TABLE I

Spectral Distribution of Visible Radiant Energy from Incandescent Lamps

Wavelength	2900°K.	3000°K.	3100°K.
.40	.1306	.1492	.1688
.45	.2861	.3120	.3383
.50	.5066	.5326	.5582
.55	.7726	.7883	.8033
.60	1.0571	1.0523	1.0476
.65	1.3352	1.3014	1.2704
.70	1.5782	1.5193	1.4584
.75	1.8006	1.6969	1.6055

Voltage Effect on Mazda Lamps.—The curve of Fig. 8 shows the changes in lamp performance with changes in the voltage on the lamp. Note that an increasing voltage causes the light output to increase rapidly, and also causes a rise of filament temperature which changes the spectral distribution. The trend is indicated in Table I.

REFERENCES

[1] PARAFIN, M.: "Progress and Development Possibilities in Field of Luminescent Tubes," *M. T. Z.* (June 19, 1930), p. 889.

[2] JONES, L. A.: "The Photographic Reflecting Power of Colored Objects," *Trans. Soc. Mot. Pict. Eng.*, **XI** (September, 1928), No. 31, p. 564.

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REPORT OF HISTORICAL COMMITTEE

In view of the settlement by the courts of the high-vacuum electron tube patent situation and the intimate relation that this subject has to the talking picture, the following articles by Robert A. Millikan and William R. Ballard, published in the Bell Telephone Record of July, 1931, have been selected by the Historical Committee as being worthy of perpetuation in the records of the S. M. P. E.

RADIOS PAST AND FUTURE*

From a Radio Address by
ROBERT A. MILLIKAN

What is this miraculous thing, the radio, and how did it ever come into being? It is an altogether typical story of modern science, not of

* An abridgement of *Radio's Past and Future* by Robert A. Millikan. The complete address will be included in *Radio and Education*, The Proceedings of the First Annual Assembly of the National Advisory Council on Radio in Education, published by the University of Chicago Press in the Fall of 1931.

modern invention. Do not think for a moment that the radio was ever *invented.* It could not be. It has a long pedigree, as have all scientific advances. It grew step by step through the forgotten efforts of a long line of workers, few if any of whom could have been left out without causing the whole structure to collapse. I should like to tell the story backward, *i. e.*, to start at the very latest end of this long history, just as I, myself, have seen and lived through it, for this part of it is only twenty-one years old. It was in the spring of 1910, twenty-one years ago, that Dr. F. B. Jewett, an old friend and associate of mine at the University of Chicago from 1898 to 1902, and at that time transmission engineer of the American Telephone and Telegraph Company, came out to Chicago to see his former associates at the Ryerson Laboratory and said, "My superiors have informed me that we must if possible get a telephone line to San Francisco by the time of the World's Fair there in 1915, and I find that to give good service over such a huge distance we need to develop a telephone repeater which will transfer the spoken word undistorted from one circuit to another, just as the telegraph repeater makes such a transfer with dots and dashes, so that when the voice has become so weak through transmission over a long line as to be almost inaudible, it can be transferred to a new, fresh circuit and boosted up by it to the desired strength. Now such a device," said Jewett, "In order to follow all the minute modulations of the human voice must obviously be practically inertialess, and I don't see that we are likely to get such an inertialess moving part except by utilizing somehow these electron streams which you have been playing with here in your research work in physics for the past ten years. Cannot you let us have three or four research men from your laboratory, who are more or less familiar with all this electronic technic, let us take them into our employ and assign them the job of developing such a telephone repeater as I have been suggesting." I responded favorably, and in the fall of 1910 sent Dr. H. D. Arnold to the Bell Laboratories in New York for this specific purpose, and a little later others followed. These men, with others in the Bell Laboratories, developed or perfected, within the first two years of their intensive effort, three different successful telephone repeaters, all of them electronic, and these three, with one mechanical device of earlier origin, were given official tests which I, myself, went from Chicago to Philadelphia to participate in, in the early winter of 1914. The perfected de Forest three-electrode tube gave the best performance, and within a year of these tests a number

