Electronic method of detecting particles in two-phase liquid—gas systems

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In our opinion, there is promise for developing electron methods of detecting particles in liquids in the following directions:

1) fast electron detection of neutral radiation (neutrons, gamma rays, and especially neutrons);2 3 5
2) the achievement of a high spatial resolution (down to 10^{-3} cm), which is made possible by the low diffusion of the electrons, their high density in the particle track, and the short mean free path of 4 electrons in a liquid;4 5
3) the use of liquid electron detectors as total absorption spectrometers.8 5

In addition, we should mention an electron detector of tracks in liquid hydrogen; the promise of such a detector does not require further comment. However, at the present time the only liquid available in large quantities in which there exist free electrons is a liquefied noble gas. Noble gases being chemically inert, it is relatively easy to extract electrons Importantly, from them. Therefore, virtually all studies on liquid electron detectors have been made with a liquefied noble gas (argon and, less frequently, xenon).

Previous investigations of electronic processes in noble gases and in liquids (see, for example, ref 1) undertaken with a view to creating liquid electronic detectors of particles similar to the well-known gas-discharge detectors (Geiger counters, spark chambers, etc.), and also the subsequent unsuccessful attempts to achieve a controlled discharge in liquid argon,5 prompted us to seek an essentially new method of detecting particles in liquids.2 Such a method, which is based on transferring the electron image of the particle track from the liquid to a gas phase with subsequent detection of the "electron ghost" of the track in the gas phase was investigated and reported on for the first time by the authors at the Conference on Filmless Spark and Streamer Chambers at Dubna in April 1969. In ref. 11 we reproduced the first photograph of a particle track in liquid argon obtained in a two-phase electronic detector. Finally, in our report12 we announced results that indicated the possibility of filmless extraction of information from such a detector.

Before we turn to a discussion of the characteristics of two-phase electronic detectors, we should mention the great successes in detecting electrons in a homogeneous liquid medium achieved by Alvarez’s group.5 They have achieved a 100% detection efficiency for α particles in liquid xenon by means of a discharge from the surface of a thin wire (diameter less than 15 μ) in a field 2·10^6 V/cm they obtained 100-fold multiplication of the electrons. They also established the possibility of 15-μ ac accuracy in the detection of α particles by collecting electrons (without their multiplication in the liquid) on thin wires arranged at a distance of 50 μ from each other at a distance 0.7 mm from the α source.

However, the creation of liquid track detectors of large volume on the basis of the method discussed above, and developed in refs. 4-8 would seem to us to be a very difficult technological problem. In contrast, it is much simpler to detect the electron image of the track in a new phase detector, because the detection is made in the gas phase; there is then no need to use electric fields of high intensity and the characteristics of the two-phase detector are similar to those of gas-discharge detectors.

1. GENERAL CHARACTERISTICS OF TWO-PHASE ELECTRON DETECTORS

In a two-phase detector, ionizing particles are detected as follows:

1) An electric field extracts some of the electrons from the tracks of the ionizing particles in the liquid, so that they do not recombine with positive ions;
2) Electrons that have avoided recombining in the drift to the liquid—gas interface;
3) Electrons pass through the interface and emerge from the liquid into the gas;
4) The electrons drift in the gas;

This process is accompanied by processes that are very important for the operation of the electron detector: diffusion and trapping of electrons, the transport of current carriers, and concentration of ionic charge.

At a lowered temperature, the drift velocity of the electrons is higher.

The electron diffusion coefficient in a field was estimated in refs. 5 and 12 and found to be - 1. At this value of the diffusion coefficient, the electron spreads by ~10^2 cm when drift in the liquid is ~10 cm.

5) The electrons in the gas are detected by means of ionization methods. The first two processes are characteristic of the liquid electronic detector, the remainder only of a phase detector. Since our method is based on the ability of electrons being transmitted (emitted) from liquid phase into the gas phase, such detectors can be conveniently termed electron detectors, to distinguish from two-phase detectors of other types (for example, Charged Particle’s well-known liquid chambers,13 in which the charge occurs in gas bubbles). Let us now discuss some basic characteristics of these processes.

