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A STUDY OF DRIFT CHAMBER AGEING WITH PROPANE

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Wire ageing effects observed in the ARGUS drift chamber are described, as well as results of laboratory studies of ageing in a small test chamber. The tests were performed under realistic conditions with small anode currents of about 14 nA. In normal purity propane a gain drop of about 1000%/(C/cm) is observed. After the accumulation of 0.01 C/cm on the anode wire, discharges begin. Purification of the propane with Oxisorb or the addition of 0.2% water vapour reduces the gain drop to about 100%/(C/cm). No discharges are observed in this case, even after irradiation of 0.2 C/cm. The addition of water vapour can also rehabilitate a chamber damaged by radiation.

1. Introduction

Wire chambers are very popular instruments in high energy physics. Almost every experiment in this field uses them, and all experiments which exploit high fluxes of particles have problems with wire chamber ageing. Ageing is a very complex phenomenon which manifests itself by deterioration of chamber performance after irradiation: the gas amplification drops, the amplitude resolution worsens, and discharges start. The degradation of wire chamber performance is usually correlated with the appearence of an observable amount of deposits on anode or cathode wires, or both simultaneously.

The ARGUS drift chamber [1], filled with a propane and methylal (97/3) gas mixture, has also encountered the problem of ageing. Problems developed after about one and a half years of data taking at the e^+e^- storage ring DORIS II. They occurred at high background rates. A sector of the chamber began to draw currents which increased linearly with time. A normal wire draws 1 nA, while wires in the affected sector were typically drawing 1 μA. The phenomenon was observed to spread with time, until a region at least 15 wires wide and 18 layers deep was affected. In this region the gain was reduced by about a factor of 2. However, since the region represents less than 1% of the chamber volume, most of the tracks recorded were not affected.

After a period of about 2 weeks, it became impossible to run the chamber with the normal gas mixture. About 1% water vapour was added to the gas mixture and then later reduced to 0.2%. There were no further discharges, and the chamber has since been successfully run in this manner. The gain was found to be uniform throughout the chamber, including the bad sector, which again ran with normal gain.

Some sense and field wires were removed from both the bad sector and other regions of the chamber for analysis. The central regions of the field wires from the bad sector were found to be covered by a sheath of material (2.0 ± 0.2) μm thick. Tests examining the X-ray and Auger electron spectra showed strong carbon lines with some oxygen, nitrogen, silicon and chlorine, but no copper or beryllium lines. In contrast, unused wires gave clear copper and beryllium lines, with small carbon signals. Used wires from other regions of the chamber had small islands of deposits, approximately 0.5 μm thick, distributed along the length of the wire and covering a total of about 5% of the surface area.

Given the behaviour of the chamber during discharge, the evidence for deposits on the wires and the nature of the solution for the discharge problem, the observed phenomenon can be explained by the Malter effect [2]. Charge from drifting positive ions builds up on the outside surface of the nonconducting deposit, until a sufficient potential is reached to enable extraction of electrons from the field wire, through the insulating layer. The electrons produced by this discharge drift to the sense wire where a new avalanche of positive ions is created, which adds to the charge on the field wire surface. Thus, a feedback mechanism is established, so that a region of permanent discharge appears

on the field wire. The current from a given wire grows because the area and the thickness of the deposit grows: the disease spreads.

The addition of water to the gas mixture makes the insulating layers on the field wires conducting. Charge is no longer built up, and no further discharges occur. On the other hand, the electronegative water molecules have a large cross section for electron capture, thus removing some of the drifting electrons. This reduces the efficiency for tracks through the outer regions of a drift cell.

