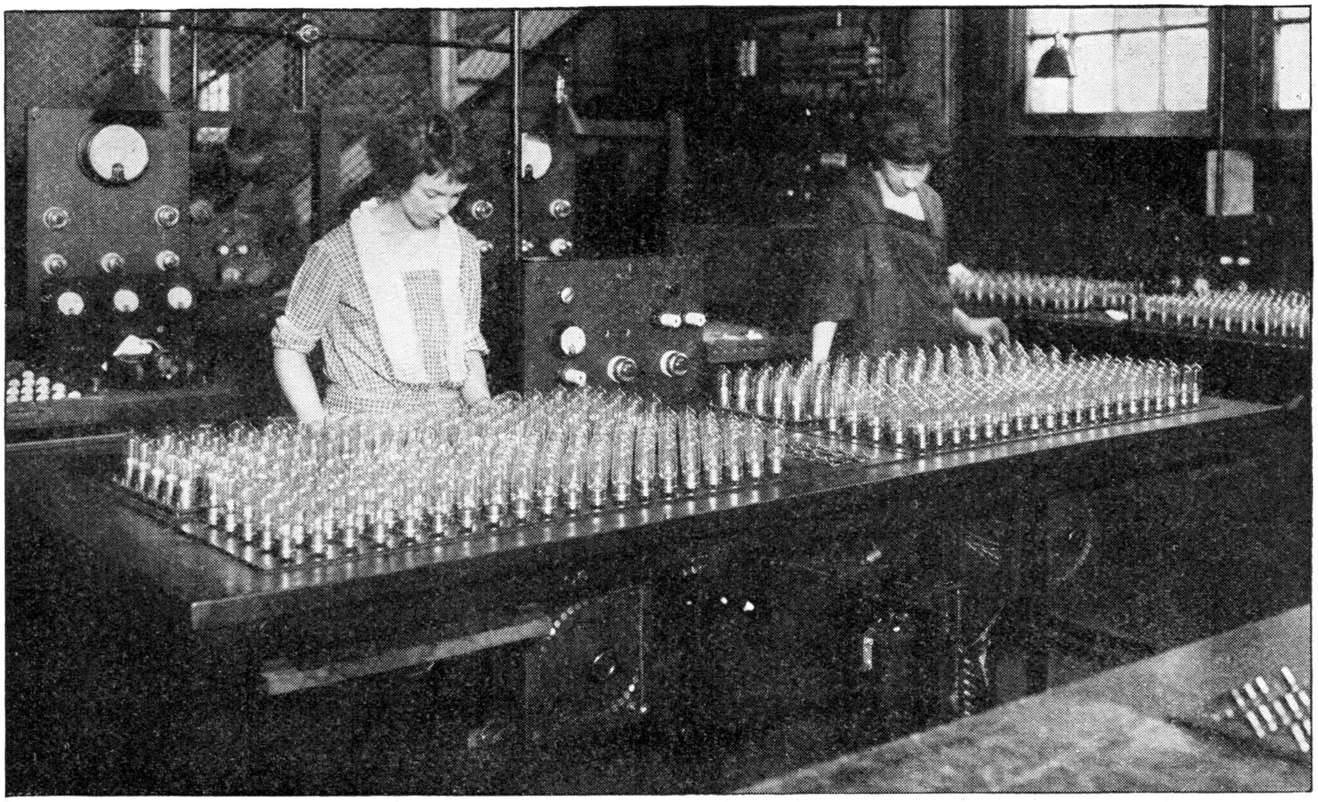

WD-11's and WD-12's on the aging table. The tubes are kept on this table one hour to increase the possible electron emission and to test for the degree of vacuum

How Vacuum Tubes are Made

Following the WD-11's and WD-12's Through One of the Plants in Which They are Made

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This is the first time that an article has been published in a radio magazine describing and illustrating the important steps in the manufacture of vacuum tubes. Except for minor modifications and a difference in the exhausting process, all vacuum tubes are made in a way much like the dry-cell tubes here described by Mr. Rodgers.—THE EDITOR.

IF ONE were asked what single factor has made radio universally popular in America, the answer might not be as difficult as it first seems. For, of the many things introduced into the radio market for the benefit of amateur and fan, the dry-cell vacuum tube stands supreme in the number of radio enthusiasts it has added to the list of those who nightly listen-in. Thousands of new fans were created as soon as the dry-cell tube began to be sold in quantities.