Extraction of electrons from the tracks of ionizing particles in the liquid.

The problem of the ionization in the liquid, the field strength, and the properties of the liquid. In present data we obtain the relative yield of eπ from particle tracks in a homogeneous electric field for various strengths in liquid argon. The liquid was α particles or x rays. The energy of the x rays was about 30 keV (the mean free path of the photoselectrons in the liquid was 0.002 g/cm^{2}); the energy of the α particles was 5.15 MeV (mean free path of about 50 μ in a density 1.3 g/cm^{2}).

Thus, we are dealing with ion densities per meter length that exceed by a factor 10 for x rays and 3 for α particles the ion density per unit track length of α particles. Nevertheless, we can see from Fig. 1, if the field strength is 10 kV/cm, practically all the electrons are extracted from the tracks of the photoelectrons and about 10% of the electrons are extracted from the α-particle tracks. Naturally, for particles of total electron yield will be α particles of appreciably weaker field (~1 kV/cm). In liquid argon, practically the same picture is observed as in Fig. 1 for the yield of electrons α α from the ionization of the electric field strength.

It is important to note that if there is no electric field in the liquid, practically all the electrons recombine in a time less than 1 μsec in the tracks of x-ray photoelectrons in liquid argon. During this time, there is a dense plasma in the electric field, and this prevents the escape of α particles. Experiments showed that if the electric field in the liquid is ab kV/cm, the electrons are confined by the plasma for a time of 1 μsec.

Drift of free electrons in the liquid argon. The process in the electric field is accompanied by processes that are very important for the operation of the electron detector: diffusion and trapping of electrons, and the transport of current carriers. At a lowered temperature, the drift velocity of the electrons is higher.

The electron diffusion coefficient in a field was estimated in refs. 5 and 12 and found to be -1. At this value of the diffusion coefficient, the electron spreads by ~10^2 cm when drift in the liquid is ~10 cm.

Fig. 1. Relative yield of electrons from the track of an α-particle photoelectron (1) and α-particle (2) as a function of the electric field strength, in the liquid argon. The solid circles are the results of measurement by the method of observing ionization measurements (see text) in thick tracks are the results of ionization measurements in liquid argon. Copyright © 1973 American Institute of Physics

References

The phase liquid–gas systems

5. Electrode detector for ionizing radiation is de-
scribed in various types of detectors and the
characteristics of ionizing particles in the liquid argon can be
used at a 100% particle-detection efficiency.

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1. GENERAL CHARACTERISTICS OF
TWO-PHASE ELECTRON DETECTORS

In a two-phase detector, ionizing particles are de-
tected as follows:

1) An electric field "extracts" some of the electrons
from the tracks of the ionizing particles in the liquid,
since they do not recombine with positive ions;

2) electrons that have avoided recombining in the track
drift to the liquid–gas interface;

3) electrons pass through the interface and emerge
from the liquid into the gas;

4) the electrons drift in the gas;

5) the electrons in the gas are detected by any of the
known methods (for example, from a gas discharge).

The first two processes are characteristic of any
liquid electronic detector; the remainder only of a two-
phase detector. Since our method is based on the possi-
bility of electrons being extracted (emitted) from the
liquid phase into the gas phase, such detectors can be con-
ventionally termed emission detectors, to distinguish them
from two-phase detectors of other types (for example,
Chargaff’s well-known liquid argon chamber,13 in which the dis-
charge occurs in gas bubbles). Let us now discuss the
basic characteristics of these processes.

Extraction of electrons from the tracks of
ionizing particles in the liquid. This de-
pends on the ionizing power of the particle, the electric
field strength, and the properties of the liquid. In Fig. 1
we present data obtained on the relative yield of electrons
from particle tracks in a homogeneous electric field of
various strengths in liquid argon. The liquid was ionized
by α particles or x rays. The energy of the x rays was
about 20 keV (the mean free path of the photoelectrons
in the liquid was 0.002 g/cm²; the energy of the α parti-
cles was 5.42 MeV (mean free path of about 50 μ in a liquid of
density 1.3 g/cm³).

