THE EFFECT OF ALKALI VAPORS AND OTHER GASES AT VARIOUS PRESSURES IN THERMIONIC DETECTORS

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INTRODUCTION

In recent years there has been put on the market, and used extensively, a class of vacuum tubes known as "gas content detector tubes". The advantage of using this type of tube as a detector lies in the fact that it does not require a high plate voltage for its operation; in fact, the plate voltage is often as low as 18 volts, but must be adjusted carefully to the best value for loudest signal response. For such tubes the adjustment of filament current is also critical, and these two characteristics constitute a serious disadvantage. In the case of higher vacuum tubes used as detectors adjustments are not so critical, which of course is a distinct advantage, the only disadvantage being that higher plate voltages are necessary for good audibility of signal response. During the past year, and recently, considerable work was done by the authors of this paper on the effect of variation of pressure and nature of gas content upon the efficiency, constants, and characteristics of detector tubes. It is not within the scope of this paper to describe the work in detail, but the results and conclusions will be reviewed, together with some of the more important curves.

Several tubes were connected to a condensation pump and vacuum gauge, see diagram A, and for various pressures readings were taken of plate voltage for loudest signal reesponse, called the "operating voltage". Readings were also taken of percent signal intensity when the tube was operating as a detector of undamped waves. Typical results are shown in Fig. 1. It will be noticed that the operating voltage decreases very rapidly with a slight increase of pressure above the high vacuum stage, and that the maximum audibility occurs at rather good vacua, .002 to .004 mm. of mercury, and for operating voltages of from 40 to 50 volts. The percent signal in-

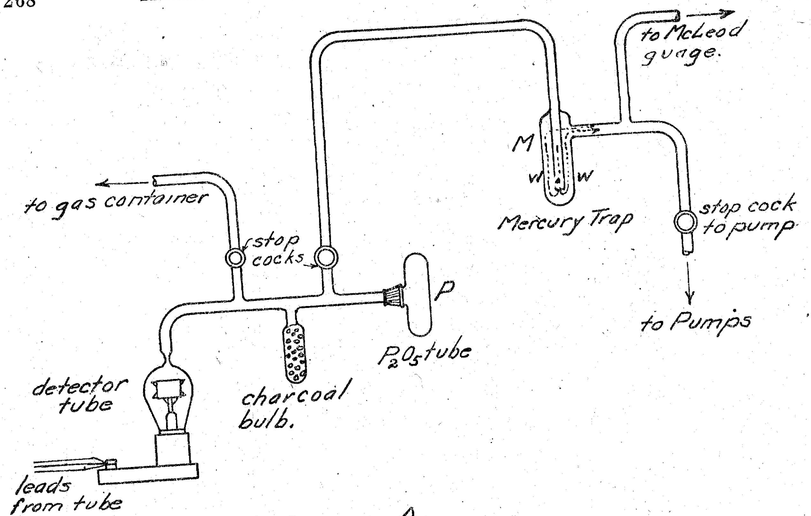
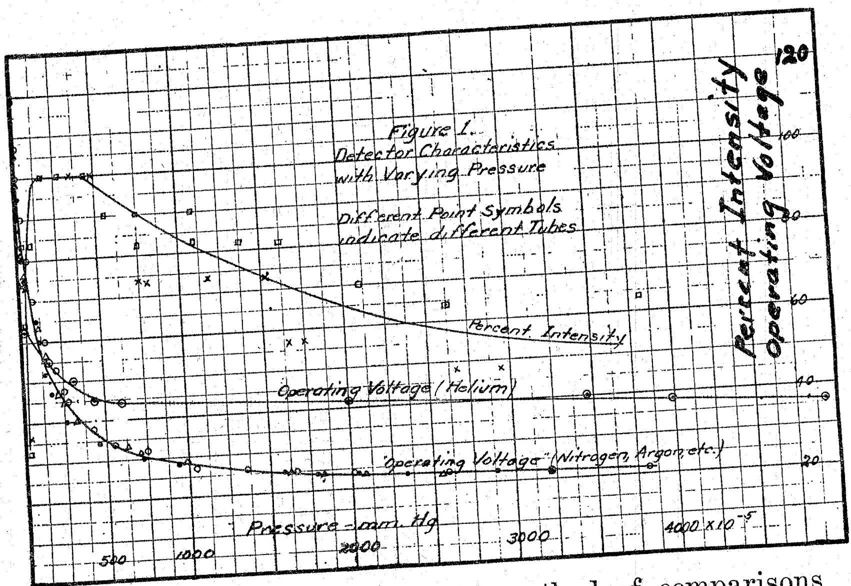


