carbon monoxide. It seems most probable that it has a similar structure and that the extra electron is imprisoned within the octet comprising the shell. This process seems more probable when we remember that the two kernels of the $NO$ molecule have a total of eleven positive charges as compared to the ten in the nitrogen and $CO$ molecule. With this structure the odd electron is so placed that it does not produce the effects usually characteristic of an odd electron. It is of interest in this connection that nitric oxide is remarkably paramagnetic. This is undoubtedly dependent in some way on this internal odd electron.

According to the last column of Table IV, the properties of nitric oxide differ very appreciably from those of nitrogen and carbon monoxide, but not more so than we should expect from the presence of an extra electron within the shell. All the differences in properties shown in this table indicate that the odd electron increases the external field of the atom. The greater chemical activity as compared to $N_2$ and $CO$ is also due to the same cause.

*Hydrocyanic Acid.* There has been much discussion as to the constitution of this compound. It is generally agreed, I think, at present that it has a divalent carbon atom like that in carbon monoxide and is represented by the formula $H-N=C$.

The total number of electrons in this molecule is 14—the same as in the nitrogen and carbon monoxide molecules. This fact together with its resemblances to carbon monoxide suggest that here again we have an imprisoned pair of electrons within an outside shell consisting of an octet. The total charges on the kernels of nitrogen and carbon is nine instead of ten as in the $N_2$ and $CO$ molecule. This somewhat decreases the stability and at the same time gives a negative charge to the whole $CN$ radical so that it must combine with a hydrogen nucleus, or form a negative ion. Two such ions can combine by sharing a pair of electrons—thus releasing the electrons and leaving the uncharged cyanogen molecule $(CN)_2$. It is well known that cyanogen has a very close resemblance to chlorine in many ways. Thus chlorides and cyanides are often isomorphous; silver chloride and cyanide have similar solubilities, etc. The theory of the constitution given above indicates that this resemblance is not accidental nor is it merely due to the fact that both ions are univalent. It depends on the fact that both the cyanogen ion and the chlorine ion have outside shells that consist of single octets. The relation between these two ions is like that between elementary nitrogen and argon.

It seems that these four substances, nitrogen, carbon monoxide, nitric oxide, and cyanogen are the only ones in which this double kernel within a single octet is possible. That this is so is also suggested by the symmetrical way in which $CO$, $NO$ and $CN$ are related to $N_2$, the element which lies just between $C$ and $O$ in the Periodic Table. With the exception of these four substances having a special structure and such an

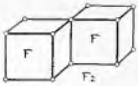

Fig 13.

**Diagram of the Fluorine Molecule**

obviously unsaturated compound as $NO_2$ we have found that all the ordinary compounds of carbon, hydrogen, nitrogen and oxygen fit in well with the simple octet theory. This theory accomplished exactly what we stated the ideal theory of atomic structure should do—namely, it leads automatically to a valence theory for carbon-hydrogen-oxygen compounds which is identical with that in common use, while at the same time it indicates that this ordinary valence theory is inapplicable to nitrogen-oxygen compounds. The octet theory on the other hand applies equally well to nitrogen-oxygen compounds as to organic compounds. In all cases it leads to more definite conceptions of the structure of molecules and compounds and explains their chemical and so-called physical properties very much more completely than the older valence theory was ever able to do.

Let us now continue with a consideration of the properties of the elements and their compounds.

*Fluorine* $N=9$; $E=7$.—The fluorine atom has seven electrons in its shell. Its properties are therefore largely determined by the tendency to take up an additional electron to complete the octet. In the elementary state two atoms combine to form a molecule because by so doing each atom can complete its octet. Thus if the molecule is $F_2$ we have $n=2$; $e=14$, whence $p=1$. By sharing a single pair as shown in Fig. 13, both octets are completed.

The very low boiling point of fluorine indicates that the stray field around this molecule is small. On the other hand, the remarkable chemical activity shows that there is a strong tendency for these atoms to avoid sharing their electrons with each other. Thus when lithium and fluorine are brought together, the extra electrons from the lithium atoms are taken up by the fluorine atoms and each atom is able to get its own octet instead of being compelled to share it with another atom. The very large heat of formation of lithium fluoride (about 110,000 calories per gram molecule) must be, in greater part, the heat equivalent to the difference between a free octet and one which shares two of its electrons. The energy liberated when an *atom* of fluorine, with its seven electrons in the shell, takes up another electron would be greater than the above by the energy required to dissociate fluorine into atoms—a quantity which has never been determined but which must be very large.

The question arises, why do atoms share their electrons with each other, if there is such a tendency for the octets to keep separate. The answer, of course, is that there are not enough electrons in the outside shells of atoms to form octets around their kernels unless they share them with each other. Furthermore, most atoms if they completed their octets, without sharing electrons would have very high charges on their atoms which would tend to prevent their formation.

*Hydrofluoric Acid HF.* The electrons from the hydrogen allow the fluorine atoms to have separate octets. The hydrogen nucleus is then held by a pair of the electrons forming the octet. The large heat of formation of hydrofluoric acid gas (38,000 calories) notwithstanding the fact that hydrogen atoms have to dissociate during the process, indicates that with fluorine there is little tendency to avoid sharing one of the pairs of the octet with a hydrogen nucleus. This is another illustration of the fact brought out in Postulate 9 that the tendency to form a stable pair between a kernel and a hydrogen nucleus (Case c) is much greater than the tendency to form a pair between two kernels (Case d).

The molecule of hydrofluoric acid from its structure should have a small stray field. Most of its surface is like that of a neon atom and the part where the hydrogen nucleus is resembles that of a hydrogen molecule. However, the lack of symmetry should increase the stray field much above that of either neon or hydrogen. We should thus expect *HF* to be a gas or liquid not greatly different from water in its boiling point. As a liquid it should be a non-conductor, but because of its polar character, it forms an electrolyte when dissolved in water. That it forms a rather weak acid in water solution is, I think, due to the small volume of the fluorine atom which greatly increases the electric force tending to prevent dissociation. The whole question of the effect of atomic volumes on the properties of the atoms will be discussed in another place.

*Lithium Fluoride LiF.* This consists of positively charged lithium kernels and negatively charged fluorine atoms. It is, therefore, a solid salt, which conducts electrolytically when molten.

*Carbon Tetrafluoride $CF_4$.* By applying the octet theory taking $n=5$, $e=32$; we find $p=4$. Or we can take $n=4$ and get $p=0$. In the first case the carbon atom shares its electrons with four fluorine atoms, while in the second it gives up four electrons to the fluorine atoms, these fluorine ions being then held by electrostatic forces to the positively charged carbon kernels. In general the first structure would be much more probable but in view of the exceptional properties of fluorine and the difficulty with which it shares electrons it may well be that the second structure applies to this case.

*Nitrogen* or oxygen alone does not form any compounds with fluorine. Together they form $NO_2F$ and $NOF$, both gases resembling fluorine in their chemical activity. This fact is very interesting for $NO_2$ and $NO$ are remarkable in that they both exist separately but *have an odd number of electrons*. The fluorine atom which has an abnormally large affinity for an electron takes the odd electron from these substances even though it is incapable of combining with oxygen or nitrogen in any other form.

The reasons that fluorine does not form compounds with nitrogen, oxygen or chlorine seem to be as follows:

Helium and neon have the most stable atoms of any of the elements. More energy must be expended to remove an electron from these atoms than from any of the others. The elements hydrogen and fluorine which differ from helium and neon in having one electron less should be expected to have the strongest tendencies to take up electrons. However, this argument needs a radical modification in the case of the hydrogen atom for the change on this nucleus is only half that on the helium nucleus. The tendency for the hydrogen atom to take up an electron will therefore be very much less than that of the helium atom to hold its electrons. In the case of fluorine and neon this effect is not so serious for the charge on the fluorine kernel is seven eighths of that on the neon kernel.

There is another factor, moreover, which largely eliminates the electronegative character of hydrogen, namely, that the stable pair of electrons held by the hydrogen nucleus can at the same time form part of an octet. For example, consider what must happen if we bring together a hydrogen atom and a fluorine atom. Let us suppose for a moment that the hydrogen atom has such a great affinity for an electron that it takes an electron from the fluorine, leaving this with only six electrons. The positively charged fluorine then attracts the negatively charged hydrogen, and, since the stable pair can at the same time form part of an octet, the fluorine is then able to bind the hydrogen nucleus together with its pair. For this reason the tendency of the hydrogen nucleus to take up electrons does not interfere with other electronegative elements from getting theirs. Hydrogen therefore can hardly be classed as an electronegative element.

According to our theory, therefore, fluorine should be the most strongly electronegative element, while for similar reasons chlorine and oxygen should come next.

Fluorine in the free state, $F_2$, already has enough electrons to form an octet about each atom. The atoms strive, however, to get a structure exactly like that of neon, that is, one in which each atom has eight electrons of its own. This means that fluorine has comparatively little tendency to combine with other elements except insofar as it can acquire its electrons outright. That is, it has a strong tendency to *take electrons from* other atoms instead of sharing them with other atoms. Now oxygen, nitrogen, and chlorine, as elements as well as in their compounds, always have octets around their kernels. The fluorine molecule, therefore, in order to take electrons from these electronegative elements, must break down these stable octets. Undoubtedly atomic fluorine would be able to do so, but it is natural enough that molecular fluorine which already has an octet for each atom (although shared) should not be able to accomplish this. On the other hand, elements like boron, silicon, phosphorus, and sulphur form some compounds in which their atoms do not contain octets, but hold the surrounding atoms by means of their charge. The charge on the kernels of these elements is not so great but that fluorine can take their electrons. It is true that the fluorine compounds of carbon and silicon and a few compounds with other elements do seem to involve a sharing of electrons between the fluorine atom and that of the other elements, but it is probable that it is easier to share electrons with atoms having small charges on their kernels than with those having large charges.

The fact that fluorine prefers to share electrons with its own atoms rather than with those of any except more electropositive elements such as carbon, phosphorus, etc., is probably due mainly to the greater symmetry of the molecule formed in this way.

*Neon.* The atoms of this element already having complete and separate octets have no tendency to take up or give up electrons nor to share them with other atoms. Neon thus forms no primary valence compounds. However, there is a stray field of force around the atoms and this accounts for the liquefaction and solidification of the gas at low temperatures.

*(To be Continued)*

# The General Electric Company in the Great World War

## PART II. RESEARCH WORK

By John R. Hewett

Editor General Electric Review

In our last issue we told of some of the Company's war activities other than research [illegible]. In this issue we deal with some of their research work. It is no exaggeration to state that [illegible] volumes might be written on most of the subjects mentioned, this being specially true in the case of the X-ray developments and submarine detection. However incomplete this story may be, it is hoped that it will show our readers the general nature of the Company's war work.—Editor.

There is a great deal of romance in the research work of the General Electric Company which has always appealed to the writer, who has always seen in that broad minded policy which built up the Company's research facilities the spirit which has raised the whole organization above the level of a mere money-making concern to be a real national asset, indeed, an asset to the world at large.

The history of the research laboratory's share in the scientific developments of recent years is too long to write, but those in any way familiar with its work know what rich fruit it has borne in converting the resources of nature to the useful service of man.

At times the investigations carried out by some of the prominent members of the research staff have seemed to be of a purely academic nature. When Dr. Langmuir started his earnest investigations of a certain phenomenon, which sometimes appears in incandescent lamps, commonly called the Edison effect, which none under-

Fig. 1. View of the Great Research Laboratory at Schenectady which was Devoting Its Entire Energies to War Work up to the Time of the Armistice. A brief account of some of this work is given in this issue

stood, his work might have been considered purely academic, but it led to the discoveries of some totally new principles governing electrical discharges in high vacua. He incidentally learned to produce a higher degree of vaccum than had ever been produced before.

This purely academic research had far reaching results and among them were some that helped to win the war. One result was that it laid the foundation for the Coolidge X-ray tube, as Dr. Coolidge started with the new principles discovered by Langmuir, and produced a radically new X-ray tube, far more effective, more powerful and more reliable than any tube in existence. There is no question but that the modern, practical, long distance, wireless telephone owes much of its development to this same research. The value of a well organized research laboratory and of its staff is high in times of peace, and it is still higher in times of war.

The Research Laboratory at Schenectady employs about 250 people. About one quarter of these are highly trained physicists, chemists metallurgists and engineers, and among these are some men in the very first ranks of science and of international reputation. The equipment is so large and of such a variety, and the experience of the staff so varied that the whole organization was a peculiarly valuable asset in prosecuting war work.

In the great Research Laboratory at Schenectady are to be found furnaces which can produce far higher temperatures than any other of their kind in existence, and then going to the other end of the temperature scale, there are daily produced several gallons of liquid air. It is here that they can produce and measure a higher vacuum than others knew how to obtain, and it was they alone that had the facilities and knowledge of shaping into all sorts of forms tungsten and molybdenum—metals so difficult to work, but of such great value in vacuum tubes.

The Research Laboratory at Schenectady was also the sole producer in this country of a number of materials, such as calcium, which before the war were made only in Germany.

It was the recognition of these facts that led the President of the Company specifically to mention the Research facilities when he offered the Company's resources to the Government to aid in prosecuting the war.

Mr. Rice's instructions to the Research Laboratory were that it was their first duty to do all they could to help win the war, and he told the Director of Research, Dr. W. R. Whitney, that the Laboratory could draw on all the engineering and manufacturing facilities of the Company as far and as fast as it needed them. It did.

The result of this combination of scientific men, engineers and unequaled manufacturing facilities, enabled results to be accomplished in record time and the value of such a combination under the management of one organization has been most highly spoken of, especially by representatives of the British Admiralty.

To give a coherent account of the Research Laboratory's war work seems impossible, so we shall only mention some of the more notable, but during the entire period after America entered the war until the armistice was signed the Research Laboratory was the scene of feverish activities; night work and Sunday work was the order in vogue for the entire period. The difficulties of getting war work out on a hurried basis were as varied as they were numerous. The troubles of getting essential materials from outside firms already overloaded with A1 priority orders, of undertaking one new job after another, each demanding more physicists, more skilled mechanics, more glass blowers, and not knowing where to turn to find them in a country already stripped by the Government's needs were hard to meet, but were met and overcome. The making of all shipments by special messenger to avoid freight and express congestion, and the need of speed and always more speed, and the wondering how much longer the men could stand the strain added to the problem of production, but these adverse factors were not allowed to hinder the constant work and accomplishments.

### SUBMARINE DETECTION

As soon as it appeared certain that America would enter the war the Research Laboratory at Schenectady started studying the problem of submarine detection. This was considered the most pressing of all war problems. All such experimental work was carried out in close co-operation with the Navy Department. It will be recalled that Mr. Daniels had created the Naval Consulting Board some little time before the declaration of war. Dr. W. R. Whitney, the director of Research of the General Electric Company, was elected by two different societies a member of this Board. The formation of this Board had the happy result of bringing technical and scientific experts from a variety of industries into co-operation with the Navy

Department to study the solution of naval problems.

As early as February, 1917, at a meeting of the Naval Consulting Board in New York, Dr. Whitney suggested co-operation with the Submarine Signal Company. During the same month the Special Problems Committee of the Naval Consulting Board visited Boston to witness demonstrations of the submarine devices developed up to that date by the Submarine Signal Company.

It was decided that a shore station was necessary for experimental purposes, which led to the Submarine Signal Company building such a station at Nahant, and it was here that so much of the early experimental work was carried out.

It is interesting to record that the Nahant Station was built and that the General Electric Company and the Submarine Signal Company started active work on April 7, 1917, the Western Electric Company joining them early in May.

It was also in May that the Secretary of the Navy created a Special Board on Anti-Submarine Devices and this Board wired to Mr. H. J. W. Fay, of the Submarine Signal Company, Dr. F. B. Jewett of the Western Electric Company, Dr. R. A. Millikan of the National Research Council, and Dr. W. R. Whitney of the General Electric Company, asking them to become advisory members of the Board. In this way a large amount of highly skilled effort backed by adequate manufacturing facilities were brought to bear on this important problem and in a short time new detection instruments were evolved.

Some of the best men in the Company's organization were devoting all their time to this work and were continually carrying out an organized campaign in both the design and manufacture of special apparatus for the detection of submarines. War-time conditions were stimulated as near as possible in carrying out these tests with the apparatus developed. These tests were carried out in connection with the Navy Department who supplied and operated the destroyers, submarines and chasers which were necessary for actual practical tests in the hunting of submarines. The Nahant group were kept informed on European developments by the Special Board through the visits of special commissions sent to this country for this purpose, who brought over samples of detection apparatus already developed in Europe. After about five months of feverish activity the Nahant group developed a submarine detector which the Special Board and Navy Department considered satisfactory and which was put into production. Some of these devices were sent over to the British Admiralty for test, and a special representative was sent abroad to keep in touch with European development.

The progress of development was rapid and other types of apparatus were produced and in December, 1917, some members of the Nahant group accompanied a Naval Commission abroad which took the different devices developed in America over to Europe and gave actual practical demonstrations of their use. Most of the detective devices used by the U. S. Navy at the time of the armistice were manufactured by the General Electric Company and many of the most important developments were made by the Nahant group; a large number of these devices were used by the British Admiralty.

A short time before the signing of the armistice the development work at Nahant was completed and many of the men who had been working there were transferred to the U. S. Naval Experimental Station in New London, Conn., which was the headquarters of the Special Board. Most of the actual production work of this special apparatus was carried out at the Lynn factory of the General Electric Company, but there were always a large number of men carrying out investigations in connection with this work at the Research Laboratory at Schenectady. In fact, a special experimental station was started on the Mohawk River, and when the river froze over some of the Company's men went to Key West to continue their investigations through the winter of 1917-18. Many experiments were also carried out in the Erie Canal.