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avistive particles the total electron yield will be obtained
at appreciably weaker fields (~1 kV/cm). In liquid xenon
density 2 g/cm³ almost exactly the same picture is ob-
served (as in Fig. 1) for the yield of electrons as a func-
tion of the electric field strength.2

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1 usec in the tracks of x-ray photoelectrons in liquid xenon.
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kV/cm, the electrons are confined by the plasma for ap-
proximately 0.1 μsec.3

Drift of free electrons in the liquid.
The process in the electric field is accompanied by two
processes that are very important for the operation of the
electron detector: diffusion and trapping of electrons by
dielectric impurities. In the range of temperatures
around 100 K and field strengths (~10 kV/cm) of prac-
tical interest, the electron drift in the liquid argon at a
velocity (~2·10⁻⁶ cm/sec. At a lower temperature of the
liquid, the drift velocity of the electrons is higher.4

The electron diffusion coefficient in a field of 1 kV/cm
was estimated in refs. 2 and 12 and found to be ~1 cm²/sec.
At the value of the diffusion coefficient, the electron cloud
spread by ~10⁻⁸ cm when drifting in the liquid over a
period of about 10 cm. The diffusion of the electrons in
the liquid in strong electric fields determines the limiting
accuracy with which the coordinates of a track can be

Fig. 2. Experimental chamber: 1) variant of the detector with filament
above the surface of the liquid argon; 2) variant of the detector with
bimetal filament immersed in the liquid argon; 3) sample holder used to
secure the filament; 4) signal output; 5) high-voltage input; 6) input of
high-voltage pulse for ionization of the panic system of the detector
(variant 1); 7) ionization; 8) liquid argon; 9) collimator.

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Dolgostor et al., 71
this, we used a generator of short (≈ 200 nsec) high-voltage pulses, the generator being triggered by a photomultiplier that detected the scintillation flash in the liquid when it is ionized by an α particle. The time lag between the scintillation and the arrival of the high-voltage pulse on the electrodes of the chamber could be varied in wide limits with an accuracy of 0.1 μsec.

The experiment was arranged in the same way as before (Fig. 2). If the electrons in argon vapor over a spark gap in an electric field strength in the range 1-10 kV/cm is (3-4) × 10^{-12} cm/sec, i.e., it exceeds the drift velocity of the electrons in the liquid by a factor of less than 2. Since the energy of the electrons in the gas is much higher than in the liquid, the electron diffusion coefficient increases appreciably in the gas (cf. Einstein's well-known relation). Therefore, to ensure maximal accuracy in recording of the track coordinates in the emission chamber, it is necessary to ensure a minimal drift length of the electrons. A CSR method was used for a short delay time of the pulse (1-100 μsec). Measured were allowed at all temperatures from 24 to 230°C. In the time interval between the static and the pulsed electric fields (τ ≈ τ_p): p is the pressure (mm Hg). The static field strength was 2, 5, and 8 kV/cm (V, G, A).

Drift of the electrons in the gas. This is a well studied process. We shall only point out that the drift velocity in argon vapor over a spark gap in an electric field strength in the range 1-10 kV/cm is (3-4) × 10^{-12} cm/sec, i.e., it exceeds the drift velocity of the electrons in the liquid by a factor of less than 2. Since the energy of the electrons in the gas is much higher than in the liquid, the electron diffusion coefficient increases appreciably in the gas (cf. Einstein's well-known relation). Therefore, to ensure maximal accuracy in recording of the track coordinates in the emission chamber, it is necessary to ensure a minimal drift length of the electrons. A CSR method was used for a short delay time of the pulse (1-100 μsec). Measured were allowed at all temperatures from 24 to 230°C. In the time interval between the static and the pulsed electric fields (τ ≈ τ_p): p is the pressure (mm Hg). The static field strength was 2, 5, and 8 kV/cm (V, G, A).

Detection of electrons in the gas. As a rule, the electrons in the gas are detected by gas-discharge methods. Previously, the spark method and also electroemission of the gas have been used for this purpose. Below, we consider methods of detecting electrons on thin wires surrounded by the gas (see Fig. 6). The advantages of using these methods are obvious: picture extraction of information about the track coordinates and the ionizing power of the particle passing through the tube is ensured in a simple manner.