Diagram A
Vacuum Connections.



tensity was determined by the method of comparisons with a variable standard, recommended by Van der Bijl on page 337 of his book, "The Thermionic Tube". The circuit and equipment actually used is shown in Diagram B. D is the tube under test, Ds is the standard tube with which the signal strength from oscillator is adjusted to a certain value. The variable signal standard for comparisons is furnished by means of tube S. T., audibility meter N being used to attenuate this signal in a given ratio to match that from D. Choke coils A and A^1 are used to maintain constant potential between plate and filament when the audibility meters are changed. Space cannot be given to a complete discussion of this apparatus. It should be mentioned here that in all signal intensity measurements, a weak signal, having a directly measured audibility of 5.5 times on a standard tube, was furnished to the receiving circuit connected to the tube under test. The curves of Fig. 1 are typical for several tubes tested, the gas content being air or nitrogen or neon, etc. The figure also shows the operating voltage curve for a tube with different gases which were introduced successively. In order to determine the effect of various kinds of gases upon the sensitiveness of a detector tube, different gases were introduced successively into the same tube and signal intensity comparisons measured for each gas. The tests were repeated several times for the same tube, and for different tubes, so that the results were conclusive. Hydrogen, nitrogen,

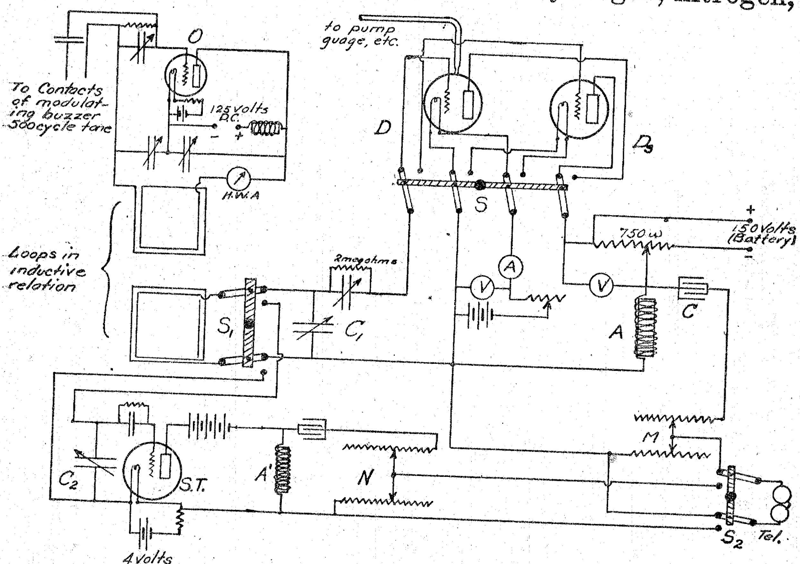
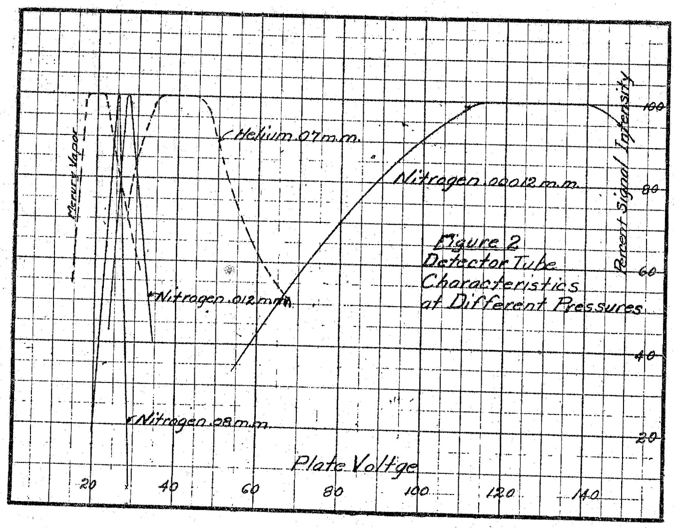


Diagram B
Standard Circuit for Audibility and Intensity Comparison Tests.