It is expected at some future date that the ban on publicity concerning the work that the General Electric Company, in conjunction with others, did on submarine detection will be removed, and then a most interesting story can be written on their contribution toward the solution of this problem which, by many, was considered the most vital of the whole war.

Prof. Elihu Thomson and others were working at Lynn on some special problems in connection with submarine detection, but the particular class of work on which they were engaged is still considered secret.

### X-ray Work

The accomplishment of the Research Laboratory at Schenectady in connection with the development of the modern X-ray tube is well known throughout the world. Their work during the war in the production of apparatus to meet the special requirements of war was, perhaps, one of the most notable contributions made to this highly important branch of the military surgical service.

It should be noted that the tube developed for this service at Schenectady is entirely distinct from any formerly made; and that the Research Laboratory designed and in conjunction with other manufacturers, put into production a portable X-ray outfit, and that these outfits were extensively used during the war.

The great value of X-rays as a diagnostic adjunct to surgery was well known at the outbreak of the war. Its special value for the location of foreign bodies and the treatment of bone injuries was well recognized. Almost from the beginning of the war a high standard of X-ray work was developed in all the military base hospitals as rapidly as possible. A few months of actual war experience taught that the most effective use of X-rays could be made at the point where the wounded receive their first operative treatment; and that it was important that the patient be operated on as soon after receiving the wound as possible. For this reason the first operating point was usually located well up towards the battle front. The difficulties of making X-rays available at this point were apparent from the beginning. It should be remembered that X-rays are usually generated by the discharge of high tension current, say from 40,000 to 90,000 volts, through a specially constructed vacuum tube, and that pre-war X-ray tubes required unidirectional current for their operation.

The apparatus for developing and controlling such high tension unidirectional current was heavy, complicated and easily thrown out of adjustment. These inherent features made its transportation and operation within the war zone almost out of the question. Various types of portable apparatus were designed and turned out by the allied armies, but none met with much success; some being too heavy and some too delicately adjusted. Most of them in an endeavor to reduce weight had sacrificed power to such an extent that the quantity of the X light produced was too small to be of practical use. There was excellent X-ray service well up toward the front of each of the various allied armies but this service had been built up around heavy immobile units installed behind what was apparently a stabilized battle line. But it was incompatible with the hope of victory that this line should not some day be in movement. Therefore the development of a portable X-ray outfit was being carefully studied by each of the allied armies at the time the United States entered the war.

Fig. 2. Special Self-rectifying, Radiator-type Rœntgen-ray Tube Developed by the Schenectady Research Laboratory for the Army Medical Service. Many thousands were made by the Company during the war and they were used extensively by the Army

This problem was solved by the Research Laboratory at Schenectady, and the solution was based on the development of a new type of X-ray tube specially designed to meet the severe requirement of this service.

This new tube had the property of rectifying the current so that it might be connected directly across the terminals of a high tension transformer. It was capable of positive control and of practically continuous operation, while the X-rays produced were limited only by the requirement of the service.

This new tube eliminated the necessity for the complicated and delicate power consuming rectifying apparatus and made it possible to reduce the weight of the machinery necessary for its operation to a point where comparatively high power units could be made readily portable.

Around this new tube two types of portable X-ray outfits were constructed, both of which were at once adopted by the United States Army for use in their field hospitals. These outfits were developed with the assistance of various manufacturers of special apparatus.

One of these outfits included a complete electric generating plant, forming an entirely independent unit which could be loaded on a Ford truck and delivered anywhere in the war zone ready for instant action. If this outfit were to be compared with the best then developed in Europe it would be found to weigh less than half and to furnish three times the power; or in other words, it was about six times as efficient in terms of X light produced per pound of equipment. The importance of these characteristics for a portable apparatus are hard to over estimate.

No part of this outfit was too heavy to be handled easily by two men and all parts with the exception of the new tube were of standard design. No adjustments were necessary and all that was needed for operation was to close a single switch. The set was fool proof, as the tube could take the whole output of the generator without damage.

The Schenectady Research Laboratory sent a special representative over to the war zone to observe the operation of these outfits and to gather suggestions for possible improvements. He spent nine months on the other side studying the field and base hospitals of the British, French and Italian armies, reporting his findings to the Laboratory. When the new outfits arrived in the hands of the U. S. Red Cross units they at once demonstrated their effectiveness, convenience, and reliability. Whatever might have been the case with other equipments, in X-ray outfits, at least, the U. S. Army had from the start a great advantage over all others.

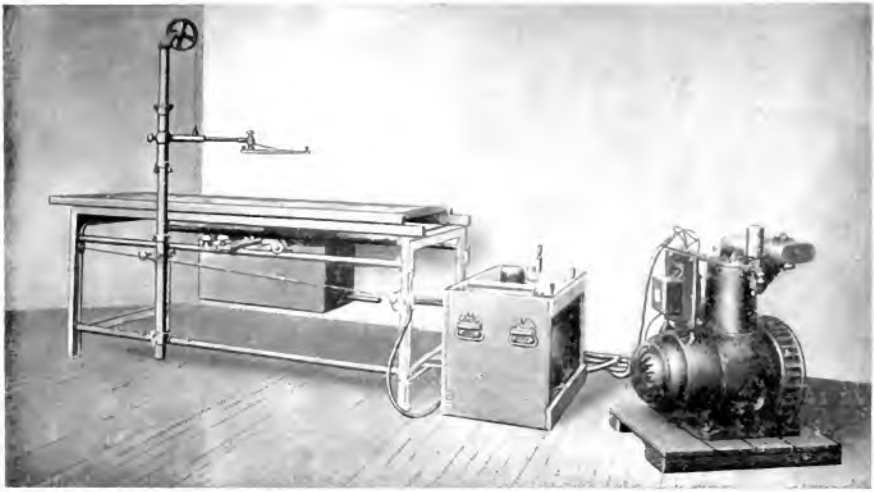

Fig. 3. A Portable Type of Roentgen-ray Outfit Developed for the Army Medical Service by the Schenectady Research Laboratory of the General Electric Company. At the right will be seen the self-contained gas-electric generating unit. In the box in the center are located the Roentgen-ray and filament transformers, the filament current control, and booster; and on the top of the box are the line voltmeter, line voltage rheostat, tube current milliammeter, and operating switch. The Roentgen-ray tube is contained in the movable box beneath the table.

The operation of these sets was so successful that before the close of the war they were being used to replace the heavier and more complicated machines in some of the base hospitals.

A great number of these tubes were made by the Company during the period of the war. An interesting point in connection with this

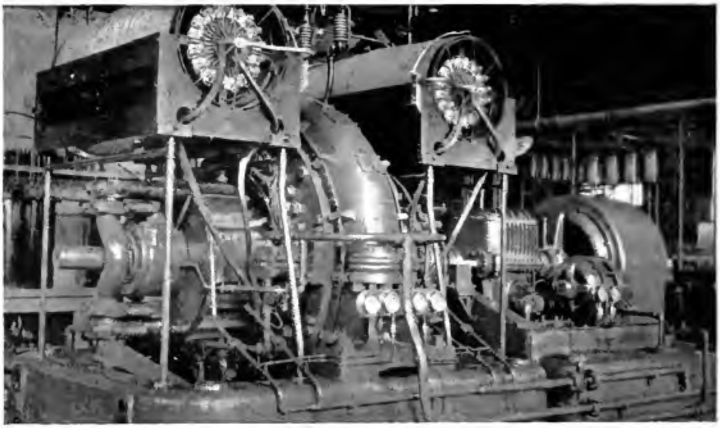

Fig. 4 The 200-kw., 25,000-cycle Radio Alternator with Transformers at the New Brunswick, N. J., High-power Radio Station which was Equipped by the General Electric Company and placed at the Disposal of the Government. This station sent direct to Germany President Wilson's famous message demanding the abdication of the Kaiser; and it then continued as our "mouthpiece" in transmitting to Germany those messages which finally led to the negotiation of the armistice

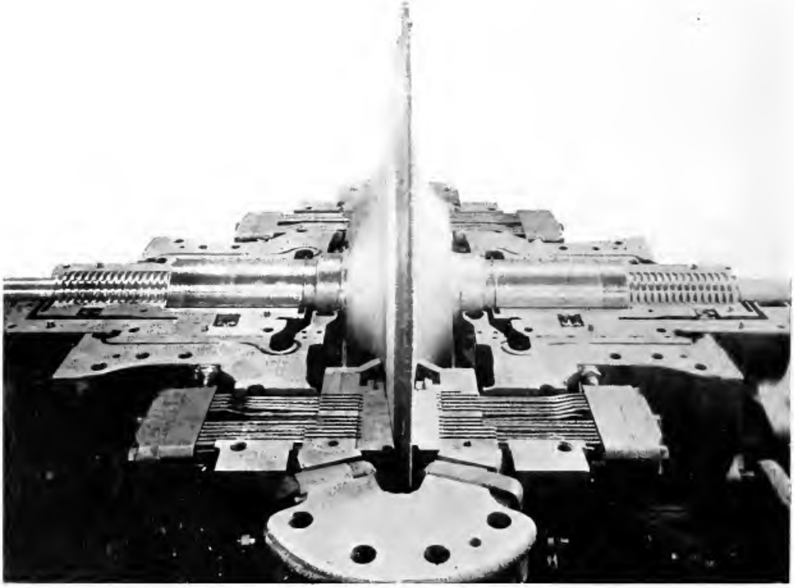

Fig 5. The 200-kw., 25,000-cycle Radio Alternator with the Upper Half Removed

work is the fact that each tube required the use of about twelve dollars' worth of platinum, which gave the Company the unenviable distinction of being the largest user of platinum in the country. It is still more interesting to learn that the Research Laboratory set to work to find a substitute for platinum and in a short time developed a special alloy which did the work equally well and released a large quantity of platinum for other war purposes.

It was no easy matter to put this new Coolidge X-ray tube into quantity production. All other parts of these portable outfits were standard, but the tube was new. It was difficult to make the required facilities for its manufacture, which existed only in the Research Laboratory at Schenectady and even here in insufficient quantity for the demands. A large number of skilled glass blowers would be required, so the Laboratory started a school for glass blowers, selecting one of their best men as instructor and some of the brightest boys in the Laboratory as pupils, and in a few months' time these boys were performing successfully all but the most difficult operations.

At the same time there were other experts set to work studying the operations and designing special machinery to perform them. The Company started a small factory under the Laboratory's supervision and called in lamp factory experts to study the manufacturing processes to help speed up production. To insure against the possibility of interruption by fire or other unforeseen causes one of the lamp factories was started on making Coolidge tubes. By these methods the Company took care of the U. S. Army and Red Cross units and before the armistice was signed were in a position to supply tubes to the Allies.

Fig. 6. Device for Amplifying Telegraphic Impulses or Telephonic Vibrations in Order that their Range of Transmission by Radio be Increased. The "magnetic amplifier," as it is called, is here shown removed from its case in which it is submerged in oil and cooled by water circulation

### Radio

The Company's accomplishments in radio work both in the field of telegraphy and telephony were many and varied. One of the striking technical results of the war that will probably have far reaching peace-

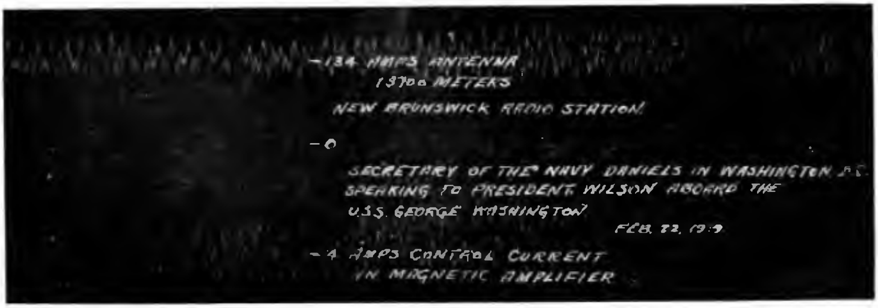

Fig. 7. On February 22nd, this Year, Secretary Daniels at His Desk in Washington Held Telephone Conversation with President Wilson on the *S. S. George Washington* 500 Miles at Sea. (The Distance was Limited only by the relatively small capacity receiving apparatus installed on the *George Washington* at that time.) Secretary Daniels' voice vibrations were transmitted via ordinary long distance land telephone lines to the New Brunswick station where they were automatically amplified and transformed into radio vibrations for reception by President Wilson's receiving outfit. This illustration is an oscillographic record of a few of the control and amplified current waves of Secretary Daniels' voice

time results is the development of Transatlantic radio communication into an accurate and dependable system that can be counted on every day of the year and almost every hour of the day.

Fig. 8. 150-watt Dynamotor for Supplying Energy to the Medium Power Pliotron Set Shown in Fig. 13

Fig. 9. Ship-airplane Radio Telephone Transmitter and Receiver Used on Smallest Type of Naval Aircraft for communication between seaplanes and ship up to 30 miles; weight 12 pounds; supplied with energy from a wind-driven generator

The demands that are now being made on this system of communication can be shown by the recently announced policy of the government to send all government department dispatches by radio to relieve the congested cables.

Now that the bar of secrecy has been lifted it is possible to announce that during the last year the greater part of the government's dispatches were transmitted by a new radio system developed by the General Electric Company. The Company equipped the high powered radio station at New Brunswick, N. J., with its newly developed apparatus for Transatlantic telegraphy and telephony and placed it at the disposal of the government for official dispatches early in 1918, to meet the urgent demand for communication. The continuous and reliable service by this station has since been favorably commented on from distant parts of the world and has caused the Government to place orders with the Company for two transmitting equipments.

It is a matter of historic interest to record that it was the New Brunswick radio station that directed the first message to Germany after America's participation in the war. It will be remembered that it was in this message that President Wilson demanded the abdication of the Kaiser. That series of history-making messages which followed one another in such rapid succession and finally led to the speedy conclusion of the armistice were also sent from the New Brunswick station.

This new system of radio communication is known as the Alexanderson system and includes improvements which have been developed by the Company's engineers in all four stages which are common in all radio systems. These stages are, first, the generation of high frequency electric oscillations; second, the modulation of these oscillations

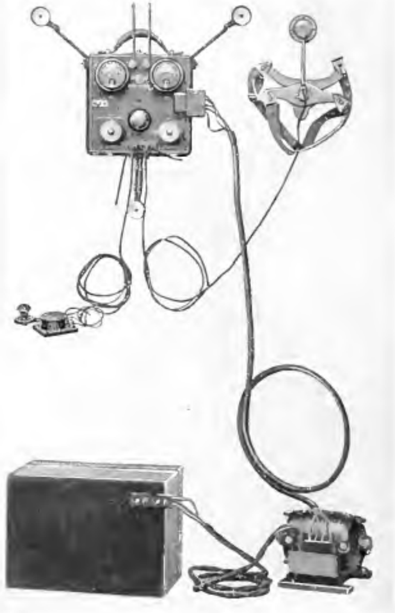

Fig. 10. Small Power Pliotron Set for Radio Communication from Seaplane to Base Stations or Other Aircraft. It has a Telephone Range of 60 Miles, weighs 8.5 pounds, and is supplied with energy from the dynamotor

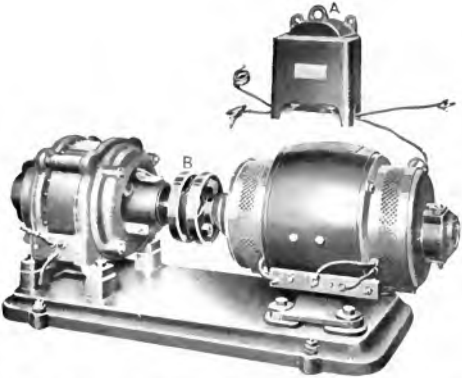

Fig. 11. Motor-generator Set and Transformer for Supplying Energy to Base-station Type Pliotrons (A) in Fig. 18

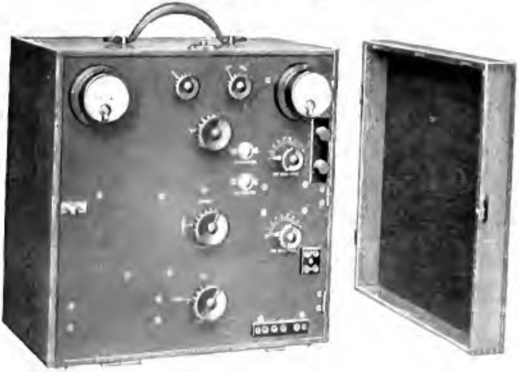

Fig. 13. Medium Power Pliotron Set for Radio Transmission from Flying Boats to Base Stations or Other Aircraft. It has a telephone range of 85 miles, weighs 18.5 pounds and is supplied with energy from the dynamotor shown in Fig. 8.

Fig. 12. 600-mile Continuous-wave Transmitter Employing Six 50-watt Pliotrons

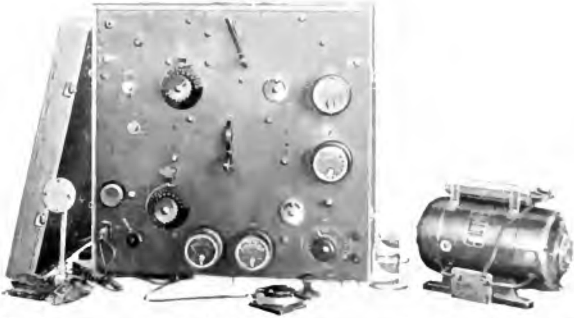

Fig. 14. High-power Pliotron Set for Radio Communication from Flying Boats to Base Stations or Other Aircraft. It has a telephone range of 200 miles and weighs [illegible] pounds.

into the dots and dashes of the telegraph code, or into the modulation of the human voice; third, the radiation of these electric oscillations in the form of waves, which travel with the velocity of light over the surface of the earth, and the fourth stage is the reception or detection of these waves by suitable instruments.