This little tube eliminated a sharp class distinction in the radio world. Before it came there were the crystal detector users and the vacuum-tube users. Crystal detector sets were numerically superior to vacuum-tube sets when all that could be obtained was the six-volt tube operated from a heavy and expensive storage battery. People who could not afford these items had to be content with crystal detectors, and thus were very limited in their range of radio entertainment.

Then came the dry-cell tube, changing this condition. The purchaser of the one-volt tube could procure his current from a 40-cent dry cell; whereas the storage battery needed for a six-volt tube cost from ten to twenty dollars. There was such a rush on the part of the public to buy, that for a time the manufacturers were swamped. In fact, two great shortages have occurred in the vacuum tube supply since they were first placed on sale.

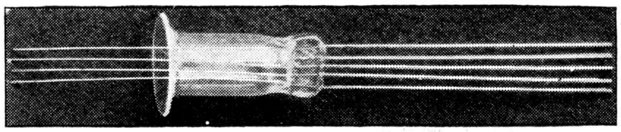

FIG. 1

The short glass tube has a flare on one end and its other end has been melted and pressed down around the five wires, which are imbedded firmly in the glass. Note that there are five wires in the glass press, but only four leads come through the flared opening. The fifth wire is a blind which acts as a support, later, for the plate

These shortages are not likely to occur again as they occurred with a type of tube made by one company, which at the time was the only concern in America capable of producing these tubes in quantities. There are now two companies making such vacuum tubes, and thus with their increased facilities a much larger production is available.

The first commercial dry-cell vacuum tube, the WD-11, is a product of the Research Laboratories of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. It was here that the need for such a tube was first seen and the research work necessary to the perfection of the finished tube carried on.

Early in radio telephone broadcasting history, after the public had indicated its interest in the concerts and the possibilities of the industry were realized, the need for a vacuum tube which could be operated at low cost was clearly seen. It was apparent to the men who had the problem to solve that the first cost of the tube was not what prevented an almost universal interest in radio, but that it was due to the upkeep, as they say in the automobile world. Storage batteries cost money to buy and to keep charged.

Long before the first order was given the Research Laboratory to start experimenting on the proper material for a low-voltage filament, preliminary work had been started by the research engineers. It had been discovered that a new filament was necessary. This filament must consume a very small amount of current yet have a satisfactory electron emission.

However, in spite of the preliminary experimenting on the tube, it was nearly eight months before the Research Laboratory, which received its order from the Company officials to start developing a tube having the WD-11 characteristics in March, 1921, was able to furnish the perfected tube. The first commercially practical tube was completed October, 1921. During the eight months intervening a new oxide-coated filament was perfected and the WD-11 type designed.

At first there was some trouble in securing the proper type of worker—one who required no small degree of skill in the various stages of assembly. Girls had been decided upon for a large number of the manufacturing operations, and a few thought that it would require a long period of training to fit them for the work.

While the organization was being perfected the Research Laboratory undertook the construction of 400 tubes. This order came in October, 1921. With an augmented force the 400 tubes were completed in a short time. Then another order for 400 tubes was placed with the Research Laboratory and upon its completion, another and still other orders. The tube became popular at once and the demand for it by the public exceeded expectations.

At the time the tubes were being assembled in the Research Laboratory, a section of the factory in East Pittsburgh was being equipped to build the tubes. The men and girls trained by the research engineers formed the nucleus of the larger force required in the department of the Main Works where the tubes are now assembled. Soon this department was building tubes in daily increasing quantities.

Since the vacuum tube department was given the task, production has so increased that