2. TWO-PHASE WIRE DETECTORS

We investigated wire detectors of three types:

A. The electrons from the track of the ionizing particle in the liquid are collected on a thin wire, the anode, which is placed above the liquid parallel to its surface. Near the surface of the wire a discharge arises in a weak electric field. The discharge current is measured.

B. The same, except that the wire anode is immersed in the liquid gas. The gas surrounding the anode heats the wire with a direct electric current. The discharge develops in gas bubbles on the surface of the wire.

C. The same as B, but the wire operates in a pulse regime.

The argon was ionized in these experiments by a pulsed beam of x rays with mean photon energy 30 keV: the x-ray pulse lasted less than 300 nsec. In addition, x rays used the γ-ray sources 53Co (1.2 MeV) and 85Sr (0.6 MeV) which were placed outside the chamber. Some of the experiments were made with an α-particle source situated on the plane cathode (see Fig. 7).

The ionization of the liquid argon by the x rays was varied by means of copper filters and measured from the ionization current. The total energy absorbed in the liquid was determined from the number of ion pairs in the liquid. It was assumed that an energy of 26.6 eV was required for the formation of one ion pair.

Figure 4 shows typical oscillograms of the signals initiated by a γ-ray detectors of types A and B, and also the pulse-height spectra of the signals for different absorbed energies E. In our experiments the pulse-height resolution was determined primarily by fluctuations in the energy of the x-ray pulses (see Fig. 4) and also by the instability of the gas pressure (see below). Figure 4 reveals a clear dependence of the signal height A on the ionization energy E. Let us dwell in more detail on the characteristics of the detectors of each type with one wire.

A. Wire anode over the surface of the liquid. We investigated wires of diameter 39, 59, 100, and 200 μ. Since the characteristics of the detectors with different diameters were essentially the same, we give the results obtained for the wire anode of diameter 100 μ. To ensure stability of the results, it was necessary to heat the wire with a current of 0.2 A (a thin uncontrollable film of liquid forms on a cold wire in the electric field).

The linear dependence of the signal height A on the absorbed energy E at different values of the voltage U of the...
we measured the wire, resulting in a decrease of the capacitance of the wire by about 10%. It is important to note, however, that a wire with a gas bubble on it may reduce the effective capacitance. The capacitance of the wire with a gas bubble on it is smaller than that of a wire without a gas bubble on it. The capacitance of the wire with a gas bubble on it is also smaller than that of a wire without a gas bubble on it.

Finally, we performed experiments on the capacitance of a wire with a gas bubble on it. The capacitance of the wire with a gas bubble on it was measured using a capacitance meter. The capacitance of the wire with a gas bubble on it was smaller than that of a wire without a gas bubble on it. The capacitance of the wire with a gas bubble on it was also smaller than that of a wire without a gas bubble on it.

The results of these experiments show that the capacitance of a wire with a gas bubble on it is smaller than that of a wire without a gas bubble on it. The capacitance of a wire with a gas bubble on it is also smaller than that of a wire without a gas bubble on it. These results suggest that a wire with a gas bubble on it may be a useful tool for measuring the capacitance of a wire.
of bubbles of diameter about 10 \( \mu \) in which the electrons can multiply.

The \( \alpha \)-particle pulse-height spectrum with voltage \( U = 6 \) kV is shown in Fig. 8a. At this voltage, a total of \( 6 \times 10^6 \) electrons were extracted from the \( \alpha \)-particle track which is equivalent to the number of electrons from the track of a relativistic particle that loses an energy 160 keV (850 keV) in the liquid. I.e., to a particle that passes through a layer of liquid comparable with the mean free path of an \( \alpha \) particle (56 \( \mu \)). In this case the pulse-height resolution is determined by the dependence of the \( \gamma \) number of extracted electrons on the position at which \( \gamma \) a particle emerges (the field is inhomogeneous) and on the angle between its trajectory and the direction of the electric field (reaccumulation of the electrons in the track is maximal when the angle is zero).