Fig. 15. Combination of Radio Receiver and Barrage Device. The upper portion comprises the receiver and the lower portion the Barrage Section. The Latter Device Screens out all disturbing static "noises" and thus permits the clear reception of the signals emanating from any selected transmitting station

In this new system the machine that generates these electrical oscillations is known as the Alexanderson alternator which has the advantage of giving a "pure wave" by virtue of which messages sent by different stations do not interfere with one another. There is just as much improvement in this new system over the older method as there is between the modern balanced telephone line and the old single-wire telephone on which the cross talk of neighbors could be overheard.

A new device known as the magnetic amplifier is employed as a modulator of the electric oscillations. This new device has no moving parts and this fact, coupled with its magnetic properties, renders it so quick as to make possible the transmission of telegraph messages at the rate of several hundred words a minute and also enables the amplification of the modulations of the telephone currents into oscillations sufficiently powerful to carry the human voice across the Atlantic. In all the different radio systems the radiator is called the antenna and up to the present time the antenna has been very inefficient, the useful energy radiated amounting to from 5 to 10 per cent. In the Alexanderson system a multiple tuned antenna is an important feature and increases the radiation efficiency from 20 to 50 per cent.

An improvement in the technique of receiving radio messages, which was primarily developed for military reasons, has become known as the "barrage receiver"; it promises to play an important part in the art of commercial communication. The nature of this problem can perhaps best be understood by comparing it with an equivalent in sound waves. For certain purposes it might be possible to have an ear which could be so adjusted that a person could stand close to a steam whistle and still listen to words spoken from a distance of several hundred feet. Distances are only relative and a steam whistle located in Germany might be caused to make such a noise that it would completely drown out the sound of the voice calling from America. This contingency was really seri-

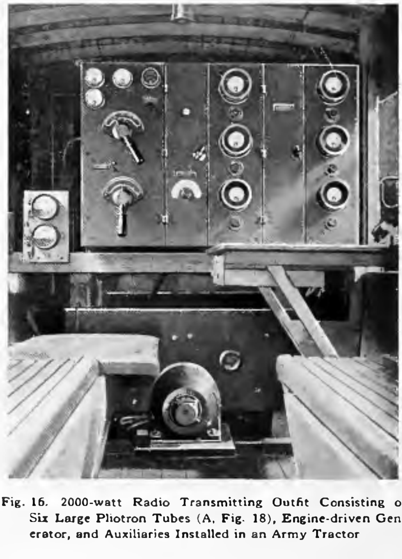

Fig. 16. 2000-watt Radio Transmitting Outfit Consisting of Six Large Pliotron Tubes (A, Fig. 18), Engine-driven Generator, and Auxiliaries Installed in an Army Tractor

ously feared and to counteract it the "barrage receiver" was developed. A demonstration of this receiver was made three miles from the New Brunswick transmitting station and it was shown that the overwhelming intensity of the New Brunswick signal could be completely neutralized so that messages could be received from European stations as well as if the transmitting station were not operating. This demonstration caused the officials to immediately adopt "barrage receivers" at the receiving station of the American and French governments.

The high frequency alternator used in this new radio system is known as the Alexanderson alternator, and although the greater part of the development work on this machine had been accomplished before the beginning of hostilities, it is so much a part of this new system and has played such an important function in Transatlantic communication that the following remarks seem in order here:

The Company has developed such high frequency alternators for radio work in capacities of 1, 2, 50, and 200 kilowatts. It was one of these 200 kilowatt machines that did such good work at the New Brunswick station during the war, so it is interesting to note that a unit of this size radiates approximately 250 h.p. of energy into space when it is sending a radio message. The peculiar advantages of this type of generator is that it gives out an undamped wave and puts such a large amount of energy into the antenna; factors which led to the rapid extension of the use of radio communication during the war, and also led to the building of so many new transmitting stations as well as the use of this means of communication for spreading propaganda.

Over and above the radio work referred to, the Company's radio developments were many and varied. A description of all the work done seems impractical, so to give a general idea of some of this work that had been completed or was nearing completion at the time the armistice was signed, it will be well to classify it as follows:

(a) Large size vacuum tube apparatus
(b) Medium size vacuum tube apparatus
(c) Small size vacuum tube apparatus
(c) Receiving apparatus

All these new developments were carried out under war-time conditions, at high pressure, and under numerous difficulties caused by the rapid change of requirements.

The term "vacuum tube apparatus" may need a word of explanation; it refers to that type of transmitter and receiver which make use of the vacuum tube as an oscillator, amplifier and receiver. Such tubes are usually made of glass and generally contain three electrodes. The tube is exhausted and the Research Laboratory at Schenectady has done much notable work in producing a tube of higher voltage and greater power output than hitherto had been found possible. The physical properties of the tube, which is termed a "pliotron," are dependent upon the motions of the electrons set free from the heated filament in a nearly perfect vacuum. We shall refer at greater length further on to this subject.

Fig. 17. Side View of the Pliotron Cabinet, Front View of which is Shown in Fig. 16

Most radio apparatus, previous to the development of these tubes, employed what are commonly termed "damped waves," which means that for a portion of the time there was no activity. With the vacuum tube undamped waves are used in which there is no period of inactivity; this results in a higher efficiency.

In pre-war days the advantages of the undamped oscillations were well recognized and apparatus of this description had largely displaced the older damped apparatus on the score of greater efficiency, the ability to use the lower voltage, small size, and also because of certain advantages in reception; but this new type of apparatus had not been used to any large extent in the smaller radio outfits.

The war-time requirements of both the army and the navy were of a very special nature and called for a great number of small sized, short range radio sets of light weight and small cubic capacity; these features being particularly valuable in aircraft outfits. To meet these requirements, the vacuum tube apparatus was developed and was applied in several unique ways to the aircraft service, particularly in its application to telephonic communications. All sets developed by the Company were arranged for telephonic com-

**Fig. 18. Various Sizes of Vacuum Tube Apparatus Developed and Manufactured by the General Electric Company for Radio Transmission and Reception**

A. High-power pliotron used as generator of high-frequency energy; 250 watts capacity when using a plate voltage of 1500

B. Medium-power pliotron used as a generator of high-frequency energy; 50 watts capacity when using a plate voltage of 750.

C. Small-power pliotron used as a generator of high frequency energy; 5 watts when using a plate voltage of 350.

D. Regulator tube used to control output of wind-driven generator.

E. Ballast lamp used to control filament current in small pliotrons.

F. Resistance tube; a special form of very high resistance employed in radio receiving sets.

munication on the continuous wave and telegraphic communication on both continuous and "chopped" wave.

Aircraft are of various sizes and therefore several different types of apparatus were designed to meet the differing requirements, but finally the design settled down to three types, each particularly suitable for a certain class of airplane. Thus the large size vacuum apparatus was primarily intended for bombing planes, flying boats, and balloons; the medium size for such craft as seaplanes and biplanes; and the small size for the smallest class of flying machines, which usually carry only one aviator.

The large size vacuum tube apparatus uses the largest type of pliotron that the Company has developed and is adapted for use at fixed land bases for controlling the fleet movement of a large number of planes by telephone. Such sets radiate about 1½ horse power of energy and are capable of giving telephonic communication with a flying boat at a distance of at least 200 miles. Similar units were designed for installation on army tractors for field operation. These also had a range of 200 miles, and at the time the armistice was signed a number of orders were underway for radio telephone sets for this service. An aircraft unit using this large vacuum tube was designed which only weighed 70 pounds, exclusive of the storage battery.

An aircraft radio telephone unit using the medium size vacuum tube was developed, and is now being produced in large quantities. It has a telephonic range from plane to ground of a hundred and fifty miles and weighs only about 40 pounds, exclusive of the battery.

A great amount of work was done on a radio telephone set using the smallest size of vacuum tube and the weight had been brought down until the complete transmitter, exclusive of the battery, weighed only 25 pounds. This set had a range of 60 miles from the fixed station and communication was obtained over a distance of ten miles between two similar planes.

The vacuum tube, commonly called the pliotron, and mentioned so often in this story, deserves many chapters to cover the fascinating story of its development; particularly the truly wonderful scientific laws which govern its action and the almost unbelievable amount of work that was accomplished by the Company in supplying the needs of the army and navy with these tubes. The amount of progress that the world owes to these tubes is a source of just pride to the workers of the Research Laboratory at Schenectady where so much of the development work was done that led to their present highly developed state. But owing to there being so much that is of interest, we shall have to confine our remarks to one or two brief paragraphs.

The practical long distance telephone really owes its development to the pliotron, and the advances it has enabled to be made in wireless telegraphy are great and far reaching.

These tubes depend for their action on the emission of electrons from a heated cathode which crossing a gap arrive at the anode, thus conveying an electric current across the gap. The ability to produce high power tubes depends on many factors, but the most important is to obtain a very high degree of vacuum. The realization of the necessity of the high vacuum and the development of the technique for producing it are due to the Research Laboratory.

As soon as America entered the war and the requirements of the government were learned, the Company started two lamp factories on the wholesale production of the vacuum tube and provided equipment to turn out 20,000 per week. The Company supplied the army and navy with may thousands of pliotrons for the airplane and seaplane services and many hundreds of the complete wireless outfits already described.

If one reviews the developments of the last two or three years, when virtually the whole world was at war, we seem to have lived a century in this brief period. A cold description with all its technicalities, of some of these new developments can convey none of the romance that is inseparable from the efforts of the engineer and scientists, so let us consider briefly what some of these devices were designed to do, what an important part they played in the war, and how greatly their use would have extended had the war continued. What a far fetched romantic fairy story the truth of today would have seemed even to us in our childhood.

Men talking across the broad expanse of the Atlantic Ocean without a wire is romantic enough of itself, but what of an ace with his radio set controlling the fleet action of a mighty host of flying battleships engaged in deadly battle miles up in the air.

It seems fanciful, but it is real that today we send men miles up into the air to obtain meteorological information of distant points and have the information telephoned back to us on earth. These are indeed messages from the etherial blue.

What would Napoleon or Wellington not have given for just one hour of aerial telephone service to direct the fire of his artillery?

Airplanes and mighty dirigible balloons fitted up with wireless telegraph and telephone sets scouring the sea for pirate submarines preying on merchant ships, fighting their enemy with bombs and calling the patrols to destroy their quarry sounds like a fairy story, but it is a grim reality.

Fig. 19. The device recently developed by the General Engineering Laboratory of the General Electric Company for the visual and photographic reception of radio signals. The galvanometer element is located in the box near the bottom of the right-hand standard. The reel of unexposed photographic tape is situated above the large panel. The vertical tubes contain the agents for developing, fixing, washing, and drying the photographic tape. At the left-hand end of the machine appears the record-bearing tape, samples of which are shown in Fig. 20

Airplanes calling on airplanes for assistance when hard pressed in a death struggle in the air was all too real, although it seems like a story only built of fancy. We need someone to write this story, but those who know it best are too busy still developing the marvels of scientific age—they are too busy to write—the problems of reconstruction in peace are almost as great as the problems of war and the strenuous efforts of these men during the war seem only to have whetted their appetites for more work and more accomplishments. Many are even too busy to tell the story to someone else who would write it.

Many volumes might be written about all the wireless developments of the Company during the war, but space will permit the citation of but one more. The high-speed photographic telegraphic recorder invented by Mr. C. A. Hoxie and developed by the Company at Schenectady in the General Engineering Laboratory deserves special mention. Many attempts had been made to make such a device, but each had in turn been abandoned largely because of the multiplicity of parts, also because of unreliability and the difficulty in obtaining uniform operation. The recorder developed at Schenectady has proved its worth in actual Transatlantic work in the naval receiving station at Bar Harbor, Me. They are primarily intended for the high speed reception of radio telegraph signals, but can be used for other purposes. To appreciate the value of this device it should be pointed out that an expert operator is capable of receiving about 35 words a minute for a short period under the most favorable conditions, but average conditions usually bring this down to say 15 or 20 words per minute, or about 1000 words per hour. Interference and static are often troublesome and then the speed is even less. For some time past it has been possible to transmit radio messages at a considerably greater speed than they could be received.

Various photographic recorders have been tried out, but up to the present time none has found general application. With the device developed by the Company it is practical to photographically record on a paper tape radio signals at a speed of 500 words per minute. These messages can be translated at leisure by even comparatively inexperienced operators and the photographic records are permanently available for future reference.

An instrument of this type has been standardized to receive 200 words per minute. It is of interest to note that the time elapsing between the arrival of the signal and the time when the printed record can be read is only three minutes. During this three minutes the signal has been received, recorded, developed, fixed, washed and dried.

This high speed photographic recording machine has the unique distinction of being able to record signals even through moderate static and other interference by virtue of its mechanical selectivity and thus to record good clear signals under conditions where an oral reception would be difficult.

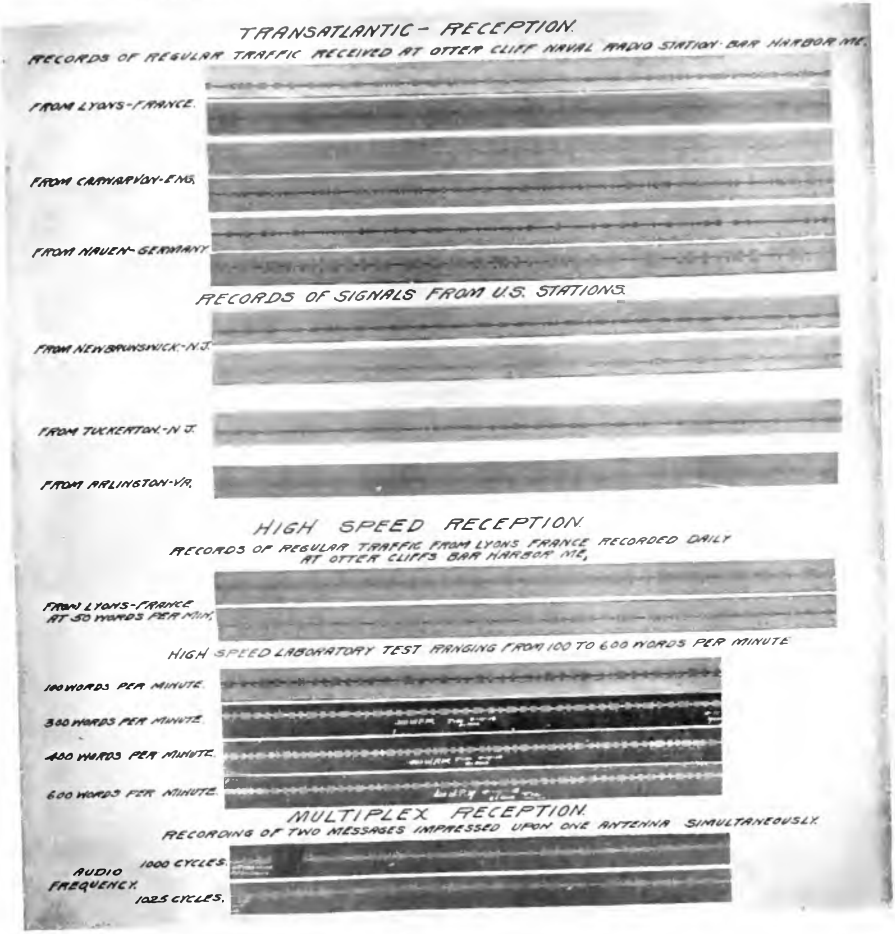

Fig. 20. Sample Photographic Records of Radio Signal Reception by the Visual and Photographic Recorder Shown in Fig. 19. The photo-engraving fails to produce clearly the accurate and precise indications made by this new type of radio recorder.

### Electric Welding

To increase the rate of building ships was one of the most vital problems of the war, and the rate of building was largely dependent upon the speed of driving rivets. England had been up against the same problem for three years and found that the number of rivets needed could be materially reduced by using arc welding in many places instead of rivets. At first England used acetylene welding, but found the supply unequal to the demand, so substituted electric welding which was found equally satisfactory, and could be used in places where gas welding was impractical.

When this country entered the war, in pursuance of its policy of benefiting by the war experience of others, the Emergency Fleet Corporation invited England to send an expert on welding to this country. This expert was sent to the Research Laboratory at Schenectady to teach all he knew about welding. His work was supplemented by careful studies of different methods of welding by physical tests, chemical analyses and microphotographs.

Next under the auspices of the Emergency Fleet Corporation, the Research Laboratory established a school for welders where about 60 men were trained to become proficient welders, and then sent to act as instructors at the various shipyards.

### Other Research Work

So far as concerns the magnitude of the work done and perhaps its relative importance the most notable war work of the Research Laboratory was that already cited in connection with submarine detection, X-ray outfits and radio communication; but they undertook a host of other problems and were at all times prepared to assume more work on the request of the different government departments. The following paragraphs will deal briefly with some of the work done.

The extensive use of aeroplanes in the war made the high power searchlight an essential part of the anti-aircraft warfare. The Company's engineers in co-operation with the Government undertook to develop a very light searchlight more suitable for this purpose than the heavy equipment in use. The necessary simplification of the searchlight mechanism imposed new and heavier requirements on the electrodes. To develop suitable electrodes was the Research Laboratory's share of this work and they successfully solved the problem, producing electrodes suitable for the 200 amperes which was the current first required, and then they made electrodes for 500 amperes, a higher current than had ever been used before.

The Navy was using "Blinker Lamps" for certain signalling operations, that is, incandescent lamps were flashed with a telegraph key for night signalling. The Navy wished to increase the range, but the use of a heavier filament retarded the rate of heating and cooling and so reduced the speed of signalling. The Research Laboratory knowing that hydrogen had the greatest heat conductivity of any gas, and that if pure it would not affect the filament, made high powered lamps filled with pure hydrogen which gave the necessary power, range and speed of signalling.