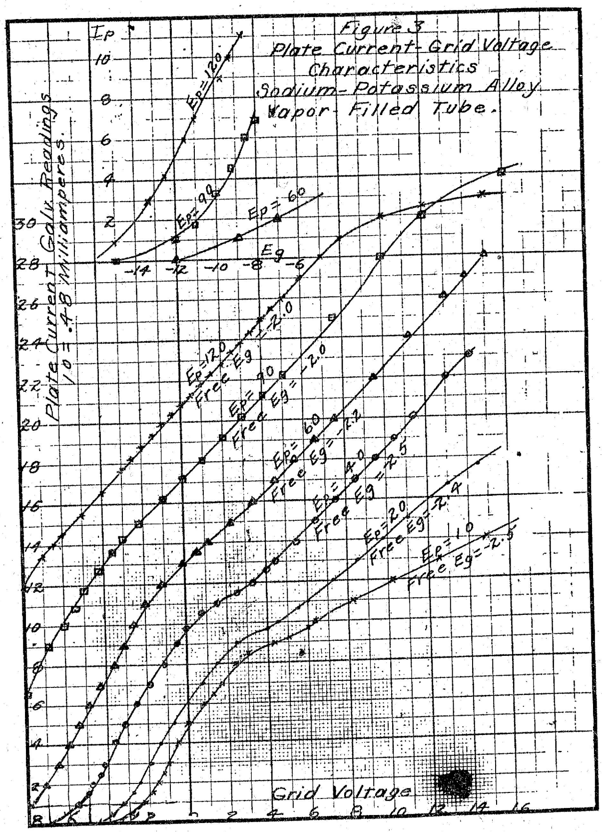
neon, helium, argon and carbon dioxide were used. Nitrogen, neon, air, and carbon dioxide gave about the same degree of signal response, argon gave 25 to 50 percent louder response, helium gave a slightly weaker response, and hydrogen a very weak response. It was found that adjustments of plate voltage and filament current were critical for all gases to the same degree except for helium. Helium filled tubes are less critical as regards plate voltage and filament current adjustment. Critical characteristics of plate voltage adjustments for various pressures and gas content are shown in Fig. 2.

Referring again to Fig. 1 it will be noticed that for very low degrees of vacuum the "operating voltage" approaches the ionizing potential of the gas in the tube. For nitrogen, hydrogen, or neon, it is about 18 volts, but for helium about 25 to 28 volts, which values represent the values of ionizing potentials for these gases. Accordingly, it should be possible to introduce a gas having a very low ionizing potential, and thus have a tube requiring a low operating voltage. Mercury vapor was introduced, and it gave an operating voltage of 14 or 15 volts. (Note that the ionizing potential of mercury vapor is 10.5 volts.) A small amount of mercury was put into two tubes, and after being pumped out and sealed off the pressure of mercury vapor pressure could be varied by varying the temperature of the tube walls. For best results the mercury vapor pressure was that corresponding to a temperature of about 25° C. At temperatures of 50° or 60° C the adjustments become very critical; at 25° C these tubes showed about 50 percent increase in audibility over good vacuum tubes. This seemed to indicate that certain metallic vapors would be desirable if the vapor pressure did not become too great when the tube walls were hot.