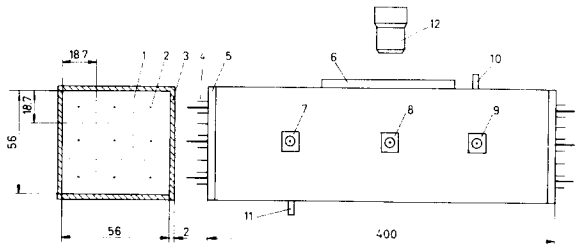
Unfortunately, due to unstable operating conditions during the first year of running, it is hard to estimate now how much charge was collected by the wires before the ageing effects appeared. Since the addition of water vapour, the wires with the highest background have accumulated about 0.005 C/cm. In order to understand the ageing process in the ARGUS drift chamber better and to predict its future development, we have studied ageing in a small drift chamber with identical cell geometry. The results of these studies are presented here.

This article is organised as follows. In section 2 the setup and the testing procedure are described. In section 3 we present measurements of ageing in propane with and without the addition of water and discuss the influence of the gas purity and the anode and cathode wire diameters. A summary and conclusions are given in section 4.

2. Test chamber design and operating conditions

Drift chamber ageing depends on a large number of parameters such as the type of gas mixture, gas purity and flow, wire diameters and quality, cell geometry, applied high voltage and the materials used in the chamber. A detailed discussion of the present knowledge, or lack thereof, about the reasons for ageing can be found, for example, in the review by Va'vra [3]. Many crucial parameters, such as gas purity, are hard to measure, let alone to keep stable. This leads to large variations in results obtained under seemingly similar conditions. For this reason people are reluctant to publish their results on ageing, and vital information is distributed by rumours. One can imagine two approaches to the problem. The ideal method would be to make a superclean chamber and to investigate ageing under completely defined conditions. Nobody has succeeded in this so far. Moreover, it is not clear how to apply the knowledge obtained under superclean conditions to real chambers. Therefore, we have adopted a more modest approach and tried to make the test chamber as similar to the ARGUS drift chamber as possible.

The experimental arrangement is shown in fig. 1. The test drift chamber is made of rectangular extruded



1. cathode wire
2. anode wire
3. aluminium tube
4. brass tube
5. plastic cap
6. transparent window
7 - 8. test points
9. reference point
10 - 11. gas inlet and outlet
12. microscope

Fig. 1. Schematic layout of the test chamber setup.

aluminium tube. All wires are crimped in brass tubes which are fixed in the plastic end caps. The end caps are sealed by silicon rubber (there is no silicon rubber in the ARGUS drift chamber, but its use simplifies the exchange of wires after irradiation). The chamber has three holes covered by 50 μm aluminized Mylar foil. Two of these are used for irradiation and the third one serves as a reference point. The chamber has a glass window through which the anode and cathode wires can be examined by an optical microscope with a magnification factor of 40.

There are nine drift cells in the test chamber which have almost the same geometry as the cells of the ARGUS drift chamber. The central cell has an almost undistorted electric field and is used for ageing studies. The anode and cathode wires are also identical to the wires used in the ARGUS drift chamber. They are made of 30 μm W(Au), and 75 μm Cu/Be correspondingly.

In the ageing test we used two types of radioactive sources. A collimated ^{90}Sr β-source with an activity of 10 mCi was fixed at test point 7 or point 8. The actual size of the exposed spot was about 6 mm and the counting rate was 20 kHz. A collimated ^{55}Fe X-ray source was used for observing the gain drop and deterioration of the amplitude resolution by comparing spectra at the test and reference points. Using the same sense wire and the same electronics chain we have minimized systematic errors. The electronics was calibrated continually by test pulses.

Ageing depends drastically on the gain and gas flow (see for example ref. [3]). These parameters were therefore tuned to the values used in the ARGUS drift chamber. The gas flow was 0.04 l/min. This corresponds to the exchange of the chamber volume every half hour. The gain was about 10^4. As a result the anode current was only 14 nA per wire. This is one of the smallest currents ever used in ageing tests. Such a small current simplifies comparison with real running

conditions because ageing increases with the decrease of the anode current [3]. On the other hand it required very long exposures of up to 900 hours.

It is also well-known that even small admixtures to the gas can change the ageing rate considerably [3]. In order to avoid the influence of uncontrollable changes in gas purity, comparisons between different running conditions were made, usually using the same bottle of propane. Data shown in any given figure in this article were obtained with the same bottle of propane. The purity of propane used in these tests was 99.7%. The main admixtures ($\approx 0.29\%$) were other hydrocarbons.