Early in the war the Research Laboratory studied incendiary bombs, made 100 according to their ideas and turned them over to the Ordnance Department for test. These tests were reported as highly satisfactory and the Company was asked if they wanted to undertake quantity manufacture. The Company did not assume this work as they thought some of the pressed steel factories could do it more cheaply, and so they informed the Ordnance Department that they were at liberty to have them made wherever they could get them done most cheaply.

The Research Laboratory also did some work on smoke screens, but the Chemical Warfare Section wanted both the smoke screens and the men who were working on them, with the result that both the smoke screens and the men were lost track of for the duration of the war. The Chemical Warfare service put up a special problem on gas masks to the Research Laboratory and they found a solution, but meanwhile the Chemical Warfare service men had found a still simpler way of doing the same thing. Even in such cases as these there was no regret felt that the work was undertaken for it is only by working out several methods that you can be sure you have the best.

The Research Laboratory made up some Tungsten bullets which were twice as heavy as steel bullets of the same size, as they realized that the increased weight would add penetrating power; in connection with work on bullets many experiments were tried on armour plates to see if a composite or laminated plate made of alternate layers of soft and hard metals would be superior to homogeneous armour plates. Theory seemed to say yes, but actual tests said no.

Among the large number of special problems presented to the Research Laboratory for solution at different times during the war, some were of special interest.

Another naval problem that was worked on was the improvement of detonators for submarine mines. The mines developed by the Navy Department were highly successful, except for the fact that the detonators took too much current. In co-operation with Naval Officers, the Research Laboratory worked out a new detonator which operated successfully on a much lower current. A great deal of other research work gave great promise, but was brought to a hasty conclusion by the signing of the armistice. As an example it may be stated that a waterproof and fireproof "dope" for the fabric of aeroplane wings had been developed, which was nearly ready for service test and a new fluorescent screen making rapid X-ray work effective was being developed.

Much research work was done in finding suitable substitutes for materials that it was difficult or impossible to obtain owing to war conditions, especially those which previously had been obtained from Germany only.

Just about two months before the end of the war Dr. W. R. Whitney, the Director of Research for the Company, had been appointed by the War Department as Director of all Experimental and Research work on nitrate production. This research was in connection with the large plants at Muscle Shoals where about ninety million dollars are being expended. The Research Laboratory had little more than started investigations along these lines when the armistice was signed.

From first to last the Research Laboratory spent about one and a half million dollars on war research work, the greater part of which was foreign to the normal activities of the Company and which would have little, if any, peace-time value. All the research facilities were devoted to war work and the loss of these to the Company's normal development was serious, but at no time was this consideration allowed to interfere with the work on hand. In fact, the only one question that those in authority asked of those who were responsible for the research work of the Company was, "What are you doing to help win the War?"

Most of the research work already mentioned was done in the great Research Laboratory at Schenectady; but several of our factories have research facilities of their own where important war work was done. To cite one example which we have so far omitted, the Research Chemists of the National Lamp Works at Nela Park, Cleveland, did some most excellent experimental work in connection with the development of poison gas [illegible]. The story of this work is [illegible] as Colonel Dorsey, Chief of the [illegible] Division of the Chemical Warfare Service, has written such an able story from [illegible] knowledge of the subject, we shall refer the reader to this story which appeared in the *Journal of Industrial and Engineering Chemistry* for April, 1919, as well as to an article on the same subject which appeared in the Magazine Section of the New York *Times* for April 20, 1919.

The National Lamp Works of the Company is preparing a report of its war activities, so possibly we may deal with these at a later date.

### Insulation

As an instance of how vital apparently small things can be to the prosecution of a great war, it is interesting to learn the British Government's experience with insulations for magnetos and to realize how vital a factor this was in the air service program. Before the war the British Government had been practically dependent on Germany for her magnetos, so at the outbreak of hostilities she immediately started to manufacture her own and made rapid progress, except that no insulating compounds were produced in England that would do for the various insulating parts such as distributor heads, slip rings, terminal nuts, brush holders, etc.

The General Electric Company was approached for assistance in the production of molded insulation which would possess the necessary properties. The Company had never made insulation for this special purpose and the requirements were quite severe, but excellent facilities existed for the production of insulation for various other purposes and the Company immediately undertook the problem. After several months' investigation a compound was developed which was even superior to that used in the Bosch machines. This material was accepted and used by the British Government for all magnetos for airplane service. For nearly two years all of this type of insulation required by the British Government was made by the General Electric Company, and then the work was transferred to the proper departments in England. The requirements for magneto service demanded an insulation material

Fig. 21. Smoke Bomb Immediately After Firing

Fig. 22. Another Type of Smoke Bomb Immediately After Firing

Fig. 23. Drift Smoke 1 Minute After Ignition

Fig. 24. Drift Smoke 1½ Minute After Ignition

The Research Laboratory at Schenectady Developed Several Different Types of Drift Smoke Devices and Smoke Bombs. These pictures have been selected from a large number taken during experiments to show the general character of the smoke screen produced which would withstand high temperature, would carbonize but slowly under arcing, was resistant to moisture and oils, possessed a high insulating value and be very strong mechanically. It should also be capable of resisting vibration and shock. The product produced was satisfactory in all these respects.

The Insulating Engineering Department was also called upon to do some special work on field coils of motors for propelling submarines. While it might be unwise to go into details of how they accomplished the results, it is interesting to record that the work they did in this direction was so satisfactory that the tests demonstrated that the coils not only had a very high insulating value, but that they were absolutely moisture-proof, and also heat-proof. In fact, the apparatus ran so much cooler than had been estimated that it was possible to dispense with the blower entirely under very low speed conditions. The excellence of this work was very favorably commented upon by the Government officials.

The General Electric Company was cooperating with the manufacturers of cases for incendiary hand-grenades so as to make them oil-proof and yet inflammable and the principles proposed by the Company had been adopted at the time the armistice was signed.

One of the urgent requirements of this country during the war was optical glass, a product which we had very largely depended on Germany for before the war. When our manufacturers undertook to make optical glass, one of their difficulties was a lack of suitable glass pots, as the material for these had also been imported from Germany. The Company's Insulation Department in co-operation with other Ceramic Engineers and manufacturers developed a satisfactory formula for making these pots with American clays.

While the Company has no specific record to show how useful the work was or if the recommendations they made for the improvement in spark plugs for airplane engines were used, they did a very considerable amount of work in this direction. They not only proposed a new method of cementing the inner electrode in place but also developed a new cement for the purpose. Work was also done in producing a special porcelain for the plug itself.

During the war certain materials were required for war work in much larger quantities than could be supplied and the industries were therefore asked to curtail the use of these materials. The Company used a great deal of acetone and this was one of the materials that the Government wanted to conserve, so the Company immediately stopped using it, and in a few weeks they found a satisfactory substitute. The use of cobalt oxide, zirconium oxide and other materials was greatly reduced at the request of the Government, and formulae and methods changed upon short notice to substitute other materials not so urgently needed for war work.

# Problems in Designing Small Turbines for Industrial Purposes

By Sanford A. Moss

Turbine Research Department, General Electric Company

This article and a companion one, "Turbines for Mechanical Drives," which appeared in our June issue, treat of the production of a line of turbines assembled from certain standardized and interchangeable parts. These parts after inexpensive manufacture on a quantity basis are placed in stock. Their proper selection to meet whatever operating conditions may be given will result in a machine fully the equivalent of one especially designed for the purpose.—Editor.

The multifarious uses of the small turbine have led to a very wide diversity of operating conditions, many of which have been considered in articles in this magazine.* These articles gave a brief resume of the way in which a special line of small turbines, known as Typ L, was designed to meet these conditions, but this matter will here be discussed in detail.

In the case of electrical machinery, standardization has been carried to a considerable degree and there are comparatively few permissible voltages, speeds, etc. Hence, a line of such machines can be restricted to comparatively few standards. Unfortunately, no such situation exists at the present time in the case of the small steam turbine. The seven variables which determine the design of a small turbine are:

Initial steam pressure.
Initial superheat (or moisture).
Back pressure (or vacuum).
Revolutions per minute.
Horse power.
Efficiency.
Direction of rotation.

The steam pressures usually specified range between 60 and 250 lb. per sq. in. above atmosphere.

Turbines for wet steam are rarely called for and dry saturated steam is usually specified. There may also be superheats up to about 250 deg. F.

Some turbines operate, with appreciable back pressure owing to the fact that the exhaust may be used for heating feed water or for other industrial purposes. Hence, the back pressure may vary from nominally atmospheric value (which usually means about 1 lb. above atmosphere back pressure) to about 35 lb. per sq. in. above atmosphere. Condensing small turbines are also often called for, usually 26, 27 or 28-in. vacuum.

The revolutions per minute without special gearing may be from 800 to 4000.

The horse-power requirement in the region here discussed is between 10 and 400.

The arrangement of wheel diameters and the number of stages control the efficiency for any combination of the above conditions. In any case a number of selections are possible, giving increased efficiency at increased cost. The circumstances under which the turbine is to be used prescribe either that price is the primary consideration and efficiency a secondary matter (calling for a single-stage machine of small diameter), or that efficiency is a

Fig. 1. Short-arc Single-stage Turbine Driving Centrifugal Air Pump on Condenser

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* "A Small Turbine for Direct Connecting or Gearing." R. H. Rice, June, 1916, p. 564.
"Turbines for Mechanical Drives." R. R. Lewis, June, 1919, p. 438.

primary consideration (calling for increased diameter and several stages) or that a compromise must be made between price and efficiency giving an intermediate condition.

The most usual direction of rotation is counter-clockwise looking from the outboard end of the turbine. However, there are a sufficient number of calls for clockwise rotation to require that provision be made for it.

**Fundamental Principles of Design**

The mechanical design adopted was so arranged that each of the various dimensions, which must be selected to suit each of the above requirements, could be set independently. This was done by dividing the complete turbine into a number of unit parts, each embodying such a portion of the complete machine as to enable the plan to be carried out in the most satisfactory way. These unit parts were selected as follows:

(1) First-stage nozzle plates.
(2) Diaphragms for successive later stages.
(3) Wheels, buckets, and intermediates for first-stage and later stages.
(4) High-pressure or inlet head.
(5) Low-pressure or exhaust head.
(6) Governor valve.
(7) Shaft, casing, and general parts.
(8) Governor.
(9) Emergency governor.

Each of these unit parts is built in a number of interchangeable types and sizes so arranged that each of the dimensions required for a given purpose can be secured independently. All of the sizes of each unit are made on a manufacturing basis with jigs, special tools, etc., and then stocked. The parts giving those dimensions required for a certain purpose are then assembled to make a complete turbine and the nozzle ports are machined to suit the exact conditions under which the turbine is to operate.

In order to give an idea of the vast number of combinations of conditions which this system meets exactly, let us suppose that it would be sufficiently accurate to standardize certain even values of the various conditions. For instance, we might suppose that we would calculate for nine standard values of initial steam pressure (60, 80, 100, 125, 150, 175, 200, 225, and 250 lb. per sq. in.), five similar values for superheat, fourteen values for back pressure or vacuum, nineteen values for revolutions per minute, twenty values for horsepower, and three values for relative efficiency and cost. There are two values for direction of rotation. Calculations if made on such a basis would enable curves to be plotted over the entire range of conditions so accurately that the data for any specific intermediate condition would be determined.

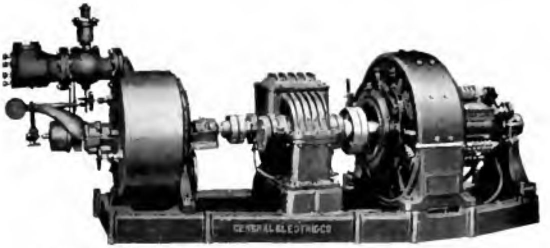

Fig. 2. Long-arc, Two-stage Turbine with Two Hand Valves Geared to Direct-connected Generator

Fig. 3. Long-arc, Three-stage Turbine Direct-connected to an Alternator

The total number of combinations which such a selection of standards involve is:

$$9 \times 5 \times 14 \times 19 \times 20 \times 3 \times 2 = 1,436,400$$

The actual number of combinations is infinite.

The line as laid out will, with a comparatively few unit parts all made and stocked on a repetition basis, enable any one of these combinations or any of the infinite number of intermediate ones to be exactly provided.

In order to make this scheme commercially feasible the total number of parts required to complete the line, consisting of the number of units multiplied by the number of sizes of each unit, must have a reasonable value. Nevertheless enough sizes are provided so as to give no compromises which will impair the performance. As already mentioned the nozzles are machined to order to meet exact operating conditions. Each turbine when completed is then especially designed for the particular customer's conditions regardless of the fact that all parts are laid out so as to be carried in stock.

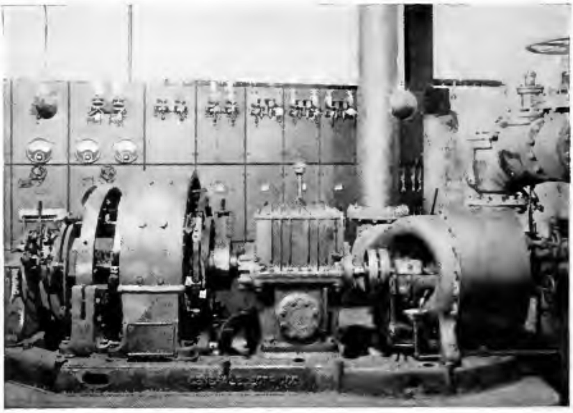

Fig. 4. Three-stage Turbine with Maximum Nozzle Area Driving a 300-kw. Generator

In order to handle the problem outlined, it was of course necessary that the complete line of turbines be laid out at one time to cover all of the conditions enumerated. It would not have been sufficient to have made designs for only a small portion of the field with the idea of making extensions as time went on.

A primary requisite is the ability to compute the water rate or performance of any given design with any combination of circumstances. Experimental work carried on through many years, together with complete analysis of many commercial turbines, gave data which enabled this part of the problem to be completely solved.

In selecting the general characteristics of the line, the various possible types of turbine were of course considered and comparisons between them were made, taking account of the necessity of securing good efficiency with comparatively low cost and having in mind the speeds, powers, and other operating conditions which commercial data showed to be most popular. It was decided that the two-bucket-row impulse type machine was the proper one to use with one, two, or three stages according to requirements. This enables the efficient use of low speeds, such as 1000 to 2400 r.p.m. as well as speeds such as 2400 to 3600 r.p.m., and permits of direct connection to the apparatus to be driven in a large number of cases. It requires the use of gears in comparatively few cases. Other designs might have been used which would have given good efficiency with very high speeds, such as 6000 r.p.m., but this would have required the use of gears in nearly all cases. Still other designs such as the use of single-bucket-row wheels in each stage would have given good efficiency at speeds in the neighborhood of 3600 r.p.m. with a moderate number of stages with consequent cost increase for lower speeds.

The use of a stage consisting of two independent axial flow bucket rows, with intermediates between, with pure impulse action, has been successful in practice for many years. A careful consideration of the use of other possible arrangements, such as radial flow, return of the steam successively to a single wheel, etc., indicated that while a comparatively slight improvement in cost might have been made there would have been an appreciable loss in efficiency. Hence, there is used the standard Curtis system of a number of pressure stages each with two velocity stages such as has often been described.

In order to meet the requirement that there be a number of machines with successively increasing efficiency for any set of conditions, a number of standard wheel diameters were selected. For a given combination of operating conditions not all of the possible combinations of diameter and number of stages are desirable. For instance, some of the combinations may be over-speeded, which means that there are more wheel rows of the given diameter than are necessary to extract the energy efficiently from the steam in a turbine of the given power. Hence, a machine with fewer stages or with smaller diameters will give a better water rate, and will also be cheaper. In other cases a combination with a certain diameter and number of stages gives a better water rate than a combination with another diameter and another number of stages and about the same cost. Thus there will always be three and sometimes four or five machines having successively decreasing water rates at successively increasing cost. An extensive set of tables, curves, and rules has been prepared whereby the water rate can be found for any one of the standard machines for any combination of conditions.

### General Mechanical Design

The turbines consist of a high-pressure head to which is bolted the governor valve, a wheel casing which surrounds the successive wheels and interstage diaphragms, and a low-pressure or exhaust head.* The heads, wheels, and diaphragms of course differ for each of the standard wheel diameters. The governor valves and governors are the same for all diameters however. For each diameter there is but one type of wheel blank and diaphragm. The various nozzle and bucket combinations are also independent of the diameter and the proper one is used in each stage.

### Governing and Hand Valves

Throttling governing is used both with and without the so called "hand valves" which may be employed to avoid extreme amounts of throttling and consequent loss of efficiency. For ordinary cases where no special circumstances are encountered, the throttling principle is entirely satisfactory. This method of governing lowers the pressure on the nozzles to a value below that existing in the steam main, and so decreases the steam flow as well as the velocity, and this, of course, decreases the power output of the turbine. There is but slight improvement of efficiency for usual ranges of load. However, when better efficiency is desired at light loads, hand valves are used which close off first-stage nozzle area and therefore restore the original pressure on the nozzles. The hand valve arrangement is as follows:

Fig. 5. First-stage Nozzles

Fig. 6. Interstage Nozzle Diaphragm

There is one bank of nozzles always directly connected with the main steam chest, and on either side are auxiliary steam chests with additional nozzles connected with the main steam chest by means of valves similar to ordinary globe valves. All the steam first passes through the main governor valve so that the machine is under governor control regardless of the hand valve opening. If the minimum number of nozzles is required all the hand valves are closed and the governor manipulates the steam pressure only on the bank of nozzles directly connected to the main steam chest. The nozzle area is successively increased first by opening the left-hand valve, next by closing that and opening the right-hand valve, and finally by opening both valves. Figs. 2 and 3 show machines with hand valves.