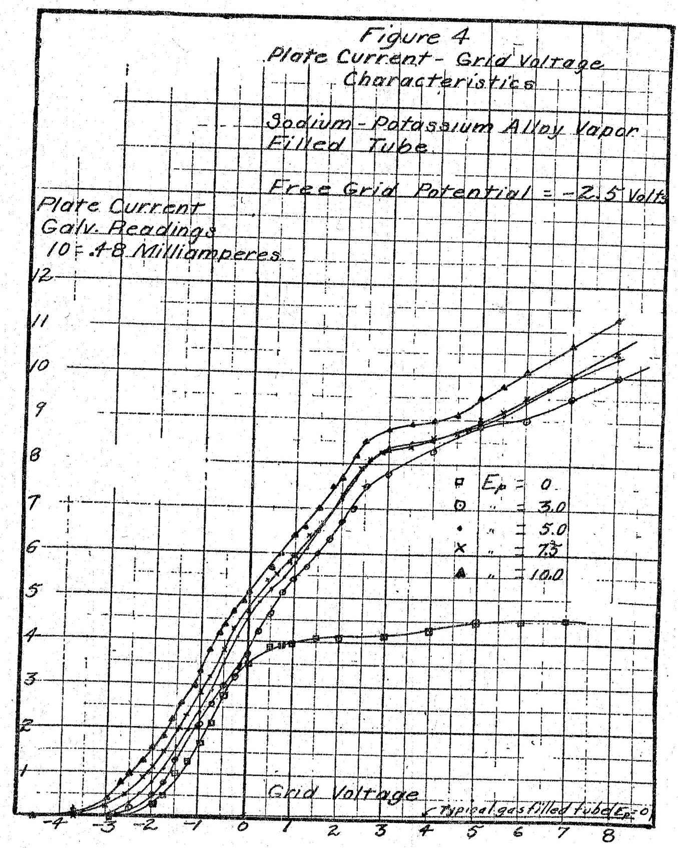
Recently this latter phase of the problem was again taken up, and three of the alkali metals were introduced into detector tubes. The vapors of potassium-sodium alloy, rubidium, and caesium have ionizing potentials of four volts and less. Potassium-sodium alloy in a liquid state similar to mercury was introduced without expos-



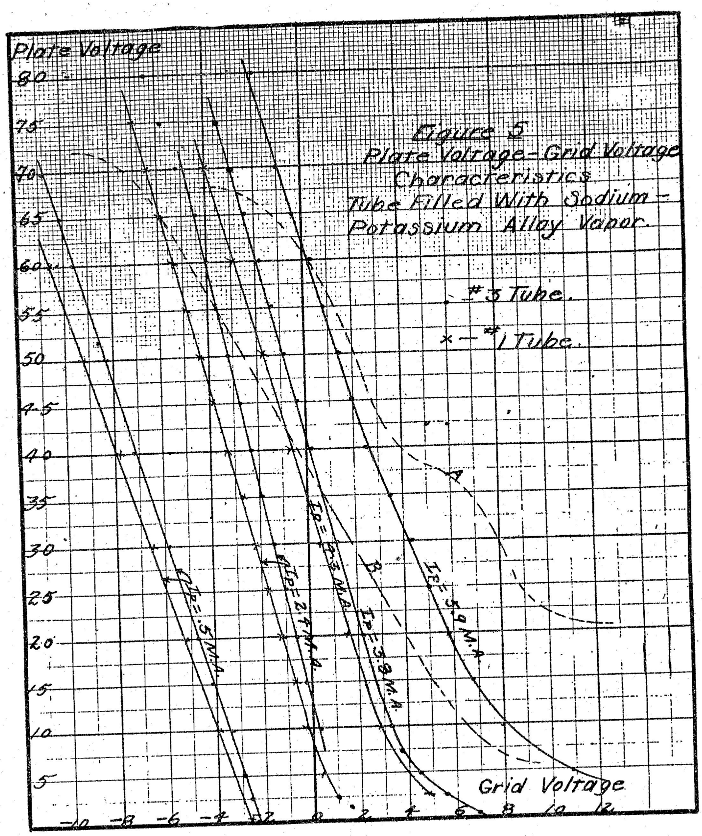
ure to air into several tubes by a laborious process. Rubidium, being somewhat sticky, was somewhat harder to introduce. The potassium-sodium filled tubes seemed to give some remarkable results, whereas rubidium tubes seemed worthless, on account of extremely high plate resistance. Accordingly, several tests were made on the potassium-sodium content tubes. Figs. 3 and 4 show plate current grid voltage curves for various plate voltages from zero up to 120 volts. It will be noticed that for low plate voltages curves are similar to those of a *vacuum* tube, and that as plate voltage increases, the bend at the point of saturation flattens out until at 120 volts the curve is a straight line from -12 volts grid potential to $+12$ volts grid potential. This would indicate that the tube might be a good amplifier. The curves of Fig. 5 show this to be the case. Each curve of this set is obtained with constant plate current, hence u, the no load amplification constant, is the negative slope of the plate voltage grid voltage characteristic. (See Van der Bijl or Morecroft). The curves of Fig. 5 indicate that these tubes are similar to high vacuum amplifiers as regards variation of amplification constant and the slope indicates a high value for u, about 10 to 12. The dotted curve A of the figure is typical for low vacuum tubes containing air, nitrogen, hydrogen, helium, etc., and B for high vacuum amplifiers. Figure 6 shows grid current characteristics for the same tube as used in obtaining curves of Fig. 4. For negative grid voltages there is no negative grid current, which is not the case for some high vacuum tubes. The curves increase suddenly at about -2 volts grid potential which indicates good de-



