

U N I V E R S I T Y O F M I C H I G A N

Department of Chemistry

FAST GEIGER-MUELLER COUNTERS

A Literature Review
to May 1947

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FOREWORD

The following report is an excerpt of a thesis submitted to the Faculty of Oberlin College in May 1947 in partial fulfillment of the requirements for Honors at Graduation in the Department of Chemistry.

Much of the original work in the thesis is now outdated but the literature survey presented here remains a pertinent review of information published prior to 1947 on the characteristics of Geiger-Mueller counters.

INTRODUCTION

A counter consists basically of two electrodes separated by a gas and operated at a difference of potential. An electric field, existing as a result of the potential difference, attracts or repels charged particles passing between the electrodes and charged particles formed within the field. The charges collect on the electrodes and are discharged through an external circuit. The process of collection, discharge, and recovery of the original voltage by the wire constitutes a voltage pulse. These pulses can be counted electronically by the external circuit.

The type of counter most frequently used consists of a cylindrical metal cathode and an axial wire anode. The main function of the cylinder is to distribute the potential and to form a volume in which the electric field is defined by the geometry of the electrodes.

We shall consider only counters operating in a voltage range within which the size of the pulse is independent of the event initiating the pulse. Such a constant size pulse can be formed regardless of whether an alpha particle, an electron, or a gamma ray enters the counting tube. The range of voltage producing pulses of constant size is called the Geiger region, and counters operating in this region are called Geiger counters.

If we plot the counting rate of a Geiger counter as a function of the voltage we obtain a characteristic curve similar to Figure 1. The literature disagrees on nomenclature, hence the following terminology will be used in this paper (Korff²¹):

Starting potential -- A -- The voltage which must be applied to a counter to cause it to count with the particular recording circuit which may be attached.

Threshold voltage for Geiger counting action -- B -- The lowest voltage at which all pulses produced in the counter by any ionizing event are of the same size, regardless of the size of the primary ionizing event.

Plateau -- B - C -- The more or less horizontal portion of the curve of counting rate as a function of voltage. (On this section of the characteristic curve the pulses are all of the same size.)

Geiger-Mueller (G-M) counter -- A type of counter with a large sensitive area designed by Geiger and Mueller to operate in the Geiger region.

Quenching -- The process of terminating the discharge in a counter.

Slow counter -- A counter containing no self-quenching gas.

Recovery time -- The time interval, after a count is recorded, before the pulses produced by the next ionizing event in the counter are of full size.

Slow counters record only a few hundred particles a minute because of the time required for quenching and recovery. External circuits like the Neher-Harper circuit were devised to accelerate the quenching. However in 1937 Trost⁴⁵ discovered that the addition to counting gases of certain vapors like alcohol would speed up the dispersion of the charge. These self-quenching tubes with alcohol added were defined as fast counting tubes.

A satisfactory counter should have a negligible number of spurious or false counts under operating conditions and should deliver pulses of nearly the same size. The counter should also have a wide plateau (200 volts or more) to insure a counting rate independent of fluctuations in voltage.

Figure 1

Characteristic curve of a Geiger counter

Figure 2

(Trost⁴⁵)

Dependence of the starting potential upon the cathode diameter at different wire diameters

Wire diameters:

0.1 mm.

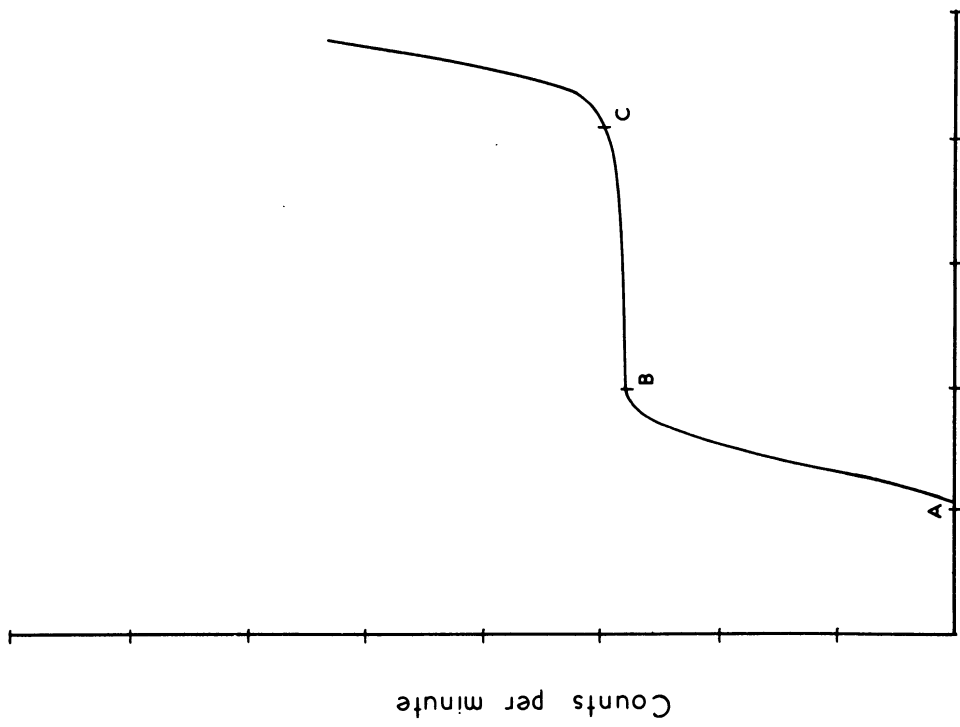
0.2 mm.

0.3 mm.

Filling:

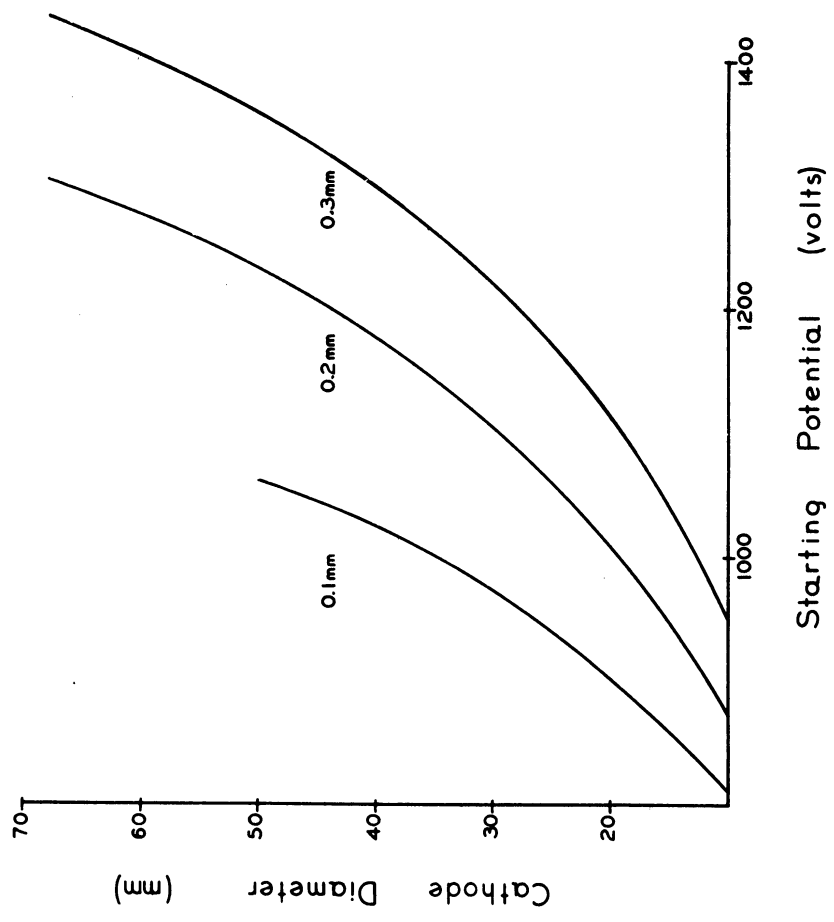
90 mm. argon

10 mm. ethyl alcohol



Voltage on Tube

Figure 1



Starting Potential (volts)

Figure 2

In this laboratory a counter was required for internal counting of the tritium in radioactive alcohol. The following properties were considered necessary: it must be a fast counter; it must have a plateau of 200 volts or more; it must operate in the Geiger region; and it must be constructed of a circular metal cathode and a central wire anode to allow internal counting.