3. Discussion of results

3.1. The influence of water

Fig. 2 illustrates the typical manifestations of ageing in propane. When the collected charge reaches about 0.01 C/cm the gain drops considerably (fig. 2a), and the relative width of the ^{55}Fe-induced peak increases (fig. 2b). After a slightly larger dose a continuous discharge starts which does not stop, even after the removal of the radioactive source. Per wire the current reaches about 200 nA. Switching off or reducing the high voltage (HV) to 2500 V stops the discharge. The chamber can be operated again at nominal HV, but only with a source of a small (≤ 1 kHz) intensity. An increase of the intensity leads to a discharge again. Addition of water vapour to the propane restores the behaviour of the chamber completely: the gas amplification and the relative width of the signal resume their original values (see fig. 2). However, even with the addition of water ageing continues, but more slowly as can be seen in figs. 2 and 3. No discharges were observed when water was added, even at a collected charge of 0.15 C/cm. The water content was chosen to be 0.2% for two reasons. Firstly, less water is not sufficient to completely restore the amplitude resolution of the aged chamber. On the other hand a larger content also leads to a deterioration of the amplitude resolution, as can be seen in fig. 4. This is a clear manifestation of the electron capture.

If one adds water vapour from the very beginning of the irradiation, the signs of fast ageing, with the gain drop of about 1000%/(C/cm) and discharges, do not show up. The ageing rate of about 100%/(C/cm) (see fig. 5) is very similar to the case where water is added after the beginning of the discharges. This indicates that the mechanisms of fast and slow ageing in propane are different. Addition of water suppresses the first mechanism but does not influence the second. The first mechanism is most probably a Malter effect, although no sizable deposits are visible on either the cathode or anode wires when the discharges start. It may be that deposits on the cathode wires are transparent and too thin to be visible with the optical microscope. The second mechanism is associated with the appearence of a deposit sheath on the irradiated region of anode wire. No deposits are observed on cathode wires, even after irradiation with 0.15 C/cm. In the following discussion we will refer to these two different patterns of ageing as to fast and slow ageing respectively.

When signs of ageing were observed in the ARGUS drift chamber, the construction of the replacement chamber was started immediately. The new chamber is almost identical to the original. However, the anode wire diameter is reduced from 30 to 25 μm and the cathode wire diameter is increased from 75 to 100 μm. This was done in order to decrease the electric field on the cathode wire surface. There are indications that ageing effects increase with increasing field strength [4]. We have not observed, however, any difference in ageing with the two sets of wires (see fig. 5).

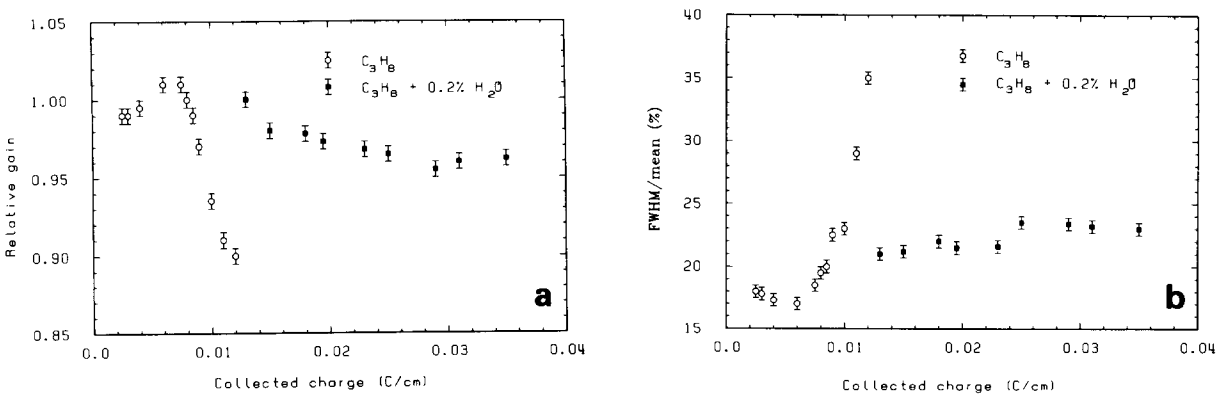


Fig. 2. (a) Relative gain versus collected charge on a sense wire (the first propane bottle); (b) Resolution (FWHM/mean of ^{55}Fe peak) versus collected charge on a sense wire.