Figure 8b shows the pulse-height spectra from \( ^{40} \text{Co} \) and \( ^{137} \text{Cs} \) \( \gamma \) rays. Unfortunately, the spectra from the \( \gamma \) sources had the appearance of decreasing spectra of a "noisy" nature. This was due not only to multiple scattering of the \( \gamma \) rays, but also to the different energies of the Compton electrons that were formed and the variation in the number of electrons extracted from the Compton-electron track with the position at which the Compton-electron form and its angle of departure. Nevertheless, the maximal values of the signals from the "tails" of the \( ^{40} \text{Co} \) and \( ^{137} \text{Cs} \) spectra differed by a factor of approximately 2, which agrees well with the maximal energies of the Compton electrons formed.

Peaks (see Fig. 8c) were obtained when the working voltage was increased, but this eliminated the dependence of the signal height on the ionization energy. The heated wire began to operate as the liquid analog of a Geiger counter. The \( ^{40} \text{Co} \) and \( ^{137} \text{Cs} \) spectra in this regime did not differ, and the gain reached \( 10^5 \). A feature of the "Geiger regime" is the long recovery time of the Geiger counter. When the counting rate was increased to 10 pulses/sec, the height of the signals began to decrease and at a counting rate of hundreds of pulses per sec it decreased by a factor of 10. This effect can be explained by the long-term required to "dissipate" the positive space charge on account of the low ion mobility in liquid argon \( 2 \times 10^{-6} \) cm\(^2\) V\(^{-1}\) sec\(^{-1}\). Some of the bubbles may also have "perished" in the discharge.

The clearest results indicating the possibility of proportional multiplication were obtained with an \( x \)-ray beam (see Fig. 4). It can be seen from Fig. 8 that by varying the working voltage \( U \) one can readily obtain proportional multiplication in almost any range of ionization energy. When the voltage was increased, so did the signal height, but the interval of proportional multiplication decreased. In our case the maximal signal with proportional multiplication was 60 mV (gain \( 2 \times 10^5 \)). From the mean gain and knowing the electric field strength within the bubble and the coefficient of impact ionization in this field, one can readily determine the mean length of the electron avalanche \( 27 \) and the bubble diameter needed for it to develop: 10 \( \mu \).

In Fig. 10a we have plotted the signal height \( A \) as a function of the energy \( W \) absorbed in liquid argon. The anode diameter was 30 \( \mu \); the heating current 0.5 A; the pressure 5.3 atm; the upper scale \( A_0 \) corresponds to \( U_1 = 4.5 \) kV; the lower, \( A_1 \) corresponds to \( U_2 = 2.5 \) kV.
of bubbles of diameter about 10 μ in which the electrons can multiply.

The α-particle pulse-height spectrum with voltage U = 6 kV is shown in Fig. 8a. At this voltage, a total of 6 × 10^3 electrons were extracted from the α-particle track, which is equivalent to the number of electrons from the track of a relativistic particle that loses an energy 100 keV (E = 150 keV) in the liquid, i.e., to a particle that passes through a layer of liquid comparable with the mean free path of an α particle (50 μ). In this case the pulse-height resolution is determined by the dependence of the number of extracted electrons on the position at which the α particle emerges (the field is kinsogemogenous) and on the angle between its trajectory and the electric field (recombination of the electrons in the track is maximal when the angle is zero).

Figure 8b shows the pulse-height spectra from 60Co and 137Cs γ rays. Unfortunately, the spectra from the γ sources had the appearance of decreasing spectra of a "noisy" nature. This was due not only to multiple scattering of the γ rays, but also to the different energies of the Compton electrons that were formed and the variation in the number of electrons extracted from the Compton-electron track with the position at which the Compton electron is formed and its angle of departure. Nevertheless, the maximal values of the signals from the "tails" of the 60Co and 137Cs spectra differed by a factor of approximately 2, which agrees well with the maximal energies of the Compton electrons formed.