REVIEW OF THE LITERATURE

Several general sources of information on counter tubes give a good foundation for the understanding of the more specialized problems presented later. Bothe² condenses much of the history of Geiger counters and lists many of their uses in an article commemorating the 60th birthday of Hans Geiger. May²⁸, supplemented by Craggs⁸, gives a fairly concise summary of developments in the field of counter tubes up to 1943. Trost⁴⁵ in his article "Uber Zahlrohre Mit Dampfzusatz" presents a good basis for fast counter preparation and theory. Montgomery and Montgomery³⁴ give a good summary of general counter theory and experimentation. And finally Korff²¹ in his book "Electron and Nuclear Counters" gives a fine coordinating basis for the study of any type of counter.

No attempt will be made here to enumerate or evaluate any of the more recent theories on the action of the self-quenching counter. Articles by Montgomery and Montgomery³⁴, Stever⁴², and Korff and Present²² indicate that the action of the counting tube is no longer a mystery.

Trost first published his discovery of the self-quenching tube in 1937. Hence we did not consider it necessary to thoroughly check literature prior to 1937. However this report does contain as complete a coverage of suitable articles on G-M counter tubes from 1937 to February 10, 1947 as the available library facilities would permit.

In Trost's⁴⁵ experiments the characteristics of counter tubes were determined for variations in electrode size and material as well as gas fillings. His findings, expanded and augmented by the literature, follow.

THE WIRE

Wire material. The wire in Trost's tubes was made of white steel although many workers prefer tungsten because of its lower reactivity. Medicus³⁰ showed that the material of the wire does not matter much since counters using brass, copper, silver, iron, steel, zinc, or aluminum wires can be used with apparently little difference in their effect upon the counting. Davis and Curtiss¹² used untreated steel and tungsten wire with no difference in performance traceable to material or construction. Milatz and Kate³² used platinum wire in their counters.

Locher²⁶ found that the wire must be very free from conducting points, including dust which may be precipitated on it while the tube is in use. These particles lead to spurious counts and destroy the precision of the counting. Most workers use tungsten wire because it can be easily sealed to glass and can be heated while the tube is being evacuated. The tungsten can be cleaned in a bath of molten sodium nitrite (340°C.) and then washed in distilled water. (Collie and Roaf⁵) Any sharp points of metal, dust particles, or grease remaining, burn off when the metal is glowed for several seconds. The process involves attaching the ends of the wire to a Variac and slowly raising the voltage. (Korff²¹) Glowing also forces adsorbed gases out of the wire. Thus if the tube is kept evacuated during the process, practically all foreign gases will be eliminated. Adsorbed gases on the wire appear to be particularly troublesome; several writers mention them as one of the major reasons why many G-M tubes will not operate quantitatively.

Milatz and Kate³² indicate that for best performance the wire (platinum in their work) must be well stretched. They placed a metal spring between the leads and the wire, thus keeping the wire co-axial

with the cathode. The geometry of the tube will be discussed more fully later.

Wire size. Trost presented data demonstrating the change of starting potential with size of wire (Figure 2). Moon³⁵ agrees with Trost and states that in general the working voltage increases with the thickness of the wire but that the diameter of the wire is not very critical.

However, Haines¹⁴ showed that the situation is reversed at low pressures (around 1 cm. total gas pressure in the tube), the starting potentials diminishing with an increase in wire size, but since 10 cm. is the normal gas pressure in counting tubes, his results will not affect ordinary work.

Table I lists the diameters of wires used by various workers in their counter tubes.

Table I
Wires Used by Various Workers

Worker	Date	Wire Material	Wire Diam. (in mm.)
Lawrence ²⁵	1941	Tungsten	0.02
Curran and Petrzilka ¹⁰	1939	Tungsten	0.05
Shonka ⁴⁰	1939	Tungsten	0.075
Hoag ¹⁷	1938	Tungsten	0.075
Montgomery and Montgomery ³⁴	1941	Tungsten	0.075
Rochester and Janossy ³⁸	1943	Tungsten	0.075
Strong ⁴³	1943	Tungsten	0.1-0.2
Strong ⁴³	1943	Copper	0.1-0.2
Collie and Roaf ⁵	1940	Tungsten	0.2
Milatz and Kate ³²	1940	Platinum	0.2
Halpern and Simpson ¹⁵	1937	Tungsten	0.25
McLellan ²⁹	1945	Tungsten	0.25

THE CATHODE

Trost and others agree that neither the material nor the treatment of the anode affects the plateau of a counter. The cathode, however, has a much more critical influence on tube characteristics.

Cathode material. Trost found that the size of the plateau and its slope depend essentially on the material and treatment of the cathode. Figure 3 shows characteristic curves for various counters with untreated cathodes. The preparation of these tubes included polishing with emery and washing with alcohol and water before assembly. A period of perhaps two hours elapsed between the polishing and the sealing of the tube onto the vacuum line. It can be seen that with an alcohol-argon mixture, usable plateaus (slope under 10% per 100 volts) were obtained with brass, gold, and chromium. Iron, silver and copper were essentially poorer, aluminum yet poorer, and lastly nickel and cadmium completely unusable.

Trost attributed the difference in characteristic curves to the various kinds of surfaces the metals present. To make the cathode surfaces uniform he coated them with a mixture of Zaponlack (a kind of cellulose nitrate varnish) made by diluting a few drops of the varnish with 50 ml. of amyl alcohol. Figure 4 shows the characteristic curves of some of these treated cylinders. It can be seen from Trost's work that many metals can become suitable cathode material if given the proper treatment.

Trost's work did establish the fact that among the common metals brass at least could be used in satisfactory counter tubes without additional treatment. Several other workers however have disregarded his results and recommend methods involving the careful cleaning of the counters with acid, frequent rinsings with water, and baking in the presence of gases rich in oxygen.

Figure 3

(Trost⁴⁵)

Characteristic curves for different metal cathodes

(Tube dimensions 30; 0.2 indicate a cathode diameter of 30 mm. and a wire diameter of 0.2 mm.)

Filling:

90 mm. argon

10 mm. ethyl alcohol

Figure 4

(Trost⁴⁵)

Characteristic curves for shellacked metal cathodes

Tube dimensions:

Cathode diameter - indicated in mm.

Wire diameter - constant

Filling:

