A NEW PARTICLE DETECTOR—THE CRYSTAL FILAMENT COUNTER

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Submitted May 20, 1972

Zh. Eksp. Teor. Fiz. 63, 1562—1575 (November, 1972)

A filament particle counter with gas, liquid, and crystalline filling has been developed and studied. It has been established that counters filled with pure gases—argon, xenon, or methane, operate unstably at high pressures. Argon-methane gas mixtures give satisfactory results up to a pressure of 100 atm. The data on characteristics of counters filled with liquid argon or xenon have been confirmed. Information has been obtained on operation of counters with liquid methane and liquid methane-argon mixtures. The properties of filament counters with crystalline argon or xenon have been studied. It has been established that the pulse-height characteristics have three typical parts: ionization, proportion (electron multiplication ~ 150), and saturation. The plateau in the counting rate has a width of ~ 3 kV. Satisfactory results were not obtained with crystalline methane.

1. INTRODUCTION

In recent years a number of laboratories have carried out persistent work on development of filament particle counters with liquid filling. It is assumed that after a counter is developed liquid filament chambers can be built which will have high space and time resolution and high density of the working medium.

Up to the present time satisfactory results have been obtained only with counters having a conducting wire 3.5 μ in diameter and filled with liquid xenon[1]. The particle-detection efficiency in this counter was ~ 1, and the proportional multiplication factor ~ 10^2. However, in working with this same counter except with a 12 μ diameter wire, it was not possible to obtain satisfactory results.

Numerous attempts to obtain operating counters with a cheaper filling—liquid argon, have not been successful[2,3,4]. In every case, on achieving a field strength of ~ 2×10^6 V/cm, weak electron multiplication occurred on individual sections of the wire, while there was practically no electron multiplication in the remaining length. Further increase in field strength led to a local spark discharge of the fluctuation type. The phenomena accompanying the operation of counters with liquid argon have received a number of explanations[2-5]. The essence of the situation is that in argon there develop intense volume and surface photoprocesses which lead to local discharges. One means of combating these phenomena was considered to be the addition to the argon of a polyatomic quenching component, for example, of the type used in self-quenching gas counters. Therefore one of the purposes of the present work was to check this assumption experimentally. For this purpose we have used in the experiments pure liquids—argon, xenon, and methane—and argon-methane mixtures.

The experiments with liquid fillings were preceded by a series of studies of the operation of counters with pure gases and gas mixtures of various concentrations and pressures up to 100 atm. The main purpose of these studies was to find the laws governing the change in the counter characteristics with increasing density of the filling. It was assumed that these laws could be extrapolated to the density of liquids and could assist in a deeper understanding of the operating features of a liquid counter. It was thought also that experiments with gases permit more definite choice of optimum concentration of the liquid mixture which would have the best discharge characteristics.

The experiments with gas filling were also of independent interest as a source of new information on the operation of counters with extremely high gas pressure.

The series of studies with gas and liquid fillings was only the first step in solution of the problem of producing filament counters with a condensed filling. The second and conclusive step in the studies consisted in analysis and study of the characteristics of a filament counter whose working medium was a crystalline material. The program of these studies was formulated previously[6]. The principal encouraging indication of the possibility of producing a filament crystal counter was the fact that electron mobility in crystals is as a rule significantly higher than in liquids, while the densities of the liquid and solid phases are about the same. We could therefore expect that electron or hole multiplication should occur in the crystals near the wire, and that this process should occur more stably and more intensely than in liquid media.

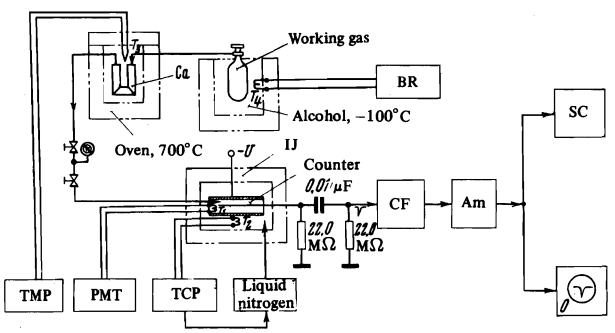

FIG. 1. Block diagram of the experimental apparatus: IJ—insulating jacket for counter, T_1—T_4—temperature probes, BR-bridge, TMP—temperature measuring potnetiometer, TCP—temperature control potnetiometer, CF—cathod follower, Am—amplifier, SC—scaling circuit, O—oscilloscope.