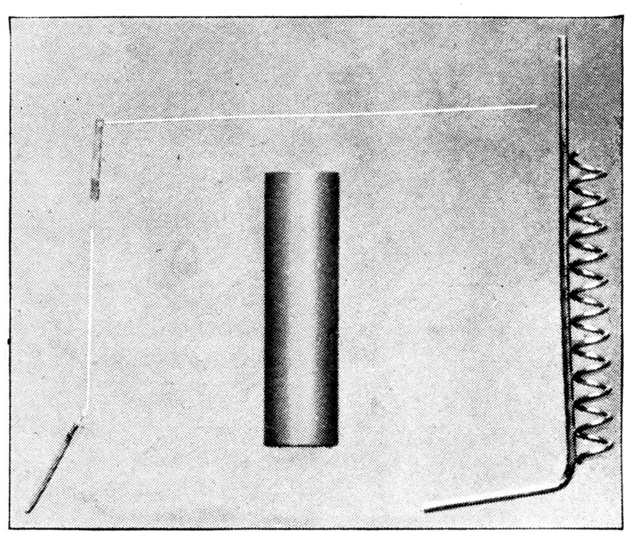

FIG. 2

The filament, plate, and grid of the WD-11 and WD-12 dry-cell tube. Note that the ends of the filament are held by two clips and that there is a support running from the upper clip. These attachments are provided so that the filament may be spot-welded to its support now the average number of tubes assembled daily is 7,500. This is quite a large quantity when one considers the care necessary in their assembly and the number of tests each tube is required to pass before it is considered ready for the purchaser.

The WD-11 and WD-12 tubes, which are identical except for their bases, despite the fragile character of the materials used and the great care and skill necessary to their proper assembly, are sturdy bits of apparatus, well adapted to withstand fair handling and give efficient service during a long life. Much attention has been given to constructing them so that they might be small yet not at all delicate. This does not mean that they are dropped on the ground to test the strength of the glass, nor that they will come up smiling after having $22\frac{1}{2}$ volts connected across their filaments. How many users have burned out their dry-cell tubes because of this error! The filament voltage should not be more than one and one-tenth volts.

FIG. 3

Mounting the filament—step seven in the assembly. The operator is holding the assembled inner unit in her hand while she spot-welds the top of the filament to its support

There are two main units in these tubes—the outer tube, from which the air is removed, and the assembled inner unit. If this is kept in mind and if it is understood that all assembly is done on the inner unit which is then inserted in the outer tube, sealed in and the outer tube exhausted of air, the various stages of manufacture may be followed very easily.

There are 13 steps or processes through which the parts go before they emerge as the complete vacuum tube. There is a test made after each stage of the assembly and still further tests after the tube is completed. The tests are so severe that a tube after it passes through them is rarely returned from a customer for failure to operate correctly.

The raw materials from which the completed tube is made consists of the glass blank, which is purchased from the glass manufacturer already shaped—this forms the glass walls of the tube; a thin glass stem; a short tube of glass, which is later shaped and which holds the wires in place in the tube; the filament, cut to size and coated at the East Pittsburgh plant; the plate; and the grid. The plates are shaped from a rectangular piece of metal, and the grid wires are wound into the spiral form they take in the completed tube.

All these units can be seen in the photographs of the assembly process.

The first step in the process is the making of the flare. This consists in heating the small tube on one end to soften it and then spinning on the flare.

It will be noted, if one looks closely (Fig. 1) that there are five wires in the press or inner unit of which four run through. The fifth wire is merely a blind inserted to act as a support for the plate. These wires are white at the top but red where they adhere to the glass in making the seal tight. Dumet wire is used for the seal, nickel being welded to it at the top. A copper covering is necessary so that when the press is melted to hold the wires at its top, a gas-tight joint is formed.

The placing of the five wires in the press is the second operation of the assembly. What this resembles with the five wires imbedded in is clearly shown in the photograph.

Next the stems are cut to the proper length so that when the plate, grid, and filament

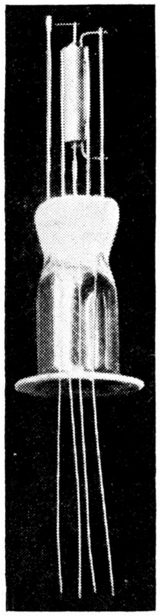

FIG. 4
The assembled inner unit complete, with grid, plate, and filament mounted. The flare at the end of the glass mount is used for sealing in this assembled inner unit to the glass blank

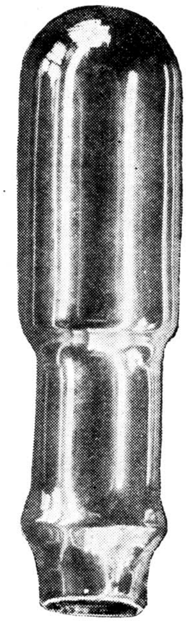

FIG. 5
The glass blank as it is received from the glass factory

(Fig. 2) are inserted they will fit in their proper places. This makes the fourth step in the operation.