90 mm. argon

10 mm. ethyl alcohol

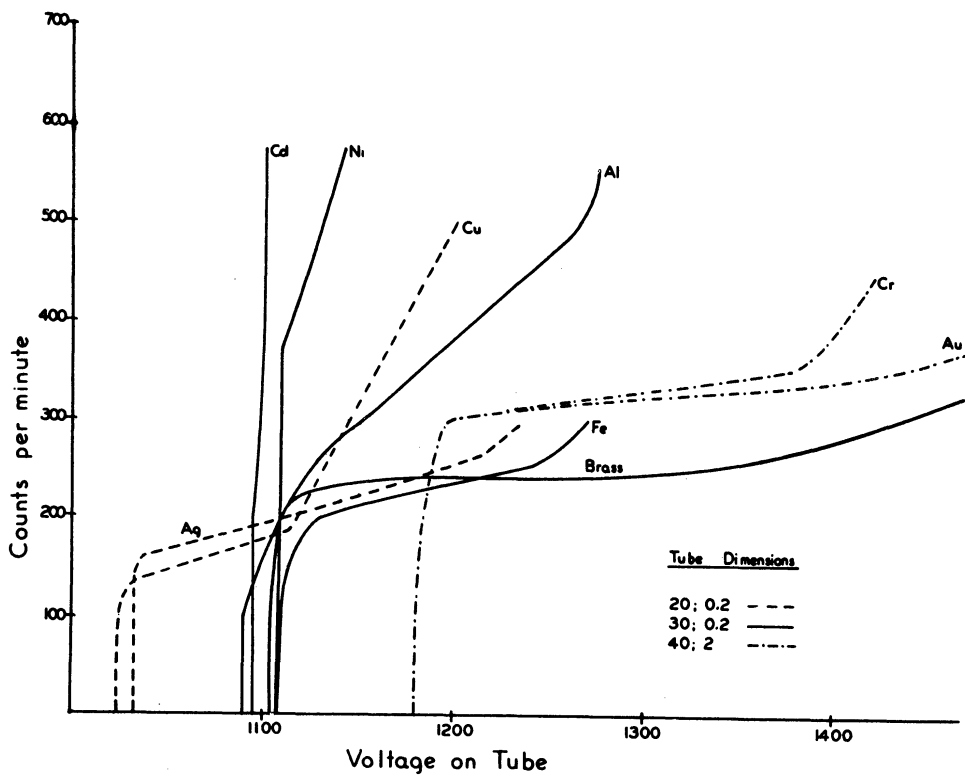


Figure 3

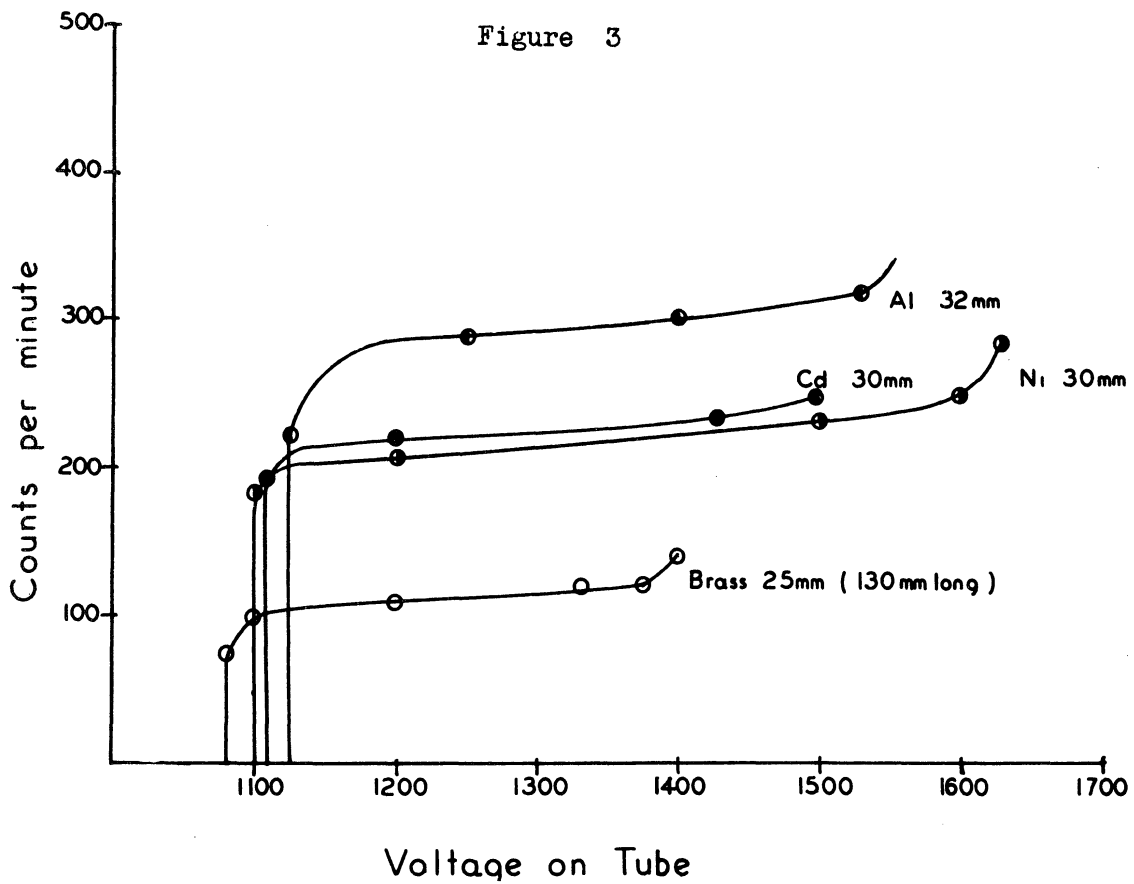


Figure 4

Cathode treatment. For making fast counters, Strong⁴³ recommends a procedure in which a copper cathode is cleaned thoroughly with 6N and then 0.1N nitric acid after which it is rinsed and dried. The tube is next heated with dry air inside, evacuated, NO₂ admitted, and heated again until a coating of Cu₂O forms. A mixture of argon and xylene is used as a filling. Hoag¹⁷ eliminates the NO₂ heating process but requires that a first oxide coating be washed off with nitric acid before the final sensitive coating be made. Shonka⁴⁰, using the methods of Hoag, obtained tubes with plateaus of over 1000 volts. Locher²⁷ on the basis of experience with the production of more than 1500 tubes advocates the use of specially treated cathode surfaces. Collie and Roaf⁵ recommend treated copper cathodes for counting tubes. Stever⁴² states that a treatment of the cathode surface improves fast counter action. The NO₂ treatment, by producing a velvety black or dark brown coating of oxide on the surface of the copper cylinder, results in a low photoelectric emission and a high work function, and hence in better tube characteristics. Copp and Greenberg⁶ indicate that the best results in their experiments were obtained with copper tubes which had received the treatment with NO₂ (very similar to that described in Strong). McLellan²⁹ uses a copper foil cathode treated by the NO₂ method.

Hans Weltin⁴⁸ on the other hand eliminates the cleaning process of the copper cathode by coating the cathode with Aquadag, applied with a small brush. Curtiss¹¹ prepared a sensitive counter tube by coating the metal (copper, aluminum, or brass) with a lacquer made from bakelite and amyl alcohol. This lacquer was left in a soft state and apparently helped in the quenching process.

Untreated cathodes. Other workers however, while admitting that these elaborate procedures result in reliable counters, maintain that from their own experience most of the chemical treatment is unnecessary. Davis and Curtiss¹² emphasize that in their work on counter tubes no special treatment of the barrel or central wire was required to make a successful counter. All their counters were made up with materials as taken from the stockroom. Copper, aluminum, and steel were used for the barrels with no noticeable difference in performance traceable to the materials or construction.

Curran and Petrzilka¹⁰ confirmed Trost's conclusion that polished brass which had been allowed to stand in air for some time before assembly was a good material for counter walls. They also found that if copper was heated gently in air so that a very thin layer of oxide is present on the surface, it was quite as good as brass. They avoided the use of Zapon-lack in improving the working of tubes because of its solvent effect upon picein. However, they did find a method of oxidizing aluminum sufficiently so that it would work consistently and well in counters for periods of months or even years. Figure 5 shows characteristic curves for tubes prepared by their methods.

