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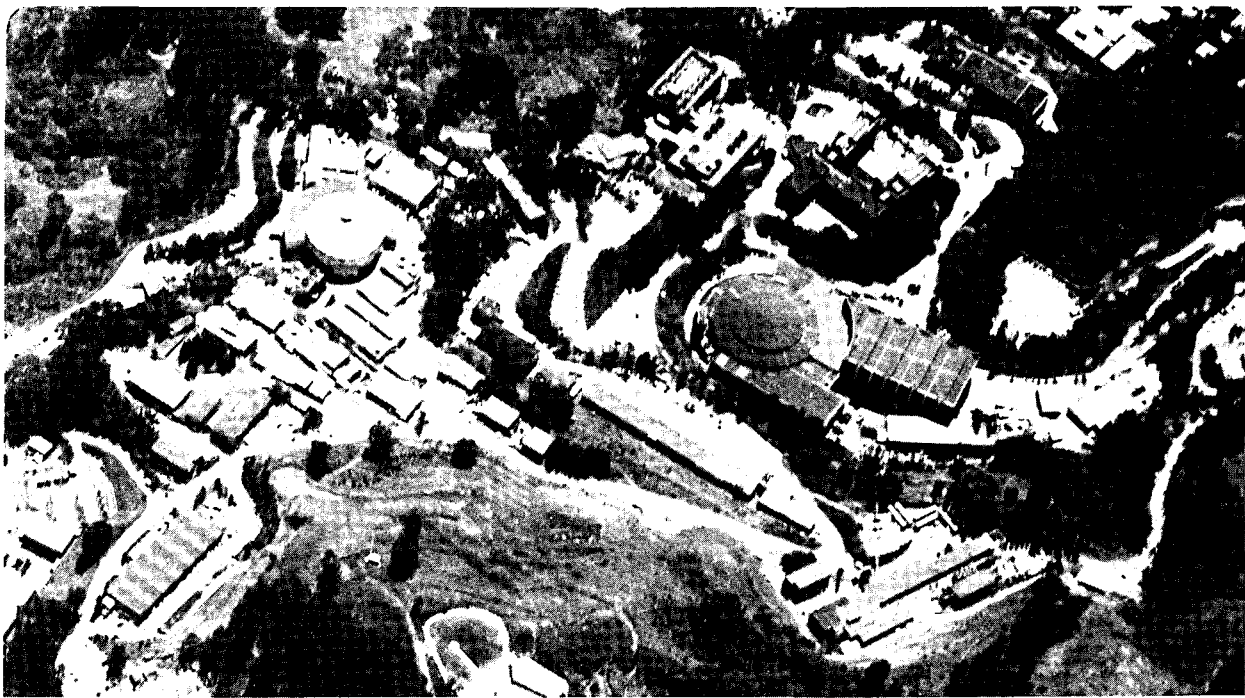
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ANODE WIRE AGING TESTS WITH SELECTED GASES

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Abstract

As a continuation of earlier wire aging investigations, additional candidates for wire chamber gas and wire have been tested. These include the gases: argon/ethane, HRS gas, dimethyl ether, carbon dioxide/ethane, and carbon tetrafluoride/isobutane. Wires used were: gold-plated tungsten, Stablohm, Nicotin, and Stainless Steel. Measurements were made of the effects upon wire aging of impurities from plumbing materials, or contamination from various types of oil. Attempts were made to induce wire aging by adding measured amounts of oxygen and halogen (methyl chloride) with negative results. Finally, the possible role of electronegativity in the wire aging process is discussed, and measurements of electronegativity are made with several single carbon Freons, using both an electron capture detector and a wire chamber operating with dimethyl ether.

I. Introduction

Wire chambers are in common use for particle detection and tracking and yet the aging effects due to radiation are only partially understood. In the field of high energy physics, a very large wire chamber ($\sim 10^4 - 10^5$ wires) is normally a component of the experimental detector, and the demands on wire chambers are becoming increasingly severe, due to operation at higher gains and in more intense radiation environments.

Effects of radiation damage to wire chambers have been published both in terms of observations and experiences in actual experiments, and also as systematic laboratory aging tests done to prove the robustness against aging of specific wire chamber conditions. A summary of principal results until 1986 may be found in the first reference.⁽¹⁾ Many other, more recent results will be referenced through the following discussion. As a continuation of an earlier study,⁽²⁾ we have expanded our search for satisfactory operating conditions by: 1) investigating other candidate gases and wires, and 2) studying the effects of certain contaminants (e.g., oils) on wire aging, attempting to find principal mechanisms responsible for wire aging. By comparison with published results from experiments done in plasma chemistry at low pressure, some insight may be obtained into the wire chamber problems.