An attractive feature of the use of a solid material in the detector was the practical consideration of the exceptional simplicity of the fixed placement in it of a wire of any length, which promised to open the possibility of producing detectors of large size.

At the time when the studies of the crystalline filament counter were undertaken, several reports had been published[7-10] on observation of ionization pulses in solid argon and xenon. One of these studies[8] observed the electron multiplication effect in solid argon, but the polarization of the crystal by space charge was so rapid that it was not possible to make any study of this phenomenon.

We have used crystalline argon, xenon, and methane as working media in counters.

2. APPARATUS

A general block diagram of the apparatus is shown in Fig. 1. It includes a gas purification system, a temperature-control system for the counter, and the electronic measurement equipment.

A. The counter had a cylindrical brass cathode 6 mm in diameter and a tungsten wire covered with a thin layer of gold stretched along the cathode axis. The wire thickness was 10 μ and the length of the working region 6 cm. A negative high voltage was supplied to the cathode, and the signal was taken from the wire. The counter had end windows and vacuum tubulations for viewing the working region along the axis. All parts of the counter were carefully washed in acetone and ethyl alcohol before assembly. Before each filling with the working medium, the finished counter was aged in vacuum and flushed with the working gas mixture. These precautions assured good reproducibility of the experimental results.

B. The counter was placed in a double-walled insulating housing made of foam plastic. The controlling elements in this system are the temperature-sensitive elements T_1—T_4, and the measuring elements are electronic potentiometric bridges. Cooling and temperature control of the counter were carried out over a wide temperature range—from room temperature to liquid-nitrogen temperature—by automatic supply of liquid nitrogen to the insulating housing. The accuracy of temperature control was $\pm 0.1°$.

C. The gas purification system (see Fig. 1) includes a cell with ethyl alcohol for cooling the gas to a temperature of $-100°C$ and a cell with metallic calcium heated to 700°C. Cooling of the ethyl alcohol in the cell was accomplished by means of liquid nitrogen. The gas in the cell was purified of water vapor by freezing out the latter to 10^{-6} parts by volume, and purification from oxygen was carried out in the calcium trap to 10^{-7} parts.

D. The measuring equipment (see Fig. 1) consists of a cathode follower, linear amplifier, scaling circuit, and an oscilloscope in which the pulse height was measured. The resistive loading for the pulses coming from the counter was 11 megohms, and the input capacitance 50 pF. The sensitivity of the equipment was $\sim 4 \times 10^{-5}$ V.

3. EXPERIMENTS WITH GAS COUNTERS

In all of the experiments described below, we investigated two characteristics of the counter—the pulse height and the counting rate. Measurements were made for argon, xenon, methane, and the argon-methane mixtures 99% Ar + 1% CH_4, 95% Ar + 5% CH_4, and 90% Ar + 10% CH_4. In all of the experiments the geometry was fixed and the counter was irradiated with γ rays from an external ^{60}Co source.

The measured pulse heights are shown in Figs. 2 and 3 and the counting-rate data in Figs. 4 and 5 (here u is the pulse height, U is the voltage on the counter, and N is the number of counts).

The procedure for recording the pulse-height characteristics was as follows. The entire spectrum of pulses from the counter was fed through a cathode follower and linear amplifier to an oscilloscope where a visual measurement was made of the pulse height of the spectrum, with the upper limit corresponding to 98—99% of the total counting rate for a given voltage. The error in pulse-height measurement was about 10%. The lower point of each curve corresponds to the limit of sensitivity of the apparatus, and the upper point to the beginning of corona or spark discharges.

