Talks in Padova and Orsay
January, 2002

Physics and Chemistry of the Wire Aging

- Examples in this talk are chosen to make a physics point and not necessarily to suit a particular interest of the audience. They a preferentially chosen from the speaker’s experience.

J. Va'vra

1)

NUCLEAR INSTRUMENTS AND METHODS 99 (1972) 279–284; © NORTH-HOLLAND PUBLISHING CO.

TIME DEGENERACY OF MULTIWIRE PROPORTIONAL CHAMBERS

G. CHARPAK, H.G. FISHER, C.R. GRUHN, A. MINTEN, F. SAULI and G. PLCH

CERN, Geneva, Switzerland

and

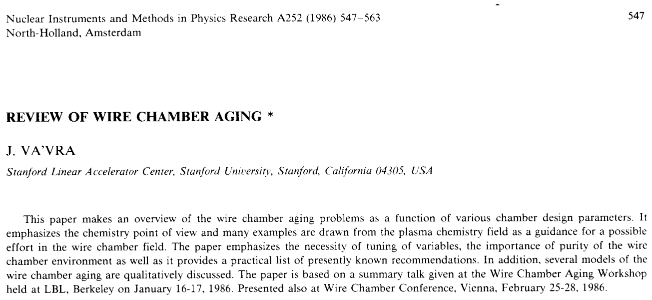
G. FLÜGGE

II. Institut für Experimentalphysik, Hamburg, Germany

Received 28 May 1971

The deterioration with time of multiwire proportional chambers using isobutane as one component of the gas mixture is studied. It is shown that by addition of methylal among others, a long lifetime can be obtained without changing the properties of the gas mixture. Irradiation tests of 5×10^{9}/cm² have not shown any alteration in the chamber performance.

2)



Nuclear Instruments and Methods in Physics Research A252 (1986) 547–563
North-Holland, Amsterdam

547

REVIEW OF WIRE CHAMBER AGING *

J. VA’VRA

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This paper makes an overview of the wire chamber aging problems as a function of various chamber design parameters. It emphasizes the chemistry point of view and many examples are drawn from the plasma chemistry field as a guidance for a possible effort in the wire chamber field. The paper emphasizes the necessity of tuning of variables, the importance of purity of the wire chamber environment as well as it provides a practical list of presently known recommendations. In addition, several models of the wire chamber aging are qualitatively discussed. The paper is based on a summary talk given at the Wire Chamber Aging Workshop held at LBL, Berkeley on January 16-17, 1986. Presented also at Wire Chamber Conference, Vienna, February 25-28, 1986.

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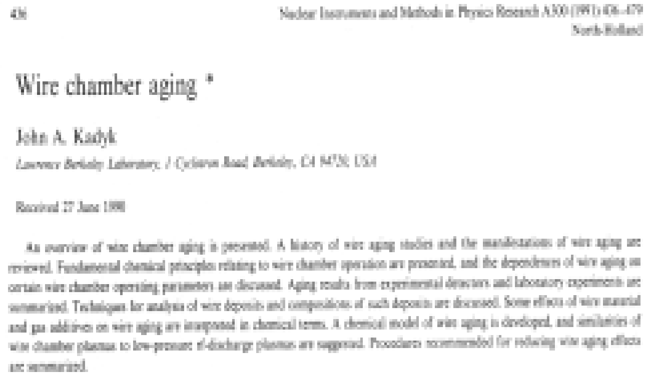

436

Nuclear Instruments and Methods in Physics Research A300 (1991) 436–479
North-Holland

Wire chamber aging *

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Received 27 June 1990

An overview of wire chamber aging is presented. A history of wire aging studies and the manifestations of wire aging are reviewed. Fundamental chemical principles relating to wire chamber operation are presented, and the dependences of wire aging on certain wire chamber operating parameters are discussed. Aging results from experimental detectors and laboratory experiments are summarized. Techniques for analysis of wire deposits and compositions of such deposits are discussed. Some effects of wire material and gas additives on wire aging are interpreted in chemical terms. A chemical model of wire aging is developed, and similarities of wire chamber plasmas to low-pressure rf-discharge plasmas are suggested. Procedures recommended for reducing wire aging effects are summarized.