of such electron-tube repeater stations had been installed on the telephone line connecting New York and San Francisco, and the job which the telephone company had set had been accomplished. And today every time I telephone from Pasadena to New York I marvel at the flawlessness of the speech that has been thus relayed and amplified several different times before it reaches its destination, the voice quality usually being so perfect that I am unconscious that I am telephoning farther than to the adjoining room. At the time of this first test, too in 1914, the possibility, by the use of larger banks of such amplifier tubes and therefore larger energies, of shooting speech frequencies up into wireless antennas, already in use for dot-dash signaling, was realized, and a radio telephone station was soon hastily erected both at Montauk Point, Long Island, and at Wilmington, Delaware; and on Easter Sunday, 1915, in the midst of a terrific snow storm, this same group of men gathered at Montauk Point, shot up into the improvised antenna Lincoln's Gettysburg Address which rippled through the ether and was picked up two hundred miles away at the Wilmington station, and from there by connecting wire lines came back to us so that we could listen to it at Montauk. Later in 1915, by using still more powerful tubes and more of them, spoken words, shot up into the ether from the Arlington station, had been heard by some of the group sent to listen at the Eiffel Tower in Paris, and by one lone listener—Espenshied, who was listening at Honolulu with the aid of a receiving wire lying on a hillside six thousand miles away—and all the essential steps had been taken which made wor d-wide radio broadcasting of human speech a possibility.

I have thus told the story of the beginnings of speech broadcasting through the ether as I myself saw it. Completely unknown to this group until the spring of 1915, somewhat similar developments, at least so far as perfection of the de Forest three-electrode tube into a speech amplifier or repeater is concerned, had been going on in the laboratories of the General Electric Company at Schenectady. Who first made the three-electrode tube into a distortionless speech amplifier is not for our present purpose important—it has been decided differently by different courts.* But we are interested here only with

[1] At the time Dr. Millikan spoke these words the decision of the Supreme Court on the vacuum tube had not been rendered. A patent interference had been declared in 1916 between H. D. Arnold and Irving Langmuir. After various conflicting opinions by successive tribunals U. S. Patent No. 1,558,436 was issued to Langmuir in 1925. The question of priority of invention, "if invention was

the fact of the development or commercialization at about this time of a new scientific device and with its applications. The essential device, not only for the whole broadcasting art, and not only for most of modern long-distance wire telephony, but also for all forms of speech reproduction and amplification, and this includes the greater part of the whole modern motion picture industry—not to mention picture reproduction at a distance in all its forms—the essential underlying device for all this is simply one new instrument, the electron tube, telephone repeater, or amplifier. The multiplicity of the new and wholly unforeseen practical uses which one new device or principle introduced into physics seems invariably to find always astonishes even the physicist who alone realizes how small and often how simple is the fundamental scientific advance that has been made. Knock out that single instrument, the telephone repeater, and much of the whole structure of modern long-distance telephony, and practically all of radio and talking pictures, comes crashing to the ground.

THE HIGH VACUUM TUBE COMES BEFORE THE SUPREME COURT

WILLIAM R. BALLARD*

On May 25, 1931, the United States Supreme Court handed down an opinion disposing of a controversy in which the Telephone Company has been continuously involved since the year 1915, and in which Dr. H. D. Arnold, Director of Research of Bell Telephone Laboratories, has had a leading role. It concerned the patentability and the paternity of what is now commonly referred to as the "high vacuum" tube, used in radio and telephone work.

The Supreme Court held that the difference between the "high vacuum" tube and the earlier vacuum tubes of Fleming and de Forest

present," was continued, however, in the defense of the de Forest Radio Corporation to a suit for infringement of this Langmuir patent, brought by the General Electric Company in January, 1926. The District Court of the United States for Delaware, before which the suit came, held that the Langmuir patent was invalid for want of invention and novelty and because of prior use, and upon the ground that H. D. Arnold anticipated Langmuir. This decision was confirmed by the Circuit Court of Appeals for the Third District; and thereafter, upon a rehearing, reversed by a majority of that court which, however, did not mention the question of priority. Judge Woolley wrote a strong dissenting opinion in which he pointed out that Arnold's priority, among other things, made the patent invalid. The Supreme Court took the case up on writ of *certiorari* and on May 25, 1931, concluded that the Langmuir patent did not involve invention.