II. Procedures and Techniques

Since earlier results were reported,⁽²⁾ a variety of improvements in techniques and procedures have been made. Perhaps the most important of these is the appreciation of the aging associated with even small amounts of certain gas contaminants. These may be already present in the supply gas, or be introduced into the gas stream through desorption from the materials in contact with the gas, such as the supply gas container, the plumbing system, or the wire chamber itself. Therefore, care was exercised in the selection and/or cleaning of components in contact with the gas, and in the purity of the source gas. In the case of dimethyl ether (DME) gas, it was found that poor results were obtained with any of several types of plastic upstream of the wire chamber under test, even in the form of a small plastic valve seal. For this reason, recent tests on DME were done with only certain metals upstream (e.g., electropolished stainless steel, hydrogen-fired copper), which required careful selection and, in the case of the control of gas flow, we used a valve of our own design and construction (3).

The aging tests were done with proportional tube wire chambers of two varieties. The earlier tests used the aluminum tubes, each of which was used for only one test; later tests used the copper tube shown in Figure 1, and these tubes are cleaned and rebuilt for each subsequent test. The reason for changing to a copper tube was the rather high rate of electrical breakdown failures encountered with aluminum tubes. This failure mode may be associated with the insulating property of aluminum oxide on the cathode wall inducing a self-sustained current by a mechanism similar to the well-known Malter discharge.⁽⁴⁾ Atac has suggest that because the oxide of copper is a semiconductor, the Malter-like discharge will not occur. The two varieties of tube have otherwise similar internal dimensions and cross-sectional areas. The aging effect measured during testing consisted of monitoring anode wire current, induced by ~6keV photons from an Fe⁵⁵ source applied through the thin window shown in Figure 1. The assumption is that the current decrease is a result of gain loss due to anode wire aging (further discussion below).

The testing and analysis system is shown schematically in Figure 2. There are four independent test systems (of which two are shown in Figure 2), and each system has its own monitors of high voltage, current, temperature and gas flow. All gases exhaust at atmospheric pressure, and a single precision barometer, Setra model 270, monitors this pressure. All currents are digitized by Keithley 485 autoranging digital picoammeters. All other monitors are scanned sequentially by a Hewlett-Packard 3495A scanner and digitized by a Keithley 196 digital multimeter. Communications between the IBM PC/AT computer and the digital meters is via an IEEE 488 bus. Data are recorded on hard disks.

Programs controlling data retrieval, graphing and analysis were written specifically for this system, in FORTRAN (Microsoft, Inc.). As many as four test runs may be displayed in color graphics for any of the monitored parameters. Completed runs may be analyzed over any portion of the run to quantify the aging rate (using Lotus 1-2-3). In addition, a pulse height analyzer board is fitted to the IBM, making it possible to display and save pulse height spectra from the test chambers (using Fe^{55} sources), as an additional means of observing anode wire damage.

As previously mentioned, precautions have been taken to prevent gas contamination upstream of the test chamber. On the downstream side, the gas is vented to atmosphere, without any bubbler, after passing through about 2m of tubing. The flowmeters are also on the downstream side, and introduce only a very small pressure change at the small flow rate used, about 20 cc/min. A permeation device (Model 570-C Generator, Kintek Precision Gas Standards) is available to introduce metered amounts of known contaminants in order to determine their effect on the aging rate.

Usually the tests were performed with initial current densities of about 0.3 or 0.6 $\mu\text{A}/\text{cm}$, corresponding to currents of about 200 or 400 nA over a wire length of a few mm, depending on the type of test counter (6). Small Fe^{55} sources of several hundred microcuries strength, placed close to the window, were used to irradiate the counter (6). Test runs usually accumulated at least several

tenths of coulombs/cm, and have collected up to 2 C/cm. Gains are known only approximately, and are about 20,000 - 50,000.