Machines are also often required to meet two types of steam conditions. For instance, the back pressure may be of one value in the summer and another in the winter. The initial steam pressure may have a certain value most of the time but at rare intervals may have a very much lower value during which time the turbine must continue to give its full output. Maximum efficiency may be

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* The general arrangement is shown in Figs. 5 and 6, "Turbines for Mechanical Drives," GENERAL ELECTRIC REVIEW, June, 1919, p. 440.

required at full load, while providing for considerable overload capacity. Hand valves are used for these and many similar situations.

The maximum efficiency of a machine with a throttling governor of course occurs at maximum load. For this reason it is customary in many small turbines to lay out the nozzles so that the full pressure will just produce the required horsepower. Then in the event of slight overload, or temporary diminution of steam pressure, the governor valve will be unable to keep the machine up to speed.

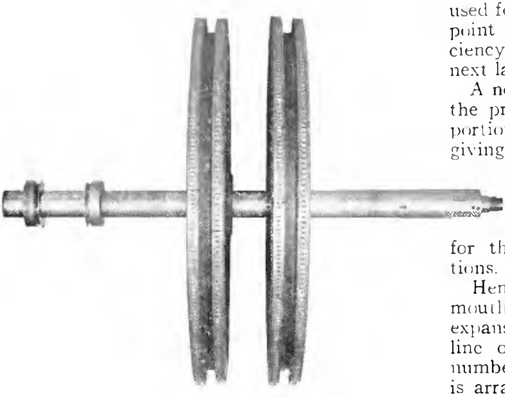

Fig. 7. Shaft and Wheels of Two-stage Turbine

In the turbine herein described, this disability is avoided without undue decrease in efficiency by suitably selecting as the steam pressure for rated load a value somewhat below the rated main pressure.

### Nozzles

The steam nozzle ports are machined in segmental nozzle plates, Fig. 5, in the first stage; and in diaphragms, Fig. 6, in the other stages.

The area of these nozzles determines the exact performance of the machine so that they are not machined as a part of the original manufacture. They are laid out to suit the exact steam pressure, superheat, back pressure, speed of revolution, and horsepower of each installation and are machined to order just before assembly.

The required area may be obtained in many ways, either with a large number of tiny holes or a very few large holes or any intermediate arrangement. The former plan gives short buckets with a considerable length of nozzle arc. The latter plan reduces the nozzle arc and increases the bucket height. Various curves of comparison led to the adoption of several standard heights of bucket requiring corresponding standard diameters of nozzle mouth. The smallest diameter is used for nozzle areas up to a certain specified point where consideration of cost and efficiency make it expedient to change to the next larger size.

A nozzle for steam under the conditions of the present design consists of a convergent portion followed by a divergent portion, giving a "mouth" larger than the minimum area or "throat." The ratio of the areas is called the "expansion ratio." In order to give efficient action the expansion ratios differ greatly for the different steam pressure combinations.

Hence for each of the standard nozzle mouth values there are a number of standard expansion ratios, for the machining of which a line of tools is provided. The necessary number of ports of the proper standard type is arranged to suit each customer's requirements.

### Materials

For the lower steam pressures and with saturated steam, cast-iron valves, casings and nozzles, and standard alloy buckets are proper. With an increase of the temperature and pressure of the initial steam, other materials become necessary. For high pressure, with or without high temperature, the governor valves must be of steel. Certain parts of the turbine are not exposed to steam at the initial conditions, but the actual temperatures to which they are exposed may become high enough with high initial temperature to require special material. Each of the parts which may be affected by temperature and pressure are manufactured not only in the material suitable for low temperatures but also in one or more of the other materials required for higher temperatures. Rules and tables are provided specifying the proper materials in all cases for all parts of the turbine. For instance, the governor valves for low temperatures are made of cast-iron with parts of standard alloy; for high pressures and moderate temperatures they are made of steel with parts of standard alloy; for high temperatures they are made of steel with parts of special alloy. The nozzle plates are made of cast-iron or of an alloy suited for high-temperature steam, and so on.

Fig. 8. Stock of Nozzle Diaphragms

Fig. 10. Insertion of Wheel Buckets

Fig. 9 Manufacture of Bucket Wheels and Intermediate

Fig. 11 Shafts as Highspe[illegible] [illegible]

### Nozzle Arcs

The turbines described in this article cover many cases; from the one with small power and high-pressure steam, requiring a few small nozzle ports, to the one of large power and low-pressure steam, requiring large nozzles for the entire circumference. Hence successively increasing nozzle arcs are called for, in the first, as well as in the later stages.

Fig. 12. Long-arc High-pressure Heads

The interstage diaphragms have nozzle spaces to suit each standard diameter of nozzle, and the required number of nozzle ports are machined in them.

For the first-stage nozzles a different procedure must be adopted. Steam must be supplied to all of these from the governor valve, requiring an intermediate steam chest or distributing passage. If this were made for the extreme case, with nozzles entirely around the circumference in the first stage, there would be a great deal more weight than necessary for the case where but a few nozzles were required. For this reason, arrangements have been provided for three different cases; a comparatively short arc, a medium arc, and an arc covering the entire circumference.

A short-arc single-stage machine is shown in Fig. 1.* In the short-arc case the front head carries no steam passages whatever. The steam nozzle is bolted directly onto an extension of the governor valve.

For arcs up to about two thirds of the circumference, the "long-arc" arrangement is used. Figs. 2 and 3 show two and three-stage machines respectively. The same governor valves as in the preceding case are used except that the inner end is cast in a different way and is bolted onto the front head. The front head carries a passage part way around, through which the steam flows to the nozzles.

This construction suffices for most cases. However, some rare cases with large powers, and very low pressure steam require first-stage nozzles around the entire circumference, and then the arrangement of Fig. 4 is used. This also requires large governor valves.

### First-Stage Nozzle Plates

Fig. 5 shows one of these plates quite filled with nozzle ports. Fewer ports are drilled than in the plate shown or similar plates are used covering greater arcs, according to circumstances. For the case of machines requiring a short arc, as in Fig. 1, the construction is such that the turbine can be completely assembled without the nozzle plate and kept in stock. When the nozzle

Fig. 13. Low-pressure Head

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* A short-arc two-stage machine is shown in Fig. 5, "Turbines for Mechanical Drives," GENERAL ELECTRIC REVIEW, June, 1919, p. 440.

plate for a particular customer is completed, it is bolted onto the head and the machine is then ready for shipment. For the case of longer arcs, as in Figs. 2, 3, and 4, the nozzle plates are bolted directly to the front head and are of such lengths of arc as to suit the hand valve distribution.

Figs. 6 and 8 show the interstage diaphragms.

### Interstage Diaphragms

The diaphragm web, as well as that in the front head, is lightened by fluting. The diaphragms as well as the heads carry a floating shaft packing. This consists of a metal sleeve having a small clearance fit on the shaft and grooves to make a labyrinth passage which resists steam leakage. The packing is not fixed rigidly but is held by springs in the exact place in which it is centered by the shaft, thus automatically obviating necessity of taking account of shaft deflection, etc. These floating sleeves are the only packings provided in the diaphragms. In the heads, there are similar floating sleeves and in addition stuffing boxes with adjustable glands and soft packing or carbon packing.

### Wheels and Buckets

Figs. 7, 9, and 10 show the turbine wheels. The wheel in each stage has a single web, with a rim carrying two bucket rows. There is but one type of such wheel, for each diameter, regardless of the stage. The rim is arranged to take any one of the various types of buckets.

The different steam pressures, number of stages, and rotative speeds call for various types of buckets in the first row and in the second row, and the proper ones are chosen from a set of standard bucket shapes.

The various steam pressures, number of stages, etc., give different values to the steam velocity or "spouting" velocity with which the steam leaves the nozzle and enters the bucket in a given stage. The revolutions per minute and the wheel diameter give the wheel speed. The ratio of wheel speed to steam speed, $W/V$, follows directly. For a given value of $W/V$, regardless of the absolute magnitudes of $W$ and $V$, there is required a certain combination of bucket angles. This is for the reason that the velocity diagrams of the stage are similar triangles with the same angles at every point for all cases with a given value of $W/V$, regardless of the values of $W$ and $V$. Hence, there are provided bucket angle combinations for a range of values of $W/V$, and that one is used which is best suited to a given case. The buckets of each angle combination are also provided in a number of different radial heights to suit the nozzle mouth radial height. In this way comparatively few bucket shapes can be used to suit any case without sacrifice of efficiency. The wheels and buckets are so arranged that the various combinations are all interchangeable.

### High-Pressure Head

Fig. 11 shows high-pressure heads for the short-arc case. In this construction the steam passes directly from the governor valve to the nozzle. This construction is also shown in Fig. 1. For cases with longer nozzle arcs the high-pressure head carries a steam passage which receives the steam from the governor valve and distributes it to the nozzles. This is shown in Figs. 2, 3 and 12, in which the front head provides for nozzles extending two thirds around the circumference, and in Fig. 4 in which the front head carries nozzles extending entirely around the circumference.

### Low-Pressure Head

The low-pressure or exhaust head is shown in Fig. 13 with a small size exhaust opening, and in Figs. 3 and 4 with a large size exhaust opening.

### Governor Valve

There are a number of sizes of governor valves for successively increasing amounts of steam flow. The smaller sizes are made with a turbine end of two different constructions for the short-arc and the long-arc cases respectively. The governor valve for a short arc is shown in Fig. 1 and in the foreground of Fig. 15. The governor valve for a long arc is shown in Figs. 2 and 3, and in the rear of Fig. 15. The largest size governor valve, which has very large steam passages throughout, is shown in Fig. 4.

Fig. 4 will illustrate the capabilities of the system of interchangeable parts employed in the turbines described in this article. It is for the case of very low initial pressure and high back pressure. There is a very large steam flow and a comparatively small pressure drop and a small amount of energy extracted from each pound of steam. Hence the steam passages leading to and from the wheel must be quite large, although the wheel itself is quite small. The largest size of governor valve, high-pressure head, and exhaust head are therefore used with the more usual sizes of other parts. As all parts are interchangeable, this combination is readily made and gives a machine exactly suited to the particular conditions under which it is to operate.

Fig. 14. Two-stage Turbine Casing

### Casing and Shafts

Figs. 14 and 16 show the casing. This is simply a barrel which separates the high-pressure and low-pressure heads, and is split horizontally so as to facilitate inspection of the interior of the turbine. It carries the intermediate buckets. Different lengths of barrel are used for different numbers of stages. Fig. 17 shows shafts which are also of different standard lengths to suit different numbers of stages.

### Governor

Fig. 19 shows the governor which is screwed to the outer end of the turbine shaft. The shaft itself does not extend through the governor, so as to avoid the friction of the governor spindle sliding in a hole in the shaft as is common in many types of small turbine governors. The position of the valve with respect to the governor lever can be altered by means of a hand wheel, and this gives the possibility of varying the speed through an appreciable range while the machine is running. It also furnishes a means of setting the exact speed necessary to produce a given pump pressure or the like. Further change of speed, when the machine is not running, is obtained by altering the spring tension by slacking off the nut which locks the governor spring to the governor spindle.

The governor as just described is the system usually employed. In some cases where there is an invariable load such as due to direct connection to a pump only an emergency governor is used and the speed is regulated by hand adjustment of the steam throttle. With this system it must of course be certain that with the least external load on the pump and the maximum possible steam pressure the speed will not exceed a safe value.

In many cases an emergency governor is needed. The valve is shown in Fig. 18. An extra set of flat springs is bolted to the back of the governor casing, so arranged that when a certain speed is reached the springs fly out and release a trigger and latch which has been holding open a butterfly emergency valve. This valve drops of its own weight, assisted by the steam pressure when the valve is nearly closed, and so positively cuts off the steam. An emergency goveror is usually provided on machines driving generators and on pump machines with no governors, and is also frequently furnished in other cases. The emergency system is completely separate from the regular valve system. In many small turbines the emergency system consists merely of an extra spring and trigger apparatus which operates on the regular steam governor valve. This is not a complete emergency system and in case of any derangement of the regular governor valve, it would not be operative. In other cases there is a butterfly emergency valve which may not be positive. The emergency system applied to the turbines described in this article is distinct from the regular governor system, and will operate no matter what derangement might occur to any part of the regular system.

### Engineering Design

Extensive sets of rules, tables, and curves have been made so as to facilitate the selection of those of the above mentioned parts which should be assembled to give a turbine exactly suited to any given requirements. These enable a quick selection to be made of the sizes of the various parts to suit a given steam flow and of the material of the various parts to suit the pressures, speeds, and stresses involved. Means are also provided for the rapid selection of the parts needed to give the best possible water rate. This

Fig. 15. Governor Valves. Short-arc type in front, long-arc in rear, and emergency valve in center

Fig. 17. Stock of Turbine Shafts

Fig. 16. Stock of Single-stage Turbine Casings

Fig. 18. Emergency Governor Valves

involves the selection of the proper stage pressures, bucket angles, steam energies, and other elements of the mathematical design of a turbine. In this way a complete turbine may be selected from the parts in a very short time.

The complete instructions for the factory are given by a table for each customer's machine. The designing engineer assigns values to each of the items of this table from his data and curves, and the sheet then gives complete information to all of the factory departments. There are no drawings, drawing lists, or any other information required for the assembly. The engineering and shop data are thus arranged on the same standardized basis as is the manufacture. Nevertheless, the net result is a turbine, each part of which is suited to the customer's exact requirements, just as if it were specifically designed for the given requirements, without regard to use in any other case. At the same time, the individual parts have been made in large quantities in a factory especially devoted to the purpose, as is evident from the photographs.

Fig. 19. Dismantled Turbine Governor

# IN MEMORIAM

**Frederick Sargent**

Frederick Sargent, senior member of the firm of Sargent & Lundy of Chicago, and probably the most prominent consulting engineer in the United States specializing in the design of electric generating stations, died on July 26, at his home, 70 Harbor Street, Glencoe, Illinois, as the result of an illness contracted while he was on a recent trip abroad in company with his close friend, Mr. Samuel Insull.

Frederick Sargent was born in Liskeard, Cornwall, England, on November 11, 1859, which is also the exact date of the birth of Samuel Insull, with whom Mr. Sargent was destined to become intimately associated during practically all of his engineering activities. Young Sargent developed a decided mechanical bent, and spent eight years of his boyhood and youth in acquiring mechanical knowledge and experience in the great shipbuilding industry near Glasgow. The young engineer further improved his education at the night school of the Glasgow University.

On coming to the United States about 1880, the young man first found ready employment as designer in eastern shipbuilding yards and then for the Sioux City Engine Company of Sioux City, Iowa. A year or so later he accepted a position with E. P. Allis & Co., predecessors of the Allis-Chalmers Mfg. Co. Here he attracted the attention of the Western Edison Light Co., and in the fall of 1884 he came to Chicago and began his career as an electrical engineer.

Succeeding the Western Edison Light Co., the Chicago Edison Co. was formed in 1887 and Mr. Sargent was made its consulting engineer. He has occupied this capacity with that Company and its successor, the present Commonwealth Edison Co., ever since.

About 1889 Mr. Sargent went to New York under contract with the Edison United Mfg. Co. In August, 1890, he returned to Chicago and established himself as an independent electrical and mechanical engineer. The firm of Sargent & Lundy was formed in 1891, Mr. Sargent being the senior partner from its organization to the time of his death.

In 1891 and 1892 Mr. Sargent was consulting electrical engineer for the World's Columbian Exposition of Chicago, and he designed the power plant of the great World's Fair in 1893.

The plans for the machinery layout of the original Edison Central Station in Chicago were made by Mr. Sargent; and the Harrison Street, Fisk Street, Quarry Street, and Northwest Stations were designed by him.

Mr. Sargent's engineering work, however, was not confined to Chicago. He was consulting engineer for many of the important electric light and power companies throughout the country. He designed the great combined Central Power Station of the American Gas & Electric Co. and the West Penn Power Co., located on the Ohio River north of Wheeling, W. Va., the great new station of [illegible] Gas & Electric Co. at Cincinnati, and also a station for the Kansas City Light & Power Co.

During the recent war Mr. Sargent was consulting engineer for the power station of the Edgewood Arsenal at Edgewood, Md., and also consulting engineer for the United States Government in other war-time projects demanding the application of power on a large scale.

In his profession Mr. Sargent was noteworthy for the clear vision and strong common sense with which he grappled with the essentials of an engineering problem. He was simple, clear, direct, and practical. He was a man of broad outlook, tolerant, modest, seeking results rather than to uphold theories. And he was eminently successful in obtaining results, for his electrical generating stations were milestones of achievement in the economical production of electrical energy. He stood in the front ranks of those men who have made electricity cheap for the people—an every-day necessity in the homes and factories of the United States.

Mr. Sargent had an exceptionally keen and active intellect, and a vigorous and forceful personality. He was a man of absolute integrity and fearless independence and high idealism in his work. He had an infallible intuition regarding engineering and scientific matters, and the responsible men in the companies for which he was doing his engineering learned to place the utmost confidence in his judgment. He had a remarkable combination of extreme daring and careful conservatism.

He was a member of several societies and clubs including the American Society of Mechanical Engineers, Western Society of Engineers, University Club, Chicago Yacht Club and Skokie Country Club, and the Engineers' Club, New York.

Mr. Sargent was married to Miss Laura S. Sleep at Sioux City, Iowa, in 1885. The widow, one daughter, Miss Dorothy Sargent, and two sons, Chester Sargent and Ralph Sargent, survive. The funeral services were held on July 28, at the family residence, the burial being in Sioux City, Iowa.

## AN APPRECIATION

"A great man has fallen!" A great, kind, generous, lovable man has gone. Not America alone, but the World is poorer. Frederick Sargent was an International Authority in the engineering profession. The many telegrams of sympathy voice the thought—that his loss is irreplaceable. His wonderful genius was an inspiration. The respect for his profound knowledge was universal. His generous heart won friends alike among the men who had millions to spend on engineering projects and among the men who came to him for advice in time of trouble. Perhaps the greatest of all his gifts was that of making and keeping friends.