* American Telephone and Telegraph Co.

is not a patentable one, and it, accordingly, found the Langmuir patent of the General Electric Company on the high vacuum tube invalid. In doing this, it has confirmed the original view of Dr. Arnold and the Bell System patent attorneys at the time the high vacuum telephone repeater was first produced by Arnold in 1912 and 1913. It is interesting to note, moreover, that the Court's finding of unpatentability is based in large part upon the directness and facility with which Arnold reached his results in producing the telephone repeater at that time. The Court's opinion does not take up the question of priority as between Arnold and Langmuir because it was unnecessary to do so after finding the patent invalid. The facts in the record of the case, however, make it quite clear that Arnold was first, both in appreciating the advantages of a higher vacuum in such tubes and in actually producing the tubes themselves. Indeed, the last court to discuss and decide this question of priority so held; and the Supreme Court, in passing on the question of patentability impliedly gives Arnold a date for these accomplishments early in November, 1912.

While it would be difficult to overstate the credit that must be given Dr. de Forest for his invention of the three-electrode tube, the fact remains that the beginning of the revolution which his device has caused in modern communication and other industrial fields, dates from about the time when Arnold, fully conversant with the physical principles involved, had turned the de Forest tube into a commercially practical telephone repeater.

There is something of romance in the story of the development of the modern telephone repeater as well as in the marvels which the device has since wrought. It furnishes, moreover, a striking illustration of how intimately and directly the most abstruse scientific discoveries may affect commercial enterprises and rapidly change our daily habits. Scientists who had, prior to that time, been studying what went on inside an atom under the influence of heat and electrical charges, furnished the magic wand with which Arnold touched the de Forest audion and transformed it into a device which at once greatly extended the possibilities of communication and now daily performs miracles, alike for technician, schoolboy, and housewife.

In 1910, T. N. Vail, President of the American Telephone and Telegraph Company, promised those who were then planning the Panama-Pacific exposition that the Pacific Coast would have telephone communication with the Atlantic coast by the time the expo-

sition opened in 1915. This meant telephone communication over something like twice the distance then commercially practicable. It was a bold promise. Not only would it require the building of some thousands of miles of new telephone lines but it meant that there must be produced some altogether new instrumentalities not then even conceived. In particular, it required an entirely new form of telephone repeater—one that would be free from distortion so that a number could be used in series.

The promise was made largely upon the assurances of Dr. Jewett, then Transmission Engineer of the Telephone Company; and upon his shoulders was laid the burden of making good the promise. He began at once to select the men to do the work. As to the repeater, he believed that the solution would be reached only by the application of the latest developments of physical research to this specific telephone problem. He went to Dr. Millikan, then professor of physics at the University of Chicago, and already famous for his research work in the field of electron physics, and laid the problem before him. Dr. Millikan replied that he had just the man for the work—a young man named Arnold then working under him at the laboratories at the University; he was an expert in the field of electrical discharges *in vacua*. Arnold was employed, and early in 1911 he went to New York and was put to work in the laboratories of the Western Electric Company to produce a telephone repeater that would make possible transcontinental telephony.

After he had spent some time upon the problem and had perfected and patented a telephone repeater employing a column of mercury vapor, an incident occurred that changed the whole course of his plans. In October, 1912, Dr. Lee de Forest, then employed with the Federal Telegraph Company in California, came East in an effort to raise money for the rehabilitation of his own company. This he hoped to do by selling to the Telephone Company rights under his audion patents for telephone repeaters. John Stone Stone, formerly an engineer with the Telephone Company and a close friend of General Carty as well as of de Forest, introduced de Forest to the Telephone engineers and arranged for a demonstration of his audion as a repeater. The demonstration was made before Dr. Jewett and Dr. Colpitts on October 30th, in the latter's office on the 8th floor of the Laboratories building on West Street. The performance of the tube was far short of what they knew would be necessary for practical telephone repeater operation. Any attempt to handle loads compar-

able to those in commercial telephone circuits resulted in choking, blue glow, and unintelligible reproduction. Nevertheless, they were greatly impressed with the performance of the audion when the power level was kept low and the variations of the voice currents were small.