Peaks (see Fig. 6c) were observed when the working voltage was increased, but this eliminated the dependence of the signal height on the ionization energy. The heater wire began to operate as the liquid analog of the counter. The 60Co and 137Cs spectra in this regime did not differ, and the gain reached 105. A feature of the "Geiger regime" is the long recovery time of the detector. When the counting rate was increased to 10 pulses/sec, the height of the signals began to decrease and at a counting rate of hundreds of pulses per sec it decreased by a factor of 10. This effect can be explained by the long time required to "dissipate" the positive space charge on account of the low ion mobility in liquid argon1 (2 × 10^-4 cm^2 V^-1 sec^-1). Some of the bubbles may also have "perished" in the discharge.

The clearest results indicating the possibility of proportional multiplication were obtained with an x-ray beam (see Fig. 4). It can be seen from Fig. 9 that by varying the working voltage U one can readily obtain proportional multiplication in almost any range of ionization energy. When the voltage was increased, so did the signal height, but the interval of proportional multiplication decreased. In our case the maximal signal with proportional multiplication was 60 kV (gain 2 × 10^4). From the gain gain and knowing the electric field strength within the bubble and the coefficient of impact ionization in this field, one can readily determine the mean length of the electron avalanche11 and the bubble diameter needed for it to develop 10 μ.

In Fig. 10a we have plotted the signal height against the working voltage U for different gas pressures p. From these data we also plotted the signal height against the pressure for three fixed voltages (see Fig. 10b). It can be seen from the data of Fig. 10 that the signal height depends almost exponentially on the voltage and the pressure, i.e., in this regime the pressure (the temperature of the liquid) and the voltage must be well stabilized.

Finally, we should mention that in the case of proportional multiplication (electron multiplication coefficient ~ 10^4) the detector also has a fairly long recovery time. Thus, additional irradiation with 60Co γ rays at a counting rate of about 100 pulses/sec reduced the signal height by 10%.

C. Pulsed regime. When the chamber is irradiated with x-ray pulses (see Fig. 1), one can put negative pulses of controlled voltage on the cathode simultaneously or with a delay time. The applied pulses reach a maximum in a time of about 30 nsec and then decay in accordance with an exponential law with time constant 9.6 nsec. At the same time there is a static field with strength 1 kV/cm in the chamber.

The results of the measurements are shown in Fig. 11. A characteristic feature of this regime is the large value of the electron multiplication coefficient: ~ 10^5. In the controlled pulse regime with φ = 1 MeV the counter has a 100% detection efficiency, and this is retained for a delay time that does not exceed the time of drift of the electrons to the wire anode (the drift time is controlled by the constant voltage). A further increase in the delay time leads to a rapid decrease in the efficiency similar to the corresponding curves for ordinary spark chambers. The measured memory time of the counter is about 5 nsec.

That a high signal was obtained for a relatively low applied pulse height can be explained by the following circumstances. In a weak static field (less than 1 kV/cm) relatively large bubbles can exist on the surface of the heated wire. In such bubbles, the pulsed field initiates a discharge with a high multiplication coefficient. It is obvious that during the time of a high-voltage pulse (0.5 usec) a large bubble does not have sufficient time to collapse or be stripped from the wire: this leads to a high gas multiplication. In addition, if the pulsed field is even stronger, there is breakdown of the liquid in the interelectrode gap. In such a regime, the detector is transformed into a liquid spark counter, which can operate with 100% efficiency.

To conclude this section, let us consider the factors responsible for the background count in liquid electronic detectors. It arises because of radioactivity of the walls and the working liquid and because of cosmic rays; certain specific features of the liquid detector are also important: the presence of particles (both charged and neutral) suspended in the liquid and gas bubbles. In the two-phase detector, background signals can arise because of fluctuations in the surface of the liquid. Since the electric fields are higher in liquid electronic detectors than in gas-filled detectors, this facilitates the emission of electrons from microscopic edges and scratches on the cathode, etc. Such a process is more probable because the work function for electrons going from the metal...
into the liquid is less than for electrons going into a vacuum or gas (for argon by about 0.4 eV).