Our first thought is of the calamity that has fallen upon the engineering profession where his idealism and his vision were wrought into practical, workable, harmonious details that made him a very genius in engineering. Those who were amazed at his daring became ardent believers in his power of achievement. His was a dominating figure in the engineering world. An Englishman by birth, most of his life was spent in this country and his intense patriotism found expression in his generous gifts and his untiring devotion to the Government when his counsel and services were sought in war-time projects. Who shall circumscribe the power and inspiration of such a life?

James Lyman.

# Secondary Connections for Constant-current Transformers

## SINGLE CIRCUIT *VS.* MULTI-CIRCUIT

By L. Arnold

Transformer Department, General Electric Company, Lynn, Mass.

The single circuit connection possesses the advantage that no ground or combination of grounds can damage the transformer, while at the same time the line is insulated for full circuit voltage. The multi-circuit connection has certain advantages under normal operating conditions, but in case of unequal loading the voltage to ground may greatly exceed that for which the line was constructed, and in case of grounds it is possible to burn out one half of the secondary winding. The liability of this trouble is also always present in the multi-circuit connection.—Editor.

The question of the relative advantage of the single circuit connection and the multi-circuit connection on the secondaries of constant-current transformers comes up periodically. The standard practice of the General Electric Company is to recommend the single circuit secondary, and if two separate lamp circuits are desired, to split these two circuits at the panel board. Other manufacturers, however, recommend the multi-circuit connection with the two lamp circuits placed between the two halves of the transformer secondary winding, and in a number of cases customers are operating this multi-circuit connection without serious difficulty. In the face of these facts our attitude on this subject has often been criticised as arbitrary and illogical.

It is perfectly true that *with the two circuits equally loaded* and all conditions normal, the voltage between line and ground on a multi-circuit transformer is approximately one half the voltage between line and ground on a single circuit transformer of equal kilowatt capacity, and built for the same secondary current. If, however, the circuits are not equally loaded, or if the line opens and grounds at the same time, this condition ceases to exist.

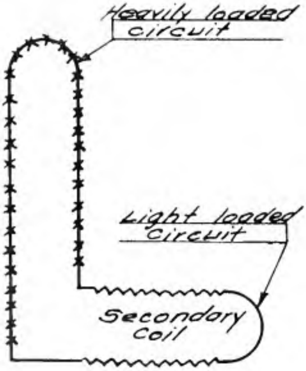

Fig. 1

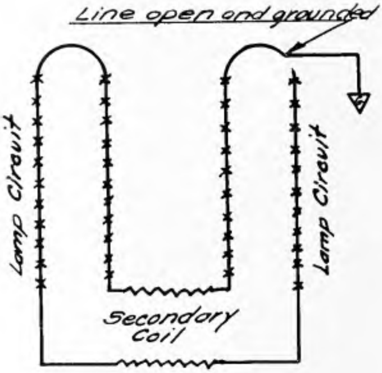

Fig. 2

*If the circuits are unequally loaded*, that is, if there is a heavy load on one circuit and a light load on the other, the voltage to ground on the heavily loaded circuit, with multi-circuit connection, becomes greater than half of the voltage to ground on the single circuit connection, and tends to approach the voltage to ground on the single circuit connection, in proportion as the load on the two circuits becomes more and more unequal. That is, on a multi-circuit connection with 75 per cent of the load on one circuit and 25 per cent of the load on the other circuit the voltage to ground on the heavily loaded circuit would be 75 per cent of the voltage to ground with a single circuit connection. The limit would be reached on the multi-circuit connection when all the load had been transferred to one circuit and the other circuit short circuited, in which case the voltage to ground would be identical with the two connections. See Fig. 1.

*If the line opens and grounds* at the same time, the voltage between line and ground becomes the same for both connections, being simply the open circuit voltage of the transformer. This condition of the line opening and grounding at the same time is fully possible if the line breaks and one end falls to the ground or drops into a tree. In this case, with the line open there is no current flowing in any part of the secondary circuit, and, with a multi-circuit connection, the circuit which has not opened becomes merely a connection between two transformer windings in series, each one supplying its own open circuit voltage. In other words, the circuit which is not opened becomes nothing more than the connection between the two halves of the secondary coil in a single circuit transformer. See Fig. 2.

Under the two conditions referred to above if the operator has installed cables, or lines based on normal conditions, and has divided the circuits approximately equally on a multi-circuit connection, he is very likely to have trouble as the strain to ground may become more than double the voltage for which he has laid out his external circuits.

Furthermore, with a *multi-circuit connection* it is possible to *get two grounds* which will burn out one half of the secondary winding of the transformer. With the connection an *external* line is connected to each end of each of the two secondary windings of the transformer. A ground on each of the two lines running from the same secondary winding, occurring close to the station, practically puts a short circuit across the winding without short-circuiting the other winding. The two secondary windings are mechanically connected and must move together. The winding which is not short circuited will attempt to regulate and carry the load. As a result we shall have a heavy current in the secondary winding which is short circuited, and a current less than normal in the other secondary winding, with the result that the short circuited winding will burn out. This we have found, by investigation, has actually happened in several cases, and has probably been the cause of other unexplainable burnouts. With a single circuit, or with the circuit split on the switchboard, there is no combination of grounds on the line which can damage the transformer or do more than shunt out one or more lamps. See Fig. 3 and Fig. 4.

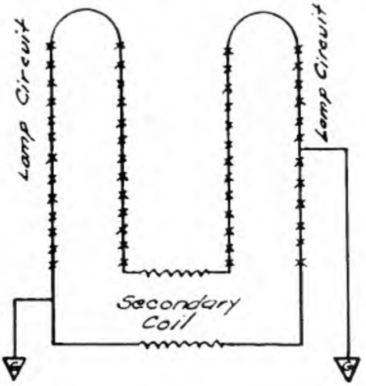

Fig. 3

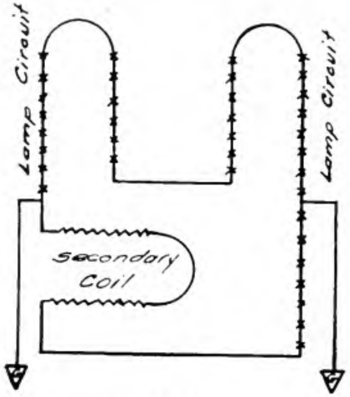

Fig. 4

The multi-circuit connection has certain advantages under *normal operating conditions* and an operator may be willing to take a chance that his conditions will always be normal, in order to reduce the cost of line construction; but attention should be directed to these points, however, in order that his choice may be based on the facts.

# Water Japan

By Wheeler P. Davey

Research Laboratory, General Electric Company

The fire risk attendant upon the use of inflammable solvents in the usual baking japan process led to the development of the water japan process. Water japan is a stable *emulsion* of japan base in water. Dr. Davey describes below the characteristics of this emulsion and the electric dip and the hot dip methods of applying it—Editor.

Baking japan, as it is ordinarily used in industry, consists of a "base" and a "solvent." The base contains one or more of the various asphalts, together with one or more siccative oils such as linseed oil or china-wood oil. The finished base is a tough rubbery mass which looks much like tar. It is the office of the solvent to dilute this base to a liquid, so that the metal may be easily coated with the desired amount of japan base. The solvents in common use are naptha, kerosene, and similar products. The use of such solvents entails a considerable fire risk, especially in the oven in which the japanned metal is baked. It was to eliminate this fire risk that "water japan" was developed.

Water japan consists of an emulsion of japan base in water. By this is meant that an enormous number of tiny ultra-microscopic globules of japan base float around in the water japan in much the same way that globules of butter fat swim around in ordinary sweet cream. The diameter of the globules is about 0.00001 inch. The emulsion is permanent, showing no tendency to settle out even after several months. It may be strained in the same manner as ordinary japan and, if desired, may be cleaned in a commercial clarifier of proper design. Since water is the "solvent," the losses due to evaporation are negligible, especially if the japan is kept cool. Scum will not form on the surface if the temperature of the liquid is kept below 100 deg. F. (38 deg. C.). After the water japan is baked, it is quite insoluble in water. The range of concentration which may be successfully used is very great, so that little supervision is required.

The viscosity of water japan is much less than that of the same base dissolved in kerosene or similar solvents. There is a possibility that, in the future, methods may be worked out by which the viscosity of water japan will be so adjusted that metal may be coated with water japan by dipping in the same way as with ordinary japan. However, the advantages of employing certain entirely different methods of applying the japan base to metal before baking seemed great enough to justify their development. They all have this feature in common—the japan base is deposited on the metal in a solvent-free condition. In this way, the behavior of the japan in the baking oven depends entirely on the characteristics of the japan base employed so that "secondary drip" is rendered negligible. These methods of applying water japan are given in detail below.

### The Electric-dip

The electric-dip method is adapted to small odd jobs of japanning rather than to quantity production. The water japan is put in an iron tank which is connected to the negative terminal of a direct-current circuit. The metal to be coated is connected to the positive terminal of the circuit. Since the globules of base in the water japan carry negative charges, the base will be attracted to the positively charged metal. The water is left behind, so that the metal is covered with a thin film of japan base, free from solvent. This film possesses some insulating properties even before baking, so that, as soon as the most exposed portions of the metal are coated, deposition starts in whatever holes and recesses may still be bare. The thickness of the deposit of base depends upon the product of the current-density and the time. Using a 125-volt circuit, the time required for a satisfactory coat is about 2½ seconds. In using the electric-dip method no special voltage is necessary. The work is connected directly across a direct-current line of high current carrying capacity without series resistance, so that the current flowing will be proportional to the area to be covered. The current on 125 volts will average about 0.8 ampere per square inch of surface to be covered. Due to the polarization effect, the current is higher at the instant the circuit is closed than at the moment of breaking. Time is most conveniently measured by means of a time switch connected to a relay. Accidental short circuits are prevented by a wooden grating on the sides and bottom of the tank. It is absolutely necessary that the surfaces of the metal to be coated be free from grease or other insulating material. During the time the japan base is being deposited, the metal should be submerged at least two inches below the surface of the water japan so as to allow it to be in approximately uniform electric field. Only one coat can be given by the electric-dip process as baked water japan acts as an insulator.

### The Hot-dip

The hot-dip method is adapted to work with large quantities of small castings, punchings, etc., where it is essential that the labor cost be kept at a minimum. The metal to be japanned is placed in wire baskets and heated in an oven to a temperature of about 500 deg. F. (260 deg. C.). It is then cooled to about 400 deg. F. (200 deg. C.) and quickly plunged into the cold water japan. The japan base leaves the water and collects in a film on the surface of the metal. After the basket has remained in the water japan about ten seconds it is removed, drained for about 30 seconds, and placed in the baking oven, where it is baked in the usual manner. After baking, the basket is emptied into storage boxes. The baskets may be handled entirely by chain-falls or an air-hoist, so that upwards of 100 lb. of metal can be handled at once. Except when the pieces of metal to be coated are very small, reinforced baskets of 1/2-in. mesh wire screen are suitable. The metal is often shoveled directly into these baskets, especially if it is in the form of small irregular castings or punchings. In some cases, however, it is advantageous to pack the contents of the baskets systematically, either for the sake of getting in a greater number of large pieces or of determining where the points of contact from piece to piece shall be. There is no handling of the individual pieces from the time the basket is filled until it is finally emptied into the storage box. Preheating was originally developed as a cheap method of cleaning grease and oil from metal before japanning. It is especially useful on steel punchings, and on brass, copper and aluminum. Most grease of this sort is thoroughly cleaned off if the metal is heated to a temperature of 500 deg. F. (260 deg. C.) and kept there for a half hour. It was soon found that if this preheated metal was quickly plunged into water japan while still hot (250 to 400 deg. F.) that the heat of the metal had the same effect as the electric field in the electric-dip process in causing the japan base to adhere to the metal leaving the water behind. There was the additional advantage, that the surface of japan base immediately in contact with the metal started to bake from the residual heat of the metal, thus tending to insure good adhesion.

In case the metal to be coated has flat faces, there is a chance that two flat faces may lie together so that neither of them would get a satisfactory coat. This may easily be obviated by dumping the hot contents of the basket into the water japan, catching the metal in another basket below.

Due to the fact that there is practically no "secondary drip" with water japan the scars due to the contact of one piece with the edge of another in the basket are negligible. After baking, the baskets are usually emptied by turning them upside down. In case it is desired to give more than one coat of japan, the basket is taken out hot from the baking oven and at once dipped. It is then put back to be rebaked.

### Conclusion

In using ordinary japan, the thickness of coat depends upon the viscosity of the japan. This is measured in terms of its density as shown by a hydrometer. In none of the foregoing methods described for using water japan has the viscosity been an important factor. Instead, the emphasis is placed upon the concentration of japan base in the liquid. Even here, the limits are quite wide for the maximum permissible concentration is about twice the minimum. For convenience, a concentration meter has been designed by which the concentration may be easily measured directly. The base is coagulated from a known amount of water japan by a solution of $Fe\,Cl_3$, $Ca\,Cl_2$, or a mixture of them. The lump of base is freed from water inclusions and is then weighed. This apparatus is very compact and requires as little supervision as the water japan itself.

It is a pleasure to express my appreciation to Buell Smith for his first work on the hot-dip method and to H. Chislet for his work in extending this process to its present state of development.

# Methods for More Efficiently Utilizing Our Fuel Resources

## PART XXX. NATURAL GAS

By SAMUEL S. WYER

CONSULTING ENGINEER, COLUMBUS, OHIO.

Recently in Charge of Natural Gas Conservation for United States Fuel Administration

Natural gas deserves to be considered the most valuable of our mineral fuels because it occurs in nature as a refined product ready for efficient utilization. (Petroleum must be refined to separate the components before it can be efficiently utilized, and this is also true of the high volatile coals. Solid fuels require either hand labor for firing or mechanical equipment for stoking or pulverizing.) Natural gas has been so easily tapped and burned that it has been the least appreciated and as the result of abusive use we shall in a very few years lose its services if the situation is not remedied. This installment of our Fuel Series treats of the production, transmission, and distribution of this gaseous fuel; and the following installment will discuss its waste and conservation. Both installments were abstracted from Bulletin 102, Part 7, of the United States National Museum, Smithsonian Institution.—EDITOR.

### PRODUCTION

#### How Natural Gas is Mined and Served to the Consumer

The first step is the securing of the lease or right to prospect for, remove, and market natural gas. This lease must usually be secured and held for a number of years—on the optimistic faith that it may contain gas—prior to beginning actual development work.

The unknown underground supplies of natural gas are found by drilling. To protect the hole, an iron pipe—called a "casing"—is driven down into the rock formation always found above the gas-bearing sand rock. A plugging device known as a "packer" is fastened in the casing or hole in the rock, immediately above the gas formation, and the gas by virtue of its inherent expansive tendency then comes to the surface—usually about one half mile above—through tubing, as shown in Fig. 1, and forces itself into the transmission lines.

As the gas travels the pressure must drop and this necessitates the installation of gas compressors. When the gas reaches the distributing plant it passes into the medium pressure lines in the city and the pressure is then in turn reduced to the low-pressure lines, where it travels through the mains at probably 5-ounce pressure to the square inch then, through the service line, consumer's meter, and ultimately is burned at the consumer's fixtures.

These steps present an unbroken chain of service features, from the reserve acreage in the field—that must be carried in order to permit of future drilling operations, and future service—to the consumer's fixtures, with this additional feature, that when the gas passes the consumer's meter it becomes his personal property and he can do with it what he pleases.

#### Reserve Acreage

Based on the United States Geological Survey statistics for 1916, natural gas producers in this country carry an average of 313 acres for each producing well, in their attempt to provide as far as possible continuity of service to their customers. However, this average will vary with different fields and localities. In West Virginia the United Fuel Gas Co. in 1917 carried 1252 acres to the producing well.

While natural gas wells are frequently drilled on tracts of less than an acre in area, by small producers intent only on getting the gas out in the fastest possible manner, the future continuity of service to the gas-using public is possible only by the carrying of reserve acreage.

#### Definition of Natural Gas

Natural gas is a mechanical mixture of several combustible and diluent gases and vapors, the number and exact proportion of the various constituents varying for the different localities and somewhat during the working lives of individual wells.

Natural gases coming from the ground may be classed—according to their gasolene vapor content—into two main groups, namely:

1. *Wet gas.*—This is gas intimately associated with oil, usually produced with oil, and is ordinarily known as casing head natural gas. It is collected by means of a metal head—called "braden-head"—connecting the casing with the tubing, as shown by the dotted lines at the top of Fig. 1.

2. *Dry gas.* This is gas not intimately associated with oil, but may nevertheless contain gasolene vapors. The term "dry" does not refer to water vapor that may be carried by the gas, but rather to the gasolene vapor, and, furthermore, this is a relative term since a strictly dry gas would be one containing no gasolene vapors.

The word "natural" came into use probably as contrasted with manufactured gas, and appears to have given a fallacious impression that natural gas was a free and unlimited resource. The misconception regarding its position has arisen from failing to appreciate that man creates no new matter and can merely get the materials of nature ready for consumption.

### Origin or Formation of Natural Gas

How, when, and where the constituents of natural gas were formed is not definitely known. For our purpose we need not bother about the various theories that have been propounded regarding the origin or formation of petroleum generally or natural gas constituents in particular. That is, whether these constituents originated from cosmic, organic, inorganic, animal, vegetable, volcanic, animal bacterial, plant bacterial, diatomic, or fatty algal sources is not germane.

The facts are that we have in natural gas a substance made up of mixtures of widely varying constituents for different natural gas fields. Some of these natural gases are wet, while others are dry; some are high in heating value, while others are low, and some are heavy, while others are light in weight.