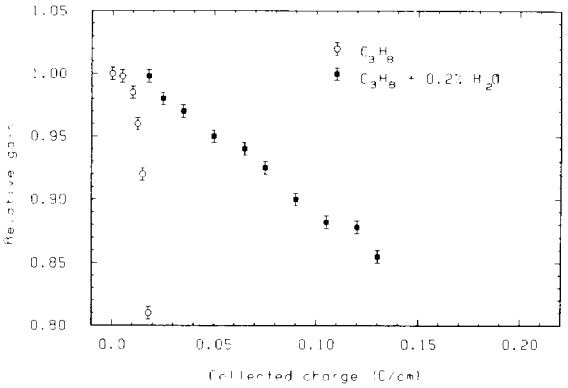


Fig. 3. Relative gain versus collected charge on a sense wire (the second propane bottle).

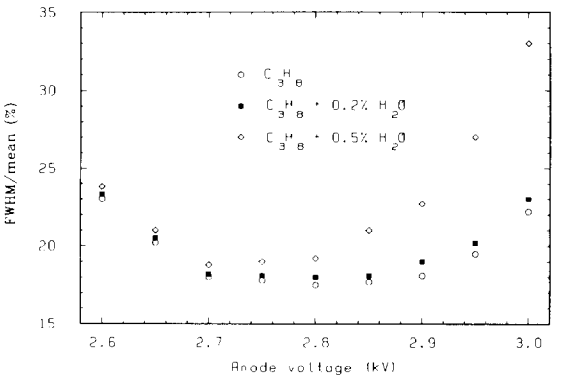


Fig. 4. Resolution (FWHM/mean of ^{55}Fe peak) versus high voltage on a sense wire.

3.2. The influence of gas purity

In order to check whether ageing is caused by some impurities in propane we have purified the input gas with the Oxisorb (F) filter. The fast ageing effect indeed disappeared in this case, as can be seen in fig. 6.

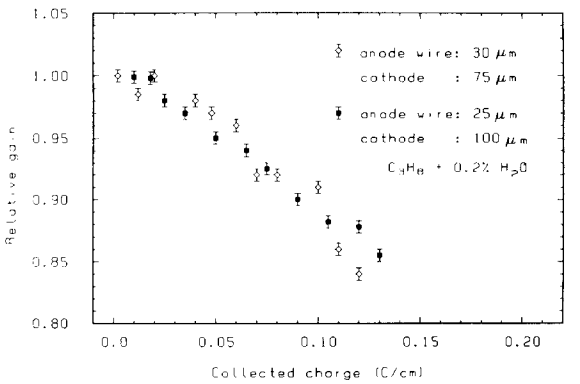


Fig. 5. Comparison of the gain drop for two sets of wire diameters.

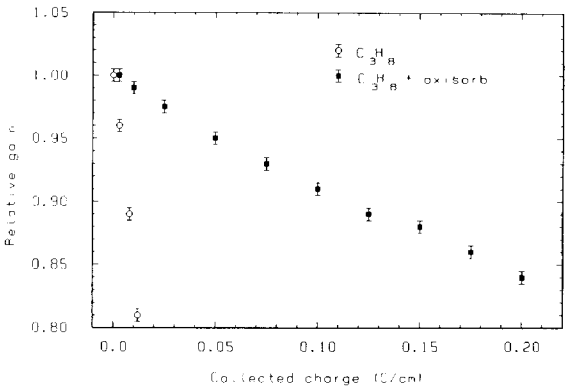


Fig. 6. Relative gain versus collected charge on a sense wire with and without Oxisorb (the first propane bottle).