After preparation of nearly 100 counters Rochester and Janossy³⁸ state that careful treatment of the counter sheath is not necessary for an efficient counter. They used a copper-in-glass type of counter with the cathode sheath 0.1 mm. thick of light copper, cleaned by rubbing over with a rag soaked in benzene. The counters, varying in diameter from 3.0 to 3.5 cm. and in length from 20 to 80 cm., were filled immediately as they came from the glass blower with a mixture of argon and alcohol and then sealed

Figure 5

(Curran and Petrzilka¹⁰)

Characteristic curves for different metal cathodes

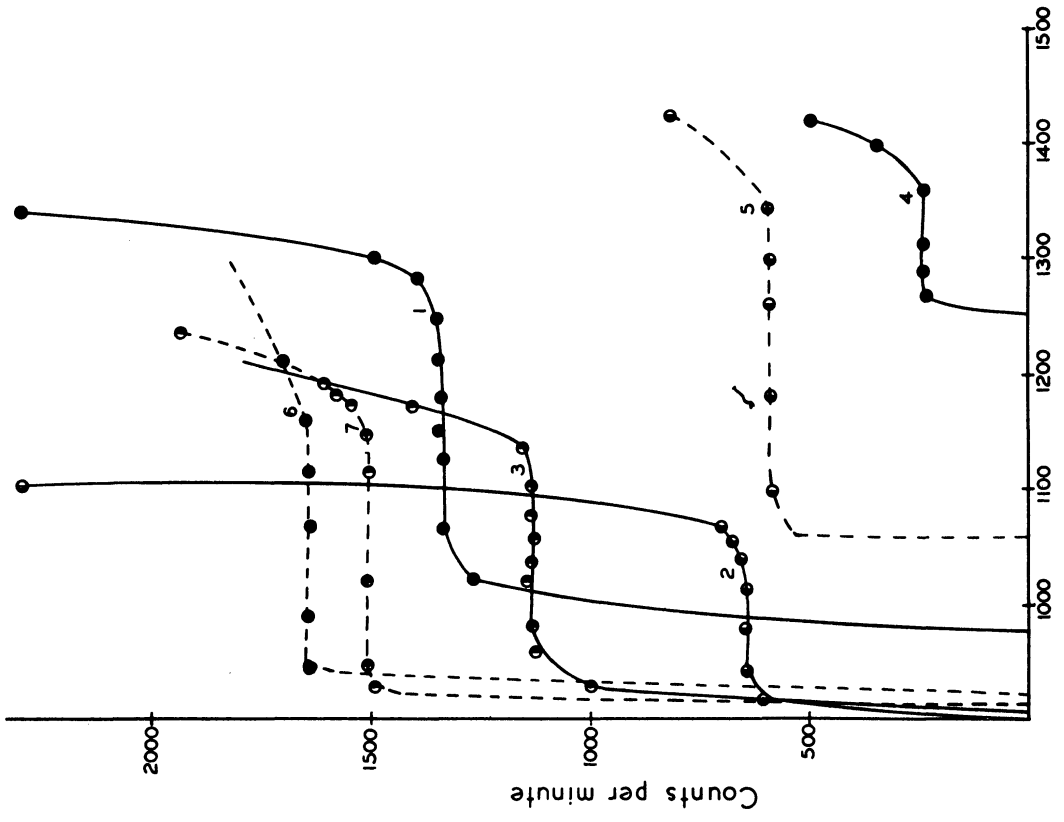
Thick walled	———
Thin walled	- - -
Copper	●
Aluminum	◐
Brass	◑

Figure 6

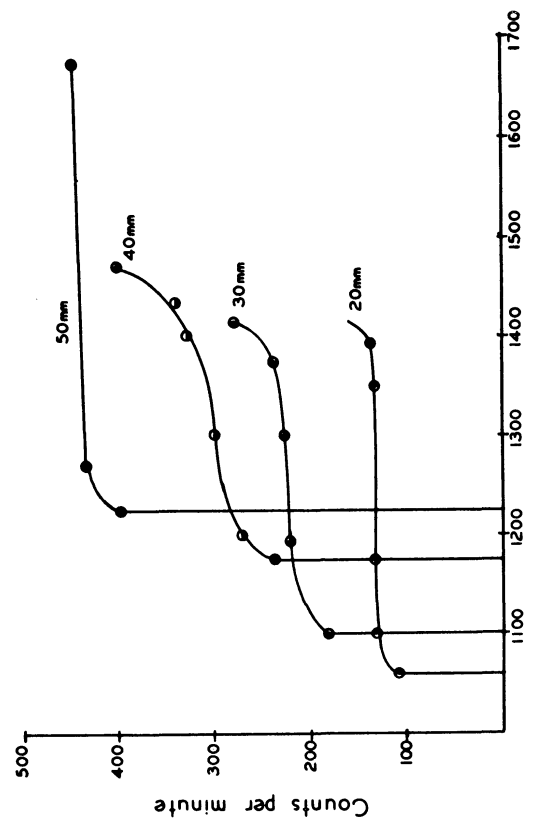
(Trost⁴⁵)

Characteristic curves for shellacked gold cathodes of varying diameters. Wire diameter constant.

Filling:
90 mm. argon
10 mm. ethyl alcohol



Voltage on Tube
Figure 5



Voltage on Tube
Figure 6

off, the whole operation for each counter taking only one quarter of an hour. The counters had the following properties: efficiency of 99.5%, starting potential of 1000 volts, and length of plateau of 300 volts. Counters prepared in this way were in use for two years without appreciable changes in their properties.

Lawrence²⁵ in preparing counters for the determination of H^3 gas used a cathode of brass (5 cm. in diameter) that had been carefully cleaned with nitric acid and rinsed copiously with distilled water.

Brown and Curtiss³ describe a method for making thin-walled aluminum counters from commercially available tooth-paste tubes thus eliminating the expense of boring metal tubes to obtain a suitable thin cathode.

Moon³⁵ states that for counting beta rays the cathode may be made of thin metal sheet, thin glass, or if very thin walls are desired, of foil wrapped around a perforated metal cylinder. He also reports that the outer electrode has relatively little influence on the plateau. In fact it need not even be a perfect cylinder, although cylindrical symmetry is necessary for a uniform field at the wire. Thus minor imperfections or scratches on the cathode will not give rise to spurious counts as they would on the wire. Locher²⁶ in corroborating this fact states that the smoothness of the cylindrical cathode is of little importance.

Cathode size. Variation of the diameter of the cathode will affect the characteristic curves as shown in Figure 6 (Trost). Increasing the diameter raises the starting potential and, by increasing the sensitive volume of the counter, raises the rate of counting. However, Lawrence²⁵ states that some counter diameters are limited by the fact that in counters of large diameter, H^3 disintegrations near the wall are not counted efficiently.

Variation of the length of the counter itself is useful at times. Strong⁴³ states that the length should always be at least 5 times the diameter of the tube. Again with increase in length, the sensitive volume is increased and consequently the counting rate increased. In the final analysis counter length and diameter are determined by the nature of the problem to be studied (Korff²¹).

THE FILLING

A third major variable in counting tubes is the filling. Many gases and gas mixtures have been suggested and tried by various workers but we will consider here only the "fast" fillings. Montgomery and Montgomery³⁴ found that the gas filling determines: 1) the starting potential of the counter, 2) the efficiency of the counter, and 3) the magnitude of time lags between the passage of the ionizing ray and an appreciable change in potential of the counter wire.

Previous to 1937, counters had such appreciable time lags (as in 3 above) that several hundred counts a minute was the limit of recording. Since the counters were used mostly as instruments in laboratories, very little was known of their actual mechanism of reaction. Furthermore, their properties were not reproducible. Trost however found experimentally that some counter tubes, though counting very poorly when first assembled and sealed off, would count well after a period of several days. His construction methods included polishing the brass tubes with emery, washing them with alcohol, and drying them before assembly. He reasoned that the added activity after several days must be due to gases adsorbed on the walls of the cathode. Further experiments in which known amounts of alcohol were added to the original filling of argon or air produced a

satisfactory counter that had the characteristic of being able to quench itself with no external help (as from a Neher-Harper quenching circuit). This was the first fast counter tube.

The principal gas. The gas filling of a fast counter tube consists of the principal counting gas and a small volume of quenching gas. Curran and Petrzilka¹⁰ determined characteristic curves for various counting gases with all other variables constant (including a constant volume addition of alcohol to serve as a quencher). From these curves (Figure 7) it can be seen that argon gives the best counting curve with neon and helium not far behind. We can see that the inert gases behave similarly in the counting tube. Hydrogen, oxygen, and nitrogen on the other hand are poor counting gases. Hence one would expect that air would also be a poor filler for fast counters, a fact readily shown when a small amount of air is allowed to leak into a tube which is counting.