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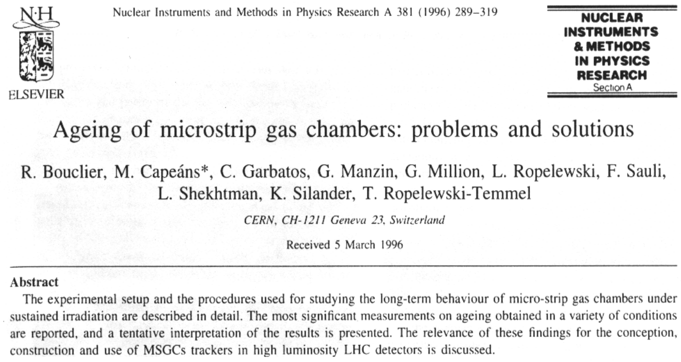

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Nuclear Instruments and Methods in Physics Research A 381 (1996) 289–319

NUCLEAR
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RESEARCH
Section A

Ageing of microstrip gas chambers: problems and solutions

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Received 5 March 1996

Abstract

The experimental setup and the procedures used for studying the long-term behaviour of micro-strip gas chambers under sustained irradiation are described in detail. The most significant measurements on ageing obtained in a variety of conditions are reported, and a tentative interpretation of the results is presented. The relevance of these findings for the conception, construction and use of MSGCs trackers in high luminosity LHC detectors is discussed.

• Major papers on aging before DESY workshop.

- There are two major groups of experiments:

1) Low radiation level experiments (<100mC/cm):

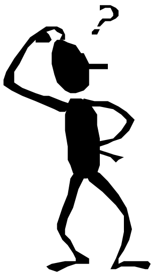
(LEP, SLD, BES, HERA ep, BaBar, Belle, CDF, D0)

- basic rules of construction are more or less known,
- large variety of gases available,
- additives such as $H_2$0, or alcohol do work,
- methodology of gas cleaning is known.

2) High radiation level experiments (1-10 C/cm):

(LHC, HERA-B and R&D activities: RD-10, RD-28, RD-6, ATLAS, CMS, HERA-B)

- Sensitive to a list of so called "bad" materials,
- left only with a few gases (NO hydrocarbons),
- some additives cannot be used.

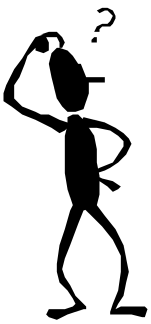


- Example: water cannot be used with the CF_4-based gas because of a formation of the HF acid.

Onion theory of wire aging:

- A multi-layer structure of an onion is a good model describing the complexity of the wire aging.

- **Macroscopic variables:**
  - a) Gas components, trace contaminants,
  - b) gas pressure and gas flow,
  - c) geometry of electrodes,
  - d) electrostatics of the cell,
  - e) chamber materials,
  - f) gas gain, charge density, rate of irradiation,
  - g) size of irradiated area



- **Microscopic variables:**
  - a) cross-sections,
  - b) electron or photon energies,
  - c) electron, ion and radical densities

- **There is no quantitative theory available at present linking these two sets of variables.**

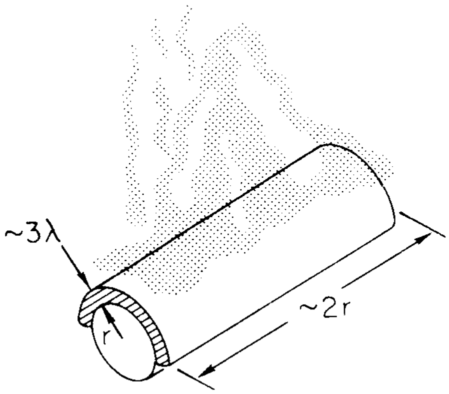
- Therefore, it is difficult to understand truly any present aging measurement. (For example, it is too naive to expect that one can express the wire aging rate using a single simple variable such as Q/cm).

- Before the 1986 LBL workshop, some of us were discovering the Plasma Chemistry books, for example written by Yasuda or Boeing, and tried to find the link between the two sets of variables.

- ~15 years later, my feeling is that we are getting only a partial help from the Plasma Chemistry because:
  (a) they do not use the same gases and do not make the experiments at similar conditions
  (b) there is no quantitative model available at present.

- Nevertheless, I will mention some useful ideas from the Plasma Chemistry at a qualitative level.

Wire Chambers vs. Plasma Chemistry



λ - Mean free path between the electron collisions (~1µm)

τ - Mean free time between collisions (~1ps)

Parameter	Plasma Chemistry [1]	Wire Chambers
Average Electron Energy	1 – 10 eV	5 – 10 eV (Ar)
Effective Volume	100 – 1000 cm^3	10^{-10} – 10^{-8} cm^3
Typical Electron Density	10^9 – 10^{12} e/cm^3	10^{14} – 10^{17} e/cm^3/avalanche
Typical Power Density	0.01 – 10 watts/cm^3	10^8 – 10^{12} watts/cm^3/avalanche
Gas Pressure	0.01 – 10 Torr	$\geq$ 760 Torr
E/p	10 – 50 V/cm·Torr	100 – 400 V/cm·Torr (on the surface of the anode)
Type of Electric Field	RF	DC
Typical Gas Flow	~ 1 Gas Volume/1-10 minutes	~ 1 Gas Volume/1-8 hours

(J.Va'vra, NIM A252(1986)547)

- Parameters are vastly different in the two fields.
- Yet, in retrospect, some conclusions from the Plasma Chemistry proved to be directly applicable to our field. (Examples: a role of H_2O, O_2, Oxygen-based additives, or CF_4)