They arranged to have the demonstration repeated the next day with Arnold present. Thus, on November 1, 1912, Arnold first learned about the de Forest audion. He was, perhaps, more impressed than his associates, for his training had equipped him to appreciate the possibilities of this device as few others could have done. He understood at once the reason for the difficulties experienced at the higher power levels, and then and there he named the cure. He explained that the trouble was due to the erratic effects resulting from gas ionization within the tube occurring at the higher voltages; and that a commercially successful telephone repeater could undoubtedly be made from the de Forest audion by such a thorough removal of the gas that the action would be purely electronic.

It was this ready and perfect appreciation by Arnold of possibilities dormant in the de Forest audion, which resulted in the creation of the high vacuum telephone repeater, destined not only to revolutionize the communication art itself, but to develop entirely new industries.

It is interesting to note how thorough was Arnold's acquaintance with the principles involved even at that early time. Colpitts, misled by statements made in a then recent paper by an engineer of another organization, questioned whether, if the gas were removed, the electrons would get out of the filament at all, and whether if they came out, they would not all rush across the space under the slightest plate voltage, thus keeping the power output of the tube too low to be useful. Arnold assured him that the electrons would be emitted without the presence of gas and that, because of the "space charge" effect, which he explained to Colpitts, a considerable voltage would be required to get the desired current across the tube.

Arnold's grasp of the situation and his conviction as to the possibilities of the audion so impressed his superiors that he was at once given the job of converting the audion into a commercial telephone repeater. To make the tube a commercial repeater, it was necessary not only to improve the vacuum but to improve the mechanical structure of the tube as well, to perfect better and longer-lived filaments and make the internal impedances such as to match the telephone apparatus.

Exhaustive tests were then made to determine the operating characteristic and efficiency of the audion. In December, 1912, Arnold worked out mathematically the theoretical $^3/_2$-power law covering the relation between current and voltage in such tubes, assuming the absence of gas ionization, and found that some of his experimental data conformed closely to this theory. His study of the "Efficiency of the Audion" made in December, 1912, was a mathematical ascertainment of the law of third-electrode control of an electron stream. It was the first definite analysis ever made of the principle upon which the three-electrode tube produces its remarkable results. At the same time Arnold had his assistants working on new filaments and on the tube structure, devising new tools, perfecting themselves in the technic of tube manufacture and exhaust, and collecting the necessary equipment for manufacture of commercial repeaters.

On at least three occasions while Arnold was thus remaking the audion into a telephone repeater, he produced high vacuum tubes of the kind which the Langmuir patent afterward purported to cover; once in November, 1912, when he effected a "clean-up" in one of the original de Forest audions upon which he was performing tests, again in April and May of 1913 when trying out the new Gaede molecular pump ordered for use in manufacturing the repeater tubes, and again the following autumn when the first tubes to go into use were made.

A license under the de Forest patents was secured in July, 1913, and the manufacture of tubes for commercial telephone use began shortly thereafter. A field trial of high vacuum telephone repeaters under commercial service conditions was begun October 18, 1913, at Philadelphia on the New York-Washington telephone lines. In the summer of 1914 these repeaters went into the new transcontinental telephone line, and with the official opening of the line in 1915, President Vail's promise of 1910 was fulfilled.

It was not until after the improved tubes had gone into commercial use that it occurred to Arnold or the Patent Department that an application for patent should be filed, and then only because they learned that the General Electric Company was attempting to patent such tubes in the name of Langmuir. Convinced of his own priority, Arnold then, upon advice of counsel, filed his application, so that the patent should issue, if at all, to the first inventor. However, Arnold and his counsel were so convinced that the subject matter was not of a patentable nature, that they afterward made a strong effort in the

Patent Office to have both applications rejected upon this ground, before the taking of testimony as to priority. As noted, the Supreme Court's decision comes as a confirmation of their original views as to patentability.