The similarity of the inert gases is particularly beneficial since argon is not suitable for all types of work. Argon becomes radioactive under neutron bombardment but a helium filling may be used for neutron counters. Helium does not become radioactive and, in spite of a gradual rise of the plateau in its characteristic curve, is a good counting gas. In 1941 Kapur, Sarna, and Charanjit¹⁹ presented the results of some of their work done with helium filled counters and more recently McLellan²⁹ described the construction of a helium filled tube with a plateau of from 200 to 300 volts. For the majority of general counting measurements however, it will be found that argon is the most suitable filling.

Figure 7

(Curran and Petrzilka¹⁰)

Characteristic curves for different counting gases

Cathode:

Thin aluminum tube

Total pressure:

Constant

Alcohol addition:

Constant

Principal counting gas:

1. Argon
2. Helium
3. Neon
4. Air
5. Hydrogen
6. Oxygen
7. Nitrogen

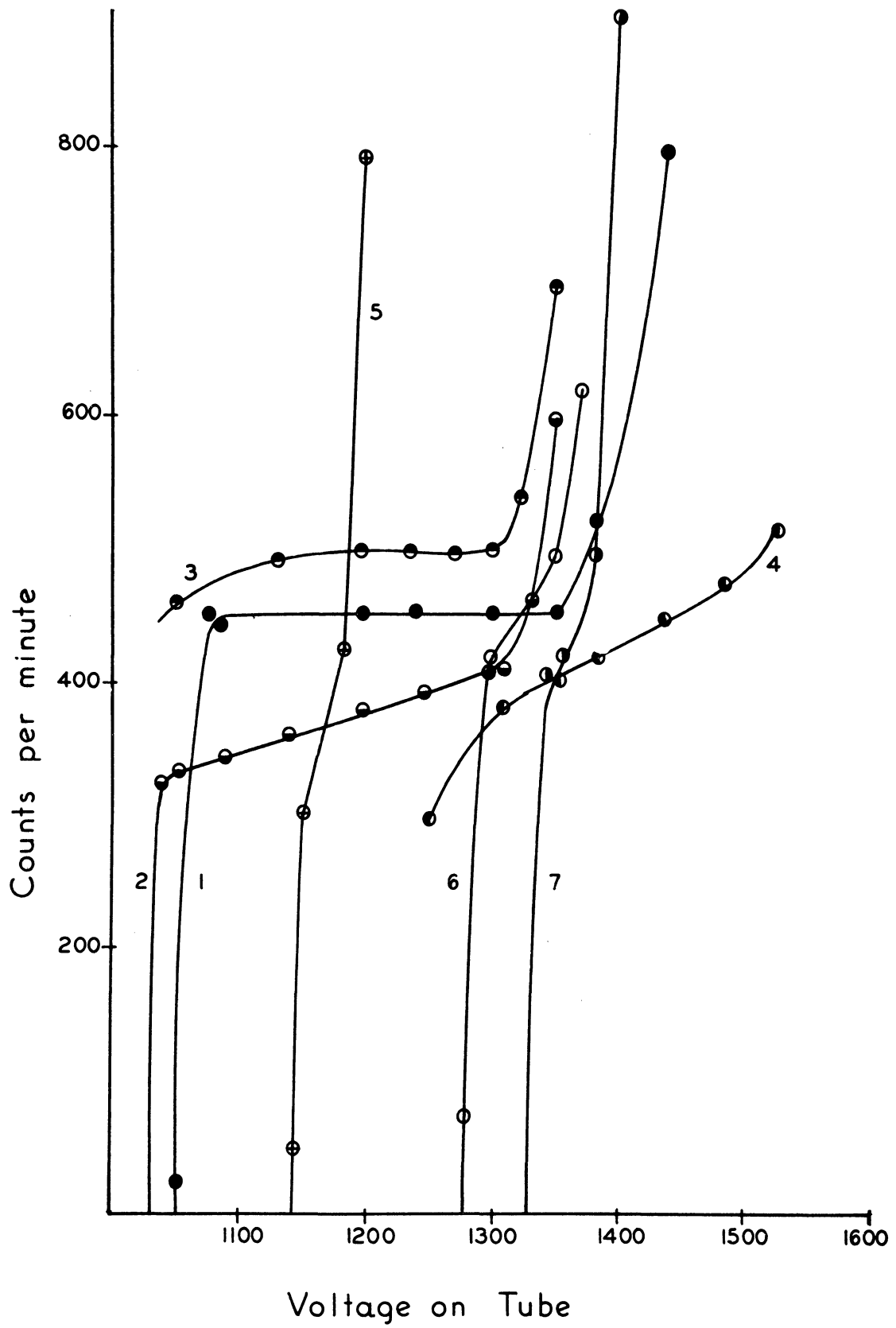


Figure 7

The quenching gas. The ideal quenching gas would have a high vapor pressure and would not be readily adsorbed on the walls of the counting tube. However very few gases will satisfy both of these requirements at room temperature and consequently any gas used will of necessity be a compromise. The work of Trost⁴⁴ in 1935 indicated that benzene is useless as a quencher and that no definite plateau is obtained with chloroform. He found that alcohol worked well but had a low vapor pressure and was easily adsorbed. In 1937 he reported that in principle, most vapors act the same as alcohol in trying to quench the tube charge. However in practice only a few vapors are useable, partly because the resulting plateau is poor and partly because too few impulses are counted. He tested many gases for ideal quenching properties and finally tried, besides ethyl alcohol, methylal and the two esters, methyl formate and methyl acetate. He also tried methyl chloride, ethyl chloride, acetone, and acetaldehyde, all of which had poorer counting regions than alcohol. He found that tubes filled with the esters would become almost unusable after a month, the slope of the curve increasing with time. After a month not even thorough washing out and refilling of the tube would restore its original characteristics. However he did find that if a tube was filled with methyl acetate for a day, pumped out, and then refilled with ethyl alcohol, a much longer plateau (500 volts) would be obtained than normally would be expected with an alcohol mixture alone. (A brass tube was used in this experiment.) Trost concluded that among the gases he had tried, alcohol was the most suitable for quenching. His work also contained illustrations of the characteristic curves of halogen compounds of hydrocarbons, showing that chemically related substances have a corresponding regularity in their counting curves.

Following Trost's lead most workers use a mixture of argon and alcohol as a filling. However Davis and Curtiss¹² report that they have found amyl acetate a more reliable filling than alcohol, possibly because its heavier molecule has a higher quenching action. Amyl acetate does seem to have definite quenching properties since Curtiss¹¹, while using it as a solvent for a Bakelite lacquer which he applied to the wall of the tube, found that if the lacquer remained in a moist sticky state, the tube would show good counting properties with a filling of alcohol and argon, but that if the lacquer were allowed to dry, the tube would be ruined for satisfactory service.

Korff, Spatz, and Hilberry²³ found that methane and boron trifluoride are suitable quenchers, having no appreciable temperature coefficients between 55°C. and minus 22°C (Figure 11). It should be noted however that the methane quenched tube requires a much higher starting potential than the alcohol quenched tube.

Kapur and co-workers¹⁹ report that methyl and ethyl alcohols are the best quenchers for helium filled tubes. McLellan²⁹ confirms this and states that 0.5 cm. of alcohol produces good quenching with 7 cm. total pressure of helium and alcohol mixture.

Montgomery and Montgomery³⁴ suggest that if an alcohol filling is used with a treated cathode the alcohol may react with copper oxide present.

Organometallic fillings. Keston²⁰ presented an interesting discussion on self-quenching G-M counters containing organometallic compounds. He found that good tubes could be obtained with $PbMe_4$ pressures from 0.8 to 2.5 cm., the tubes at 1.8 to 2.0 cm. pressure giving plateaus of 500 volts starting at 1500 volts. Unlike the argon-alcohol counters that show a very steep rise from threshold to plateau, these counters require a much

larger change in voltage between threshold and plateau. He found that less satisfactory counters could be made with dimethyl mercury while iron carbonyl gives a self-quenching counter that is decidedly unstable, decomposing overnight.