III. Aging Test Results

A. Parameterization of Aging Tests

Recent results are summarized in Table I, along with three tests previously published⁽²⁾ with different types of plastic tubing upstream. The parameterization of gain loss is fractional gain loss per coulomb/cm of collected charge:

$$-(1/Q) dG/G \text{ (\%/C/cm)}$$

Gain loss can be caused by deposits (e.g., polymers condensed from the avalanche plasma), that function by increasing the diameter of the anode wire or by forming an insulating coating forming on the wire, or both. In either case, the electric field at the wire surface is decreased, reducing the gain. There is positive evidence for each of these effects. Another mechanism for gain loss is chemical attack of the wire surface by the gas (or species in the plasma) causing, for example, oxidation of some active elements in the wire material: this is only a problem for wires that are not gold-plated. The other important effect of aging is self-sustained current discharge, or Malter breakdown, which has not been investigated explicitly here, but is seldom a limiting factor in the present tests.

B. Results

The aging test results will be discussed according to the type of gas or gas mixture used. Plots of recorded current vs. collected charge for various tests are shown in Figure 3. All tests were performed with a gas flow rate of approximately 20cc/min.

1. Dimethyl Ether

This gas has a quite low diffusion constant which makes it an excellent choice for high resolution drift chambers, e.g., vertex detectors. In some tests using DME, no measurable aging could be



found, while in other tests, very poor aging results were obtained. (2,7,8) The differences in these results can be attributed to contaminants at low concentration levels. Studies suggest that wire aging may be greatly accelerated by the presence of chlorofluorocarbons (Freons), especially Freon 11, at the level of a few ppm.(2,7) (See discussion below for a possible alternative explanation.) Other studies,(5,8,9) including our own, have shown that a large variety of plastics and even some ceramics (e.g., Macor) are incompatible with use of DME in wire chambers. In the tests shown in Table I, the DME purity was specified to be less than 1 ppm of Freon 11. The first three results listed use gold-plated wire, but different tubing for upstream gas plumbing; however, all of these tests, as well as the next one listed, had some plastic upstream in the gas pressure regulators and needle valves (see e.g., Fig. 3). For the last two DME results listed, and shown in Fig. 3; all plastics were eliminated on the upstream side by removing the pressure regulator and by constructing our own "needle valve" entirely from stainless steel tubing (3). These two results using resistive (10) wire indicate that wire chamber operation with negligible aging can be achieved with DME, even if the wire is not gold-plated, when the gas plumbing system is rigorously clean and inert and free from contamination originating in commercial plastic components. The tests were done without the use of any filter ahead of the wire chamber.

2. Argon/Ethane (50/50)

This gas mixture is very popular because of its good properties of drift velocity saturation, good quenching and relatively high gain. However, there have been many reports of rapid wire aging using this gas resulting primarily in Malter discharge.(1) It is a common practice to add a small amount of ethanol or isopropanol(11) or water vapor (12) to the gas; this has been shown to improve significantly the aging properties. That such additives are not always necessary is demonstrated by the result given in Table I and Fig. 3a, where no aging effects were observed with a charge collection in excess of 2 C/cm. In this test, no special precautions were taken with purity of gas or plumbing: the purity grade of gas is only moderately high (Matheson HP grade), and the usual gas regulators, needle valves, and plastic tubing (nylon) were used upstream of the test

counter. However, such results may well depend upon the operating gain and geometry of the wire chamber.

3. Argon/Carbon Dioxide/Methane (89/10/1)

The presence of carbon dioxide in this gas ("HRS" gas) may be responsible for the moderate aging observed with Stablohm (13) resistive wire, perhaps due to surface oxidation, while negligible aging is found with gold-plated wire (Fig. 3a).

4. Carbon Dioxide/Ethane (95/5)

The large fraction of carbon dioxide in this gas contributes to the good spatial resolution obtained (low electron diffusion) in drift chamber operation. However, there does not seem to be much degradation of the resistive wires tested here (cf. with 3. above). The addition of isopropanol vapor is not an improvement and, in fact, the aging rate seems to be somewhat worse in this case.

5. Carbon Tetrafluoride/Isobutane (80/20)

This relatively new gas mixture offers some attractive possibilities for application in challenging environments for wire chambers: (1) it has been tested to 8 C/cm with no wire aging apparent⁽¹²⁾; (2) the electron drift velocity exceeds 10 cm/ μ sec; (3) the ionization density along a minimum ionizing particle track is high (>200/cm total ion pairs); (4) the diffusion constant is low. These are the properties one would seek for operating a high resolution wire chamber ("vertex detector") near the beam pipe in a high luminosity collider (e.g., the proposed Superconducting Supercollider). The test result shown in Table I and Fig. 3c is a confirmation of the original tests at TRIUMF⁽¹⁵⁾, although at smaller collected charge and somewhat lower gain.