However, the slow ageing was not affected by such purification and proceeded with the usual rate. It should be stressed once more that the results shown in fig. 6 were obtained with the same bottle of propane in order to exclude uncontrollable changes of gas purity from bottle to bottle. We have noticed, however, that even gas from the same bottle differs at the beginning of operation from when the bottle is only half full. In order to prove that the observed improvement was not due to such a change, we repeated the test without Oxisorb and again observed discharges, although only after a 5 times larger radiation dose than in the previous case.

There is additional evidence that fast ageing depends crucially on the gas quality. Among the four propane bottles used in the tests one appeared to be very different from the others. No fast ageing was observed with the gas from this bottle (see fig. 7). The rate of slow ageing was the same as with the other bottles and it was not influenced either by the addition of water (see fig. 7) or by gas purification with Oxisorb. Unfortunately it is not clear whether the better behaviour in this case is

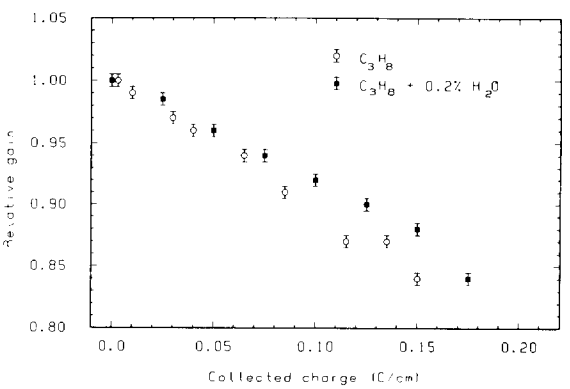


Fig. 7. Relative gain versus collected charge on a sense wire (the third, "pure", propane bottle).

due to absence of some "bad" impurities or due to the presence of some "good" additives to propane. However, water and oxygen are excluded from the list of good additive candidates because they would have been eliminated by the Oxisorb.

4. Summary and conclusions

Drift chamber ageing effects in normal-purity propane have been studied under realistic conditions with a very small anode current of about 14 nA. Two ageing mechanisms, one fast and the other slow, were observed. Fast ageing is characterized by a gain drop of about 1000%/(C/cm). When collected charge exceeds about 0.01 C/cm, discharges begin which show a behavior typical for a Malter effect. This type of ageing depends crucially on the gas quality. It can be prevented by propane purification with Oxisorb or by the addition of a small amount (about 0.2%) of water vapour. By this process the lifetime of a chamber can be improved by more than one order of magnitude.

Addition of water vapour can also completely rehabilitate a chamber damaged by radiation. This is probably because water makes deposits slightly conductive, which reduces the charge collected on them, thus preventing discharges. A water content of 0.2% is found to be close to optimal. A smaller amount does not completely rehabilitate a damaged chamber, while larger amounts lead to a large electron capture rate and hence to a deterioration of the amplitude resolution.

When fast ageing is prevented, either by gas purification or by the addition of water vapour, slow ageing is observed. This proceeds with a gain drop rate of about 100%/(C/cm) and does not lead to discharges, even if the collected charge exceeds 0.2 C/cm. A deposit sheath develops on the anode wires in parallel with this drop of the gain. This sheath is probably the main reason for the gain drop, because of the decrease of the electric field on the anode surface.

Ageing was compared for two sets of anode and cathode wire diameters, namely 30–75 μm and 25–100 μm. No difference was found, although the electric field on the cathode surface was smaller for the second set.

Propane is one of the best gases for slow (≤ 1 GeV/c) particles. It produces small multiple scattering, which for low particles is usually a dominant source of the momentum error. Propane also has a very narrow-width Landau distribution, which is crucial for particle identification by ionization loss measurements. With the addition of water vapour, propane can be used if the collected charge does not exceed 0.1 C/cm, and up to even larger values of collected charge if the amplitude of a chamber is not important.

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References

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