Filling pressure. Trost showed the dependability of the plateau upon both the total pressure of the filling and the partial pressure of the quenching gas. (Figure 8). The absolute maximum of the group of curves lies around 100 mm. total pressure with 10 mm. of alcohol added. Further investigation showed that the absolute maximum comes at higher additions with tubes of smaller diameters. With rich mixtures however, on the one hand come unwanted addition and temperature effects, and on the other hand a sharp increase in voltage. Thus Trost does not advise the use of a mixture containing more than 10% alcohol. For tubes with very much smaller diameters (under 20 mm.) a somewhat higher argon pressure seems advisable.

Rochester and Janossy³⁸ report that the efficiency of a fast G-M counter is not changed when the pressure of the argon is increased from 11 cm. to 74.5 cm.

Paul Weisz⁴⁷ in experiments using an argon-ethyl ether filling found that apparently the absolute pressure or density of the quenching gas alone determines the quenching characteristics of the tube, regardless of what the total pressure may be. Rochester and McCusker³⁹ corroborate these conclusions. They find that the alcohol counter can be used only in a narrow range of alcohol pressures which is determined by the vapor pressure of the alcohol. The useful pressure range is not much affected by the argon which merely acts as a filler to increase the efficiency of the tube. Figures 9 and 10 show the effect of alcohol and argon pressures on plateau length and starting potential.

Figure 8

(Trost⁴⁵)

Plateau length as a function of total gas pressure
at different partial alcohol pressures

Tube dimensions:

Cathode diameter - 50 mm.

Wire diameter - 0.2 mm.

Cathode surface:

Shellacked

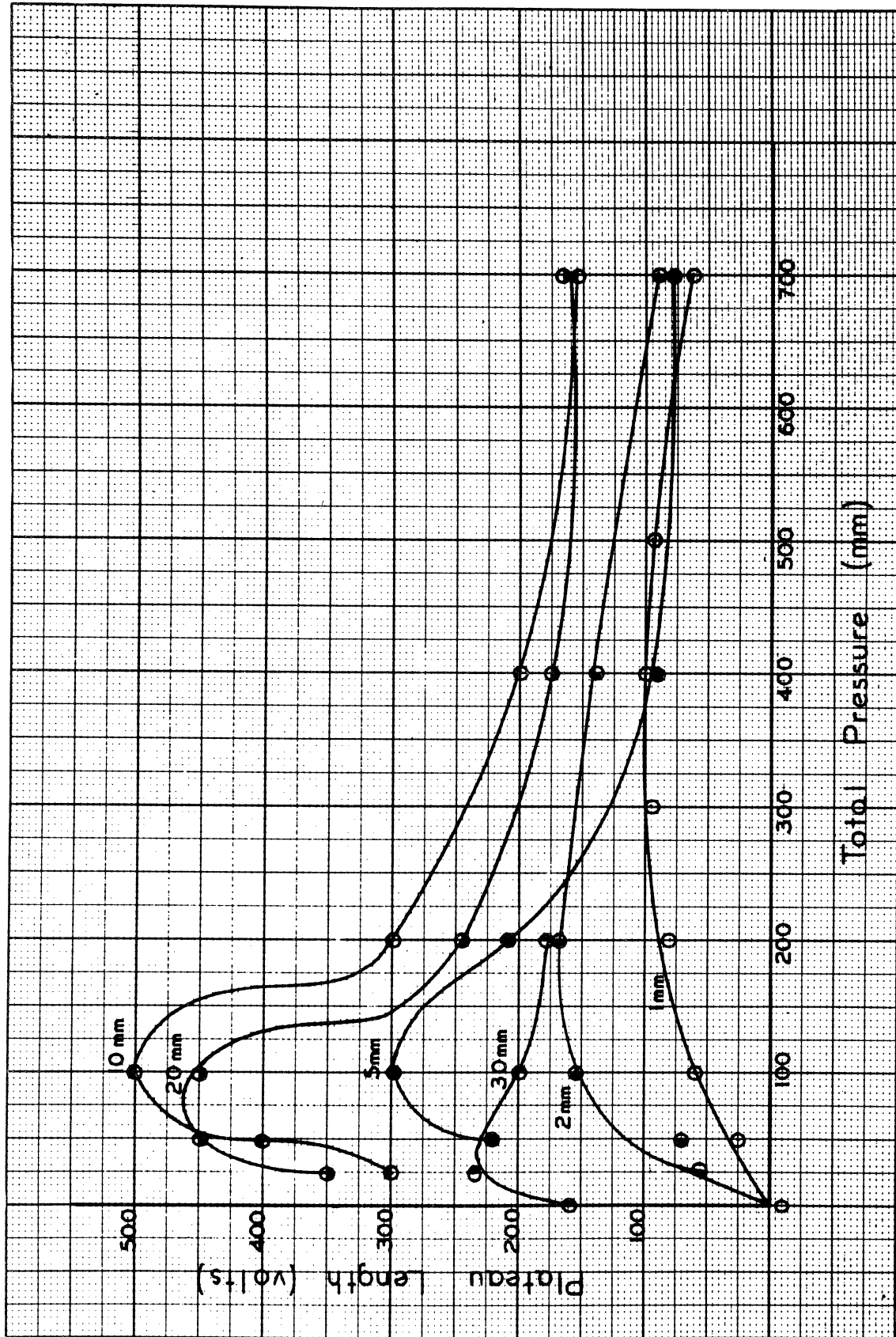


Figure 8

Figure 9

(Rochester and McCusker³⁹)

Effect of alcohol and argon pressure on plateau length

Figure 10

(Rochester and McCusker³⁹)