6. Isopropanol Additive with Resistive Wire

As indicated in 2 above, additives of ethanol (~1.5%) or water (~1000 ppm) are known to be effective in suppressing wire aging, using gold-plated wires. Subsequently it was found that such a technique does not work with certain resistive wires (e.g., Stablohm),⁽¹³⁾ apparently due to chemical action by these additives on certain constituents in the wire.⁽⁵⁾ However, a substitute

was found which does appear to inhibit aging even on resistive wire,⁽⁵⁾ and the present result is a confirmation: negligible aging was observed on Stablohm 800 wire with 0.7% isopropanol added to the argon/ethane gas mixture by bubbling.

7. Tests of Gas Tubing.

The next six tests are directed at a partial understanding of the effects of potential contaminants introduced into the gas stream by outgassing from plumbing components: tubing, regulators, valves, etc. Three types of commonly used plastic tubing, 20m long, one tubing for each test, have been introduced upstream of the test chamber in an otherwise clean plumbing system and the aging measured using an argon/ethane (50/50) gas mixture. This result has been published previously⁽²⁾ but is included here because the results may be compared with analyses using gas chromatographic techniques (in accompanying paper). As can be seen from Table I, there was very little aging observed for any of the three tubings. What is not apparent from these results is that several subsequent tests attempted on the same plumbing system in which the PVC tubing had been used and then removed all failed due to Malter breakdown (self-sustaining currents), a phenomenon which did not occur on a different plumbing system where the other plastic tubings (nylon, polyethylene) had been tested. Evidently, the PVC had introduced some pernicious contaminants into the adjacent (probably downstream) plumbing which interrupted later testing even though the original PVC tubing had been removed. A similar test was done earlier by Kotthaus, but with rather different results.⁽¹⁴⁾ There, a substantial rate of gain loss was observed, ~140%/C/cm, when 10m of PVC tubing was inserted, and a somewhat smaller but comparable rate when the PVC tubing was removed, but there was no indication of subsequent Malter breakdown. However, the wire chamber geometry and avalanche gains were rather different in that test compared with the present one, and the tubing probably came from a different manufacturer. Moreover, the effects of outgassed components on wire chambers using gases other than argon/ethane may well be different.

8. Effects of Oil Vapors

One source of contamination often implicated in wire aging are oils or greases not rigorously excluded from the gas system: they are present as mold release agents, and as lubricants in pump systems, seals, etc. A simple set of tests was done to test the effects of three commonly-used oils: 1) a silicone diffusion pump oil (Dow 704), a mineral oil (Squibb), and a mechanical pump oil (Duo-Seal). For each test, the argon/ethane was bubbled into a column of oil through a gas dispersion element to saturate completely the gas (at room temperature) with oil vapor; then this gas was fed directly into the test chamber. Only in the case of the silicone oil was any significant aging observed and in this case it was moderate. However, the vapor pressure of this oil at room temperature is only 1.4×10^{-8} torr, resulting in a very low concentration in the gas (~18 ppb). That moderate aging can occur at such low levels of contamination is of interest, since silicon has been strongly implicated in anode wire coatings, even when a source of the silicon could not be readily identified.(1)

9. Attempts to Induce Aging

As part of a program to understand causes of wire aging, certain contaminants have been added to the argon/ethane (50/50) gas mixture to induce aging. Two of these results are listed in Table I. Using the permeation device mentioned earlier, small quantities of methyl chloride were added in one test, and oxygen in another test (Fig. 4). The first test was motivated by the suspicion that chlorine-containing compounds may be involved in aging processes, and the second test by some reports of aging when the gas system is not leak-free. As can be seen, no significant aging was observed in either case. However, in the case of methyl chloride, a series of upward current "spikes" was observed in the latter part of the tests, and this phenomenon is not understood at present.

IV. Electronegativity of Gases

Gas molecules can vary greatly in their propensity to capture electrons and become negative ions. Because of the possibility that negative ions may concentrate near the anode wire where

the plasma is most concentrated, some simple measurements were made to establish the scale of such an effect.