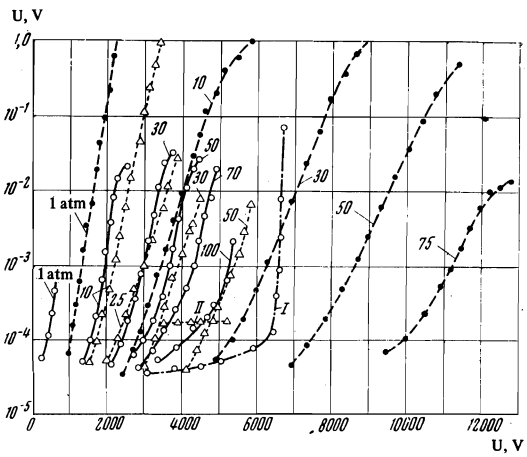

FIG. 2. Pulse-height characteristics of counter filled with gaseous argon—solid lines, methane—dashed lines, xenon—dot-dash lines. Curve I—liquid argon; curve II—liquid xenon. The numbers on the curves indicate the gas pressure in atmospheres.

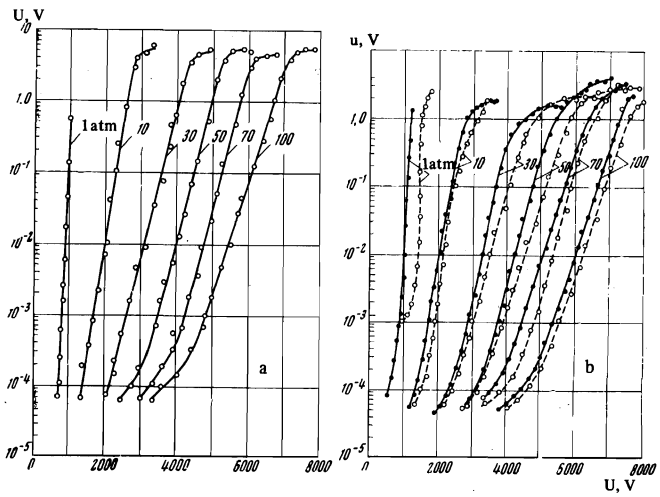

FIG. 3. Pulse-height characteristics of counter filled with gas mixtures: a—99% Ar + 1% CH_4, b—95% Ar + 5% CH_4—solid curves, and 90% Ar + 10% CH_4—dashed curves.

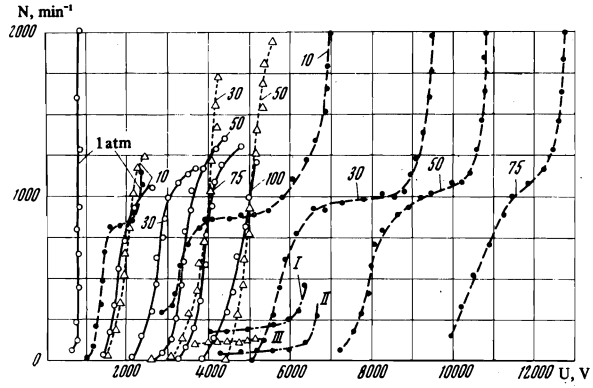

FIG. 4. Counting characteristics of counter filled with gaseous argon—solid curves, methane—dashed curves, xenon—dot-dash curves. Curve I—liquid argon filling, curve II—liquid argon with traces of methane admixture, curve III—liquid xenon.

The characteristics of the counter for low pressures of argon, methane, and argon-methane mixture are in good agreement with the experimental data of many other authors (see, for example, refs. 11—16).

It can be seen from the curves of Fig. 2 that the pulse height in pure argon drops with increasing pressure. It was found that stable operation of the argon counter is observed only up to a gas pressure of ~ 50 atm. At higher pressures the counter operates extremely unstably and the experimental results are poorly reproduced. Discharges of brief duration often occur in the counter at voltages well below the breakdown value. In some cases these discharges lead to subsequent stabilization of the operation, but in most cases after the first discharge a series of continuous discharges follows. To cut off these discharges it was necessary to reduce the voltage on the counter by 20—30%. The counting characteristics in pure argon, as can be seen from Fig. 4, do not have a plateau in voltage over the entire range of pressures.

Significantly better results were obtained in work with methane. A counter with low or medium pressures of methane (up to 50 atm) has a broad proportional region (this region approximately corresponds to the linear portion of the pulse-height characteristic, which is shown on a logarithmic scale) which is characterized by a gain of 10^4. However, with increasing pressure the gain falls rapidly. This behavior can apparently be explained by the influence of space charge on the discharge. The counting plateau in the methane counter (see Fig. 4) first broadens with increasing pressure and then narrows, practically disappearing at a pressure of ~ 75 atm.