Effect of alcohol and argon pressure on starting potential

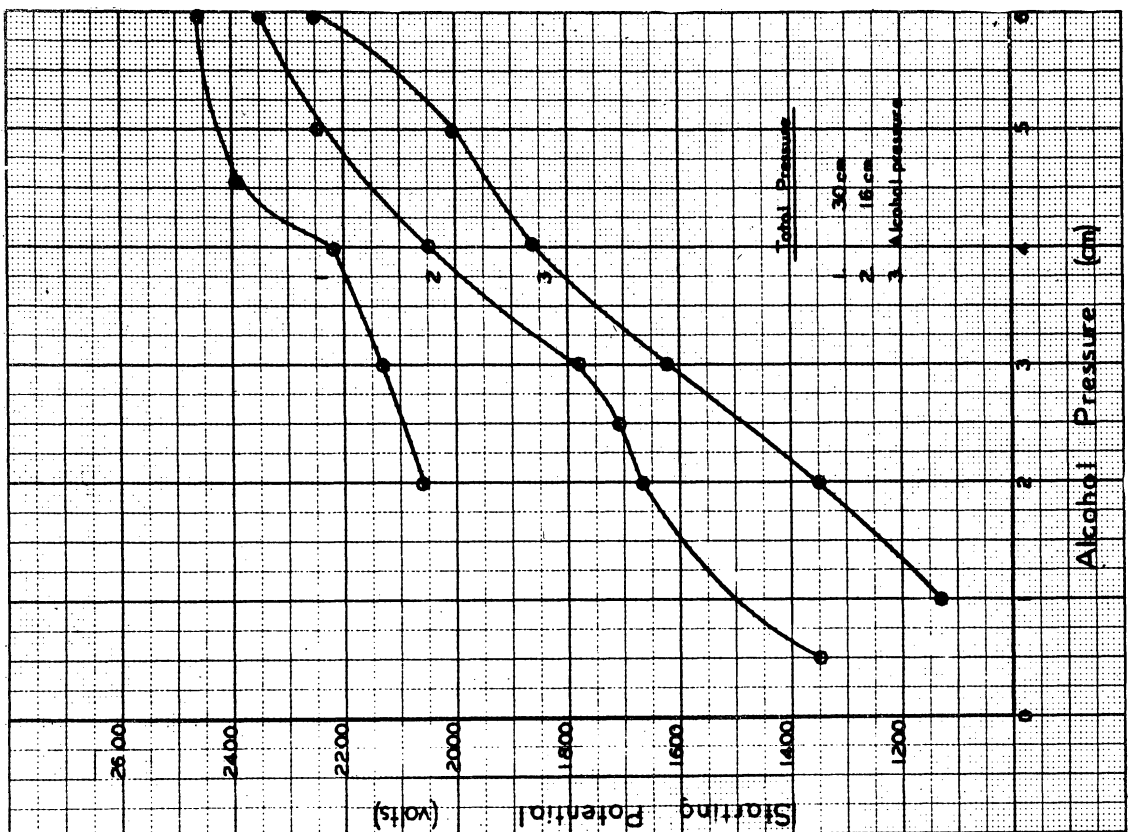


Figure 9

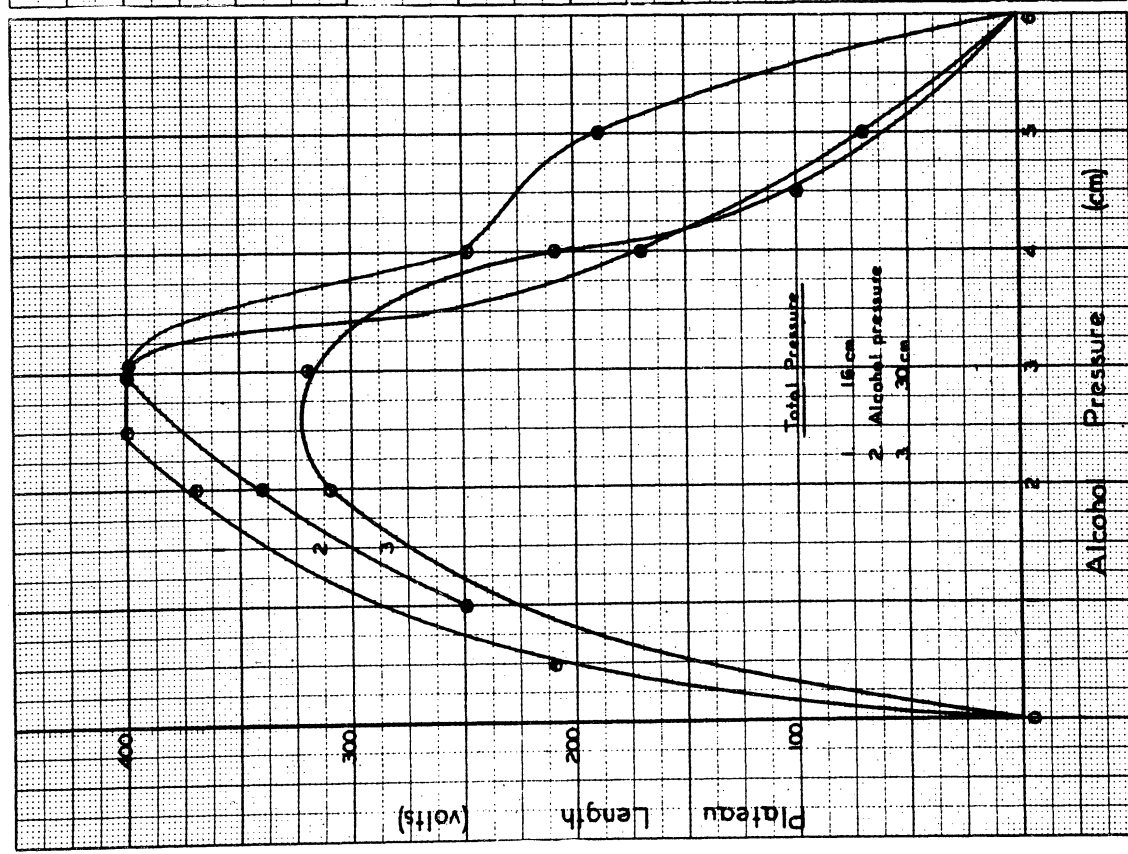


Figure 10

Technique of filling: In filling tubes, Collie and Roaf⁵ recommend the use of a cold trap (salt-ice mixture a little below 0°C.) through which the alcohol vapor is admitted. This trap eliminates any water as well as benzene which might be present, both of these substances affecting adversely the characteristics of the tube. Montgomery and Montgomery³⁴ also advise the use of a cold trap to remove harmful substances from the alcohol vapor.

CONTAMINATION

Various contaminants may still be present in the filling however. Spatz⁴¹ treated the subject of argon impurity and showed (Table II) the dependence of plateau slope and starting potential on argon purity and alcohol content.

Table II

<u>Influence of Argon Purity on Tube Characteristics</u>			
<u>%alc. vapor</u>	<u>A purity</u>	<u>Starting pot. volts</u>	<u>Plateau slope % / volt</u>
5	99.8	840	0.01
10	99.8	960	0.02
10	98.0	1000	0.15
10	90.0	1125	0.25
20	99.8	1080	0.05
20	90.0	1220	0.35

From this table we see that impurities such as air or oxygen increase both the plateau slope and the starting potential of argon-alcohol mixtures. Since air is soluble to 0.7% for a 20% alcohol mixture, it causes an increase of plateau slope of 0.05% per volt. This increase can be eliminated by degassing the alcohol.

Curran and Petrzilka¹⁰ show how the characteristic curves vary with different partial pressure (0 to 5 cm.) of air added to a counting mixture. Spatz⁴¹ also found an increase of plateau slope with an increase in alcohol content of the tube.

Medicus³¹ reported that the presence of traces of water vapor in the counter encouraged spurious discharges, not appearing in a carefully outgassed tube. On the other hand many authors have found that counters with very carefully outgassed electrodes and purified gases fail to count at all. To produce workable counters a trace of some impurity such as oxygen is allowed to be present, evidently forming a surface layer on the cathode. This surface layer is apparently essential to the working of the counter. Many authors seem to be able to reach the right degree of impurity by using commercial gases without extra purification (May)²⁸.

At one time mercury, a contaminant present in most every high vacuum system unless trapped out, had been thought to cause trouble in the counting mixture. Medicus³¹ however claimed that the presence of mercury reduced the number of spurious counts. More recently Korff and Present²² made a study of the effects of mercury vapor on the counting mixture. They found that because of the extremely low vapor pressure of mercury at room temperature, the mercury contaminates a counter to about one part in 10^5 without creating any noticeable effect. Higher mercury concentrations will change the characteristics but fortunately these concentrations can not be effected at room temperature.

DIFFUSION

Diffusion seems to cause considerable trouble during the process of filling the counter tubes. Spatz⁴¹ states that his counters required 24 hours for complete mixing and diffusion of the gas and vapor. He uses a mixture of 5% alcohol and 95% argon. Korff²¹ indicates that at least an hour should be allowed for diffusion equilibrium to be established after the mixture is made. Weisz⁴⁶ in a review states that proper mixing of gases is necessary. Davis and Curtiss¹² indicate that the difficulties experienced with their counters arise almost exclusively from failure to secure a mixture of gas and vapor of the proper proportions, brought about because of the slow diffusion rate of the gases.

However other authors whose results indicate that their counters are accurate and reproducible have apparently not allowed much time for diffusion. Rochester and Janossy³⁸ filled and sealed their tubes within one quarter of an hour. No mention is made in the papers of Trost⁴⁵, Curran and Petrzilka¹⁰, or McLellan²⁹ of any definite time allotted for diffusion.

ADSORPTION

Adsorption seems to be another one of the big problems of counter construction. Many authors have had trouble with alcohol adsorption on the waxes, resins, and plastics which they use to seal their tubes. Curran and Petrzilka¹⁰ found that ebonite adsorbed alcohol vapor and shortened the life of their tubes. Trost⁴⁴ indicates that adsorption is one of the main disadvantages of alcohol filling, for within a month, alcohol vapor in his tubes appeared to have been deposited on the insulators and metal parts in the form

of a hard rubbery substance. However these tubes could be regenerated by simple warming. Others found that picein readily absorbs the alcohol as do hard rubber insulators and stoppers (Curran and Petrzilka¹⁰). The adsorption is dependent upon the temperature and thus gives the tube an undesirable temperature correction. Strongly alkaline glass tends to absorb vapors and should be avoided.