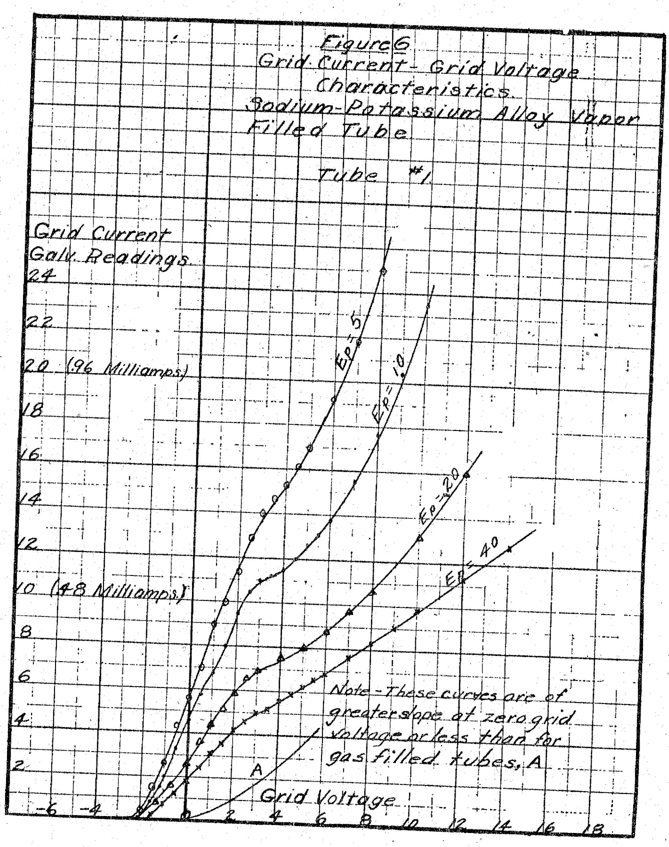
tecting characteristics. It should be mentioned that the detecting efficiency depends greatly upon the assymetry or variation of the slope of this curve. (See page 456, "Principles of Radio Communication" by Morecroft.) If the grid were connected to the positive end of the filament, the grid current would rise at zero grid voltage instead of at -2 volts, but its slope would be the same. To show how the tube constants vary with plate voltage the mutual conductances and amplification constant of three of these tubes were measured by Van der Bijl's methods for varying plate voltages and the results plotted in Figs. 7 and 8. It should be noticed that the mutual conductance is high for low plate voltages and falls off gradually (See Fig. 7) as plate voltage increases. This constant increases gradually with filament temperature. The sam-



ple curves A and B of Fig. 7 show the variation of this constant for gas content tubes and high vacuum tubes respectively. For a discussion of mutual conductance see Van der Bijl, "The Thermionic Tube". It is usually the case that the tubes with high values of this constant are good detectors, although they should also have high amplification constants and large change in the slope of the grid current curve. Fig. 8 is very interesting as it shows that the potassium-sodium content tubes have high amplification constants even at high plate voltages, but that they would function best as amplifiers at about 6 to 10 volts on the plate. The curves A and B, typical for gas filled and vacuum tubes, should be noted for comparison. Fig. 9 shows how the potassium-sodium tubes be-