A particularly serious cause of a background count in gas-discharge detectors is usually considered to be processes that give rise to the appearance of afterpulses that accompany the pulse initiated by the detected radiation. Such processes include the photoelectric effect and stripping of electrons when the cathode is bombarded with positive ions and also metastable excited atoms (molecules). Quenching impurities are used in gas-discharge detectors to combat these factors responsible for a background count. In liquid electronic detectors, it would be difficult to use such impurities in the necessary concentration, since almost all known quenching impurities freeze onto the chamber walls at liquid-argon temperatures and do not dissolve at all well in the liquid.

However, as our experiments have shown, the detectors described here work satisfactorily with argon of maximal purity. This result can be readily explained. Indeed, for an electron to become free, it must overcome the potential barrier caused by the electrostatic attraction to the surface of the solid (the image potential).

The width of this barrier in argon is in the presence of an external electric field of E = 10^6 V/cm is about 5 \times 10^{-7} cm, and the mean free path of an electron in the liquid is smaller by a factor of almost 10. Thus, even if an electron has an energy sufficient to overcome the barrier, there is a high probability of its returning to the cathode because of scattering by atoms of the liquid. For example, in ref. 20 the photocurrent in a cell filled with liquid argon amounted to only 10^{-6} of the photocurrent in vacuum.

We should point out that, to improve the characteristics of the detectors, we introduced certain impurities into the working volume: hydrogen, neon, nitrogen, methane, and diethylamine (C_2H_5NH). None of these substances had an appreciable effect except neon. Addition of neon (up to 50% in the argon vapor) facilitated the development of the discharge in regimes A and B, however, this question must be studied.

3. POSSIBILITIES OF TWO-PHASE EMISSION WIRE DETECTORS

The experimental material we have set forth here enables us to evaluate the mechanism of operation and the possibilities of emission wire detectors. Let us dwell first on the possibilities of detectors with one wire.

Working liquid. The working liquid of the detector must satisfy the following requirements: It must be a dielectric in which free electrons can exist; the electrons must be capable of being emitted in the electric field from the liquid to the gas phase. Liquid argon satisfies these requirements. There are many other liquid dielectrics (noble gases, organic liquids) which could evidently be used in emission electron detectors if it is shown that electrons can be emitted electrostatically from their surface. As the possibility of this has not been adequately studied, we shall consider only detectors filled with liquid argon, whose emission of electrons was observed for the first time in our experiments.

Working volume of the detector. Modern methods of pulsifying argon enable one to obtain an electron drift length of several tens of centimeters. It is therefore advisable to take the interelectrode gap not more than 50 cm. The diffuse spreading of the electron cloud during its drift to the anode over such a distance is about 10 \mu.

Energy resolution of the detector. As the measurements showed (see Fig. 4), the detection of ionizing particles that lose about 1 MeV in the liquid, this can be about 10\% for detectors of type A and about 20\% for detectors of type B. We showed that the signal height could be made proportional to the ionization losses of the particles in the investigated range of \alpha from 30 keV to 10 MeV.

Detection efficiency. This reaches 100\% for different fission fragments in the given energy range.

Signal height. In any range of detectable ionization loss, the signal height can be raised by an appropriate choice of the working voltage, to 10–100 MeV for a capacitance of 300 pf (see Figs. 5, 6, 9, and 10), and to 1 V in the pulsed power regime.

Time resolution. For the detector of type A better than 50 psec and that of type B better than 200 psec. (see Fig. 4); in the pulsed regime the time resolution can be improved to 3 psec.

Dead time (or recovery time). For detectors of types A and B in the proportional multiplication regime the dead times are \sim 2 \times 10^{-5} or \sim 10^{-5} sec, respectively. In the Geiger regime the dead time of the type B detector increased to 10^{-3} sec.

Spatial resolution. The spatial resolution of the wire emission chamber is determined primarily by the distance between the wires and also the anode—cathode gap, because the electron image of the track is spread out by the electron diffusion during drift in the gas. The coordinates of any point of the track can be found by means of two planer series of wires (the transparency of wire meshes for electrons in liquid is about 90\% and in gas 80\%).

To determine the third coordinate — in the direction of the electric field — one can measure the drift time of the electrons from the track to the wire, which is the anode. In two-phase liquid track detectors one can evidently hope to achieve a detection accuracy for the coordinates of the track of about 100 \mu, but this question requires further experimental study.