Step five consists of mounting the plate. This is spot-welded to its support by a girl who has a special machine for the task.

Step six consists in mounting the grid. This is also spot-welded at the top and bottom to its mounting.

The next step is mounting the filament (Fig. 3). This filament, which is a platinum iridium alloy, coated with an oxide of barium and strontsium, comes to the girls already cut to the right length, properly tested and with its ends ready for mounting. Mounting the filament is probably the most delicate task in the assembly of the tube.

There is a good reason for using an alloy for the vacuum-tube filament. Ordinary metals are not used because they are not as strong at the temperature to which they are subjected as is the alloy. Making the tube strong enough to stand the wear and tear of daily use was ever a problem before the research department. All sorts of metals were tried. The WD-11 filament has a long life which accounts for the fact that it will give service for a period often ranging between 2,000 and 3,000 hours.

Step seven is completed with the mounting of the filament (Fig. 4). The weld press is completed and is ready to be placed in the glass blank (Fig. 5), which first must be prepared for exhausting.

Step eight in the process is called tubulating the glass blank (Fig. 7). A thin point of flame is blown against the rounded end of the glass blank, so that a tiny hole is melted through. Then the glass tube is welded around this hole. The blank now has a glass tube running from its end (Fig. 6). This glass tube is attached for the purpose of exhausting the tube. As the other end of the tube is sealed this end remains so that it can be attached to the pumping machines.

The next step, number nine, is termed sealing-in (Fig. 8). When it is finished, the glass weld with its mounted plate, grid and filament and the four wires, running out of its end, is firmly sealed to the glass blank. The flare, first spun on the press, is used to make this joint.

At this point, the tube resembles a completed vacuum tube except that it has no base and has a long glass tube mounted on its top.

When the sealing is completed, the tube is tested for leaks in any part of it. It is also tested for short circuits from filament to grid and from grid to plate.

Step ten—exhausting the air from the tube—is a very important one (Fig. 9). Before arriving at this stage, a getter has been painted on the base of the glass weld. It can be seen as the white dab on the press holding the five wires in place. From 10 to 15 minutes are required to exhaust each tube.

In exhausting the tube, the glass stem at the top is inserted in a piece of rubber tubing which leads directly to the pumps. These are two in number, an oil pump and a mercury-vapor pump.

A covering is pulled down over the tubes. This covering serves as an oven to bake them at a temperature of 400° Centigrade and thus reduce the gas content.

Then the pumps are turned on and the tubes exhausted to a pressure of one-millionth of a millimeter of mercury. This is a much higher point of exhaustion than that given the electric lamp.

As the tube sits in the holder, it is surrounded

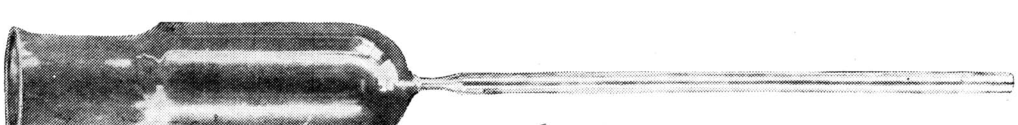

FIG. 6
The glass blank with its stem attached. This stem is used in the process of removing the air from the tube

by a coil of heavy copper wire. The covering is now pulled up and a high-frequency spark is thrown on this surrounding coil to test the tube for cracked glass.

After this, the plate is heated red hot by an oscillating current having a frequency of 1,000,000 cycles —these are generated by two 250-watt tubes similar to those used for transmitting purposes—to remove the gas from the plates and metal supports.

Next in order is the turning off of the plate oscillations and heating the filament to obtain the proper chemical reaction on the filament oxide and thus increase the possible electron emission.

The tip is now sealed off by the machine operator using a gas flame, which he runs around the bottom of the glass tube until it melts off and forms the tip.

Finally the tube, properly exhausted is removed from the machine, complete now except for the base (Fig. 10).