Adsorbed gases in the tube can be eliminated from the wire by glowing and from the cathode and tube walls by baking. Thus tubes completely sealed in a pyrex envelope and thoroughly outgassed would have a minimum adsorptive tendency.

TEMPERATURE EFFECTS

Several authors report temperature effects on various types of fast counting tubes. Trost observed a rise of counting voltage of 2 volts per degree temperature lowering. He explained this rise by the tendency of the vapor to precipitate out on the wall of the tube even above its saturation temperature. Cowie⁷ noted an increase of counting rate with rise in temperature and attributed the change to thermionic emission from the walls of the counter. He also found that a slow counter at 100°C. started to count 100 volts lower than at room temperature. Korff, Spatz, and Hilberry²³ made a study of this temperature coefficient and explained it in terms of the Montgomery and Montgomery³⁴ theory of counter action. As the temperature is lowered, too few quenching molecules remain to efficiently quench the discharge. Thus Korff and co-workers tried filling tubes with gases such as methane and boron trifluoride that are not saturated vapors at ordinarily encountered temperatures. Figure 11 indicates the difference in characteristic curves of the methane and alcohol quenched tubes at 55, 26, 0, and minus 22°C. We see then, that

Figure 11

(Korff, Spatz, and Hilberry²³)

Characteristic curves for counters with argon-alcohol and methane fillings at various temperatures. Lower voltage scale (higher voltages) applies to methane counter only. Argon-alcohol counters show temperature effects below but not above room temperature; methane counter has negligible temperature coefficient in this range.

Temperatures:

-22° C. ----- ●
0° C. ----- ◐
26° C. ----- ◑
55° C. ----- ○

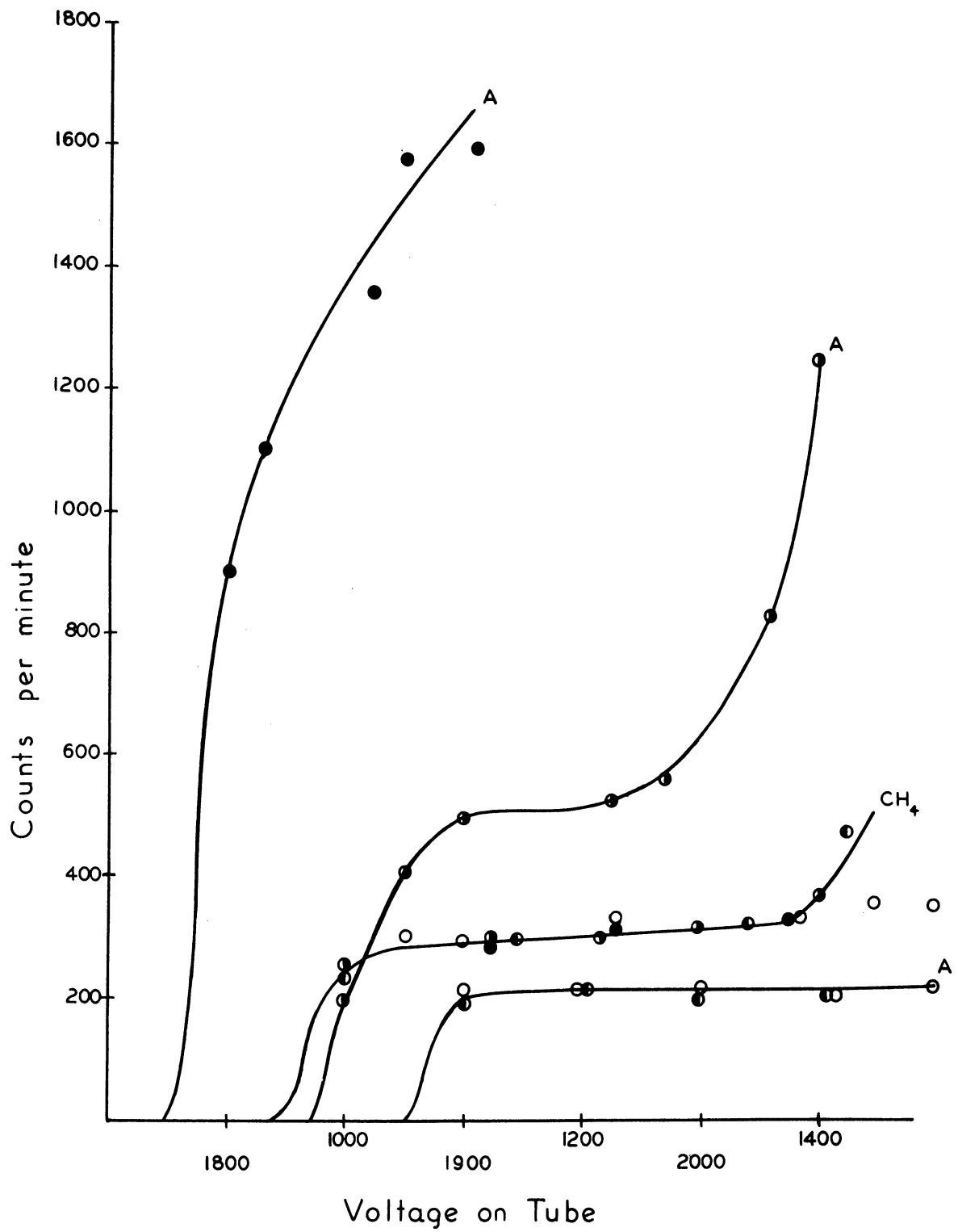


Figure 11

using methane as a quencher has eliminated the bad temperature effect of alcohol quenched tubes.

Following this explanation, McLellan²⁹ prepared tubes with 5 mm. pressure of alcohol vapor added. At this pressure, the vapor condenses only below minus 15° C. These tubes proved workable down to at least 6° C., the starting potential of the tubes remaining constant for varying temperatures.

DECOMPOSITION

While investigating factors that influence the plateau characteristics of self-quenching G-M counters, Spatz⁴¹ found that the alcohol in a fast counter decomposes constantly with use. Korff and Present²² state that about 10^{10} alcohol molecules are decomposed at the cathode for every discharge. Since there are about 10^{20} alcohol molecules in the counter volume, the counter will go bad after about 10^{10} counts. The primary decomposition products are usually free radicals which then combine to form organic compounds, some with and some without quenching properties. With continuous use the larger vapor molecules break up into non-quenching gases such as oxygen and hydrogen, or hydrocarbon polymers. Spatz⁴¹ lists the decomposition products of alcohol vapor in a discharge (condensed from data by Cummings and Bleakney⁹). Yaddanapalli⁴⁹ presents the same type of data for methane.

SPURIOUS COUNTING

Several authors have investigated spurious counting and inconsistencies of tubes. Nunn May²⁸ lists certain precautions to be followed in the elimination of these spurious counts. Hull¹⁸ mentions a warming up

correction which seems to be an inherent property of the tube itself. Montgomery and Montgomery³⁴ discuss causes of spurious counting and list several tests for spurious counts. Greisen and Nereson¹³ discussed the efficiencies of alcohol filled counters used in coincidence work and cosmic ray counting. Rochester and Janossy³⁸ compare efficiencies for different types of fillings of copper and brass in glass counters. Their data are taken from six observers with different methods of preparing the tubes.

GEOMETRY OF THE TUBE

The geometry of the tube affects the electric field around the wire considerably. May²⁸ states that any slight asymmetry of the electrodes leads to variation in the electric field in different parts of the counter. Thus the critical value at which counting begins is not attained at the same voltage over the entire tube. Moon³⁵ reports that the cathode does not even have to be a perfect cylinder but that cylindrical symmetry is necessary for a uniform field at the wire. Christoph⁴ investigated the effect of deliberately placing the wire at a variable distance from the axis of the outer cylinder. He found that even a small displacement had a marked effect on the plateau of the characteristic curve.

Thus the good counting tube requires a symmetrical electric field. As previously stated however, any considerations of size are entirely dependent upon the nature of the problem to be studied.

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