### Gas Sand or Gas Rock

In no case is the gas found in rooms, caverns, or large crevices, as popularly supposed. "The oil and gas sands are simply very porous rocks which contain not only one great cavity, but millions upon millions of small or microscopic cavities, so that the oil, gas, water, or all three together, it may be, occupy these numerous little spaces, and thus saturate the rock. The larger these pores are, and the greater the volume they occupy in proportion to the volume of the rock mass, the greater will be the contained oil or gas supply, and this proportion in fairly good producing sands usually varies between one fifth and one tenth."* The degree of compression employed by nature in the formation process determined the intensity of the resulting pressure in the reservoir. The rock pressure and volume must decline as gas is removed.

Food and trees can be grown. Water supplies are constantly replenished by nature, but there is no regeneration in natural gas, and when the gas is consumed it is gone forever. While no one knows exactly how natural gas is formed, yet enough facts are known about it to indicate that nature's process was a very slow one. It has taken millions of years to make the present concentrated supplies.

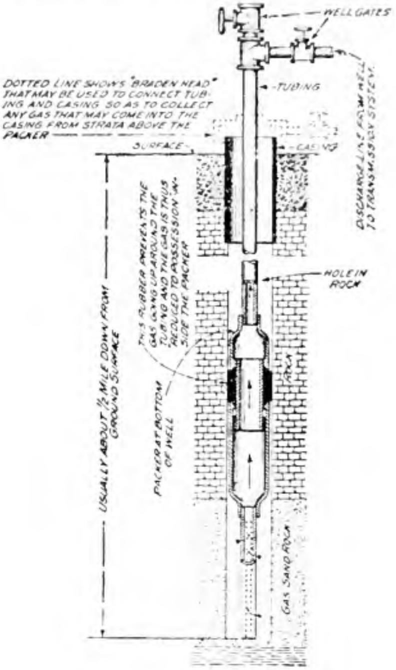

Fig. 1. Cross Section of a Natural Gas Well showing the Method Adopted for Collecting the Gas

### Geological Indications

While earth structure is the essential element in the accumulation of large quantities of natural gas or oil, geological science is a directional indicator only, and not a guarantor of commercial results. While surface conditions may be indicative, the question of underground location can be

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* I. C. White, West Virginia Geological Survey, vol. 1, p. 155.

established by the drill alone. Even the presence of gas sand is not necessarily an indication of the presence of gas, as many dry holes show the full sand formation, without any gas in the sand.

Fig. 2. Decline in the Natural Gas Resources of West Virginia based on data compiled by the U. S. Geological Survey

#### Storage

Storage facilities for natural gas are not commercially feasible in the field nor at the delivering end of the transmission line, except the very limited use of gas holders in distributing plants. The large variation in service demands must therefore be met by the wells and reserve acreage. That is, the entire field operations must be sub-ordinated to the peculiar service demands made on the natural gas company. An interesting contrast with these stringent operating conditions is the large storage equipment in acres of tank farms that may be used to equalize the load in the oil industry.

#### Well Capacity

The natural gas well capacities that are given to the public are always the open flow capacity; that is, the capacity of the well in 24 hours when discharging freely into the atmosphere. This is misleading, and comes far from representing the true service capacity, under operating conditions, of any gas well, because:

1. The first open flow measurements are nearly always made by the drillers, who do not have the facilities to make an accurate test, and the errors are invariably on the side of a capacity larger than the actual facts. The volume is determined immediately after the well comes in, and is therefore larger than it would be several days afterward, on account of the fact that the well has not been drawn upon.
2. It is not possible to keep a well in service 24 hours, day in and day out. For various reasons, such as repairs, salt-water troubles, etc., it is necessary to rest the wells at intervals.
3. The wells must discharge against considerable back pressure.
4. Based on actual operating tests, it has been determined that 25 per cent of the open flow capacity is about all that can be delivered from the average natural gas well. It must also be borne in mind that the open flow capacity will constantly decrease with the removal of gas from the well.
5. As the rock pressure declines it will be necessary to install compressing stations in order to transmit the gas through the main transmission line.

#### Migratory Nature of Natural Gas

On account of its inherent tendency to expand it is capable of flowing from place to place in the underground reservoir, or of being drawn off by wells penetrating the natural reservoir at any point. Therefore, when one owner of the surface overlying the common reservoir exercises his right to remove natural gas the amount available to other owners of the surface in contiguous territory must diminish.

#### Quality and Quantity of Natural Gas Fixed by Nature

The quantity is always uncertain and the quality may vary through a small range for the different fields. However, it is not commercially feasible to attempt to correct variation in quality by any artificial means and furnish a gas that is uniform, as may be done in an artificial gas plant, for the simple reason that the cost of doing this would be much more than the additional worth of the service.

### Scarcity of Natural Gas

The number of natural gas consumers is increasing faster than the number of producing wells, thus placing an additional burden on each well, and the wells that are being drilled at the present time have a lower average capacity than wells that were drilled several years ago.

The decline in average acres land held per natural gas well and average delivering capacity per natural gas well for the entire state of West Virginia is shown in Fig. 2.

The decline in number of acres for a natural gas well of the United States Steel Corporation, operating under the name of the Carnegie Natural Gas Co., in West Virginia, is shown in Fig. 3.

For another operating company representing nearly 40 per cent of the state's production we have the following:

1. Number of acres natural gas land owned to a domestic consumer decreased from three acres in 1910 to two acres in 1917.

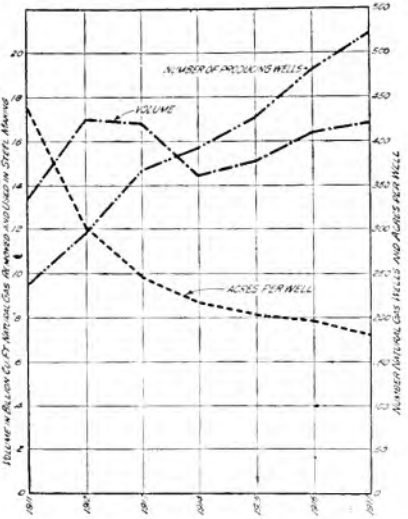

Fig. 3. Use of West Virginia Natural Gas for Making Steel by the U. S. Steel Corporation

2. The average open flow capacity of new wells drilled declined from 1200 M* in 1913 to 700 M in 1917.

3. The average annual production of a well declined from 3600 M in 1910 to 2200 M in 1917.

4. The number of domestic consumers that could be served by each producing well declined from 250 in 1910 to 170 in 1917.

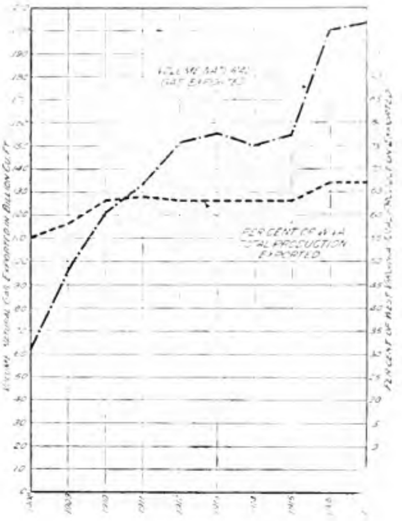

Fig. 4. Natural Gas Exported from West Virginia

5. Simultaneously with the above decline, the average annual gas service demands to the domestic consumer increased from 110 M cubic feet each year in 1910 to 153 M cubic feet each year in 1917.

The natural gas business is unique in that it is the only public utility service that does not, and in fact can not, create the basis feature of the service that it renders to the public. Manufactured gas companies merely produce their gas from the raw fuel that they can buy in the open market.

The natural gas industry depends entirely on the caprice of nature for first the finding, and secondly the continuity of the supply of its primary source of public utility service.

### Drying Natural Gas

In the transmission of the gas, due to the changes in temperature and pressure, part of the gasolene and water vapors are condensed

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* The letter "M" represents "1000 cubic feet," the unit of gas measurement.

and will give trouble in choking up the line, and the water may freeze, closing the line entirely. The gasolene will soften and decompose the rubbers in the couplers. This is due to the solvent action of the gasolene on rubber, and the immediate effect will be to cause the joints to leak.

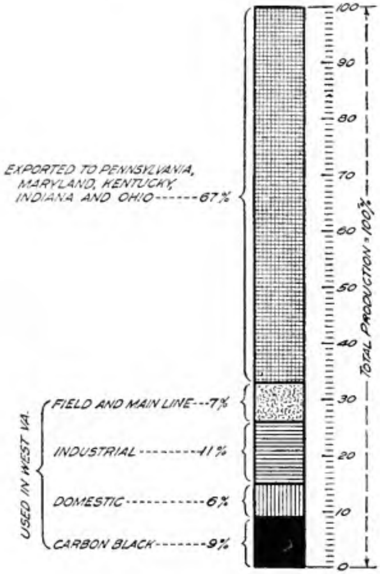

Fig. 5. Uses of West Virginia Natural Gas in 1917

The general tendency of natural gas is to become wetter as the well becomes older, and, therefore, natural gas from a new well that may be so dry as not to yield any gasolene at all, may yield gasolene in commercial quantities after the well has been in use for several years. The removal of the gasolene and water vapor carried by natural gas is desirable from the consumers' viewpoint for the following reasons:

1. Heating value is little disturbed, the removal of the gasolene from dry natural gas lowering the heating value only about 2 per cent.

2. Gasolene vapor exists in such a form that practically none of it ever can be delivered to the ultimate consumer.

3. The removal of water and gasolene by blowing the drips results in a large waste of gas.

4. The drying of the gas tends to stabilize the gas service by decreasing line troubles.

## TRANSMISSION

The broad public interest in an effective and continuous service and a future supply makes it the duty of the gas-producing company to conserve the supply of gas in every way possible. By conservation is meant not merely saving, but using in the most effective manner. This means that it is the duty of the gas company—when it can be done without financial loss—to remove every foot of gas from the ground that can be obtained; and as the fields grow older it is necessary for the gas company to increase the rapidly declining pressure by mechanical means.

The art of natural gas compression is now over 29 years old and has grown at practically the same rate as the increase in domestic consumers. There are now over 220 natural gas compressor stations in North America, aggregating approximately 350,000 horse power of compressor capacity and compressing about 90 per cent of all the gas used.

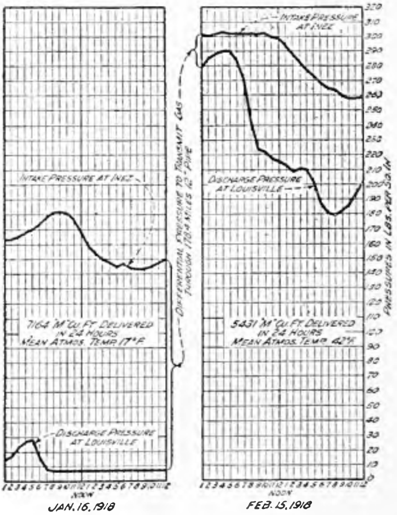

Fig. 6. Typical Line Pressure Conditions for Natural Gas Transmission

As the rock pressures of the wells decline, the pressures that have been maintained on the intake side of the compressors are lowered. This has the immediate effect of lowering the capacity of the compressing station.

The output of a typical compressor operating against a discharge pressure of 300 pounds gauge is as follows, for the respective intake pressures:

| Intake Pressure in Lb. Above Atmosphere | Capacity in Million Cubic Feet Free Gas Each 24 Hours, Based on 14.4 Lbs. Atmospheric Pressure |
|---|---|
| 150 | 30 |
| 100 | 20 |
| 75 | 15 |
| 50 | 10 |
| 30 | 6 |
| 20 | 4 |

## Not Feasible to Make Natural Gas Main Line Common Carriers

A number of attempts have been made by large consumers, owning natural gas in the field, to have the main transmission lines made common carriers so that they could be compelled to haul gas to market. The converting of main lines into common carriers is not only not feasible from an operating viewpoint, but the idea could be based only on distinctly local and selfish interests and would ignore entirely the domestic consumers' interest. That is, this plan would greatly injure service to the over 2,000,000 domestic natural gas consumers because it is not generally appreciated that there is a clear distinction between the duties of a common carrier and the duties of a public utility.

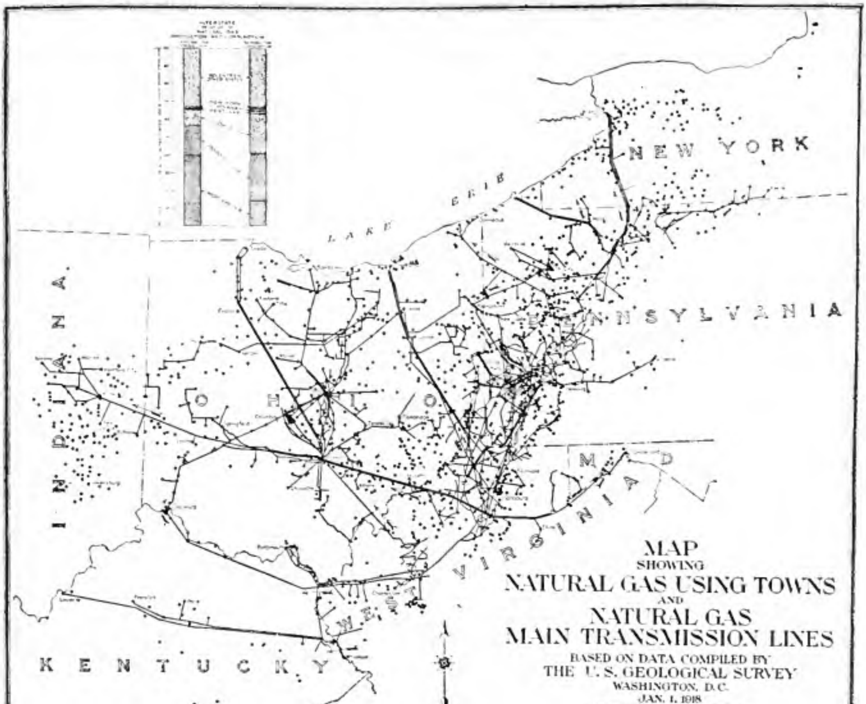

Fig. 7

The fundamental requirement of a common carrier agency like a railroad is nondiscrimination. A natural gas company operating a transmission line and supplying domestic consumers, from the very nature of things, gives its own consumers preference on account of public policy and the contractual relations existing between such consumers and the gas company.

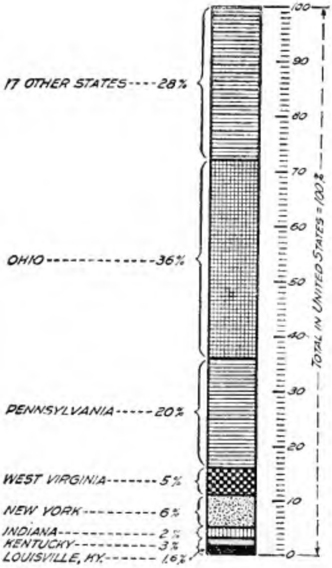

Fig. 8. Geographical Distribution of Domestic Natural Gas Consumers by States

The consumers' interests and rights extend clear back to and depend on the gas wells and reserve acreage the producing company maintains to insure an adequate present and future service. Common carrier obligations for the transmission line would:

1. So disorganize the existing business as to make it impossible to render satisfactory continuous service to either domestic or industrial consumers.

2. Make the consumers—especially the domestic—subordinate to occasional producers; that is, to men who have no intention of following the business of hunting for gas for future service, but would be interested only in finding a good market, at the expense of others, for such gas as might be found as a result of an occasional accidental venture.

3. Greatly increase the amount of gas used for manufacturing purposes, thus hastening the day when natural gas will be merely the memory of a wasted and unappreciated resource.

In West Virginia the total production is delivered as follows:

| | Per Cent |
|---|---|
| Utilities | 82 |
| Small producers, with no public utility duties | 13 |
| Carbon black manufacturers | 5 |
| | 100 |

Experience has shown that satisfactory continuous service can be rendered only when the production, transmission, and distributing features are properly co-ordinated. To subordinate the transmission side of the business to either the producer's or the larger industrial consumer's interest is indefensible

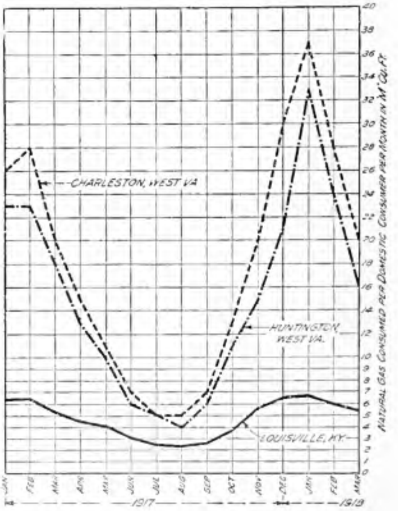

Fig. 9. Average Monthly Natural Gas Consumption per Domestic Consumer

The furnishing of a service, rather than the delivering of a commodity or product, is the dominating feature of the natural gas business.

## DISTRIBUTION

### Gas Consumers Use More Natural Gas Than Manufactured Gas

The average consumption in M cubic feet of natural gas for all the domestic natural gas consumers in the United States is 100 M cubic feet by each domestic consumer annually.

The average annual load curves for each domestic consumer in three cities are shown in Fig. 8, and the annual average consumption for each consumer were as follows:

| City | 1916 | 1917 |
|---|---|---|
| Charleston, W. Va. | 159 M | 187 M |
| Huntington, W. Va. | 133 M | 158 M |
| Louisville, Ky. | 40 M | 53 M |

The average of 682 manufactured gas companies is 22 M cubic feet of manufactured gas to each domestic consumer a year. The actual average annual consumption of manufactured gas at Louisville, Kentucky, prior to the introduction of natural gas was 24 M cubic feet.