The qualitative pattern of operation of the methane counter at high pressures differs noticeably from that for the argon counter. Thus, appearance of individual discharges usually is not accompanied by a subsequent series of discharges. And only at the highest pressures are the working pulses accompanied by a series of decaying post-discharge pulses. Here the mode of operation of the counter is preserved.

The best results were obtained in the investigation of mixtures of argon with methane (see Figs. 3 and 5). For all mixtures a high gain (10^4) is retained up to pressures of 100 atm. Up to these pressures a plateau is observed

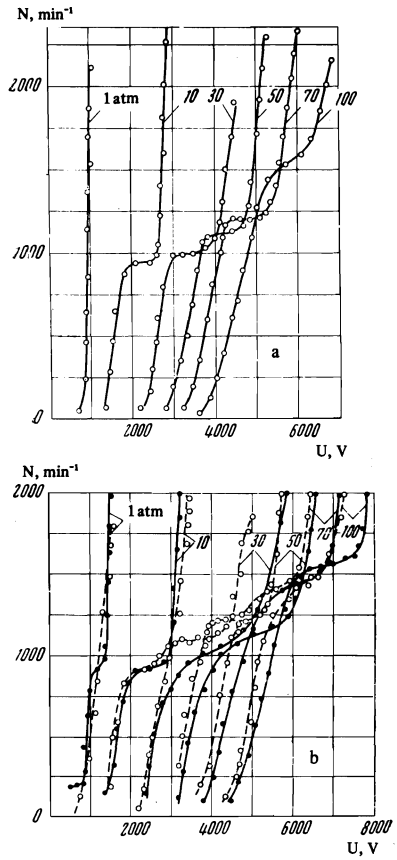

FIG. 5. Counting characteristics of counter filled with gas mixtures: a—99% Ar + 1% CH_4, b—95% Ar + 5% CH_4—solid curves, and 90% Ar + 10% CH_4—dashed curves.

in the counting characteristics as a function of the applied voltage. However, the slope of the plateau rapidly increases with increasing pressure. The qualitative pattern of operation of the counter with the mixtures is similar at all pressures. The counter operates stably both at low and high pressures.

In the measurements with gases the rise time of the pulses depended on the type of gas, the pressure, and the applied voltage, and varied over the range 2—10 μsec. The fall time of the pulses was 500 μsec and was determined by the time constant of the counter circuit and the input of the measuring equipment.

It was noted above that the main purpose of this part of the investigation was to study the features of operation of the counter at high gas pressures. In this regard the results obtained permit the following conclusions to be drawn.

First, with increasing gas pressure above 50 atm the pulse height drops appreciably. This drop appears especially clearly in operation with homogeneous pure gases. The width of the plateau decreases and the slope increases. For gas pressures of about 100 atm the plateau practically disappears.

Second, the counter operation with pure gas fillings—argon, xenon, methane—becomes unstable at high pressures. Stable operation occurs only in counters filled with mixtures of argon with methane. Here the composition of the mixture can be varied over a wide range. Stability is apparently provided here by the action of the

same well known discharge-quenching mechanisms which accompany operation of a self-quenching counter at low and medium pressures (several atmospheres).

The results of the studies with gases at high pressure, extrapolated to a density corresponding to the density of a liquid, uniquely indicate that liquid counters with pure argon, xenon, or methane should work very unstably. This conclusion is in good qualitative agreement with the actual results obtained in study of liquid-argon[2,3,4] and liquid-xenon[1] counters. The experiments with gas mixtures give an encouraging indication that counters with liquid solutions of monatomic and polyatomic media may have stable characteristics.

4. EXPERIMENTS WITH LIQUID COUNTERS

In these investigations the counter was filled with liquid argon, xenon, methane, and argon-methane mixtures, respectively. The first two experiments in this series—with argon and xenon—were, to a degree, control experiments, since the experimental data for these cases are well known[1-4].

As has already been noted, the sensitivity of the apparatus in the experiment was 4×10^{-5} V. With a capacitive loading of 50 pF this permitted recording pulses with $\sim 1.2 \times 10^4$ charges. Compton electrons from ^{60}Co γ rays could produce in liquid argon or methane in the counter volume $\sim 4 \times 10^4$ pairs of primary charges, and in liquid xenon 5×10^4. For complete collection of these charges at the counter electrodes, the maximum pulse height should reach 1.5×10^{-4} V.