A. Relative Measurements of Electron Attachment Using an ECD

Using an electron capture detector (ECD) coupled to the gas chromatograph, the relative signal due to electron capture in the ECD was measured for six common single-carbon (methyl) Freons, and the results are given in Table II. It is interesting to note that the cross-section for electron attachment depends strongly upon the number of chlorine atoms present. Indeed, the signal for CFCl_3 is more than three orders of magnitude larger than for CF_2Cl_2 . Moreover, DME aging appears to be much more sensitive to CFCl_3 than to CF_2Cl_2 .⁽¹²⁾ This suggests that the aging in DME may be correlated with electron capture, and this mechanism may have more general validity. On the other hand, an alternative explanation for the apparent gain reduction (current decrease) in aging tests in DME may be due to a progressively larger amount of Freon 11 in the gas as the DME "distills" from the gas cylinder, leaving behind an increasingly larger concentration of the Freon 11 contaminant. Of course, the relative signal responses in a wire chamber may be different than measured with an ECD, hence the test described below in B. was done.

B. Test Chamber Response to Freon Injection Into Gas Supply

Small injections of Freons 11 and 12 were made through a septum just upstream of a test chamber operating on DME. The response is shown in Figure 5 (a) and (b) for the two different Freons, and the peak amplitude of response is indicated in Table II. Again, there is a larger response observed for Freon 11, but not by the factor seen using the ECD. In each case, the current appeared to fully recover, indicating no aging effects due to such a short exposure to Freons.

C. Discussion

The large cross-section for electron capture of certain molecules, e.g. those containing halogens, may have a connection with a mechanism of aging: it is known from studies of plasma chemistry that certain halogens, especially chlorine, can act as hydrogen abstractors in the presence of hydrocarbons and can greatly accelerate polymerization reactions.⁽¹⁵⁾ Although there is no

direct evidence that such a mechanism as outlined is a major contributor to wire aging, the conditions would nevertheless seem quite favorable for the concentration of chlorine radicals in the plasma near the wire, leading in turn to accelerated polymer chain growth and wire coating. Further tests will be done to elucidate the effects of halogens upon wire aging.

V. Conclusions

Some new candidates for wire chamber gases have been tested under laboratory conditions, with control and monitoring of purity, materials, plumbing, etc., and some previously known gases have been more thoroughly investigated. Special emphasis has been given to the testing of very pure dimethyl ether (DME), and the conditions necessary to maintain good aging stability. It is found that this gas appears to be extraordinarily sensitive to materials in the gas stream, especially certain plastics. However, with sufficient precautions, very good stability against aging was found with the resistive wires Stablohm and Nicotin. Another, newer, gas that appears to be promising for future, more demanding operation, is $\text{CF}_4/\text{iC}_4\text{H}_{10}$ (80/20). This gas has been tested at TRIUMF, and confirmed here to have excellent aging properties, to quite high levels of collected charge/wire length. It also has the advantages of high drift velocity, high linear ionization density, and low diffusion. Another gas exhibiting good aging and low diffusion, and perhaps less sensitive to contaminants than DME is $\text{CO}_2/\text{C}_2\text{H}_6$ (95/5). Also tested are conventional gases $\text{Ar}/\text{C}_2\text{H}_6$ (50/50) and $\text{Ar}/\text{CO}_2/\text{CH}_4$ (89/10/1), which have negligible anode aging together with gold-plated wire. However, the latter gas seems to attack somewhat the resistive wire Stablohm.

An investigation of three types of oil vapors showed that only silicone oil caused any appreciable aging. Studies were made of various types of tubing commonly used for gas plumbing or implicated in bad results. In one study, nylon, polyethylene and polyvinyl chloride (PVC) tubings were tested, and only the PVC tubing exhibited aging effects. In that case the aging was not in the form of gain loss, but rather sustained current breakdowns experienced in subsequent tests

using the same plumbing system which was exposed to the PVC, even though the PVC tubing itself had been removed.

The response of an electron capture detector (ECD) to six Freons showed a very wide range of electron attachment cross-sections, by a factor of more than 10^6 , under the conditions of the ECD operation. Test injections of two Freons in a DME gas stream confirmed qualitatively the ECD results; however, no induced aging was observed from this brief exposure. The possible role of electronegative components in anode wire aging was examined. Further study is needed to establish (or disprove) any connection between electronegativity and potential mechanisms of wire aging.

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