We should also mention a serious shortcoming of the multwire detector: the need to heat the wires. As an example, let us consider the possibility of using liquid electronic detectors of type B to detect solar neutrinos. The requirements that such a detector must fulfill are formulated in ref. 3.

The equipment must detect electrons from the process of \beta scattering or electrons of inverse \beta decay with an energy of about 1 MeV. In liquid argon, an electron with an energy of about 1 MeV has a mean free path of a few millimeters. To determine the trajectory of such an electron, one must have at least two series of wires that are separated by \sim 1 mm (the coordinate in the field direction is determined from the drift time). On the average, about 10 wires (five points of the track) will be affected by each event; the ionization energy per wire is about 100 keV. Such an energy can be efficiently detected, and each wire will operate in the proportional regime.

Since the sensitive part of the detector must contain not less than 10 metric tons of liquid argon (about 5 m^3), the total length of the wires (at an interelectrode distance of 0.5 m) must be about 10 km, and a power of about 1 MW will be required to heat the wires.

We see that the use of a two-phase detector to detect neutrinos in such an arrangement would be rather difficult. Nevertheless, the use of two-phase systems for the electronic detection of particle tracks is very promising, especially for detecting neutral radiation.

We should like to thank Academician B. M. Posteev for helpful discussions and support in every way.

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Energy resolution of the detector. As the measurements showed (see Fig. 4), for the detection of ions in the liquid, this can be about 10% for detectors of type A and about 25% for detectors of type B. We showed that the signal height could be made proportional to the ionization losses of the ions in the investigated range of A from 50 keV to 10 MeV.

Detection efficiency. This reaches 100% for different ionizing particles in the given energy range. Signal height. In any range of detectable ionization loss, the signal height can be raised by an appropriate choice of the working voltage, to 100-1000 μV for a capacitance of 3-9 pF (see Figs. 1, 6, 9, and 10), and to 1 μV in the pulsed regime.

Time resolution. For the detector of type A better than 50 μsec and that of type B better than 200 μsec (see Fig. 4); in the pulsed regime the time resolution can be improved to 5 μsec.

Dead time (or recovery time). For detectors of types A and B in the proportional multiplication regime the dead times are 2-10 μsec or 10-15 μsec, respectively. In the "Geiger regime" the dead time of the type B detector increased to 10-20 μsec.

Spatial resolution. The spatial resolution of the wire emission chamber is determined primarily by the distance between the wires and also the anode-cathode gap, because the electron image of the track is spread out by the electron diffusion during drift in the gas. Two coordinates of any point of the track can be found by means of two plane series of wires (the transparency of wire meshes for electrons in liquid is about 30% and in gas 80%).

To determine the coordinates of the track, one can either detect the drift time of the electron or the field direction of the track, which is the anode. In two-phase liquid track detectors one can further improve the detection accuracy of the coordinates of the track of about 10 μsec, but this question requires further experimental study.

We should also mention a serious shortcoming of the MWPC detectors: the need to keep the liquid. For example, let us consider the possibility of using liquid electronic detectors of type B to detect solar neutrinos. The requirements that such a detector must fulfill are formulated in ref. 3.

The equipment must detect electrons from the process of ν-e scattering or electrons of inverse B decay with an energy of about 1 MeV. In liquid argon, an electron with an energy of about 1 MeV has a mean free path of a few millimeters. To determine the trajectory of an electron, one must have at least two series of wires that are separated by 1 mm (the coordinate in the field direction is determined from the drift time). On the average, about 10 wires (five points of the track) will be detected by each event; the ionization energy per wire is about 100 keV. Such an energy can be efficiently detected, and each wire will operate in the proportional regime.

Since the sensitive part of the detector must contain not less than 10 miconmeter tons of liquid argon (about 7 m), the total length of the wires (at an interelectrode distance of 0.5 m) must be about 10 km, and a power of about 1 MW will be required to heat the wires.

We see that the use of a two-phase detector to detect neutrinos in such an arrangement would be rather difficult. Nevertheless, the use of two-phase systems for the electronic detection of particle tracks is very promising, especially for detecting neutral radiation.

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