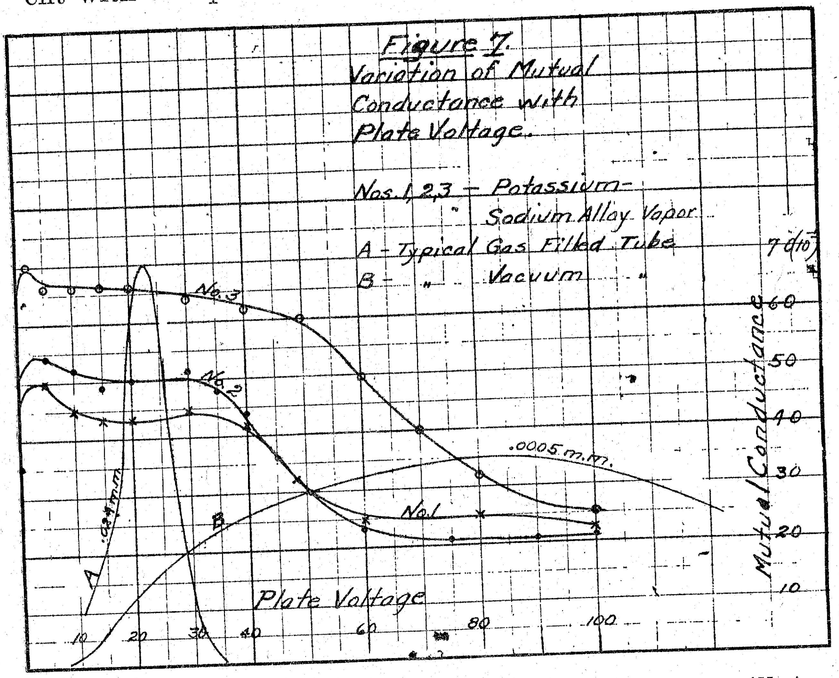
have as detectors with varying plate voltages. Comparing these curves with those of Fig. 2 it will be noticed that the tubes containing potassium-sodium alloy are quite remarkable. The best signal response is for plate voltages of from 8 to 10 volts, or less than half of that necessary for gas filled tubes, while they are much less critical than the latter, and give good audibility at 40 volts or more on the plate. The variation of signal intensity with filament current is like that for high vacuum tubes, the intensity gradually increasing until the filament is at very high temperature, and then gradually decreases. The maximum received signal intensity seems to be from 3 to 5 times as great as for the same type of tube filled



with argon or neon. This comparison was carefully made and results were practically the same for the three tubes tested.

In all of the tests a variable grid condenser was used in series with the grid together with a grid leak of 2 megohms. This always gave at least as good audibility as any applied negative grid potential, except for mercury vapor filled tubes, in which a positive grid potential was used.

The above test, being quantitative, was fairly conclusive proof that the potassium-sodium alloy content tubes are superior to the gas filled or vacuum detectors. However, to be sure as to their practical utility, the tubes were placed in standard receivers to receive the 2500 meter spark station at Arlington, the 17000 meter station at Annapolis, and the 360 meter radiophone broadcasting stations at Pittsburgh, Schenectady, N. Y., Detroit, and Chicago. The results obtained were consistent with the quantitative measurements. For receiving



the radiophone stations the tubes were used as oscillating detectors by the "zero beat" method, and also by the heterodyne method for the 17000 meter station, and the writers and their assistants were astonished at the results. Speech and signal reception were remarkably loud and distinct, and with practically no need of any frequent readjustments, as are often necessary with gas filled tubes. The tubes even functioned fairly well as oscillating detectors with zero plate voltage, receiving the above stations. They were also used as amplifiers