The reasons for this large increase in domestic natural gas consumption are as follows:

1. Natural gas prices have been so low as not to make the gas worth saving.
2. The efficiencies of most natural gas using appliances are generally less than for manufactured gas using appliances.
3. Manufactured gas is used primarily for cooking, hot water heating, and lighting only. The largest part of the natural gas business results from its extensive use for house-heating where the volume required is very much greater.

The load factor data in Fig. 11 emphasize the erratic nature of natural gas loads.

### Peak Load Service

Abnormal peaks of very short duration are characteristic of all natural gas loads for domestic consumers. This necessitates a large investment for equipment that is actually used only a very short period out of each year. Every natural gas company must have considerable equipment that will be used not over four hours daily during say 30 of the coldest days of a year of normal temperature. The smallest of this is evident from the following:

Total number hours in the year = 8,760 = 100 per cent.

Hours peak load equipment is actually used = 120 = 1.4 per cent.

The hourly demand varies from a maximum value of 100 per cent to a minimum of [illegible] per cent, the average demand being 34 per cent.

Industrial loads ordinarily [illegible] more uniform than domestic load. This is especially true of the carbon black industry in the field.

An increase of volume of business can decrease the cost of production only when the increment of increase is distributed so as to make possible the more efficient use of existing equipment. When the increment of increase is concentrated so as to require more equipment, as is the case in all peak loads, the cost of production to the unit of service is increased. Therefore, the cost of peak load natural gas service is greater than the cost of normal service. A rate schedule, to be equitable to all consumers of natural gas, must make the consumers who need and create the peak load service pay a price that will be commensurate with the extra cost of the service they are receiving.

As long as natural gas prices for the higher costing peak load service remain the same, the consumer must expect a lower standard of service during that period.

### Use of Auxiliary Heating Appliances

It is desirable in all cases where possible to have auxiliary heating equipment available for supplementing or entirely replacing for a short period natural gas for house-heating service, during the peak period of the load. Where gas furnaces are used, auxiliary oil burners can be installed in such fire pots, or auxiliary coal furnaces can be installed along side the gas furnaces, where the coal furnace would discharge its heated air into the gas furnace shell.

### Basic Reasons for Large Sales of Industrial Gas

The inadequate domestic price and the policy of the Government in fostering competition in the gas field are the basic reasons for the large sales of industrial gas.

During the domestic off-peak period—usually nine months of the year—about 60 per cent of the equipment of a gas company is not needed for domestic natural gas service. Under competitive conditions in the field the gas can not be conserved for future use, except by unity of action of all producing companies. As the Government has always fostered competition, and therefore waste, the inevitable result has been to stimulate low-priced industrial gas sales, because:

1. The companies needed the revenue to make up the deficit from their too low priced domestic gas service.

2. As no one company could save its gas, except by the prohibitive "unity of action of all producers," each took all the gas it could get, as fast as it could get it out, thereby greatly depleting the supply for future service.

Fig. 10. Typical Hourly Natural Gas Consumption in Winter

At the present time of all the gas produced in the United States, practically two thirds is used in industrial service. The percentage of total State consumption that is used for industrial service, for several states, is shown in Fig. 10.

### Few Improvements in Art of Using Natural Gas

On account of the low prices that have prevailed, gas-appliance manufacturers have not been stimulated to the development of efficient gas-using equipment. There have been few improvements resulting in increased efficiency in the last 15 years. In testing house-heating furnaces it has been found that:

1. The use of natural gas in the fire pot of a coal furnace gives an efficiency of about 25 per cent.

2. The use of natural gas in the ordinary gas furnace gives an efficiency of about 35 per cent.

3. The use of natural gas in a correctly designed and built gas furnace, where the construction conditions permit the fullest utilization of the heat in the gas, gives an efficiency of about 75 per cent.

In tests made by the Bureau of Standards, it was found that the ordinary incandescent mantle lamp where used with natural gas wasted nearly half of the possible heat that could be used if such lamps were designed for as efficient operation on the high heating value natural gas as they give on the low heating value manufactured gas.

In tests made by the department of home economics, Ohio State University, the efficiencies of a natural gas range varied from 37 per cent with 0.2 ounce pressure down to 13 per cent at four-ounce pressure,* while with a manufactured gas range, using natural gas, the efficiencies varied from 43 per cent at 0.2 ounce pressure to 23 per cent at one-ounce pressure.

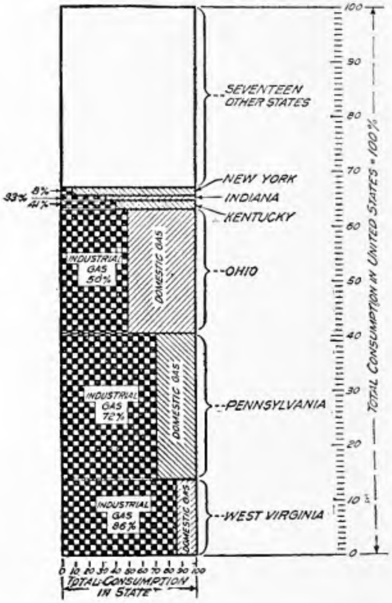

Fig. 11. Relation of Industrial to Domestic Natural Gas Consumption

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* Ohio State University Bulletin, vol. 22, No. 28, May, 1918, "Effect of Gas Pressure on Natural Gas Cooking Operations in the Home."

### Cooking and Heating Distinguished

In a heating operation it is merely necessary to secure perfect combustion in the heating device, because in so doing all of the available heat in the gas can be utilized. In cooking it is not only desirable to secure a perfect combustion, but absolutely necessary to direct the heat to a particular place and sometimes at a particular time. It is for this reason that gas-cooking operations are more to changed pressure conditions than heating operations.

It may not be amiss to emphasize that the time element in many cooking operations is of much more importance than intensity.

### Gas Pressure

The pressures carried by most natural gas companies have been too high for efficient service. This has had the further undesirable feature of teaching the consumer to believe that he was not receiving service unless the gas could be heard hissing through the orifice in the gas mixer. It has been demonstrated that*—

1. Satisfactory cooking operations in frying potatoes, boiling potatoes, frying beefsteak, and pan-broiling beefsteak can be carried on with 0.2 ounce natural gas pressure. This merely requires that the short flame and cooking vessel be brought together.
2. Better results are obtained with pressures in the neighborhood of two ounces than at four ounces, and less gas is used.
3. Manufactured gas range gives better results than natural gas range because the former is designed for low pressures.
4. There is very little difference in the time required to carry on cooking operations with pressures of from one to five ounces.

Therefore, if the consumer will use proper appliances, satisfactory cooking operations can be carried on with pressures as low as 0.2 ounce and the gas will perform a usable service.

With heating appliances, if the mixer is properly adjusted the combustion at low pressures can be made substantially as thorough as at high pressures, and the consumer can have the benefit of all the heat generated by the burning gas, although if the pressure is low he will invariably not have nearly as much as he would like to have or as he needs.

### Consumer is Responsible for Economic Use of Gas

Few people appreciate that even in an ordinary frying operation effective results can not be obtained unless the vessel position is close enough to the flame so that the tip of the flame can deliver the heat generated in an effective manner. Even with high pressure and long flames, if a strong draft should deflect the flame the cooking service will be unsatisfactory.

### Distinction Between Luxury and Necessity in Natural Gas Service

To the average family for cooking, water heating, lighting, and incidental house heating service, natural gas may be a necessity, but when used in larger quantities or for house-heating furnace work it becomes a luxury. Furthermore, the peak load characteristics of house heating furnace service make this service cost more to the natural gas company. An equitable schedule of rates ought, therefore, to provide for a fixed net price for a large enough monthly consumption to permit of the cooking, water heating, lighting, and incidental house heating service necessary in the average family. The price for excess consumption ought to be increased to make the consumer pay for the higher priced service he is receiving.

It is a trite observation that the luxuries of one day tend to become the necessities of the next. Most complaints for inadequate service during the few peak load hours, usually less than one per cent of the total 8760 hours in the year, are based on the fallacy that a service that is purely a privilege has become a prerogative; that is, natural gas consumers as compared with other fuel users who have to use solid fuel or manufactured gas are a privileged class enjoying a luxury that is seldom appreciated until it becomes difficult to obtain, and on account of the limitations fixed by nature they do not possess and can not ask any inalienable rights of service, under conditions that are physically impossible to meet.

### Effect of Pressure on Temperature Changes on Heating Value of Gas

The variation in temperature of natural gas in the underground mains makes more difference in the heating value than the variation in gage pressure. The maximum fluctuation in temperature produces a difference in heating value of about 5 per cent, while the maximum fluctuation in pressure produces a difference in heating value of less than 4 per cent.

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Furthermore, these variations work in opposite directions; that is, in winter time when the pressure is low, therefore tending to decrease the heating value, the temperature is low, tending to increase the heating value. This increase due to low temperature will always be more than the decrease due to low pressure.

The volumetric changes will alter the distribution of the total number of heat units, as shown in Table II.

TABLE II

| Gage Pressure in Ounces Above Atmosphere | Relative British Thermal Unit | Relative Per Cent | Gage Pressure in Ounces Above Atmosphere | Relative British Thermal Unit | Relative Per Cent |
|---|---|---|---|---|---|
| 8 | 1034 | 103.4 | 3 | 1013 | 101.3 |
| 7 | 1030 | 103 | 2 | 1009 | 100.9 |
| 6 | 1026 | 102.6 | 1 | 1005 | 100.5 |
| 5 | 1022 | 102.2 | 0 | 1000 | 100 |
| 4 | 1017 | 101.7 | | | |

| Gas Temperature Deg F. | Relative British Thermal Unit | Relative Per Cent | Gas Temperature Deg. F. | Relative British Thermal Unit | Relative Per Cent |
|---|---|---|---|---|---|
| 70 | 960 | 96 | 50 | 1000 | 100 |
| 65 | 970 | 97 | 45 | 1010 | 101 |
| 60 | 980 | 98 | 40 | 1020 | 102 |
| 55 | 990 | 99 | 35 | 1030 | 103 |

### Combustion of Natural Gas

Each cubic foot of natural gas burned requires approximately 9½ cubic feet of air, forming 10½ cubic feet of combustion products, which are made up of 2 cubic feet of steam, 1 cubic foot of carbon dioxide, and 7½ cubic feet of nitrogen.

The combustion of 1000 cubic feet of natural gas will form 2000 cubic feet of water vapor or steam, and this when condensed will make approximately 10½ gallons of water. This is true of all gases containing hydrocarbon compounds. Manufactured gas will form about one half the water vapor produced by the combustion of natural gas. It is this water vapor that causes the bakers and broilers of stoves to rust, and where gas is used in open fires without flues, or for lighting, makes the walls and windows sweat and glued furniture open up.

If the combustion is not perfect, then carbon monoxide, which is a deadly poison, may be formed. The toxic action of this is so marked that one tenth of one per cent is enough to produce fatal results. This is especially likely to be formed when a flame is suddenly impinged on a cold surface, as, for instance, the first few seconds' operation of an instantaneous hot water heater.

### Effect of Atmospheric Temperature on Demands for Gas

The temperature of the atmosphere has a direct bearing on the demands for natural gas for heating service. However, the quantity of cooking, incidental water heating, and lighting is independent of the temperature of the atmosphere and would be practically constant for the year. The humidity of the atmosphere, direction and velocity of wind, and hours of sunshine, also affects gas consumption, as far as heating service is

TABLE III

DAILY GAS HEATING CONSUMPTION FOR EACH DEGREE OF TEMPERATURE BELOW 70 DEG. F.

| Date | Mean Temperature of Atmosphere, Degrees F. | Difference Between Mean Temperature and 70 Degrees. 70-A | M CUBIC FEET NATURAL GAS A DAY | | | |
|---|---|---|---|---|---|---|
| | | | Delivered to Louisville | Service Independent of Atmospheric Temperature | Heating Service | Heating Service per Degree Below 70 Deg. F. (E ÷ B) |
| | (A) | (B) | (C) | (D) | (E) | (F) |
| 1917 | | | | | | |
| Feb. 2 | 2 | 68 | 13,209 | 4,500 | 8,709 | 128 |
| Jan. 14 | 10 | 60 | 12,193 | 4,500 | 7,693 | 128 |
| Jan. 11 | 20 | 50 | 11,370 | 4,500 | 6,870 | 137 |
| Jan. 26 | 30 | 40 | 10,869 | 4,500 | 6,369 | 159 |
| Jan. 6 | 39 | 31 | 9,142 | 4,500 | 4,642 | 149 |
| Jan. 3 | 48 | 22 | 7,852 | 4,500 | 3,352 | 152 |
| Jan. 29 | 58 | 12 | 6,830 | 4,500 | 2,330 | 194 |
| Average | | | | | | 150 |

concerned. In general, a high wind causes more of an increase than merely a low temperature. The mean monthly temperature curve plotted upside down will always show a close relationship between volume of gas used and temperature of atmosphere.

### Daily Demands for Gas Heating Service

The daily gas heating consumption to each degree of temperature below 70 deg. F., at Louisville, Ky., from mean temperatures ranging from 2 degrees on February 2nd, to 58 degrees on January 29th, is shown in Table III.

It will be noted that the heating service for each degree is larger at the warmer temperatures. This is because the general tendency is to keep most houses at a higher temperature than necessary, and for this reason on account of the cheapness of the gas, and the general absence of thermostat control devices, the gas is not used as efficiently.

### Monthly Demands for Gas Heating Service

When the atmospheric temperature drops below 70 deg. F. demands for heating service are created which are practically proportional to the number of degrees that the atmospheric temperature is below 70. The variation in monthly demands for each degree of atmospheric temperature below 70 deg. F. is given in Table IV.

The data in column D is the estimated consumption for cooking, incidental water heating and lighting, which is entirely independent of the atmospheric temperature and the estimated figure is taken approximately as the total amounts delivered during the months of June, July, August, and September, when there are practically no demands for heating service.

The average of the demands for heating service at Louisville, Ky., for each degree below 70 deg. F., for the months of January, March, April, May, October, and November, 1917, and March, 1918, when enough gas was available to meet the demands, was 5,500,000 cubic feet for each month for each degree below 70 deg. F.

### Why Standards for Natural Gas Service Must be Lower Than for Manufactured Gas

The operating conditions in a natural gas plant are so different from those prevailing in a manufactured gas plant that the standards of service that would reasonably be applicable to the latter would not be feasible or expedient with natural gas, because:

1. The volume of natural gas business for each domestic consumer is generally

TABLE IV

MONTHLY GAS HEATING CONSUMPTION FOR EACH DEGREE BELOW 70 DEG. F.

| Date | Mean Monthly Temperature of Atmosphere, in Degrees F. | Difference Between Mean Temperature and 70 Deg. F., 70-A | MILLION CUBIC FEET NATURAL GAS A MONTH | | | |
|---|---|---|---|---|---|---|
| | | | Delivered to Louisville | Service Independent of Atmospheric Temperature | Heating Service (C-D) | Demands for Heating Service per Degree Below 70 Deg. F. (E ÷ B) |
| | (A) | (B) | (C) | (D) | (E) | (F) |
| 1917 | | | | | | |
| January | 36 | 34 | 302 | 140 | 162 | 4.8 |
| February | 32 | 38 | 260 | 140 | 120 | 3.2* |
| March | 46 | 24 | 260 | 140 | 120 | 5.0 |
| April | 55 | 15 | 232 | 140 | 92 | 6.1 |
| May | 60 | 10 | 204 | 140 | 64 | 6.4 |
| June | 72 | ... | 140 | ... | ... | ... |
| July | 76 | ... | 131 | ... | ... | ... |
| August | 76 | ... | 134 | ... | ... | ... |
| September | 69 | ... | 149 | ... | ... | ... |
| October | 51 | 19 | 243 | 140 | 103 | 5 |
| November | 45 | 25 | 270 | 140 | 130 | 5.2 |
| December | 26 | 44 | 269 | 140 | 129 | 2.9* |
| 1918 | | | | | | |
| January | 20 | 50 | 263 | 140 | 123 | 2.4* |
| February | 38 | 32 | 223 | 140 | 83 | 2.5* |
| March | 51 | 19 | 232 | 140 | 92 | 4.9 |
| Average of normal months | | | ... | ... | | 5.5 |

* Not enough gas available to meet demands.

about five times as large as for manufactured gas.

2. The peak load difficulties in a natural gas load are much more troublesome than in manufactured gas.

3. The service standards can not be limited to merely the distributing plant limits, but would be closely related to the main pipe lines, back into the field to the compressing stations, and general field operating conditions.

4. The supply can be kept continuous only by constant and persistent hunting for new supplies.

5. Although the distributing end is a public utility service, the field or producing end is a mining proposition, and the continuous connection of the two by the transmission line has the immediate effect of also connecting the mining hazards to the distributing end of the business.

6. In general, the prices for natural gas service have not been adequate, and have not been made on the basis of rendering as uniform a condition of service, especially with regard to pressure, as can be maintained in a manufactured gas plant.

### Discount for Lower Pressures Stimulates Waste

A penalty clause providing for a discount when pressures less than four ounces are maintained has been suggested as a means of guaranteeing good service. However, instead of guaranteeing service it stimulates waste. The penalty clause is inequitable and fails to recognize the well known operating characteristics of the mining, transmission, and distribution of natural gas, which differentiate this from other type of public utility service for the following reasons:

1. The heating value of the gas does not decrease proportionally with the decrease in gage pressure.

2. Higher efficiencies may be obtained at pressures below four ounces than at four ounces and above.

3. It ignores the volume of gas to be delivered and the close relationship between volumetric demands and the constantly changing atmospheric temperature.

4. General conservation methods in the field have not been followed in the past; gas has been produced, transmitted, and distributed in a wasteful manner, which has greatly depleted the available supplies.

5. The gas in the underground reservoirs is entirely beyond control, and yet its expansive properties must be taken as the initial step for the delivering of service to consumers 200 miles away. It is evident, therefore, that considerable leeway must be allowed in service standards.

*(To be Continued)*

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