The experimental results with liquid argon and xenon are shown in Figs. 2 and 4. It is evident from the curves for argon that the pulse height did not exceed 10^{-4} V over a wide range of applied voltage. Only for a voltage of 6.5 kV on the counter did the pulse height rise sharply. However, this voltage region was characterized by extreme instability in the counter operation. The γ-ray detection efficiency was appreciably lower than in the gas-filled counter (see the curves in Fig. 4). In essence, the experiment recorded only those γ rays whose Compton electrons completely lost their energy in the counter volume. A similar pattern was observed also in operation with liquid xenon (see Fig. 2 and Fig. 4). Here also no electron multiplication was obtained in the counter. However the primary-charge collection coefficient in liquid xenon was somewhat higher than in liquid argon.

The pattern of operation of the argon and xenon counters qualitatively reproduced in its details the pattern which appeared in the experiments described by Alvarez and others[1-3].

In the experiments with liquid methane we were unable to detect pulses from γ rays. For applied voltages of 10 kV local discharges appeared which were accompanied by abundant formation of dark spots ("flakes") and intense agitation of the liquid near the wire. In these experiments the methane was first purified by repeated recrystallization and distillation of heavy and light fractions, including water and oxygen, to a level of 10^{-5}—10^{-6} parts by volume. Therefore the absence of pulses from γ rays was probably due to the presence in the methane of electronegative impurities such as secondary fragments from methane molecules. We were surprised to observe the occurrence of spontaneous discharges in liquid methane at a counter voltage of only 10 kV, whereas in gaseous methane at a pressure of 75 atm a similar discharge set in only at 13 kV (see Fig. 2). This fact can be explained only by the formation of discharges in bubbles of methane.

On filling the counter with mixtures of argon and methane, a stratification boundary between these media was clearly observed in the liquid state. The concentration of the phases formed was unknown. It was not possible to detect pulses from γ rays in any of these phases. The breakdown voltage was 6—7 kV. Only when there remained in the argon only traces of methane were pulses from γ rays recorded (see Fig. 4). The height of the pulses remained at the level of sensitivity of the apparatus.

The absence of electron multiplication in the liquid mixtures and in pure liquid methane is due mainly to the low breakdown potential of these liquids, the breakdown probably occurring in gaseous microbubbles.

5. STUDY OF A COUNTER WITH SOLID ARGON

In part of the experiments argon of "special purity" was used. In another series the argon was further purified from oxygen in a calcium trap at a temperature of 700°C and from water vapor in a special low-temperature bath at −100°C. The purity of the argon was 10^{-7} parts by volume of oxygen and 10^{-6} of water vapor.

The procedure for obtaining crystalline argon in the counter was as follows. First the argon was heated to a temperature 5—6°C above the triple point and then cooled to the triple point and kept at constant temperature. It was found that the counter characteristics are well reproduced for a rate of cooling of liquid argon near the triple point less than 1.5 degrees/hour and a constant-temperature period at this point or 0.3—0.6°C below it of more than three hours. The argon crystal obtained is transparent. Immediately after crystallization the crystal has a brown shade which turns to a light gray after the constant-temperature period.

The counter works exceptionally stably with the transparent crystal. No space-charge loading of the crystal is observed, and the characteristics are quite reproducible. The stability of the counter operation is not destroyed when it is cooled to liquid-nitrogen temperature. However, the rate of cooling must be less than 1.5 degrees per hour.

Figures 6 and 7 show the pulse-height and counting characteristics of the crystalline argon counter irradiated by ^{60}Co γ rays. It must be noted here that, for comparison of these counting characteristics with the similar characteristics of the gas and liquid counter, all of the counting-rate data shown in Fig. 7 must be multiplied by 3.7. This is due to the decrease by this factor of the γ-ray flux in the experiments with the crystalline counter.

It is evident from analysis of the pulse-height characteristics that the counter has three typical regions of operation: the ionization regime up to 2 kV, the proportional regime up to 5.2 kV, and the saturation regime above 5.2 kV. In the proportional region the gain is ~ 150. In the saturation region the pulse-height spectrum is substantially equalized. The spread does not

exceed a factor of 1.5. The limiting pulse height, as can be seen from Fig. 6, is 4×10^{-2} V. This is apparently limited by space charge arising at the moment of electron multiplication near the wire.