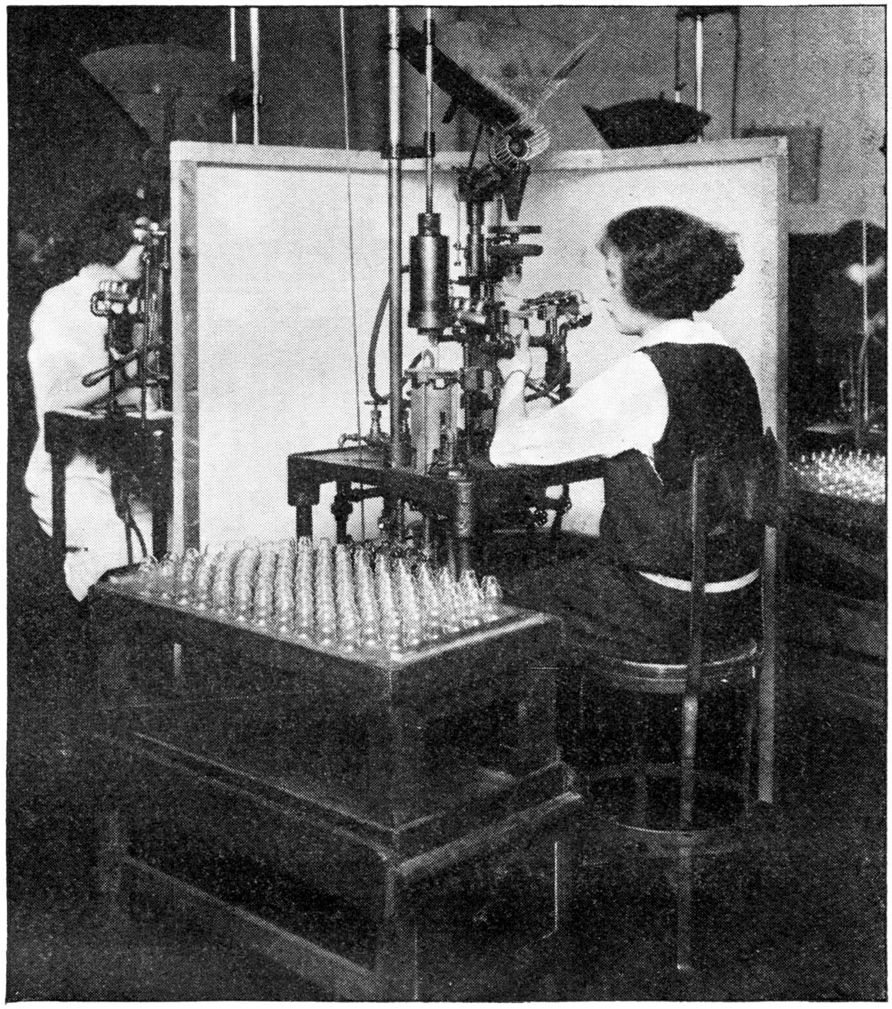

FIG. 7
Tubulating the blank. A tiny hole is melted in the rounded end of the glass blank and around this hole is sealed a glass stem

The tube now passes through several stages of inspection before the bases are cemented on. During this inspection, the tube is carefully looked over for appearance and poor tips, and for degree of vacuum. Opposite the inspectors who take the tube at this stage there is a box into which the rejected tubes are tossed and smashed to fine bits.

Step number eleven is cementing the base to the tube. Just before "basing," a small glass stem is slipped over each of the four leads to prevent any shorts at this point. The base is filled with a cement, an operator draws the four wires through the stems in the bottom of it, and the tube with its base attached is placed in a machine which bakes the base on firmly. Included in the basing operation is the soldering of the bottom of the tips on the base and rounding off the ends of the stems. An operator dips the stems in a solder pot so that the wires running through the stems are soldered firmly in place. To make a neat job, the stems are next placed in a machine so that they are rounded off properly. Just look at the tips on the base of your vacuum tube to understand this operation.

Thus when the tube reaches this stage it resembles the one used in the receiving set. But it still has some tests and processes to go through before it can be called completed.

The next step is a test, and while it is given no number in the order of assembly, it is important. This test is termed lighting out the tube (Fig. 11). An operator places the tube in a base connected to three electric lamps; one red, one blue, and one white. The red lamp is in series with the grid, the blue lamp is in series with the plate and the white lamp is in series with the filament. If, when the tube is placed in this base, one of the lamps glows, it is discarded, for it plainly can be seen that the wires are short-circuited and the tube is unfit for use.