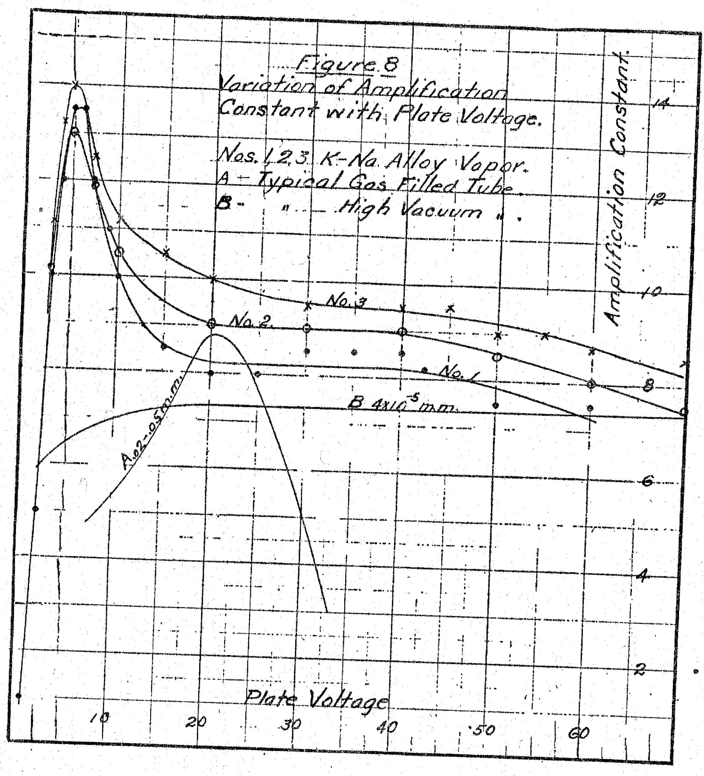


Figure 8
Variation of Amplification Constant with Plate Voltage.
Nos. 1,2,3. K-Na Alloy Vapor.
A - Typical Gas Filled Tube.
B - " High Vacuum " .
No. 3
No. 2
No. 1
A .02-.05 m.m.
B 4x10-5 mm.
Amplification Constant.
Plate Voltage
10
20
30
40
50
60
2
4
6
8
10
12
14

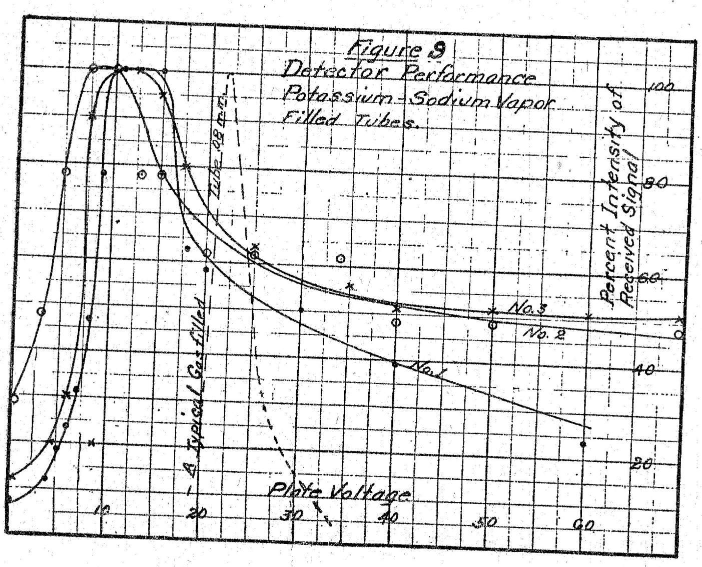


Figure 9
Detector Performance
Potassium-Sodium Vapor
Filled Tubes.
Percent Intensity of Received Signal
A Typical Gas filled Tube .08 m.m.
No. 3
No. 2
No. 1
Plate Voltage
10
20
30
40
50
60
20
40
60
80
100

in these same circuits and gave louder and clearer speech amplification with six volts on the plate than did the vacuum amplifier tubes with 30 or 40 volts.

The potassium-sodium alloy is used for the sensitive coating in the photo-electric cell, and it seems certain that the resulting plate current with zero applied plate voltage is due to the photo electric effect of the light from the incandescent filament. The plate current, and also the detector action at zero plate voltage, were maintained when the return plate circuit was connected to either the negative or positive terminal of the filament, indicating that the result was not due to potential drop along the filament.

CONCLUSION

Investigation of the action of the various gases mentioned in detector tubes shows that if inert gases are used the pressure should not exceed .005 mm. of mercury for best results as regards sensitiveness and non-critical adjustments. If certain metallic vapors are used, low "operating plate voltages" may be used if the ionizing potential of the vapor is low, and the tubes will be still more sensitive and much less critical in adjustment than low vacuum tubes containing an inert gas. The sensitiveness increases with the atomic weight of the gas in the tube, or more probably with the number of free electrons in the gas atom. It is hoped that further investigation will show some other gas or metallic vapor to be still better than the ones discussed in this paper. The potassium-sodium alloy and rubidium were kindly furnished by Dr. Jakob Kunz. Dr. Kunz recommended these substances in response to an inquiry as to what gases had very low ionizing potentials. Acknowledgment is also due Mr. W. E. Davis, a senior student, for his faithful assistance in the work.

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