The counting characteristics (Fig. 7) have a flat plateau of length 3 kV. The counting rate in the middle of the plateau is 1600 per minute, which is of about six times greater than in the gas at a pressure of 100 atm (see Fig. 4; the factor 3.7 has been taken into account in this comparison). This increase in counting rate corresponds approximately to the change in density of the medium.

The rise time of the pulses had a duration of 1 μsec, while the fall time was 500 μsec and was determined, as we have pointed out, by the time constant of the counter circuit and the input of the measuring equipment.

From the rise time of the pulses we have calculated the mobility of positive ions in solid argon. It turned out to be 0.1 cm^2-V^{-1}-sec^{-1}. The mobility apparently is of the hole type, as is usual in crystals. We note that the mobility of positive charges in solid argon has not been observed previously. The mobility was known only for solid xenon and amounted to 2×10^{-2} cm^2-V^{-1}-sec^{-1}.[9] It will be shown below that the mobility of charges in solid argon, as in xenon, is completely determined by the purity and degree of perfection of the crystal.

We also checked experimentally the γ-ray detection efficiency for different parts of the wire. For this purpose a collimated γ-ray beam was moved along the wire. It was found that the detection efficiency was constant over the entire length of the wire.

6. SOME OPERATING FEATURES OF COUNTERS WITH AN IMPERFECT ARGON CRYSTAL

On rapid freezing of the argon or a short constant-temperature period of the crystal near the triple point, a rapid darkening of the crystal is observed. Under forced cooling conditions the crystal obtained is completely opaque. Even in these imperfect crystals, electron multiplication is still observed; however, the crystals rapidly charge up and the pulse height and counting rate drop. The charging time is proportional to the imperfection of the crystal, the intensity of γ-ray bombardment, and the magnitude of the applied voltage. Thus, for completely opaque crystals the drop in pulse height occurs in a few seconds or minutes. For partially transparent crystals this time lengthens to tens of minutes and even hours. A transparent crystal which has just been formed but which has a brown shade has the same charging time.

A charged crystal with the external field applied or removed, but with the γ source removed, recovers very slowly. Rapid neutralization of the space-charge potential in the crystal is achieved on reversal of the applied field. Thus, on application of a reverse voltage of 3 kV the counting and pulse-height characteristics are restored after 3—5 sec. During the action of the reversed field, cold injection of electrons from the wire into the crystal is easily observed by means of the oscilloscope. Subsequent application of the working voltage to the counter is accompanied, as a rule, by appearance of large-amplitude pulses, reaching 1 V. Part of these pulses are spurious, and another part are associated with the γ rays. After 2—3 minutes the transition process is completed and the spurious pulses disappear. The height of the pulses from the γ rays becomes equal to the height corresponding to the total sensitivity of the counter for a given voltage. The observed effect is satisfactorily explained by the mechanism of capture and release of injected electrons in shallow energy levels in the crystal[6]. The charging of imperfect crystals by space charge is apparently explained by the effective capture of holes by surface and volume traps.

A second feature of the operation of an argon counter is that a partly imperfect crystal becomes more perfect after being held near the triple point for several hours. Such a crystal does not charge up and gives stable reproducible characteristics.

In a special test we checked the effect on counter operation of an admixture of air introduced into the argon at the stage of the gas or liquid phase. It was established that a content in solid argon of 10^{-4} parts by volume of air completely destroys the operation of the counter.

In one experiment we checked the possibility of producing vapor bubbles in solid argon and electron multiplication in them near the wire. By rapid pumping of the argon vapor at the triple point we achieved boiling and freezing. Bubbles of various diameters were visible in the counter. Multiplication of electrons from γ rays was also observed in this argon at a counter voltage of about 1 kV. The pulse-height reached 0.1 V. However, the crystal rapidly charged up.