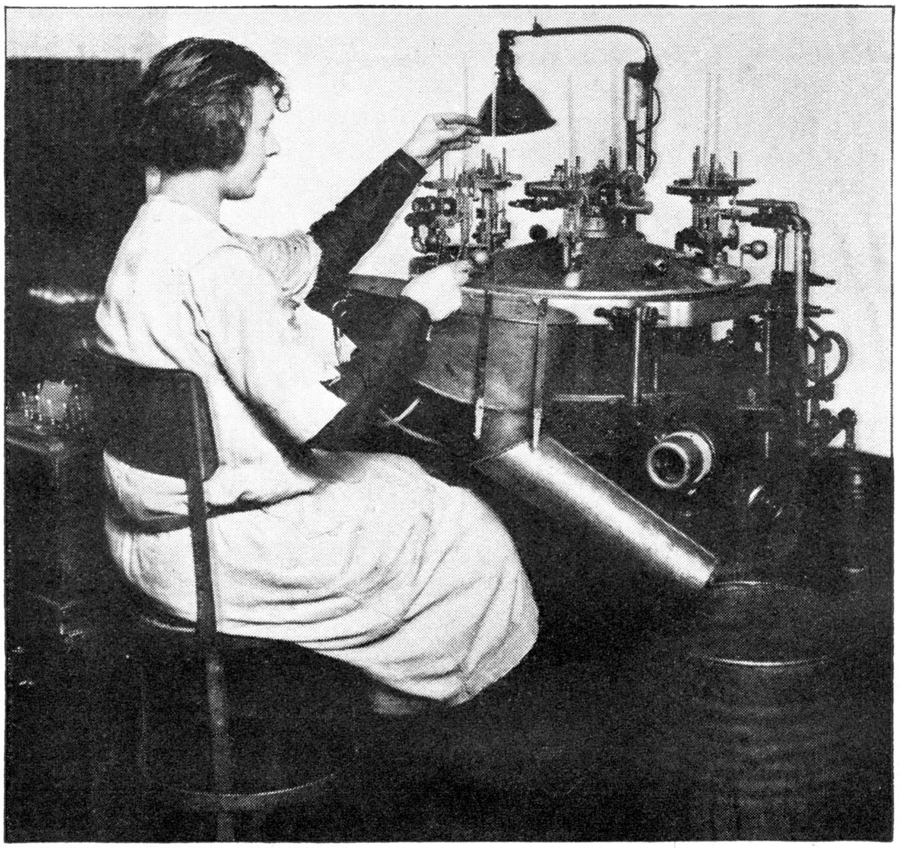

FIG. 8

In this process, the assembled inner unit is sealed by means of its flare to the bottom of the glass blank

Those of the tubes which pass this test go on to the next stage. This is a test and a process combined for developing more efficiency in the tube. It is step twelve, otherwise known as the aging process. In it the tubes are placed upright, several hundred at a time, on a table, with their leads connected to circuits which are slightly stronger in voltage than the tube is subjected to in normal use (photo p. 397). The tubes are kept on this table one hour to see if any faults develop and to obtain the maximum electron emission from the filament. During this aging test, sometimes the degree of vacuum is found to be insufficient. This condition can be determined by a measurement of the negative grid current. During the aging process, the getter absorbs such gases as might remain in the tube.

After leaving the aging table, the tubes are stored for three days. This is time enough to determine whether there are any air leaks. After this final storage, they are again tested for all circuits, filament emission, degree of vacuum and appearance and are ready for shipping.

The final stage is the packing. Those who have purchased the WD-11 know how carefully it is packed in its cardboard box with many layers of packing material wrapped around it.