7. STUDY OF SOLID XENON COUNTERS

The initial xenon gas before condensation was purified of water vapor to 10^{-6} parts by volume and of oxygen to 10^{-7} parts. As in the case of argon, depending on the rate of cooling near the triple point and the period of constant temperature at the triple point, crystalline xenon of various transparencies is obtained. The crystal had the best transparency for the same cooling schedule as in argon, i.e., for a rate of cooling of the liquid near the triple point less than 1.5 degrees per

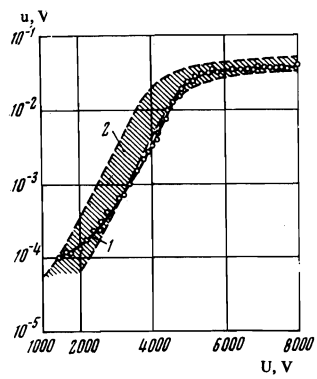

FIG. 6

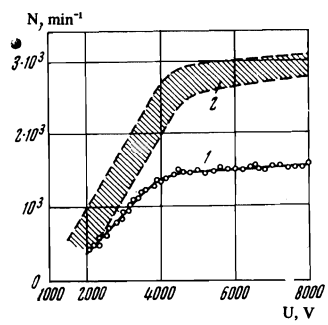

FIG. 7

FIG. 6. Pulse-height characteristics of crystal filament counter: 1—argon-counter characteristics 2—region of values of pulse-height characteristics of xenon counter.

FIG. 7. Counting characteristics of crystal filament counter 1—argon-counter characteristics 2—region of values of counting characteristics of xenon counter.

hour and a constant-temperature period at the crystallization point of more than 3 hours.

The results obtained with transparent xenon in the counter are shown in Figs. 6 and 7. Both the counting and the pulse-height characteristics have an entire band of values. These bands have the following meaning. Well defined counting and pulse-height characteristics were obtained in each experiment. However, from experiment to experiment (from freezing to freezing) these characteristics were not accurately reproduced. The large set of these characteristics obtained in many experiments formed these bands.

The crystalline-xenon counter has an additional feature, namely, polarization of the crystal by space charge. We were unable to obtain a crystal which would not charge up. The degree of charging was always proportional to the number of pulses recorded and to the gain. Very good crystals with a high transparency became appreciably charged only after 5×10^5 counts for a gain of 100. The counting rate at the end of the charging fell by 20—40%, and the pulse height by up to 50%. Crystals with a gray color charged several times more rapidly. However, if no voltage was applied to the counter or if the counter was not irradiated with γ rays, the sensitivity remained constant indefinitely. During extended operation of a counter a dynamic saturation set in at which further drop in counting rate and reduction of pulse height were cut off. The residual counting-rate and pulse-height level usually depended on the voltage: the higher the voltage, the higher the level.

A remarkable feature of the xenon counter operation is that on application of a reverse field of 1 kV amplitude, the original sensitivity was completely restored in 1 sec, independent of the previous degree of charging.

All of the features and characteristics of the counter are practically unchanged if the counter is very slowly cooled below the triple point right down to the temperature of liquid nitrogen.

It is evident from the curves of Figs. 6 and 7 that the counting characteristics have a comparatively broad plateau. The maximum counting rate in the xenon counter is about a factor of two higher than in argon. This is apparently explained by the large stopping power of the xenon.

The pulse-height characteristics of the counter have two clearly defined portions—the proportional region and the saturation region. The maximum gain in the proportional region is ~150. It can also be seen from Fig. 6 that the pulse-height characteristics of xenon and argon counters are nearly identical.

A separate experiment checked the γ-ray detection efficiency for different portions of the wire. As in the experiment with argon, this was accomplished by a collimated γ-ray beam which was shifted along the wire. It was found that the detection efficiency was identical over the entire wire length.

Operation of the counter was also checked with unpurified xenon in which the impurity of oxygen, nitrogen, and water vapor amounted to 10^{-5}. This investigation showed that a xenon crystal of this type charges up somewhat more rapidly than a crystal of purified xenon. To restore the sensitivity of this counter it was necessary to apply a reverse field of more than 2 kV.

The rise time of the pulses depended on the degree of perfection (transparency) of the crystal and varied from test to test over the range 0.5—5 μsec. It was determined from this that the positive-charge mobility in solid xenon was 10^{-1}—10^{-2} cm^2-V^{-1}-sec^{-1}. This value is close to the mobility 2×10^{-2} cm^2-V^{-1}-sec^{-1} obtained by Miller et al.[9]

8. STUDY OF COUNTERS WITH SOLID METHANE

Solid methane has a lattice similar to the silicon lattice. Therefore we would expect that in solid methane both electron mobility and multiplication should be observed. For this reason it is of interest to carry out an experiment with this material.

Before use in the counter the gaseous methane was purified of the light and heavy fractions by repeated recrystallization and pumping. In our estimation the total amount of impurity left in the purified methane was at the level 10^{-5}—10^{-6} parts by volume.

The result of the test with solid methane was such that we were unable to obtain a transparent crystal. We also did not record pulses from γ rays in solid methane, although counter voltages up to 20 kV were used. This result may be explained by the fact that there were many impurity levels for charge capture in the crystal. It is also not excluded that a high density of dislocations, which are rich in capture levels, is formed in the methane crystal. The dark color of the crystal favors this assumption.

9. DISCUSSION AND CONCLUSIONS

Inert-gas studies have once more confirmed the favorable effect of methane addition on counter operation, with a significant extension, relative to existing data, of the range of gas pressure, going up to 100 atm. However, the applicability of this statement to liquid solutions needs further experimental proof.

The main result of the studies with liquid counters, obtained in the present work and in refs. 1—4, reduces to recognition of the fact that such counters are distinguished by high instability. The counters are extremely sensitive to small impurities which occur in the liquid in indeterminable doses. Roughness and microbubbles of gas and vapor on the surface of the wire are the main centers for formation of spurious discharges which occur at comparatively low voltages. Development of these discharges may be facilitated by various molecular films formed on the surface of the wires, in which a Malter effect can occur. The instability of counter operation is apparently affected also by attraction to the wire surface, under the influence of the nonuniform electric field, of molecular impurities present in the liquid. This effect should appreciably change the composition of the liquid directly at the wire and in this way affect the development of electron cascades. Finally, we must mention the effect of spatial disorder of the molecules in the liquid medium. This effect unavoidably must lead to brief but large fluctuations in electron energy in the electric field and bring about the early development of uncontrollable discharges.

The factors discussed will invariably be present in all studies of liquid counters with constant applied voltage and will unavoidably prevent formation of a controlled discharge. The way out of this difficulty is evi-

dently to look for means of using pulsed and high-frequency applied fields or for means of covering the wire with a layer of dielectric with poor conductivity.[5]

In the development plan for detectors with a dense medium, the results obtained with the crystalline filament counter are encouraging. These counters have good reproducibility of characteristics, a broad counting plateau, and a high proportional gain. The polarization of an imperfect crystal by positive space charge in a number of cases can easily be neutralized by brief application to the counter of a small reverse field.

Stable operation of the crystalline counter opens the prospect of producing a filament chamber of large size, in which the filaments can be rigidly fixed in space as the result of crystallization of the material. Adjacent electrodes in these chambers should be made of wires of different diameters: the anode of fine wire, and the cathode of thicker wires or plates, since in fields of 0.5—1 MV/cm intense injection of electrons from the cathode into the solid dielectric occurs.

In view of the suggestion by Dolgoshein et al.[17] for development of a two-phase chamber with transfer of an electron track from the liquid to the gas, construction of such a chamber with only one phase—crystalline—is extremely promising. The filaments in such a chamber can be frozen near the side walls and electron multiplication will occur directly in the crystal. Even the possibility of detecting two projections of particle tracks is apparent here in principle. In fact, if the working medium is, for example, crystalline heptane or benzene, in which electrons are captured in shallow energy levels[18,19], the electrons in the particle tracks, by two successive pulses, can be released from the traps and transported for multiplication and detection to electrodes which are orthogonal planes of the chamber.

It now appears possible that a solid-state filament chamber can be developed also in crystalline helium, in which the electrons and holes have high mobility[20]. Use of counters or chambers of solid hydrogen is still problematical, since charge mobility has not yet been observed in it[20].

Undoubted interest will be presented by studies with materials which are crystallized at room temperature or higher and which have charge mobility.

In conclusion the authors are happy to thank V. P. Dzhelepov, B. M. Pontecorvo, G. I. Selivanov, L. M. Soroko, and V. I. Nikanorov for their unflagging interest in this problem and their support of this work.

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Translated by C. S. Robinson
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