The process of assembling these tubes is one that is long and tedious, calling for the utmost skill on the part of the various operators. In assembling the

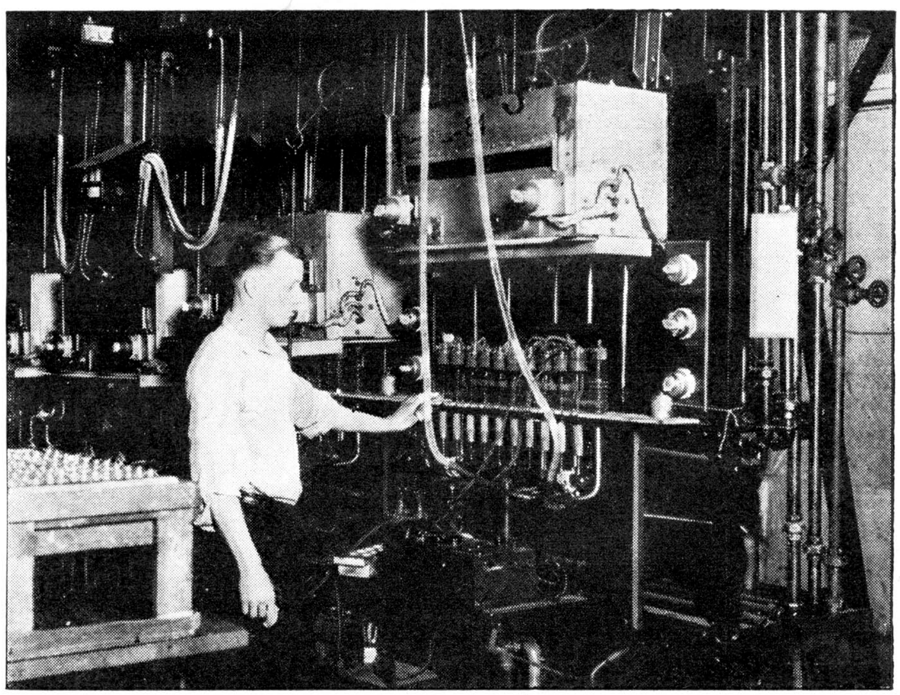

FIG. 9

Exhausting the tube—step ten. Ten tubes are exhausted simultaneously in this machine. Each one is surrounded by a coil, described in the article, and its glass stem is attached to a rubber tube (seen underneath the shelf) which leads to the pumps. The white box-like affair just above the row of tubes is the oven. It is pulled down over the tubes to bake them as a part of the exhausting process plate, grid and filament, girls do the task. They do, also, most of the preliminary tests. Men operate the exhausting machines and do the final testing.

A visit to the vacuum-tube department at East Pittsburgh is a revelation of the efficiency of the workers. The recruits are trained by skilled operators a number of weeks before they are placed at the task of doing the actual assembling. Some difficulty is experienced in obtaining girls who are dexterous enough to do the work properly. The employment department thinks that if one girl out of ten or fifteen sent to it is found satisfactory, it is doing well. All these things must be considered in the assembling process. The skill of the worker is largely responsible for the efficiency of the tube.

Dry-cell tubes have been brought to a high point of efficiency, and experiments are constantly being carried on to develop this efficiency further. The point now has been reached where it costs much less to operate the filament of a vacuum tube than it does to light the electric lamp above the head of the radio enthusiast operating his receiver.

Each tube is a monument to masterful research, inventive genius, the wizardry of modern machinery and a perfect organization of workers and officials.

It is certain that further experiments now going on will reduce this operating cost and still further lengthen the life of the dry cell. The Research Laboratory which first developed the tube is constantly working on various forms of low-voltage tubes. These stories, however, must wait until the tubes are perfected.

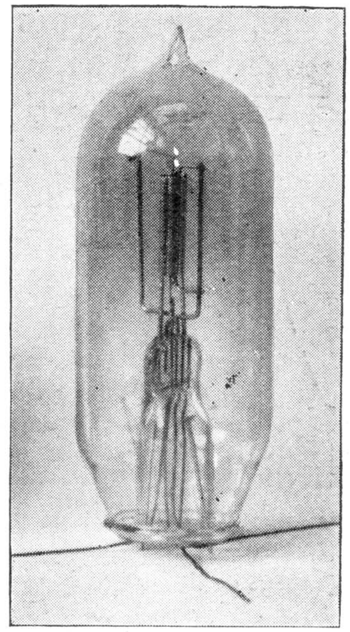

FIG. 10
After the tube has been exhausted and the glass stem sealed off, it resembles the completed tube except that it has no base

FIG. 11
"Lighting out." The tube is placed in a holder leading to the three lights in series with the grid, plate, and filament. If one of the lamps lights when a tube is placed in the holder, the operator knows that the tube has developed a short circuit