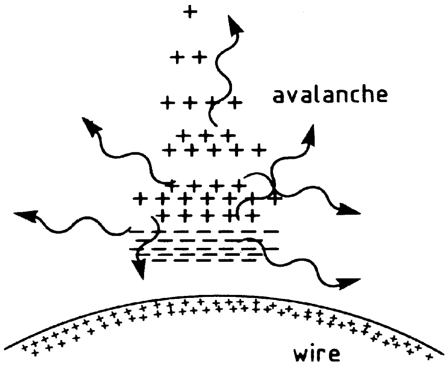
Processes relevant to aging

- **Production of γ’s by electrons and ions**
- **Secondary electron emission due to:**
  - (a) Ion recombination,
  - (b) Photosensitivity of cathode surface,
  - (c) Photosensitivity of gas (aval. breeding),
  - (d) Emission on sharp points,
  - (e) The Malter effect.
- **Molecular dissociation due to:**
  - (a) Electron impact,
  - (b) Heat,
  - (d) Photon impact.
- **Polymerization of molecular fragments**
- **Prevention of the polymerization by:**
  - (a) Molecular charge exchange,
  - (b) Molecular dipole moment,
  - (c) Choice of suitable additives.
- **Electrolytic processes in the insulators**
- **Chemistry of gases and nearby electrodes**

Production of γ’s by electrons and ions

- γ’s contribute significantly to the secondary electron emissions.

- Production of γ's by electrons and ions



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1) Photon emission by electron-atom collisions:

a) $E > E_{critical}$: $e^-+A \Rightarrow e^-+A^* \rightleftharpoons e^-+A+\gamma$

b) E > 10kV/cm at 1 atm in Argon:

$$e^- + Ar \Rightarrow Ar^{*+} (\Rightarrow Ar^+ + \gamma) + e^- + e^-$$
$$+ Ar \Rightarrow Ar^+ + Ar^* (\Rightarrow Ar + \gamma)$$

2) Photon emission by ion-electron recombination at the cathode:

$A^+ + \text{Cathode } (e^-) \Rightarrow A + \gamma \quad (E_\gamma = E_{ioniz.potential} - E_{work\ function})$

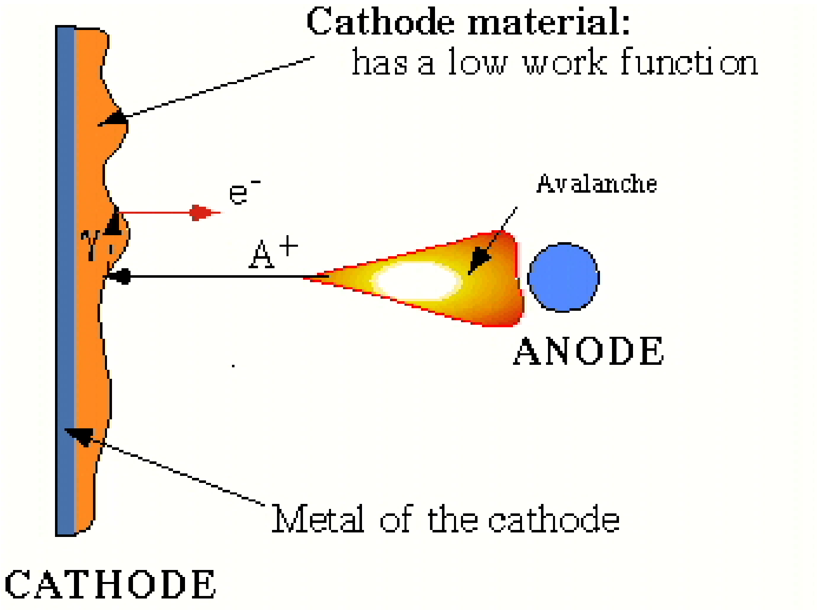
3) Photon emission by ion-electron radiative recombination in the gas:

$$e^- + A^+ \Rightarrow A^* + \gamma \qquad (E_\gamma = E_e + (E_i - E_k))$$

Secondary electron emission

- Secondary electron emission accelerates the aging rate by increasing the charge dose.
- They play a similar role as secondary neutrons released in the fission of ^{235}U.

Secondary electron emission due to the ion recombination on the cathode:



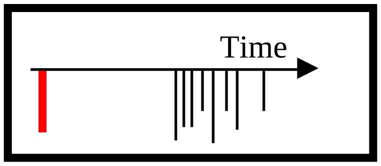
<u>Necessary condition for electron emission:</u>

a) A^+ + Cathode (e^-) => A + γ ($E_\gamma = E_{\text{ioniz.potential}} - E_{\text{work function}}$)

b) γ + Cathode Metal => e^- (photoeffect)

c) γ + Photosensitive film on cathode => e^-

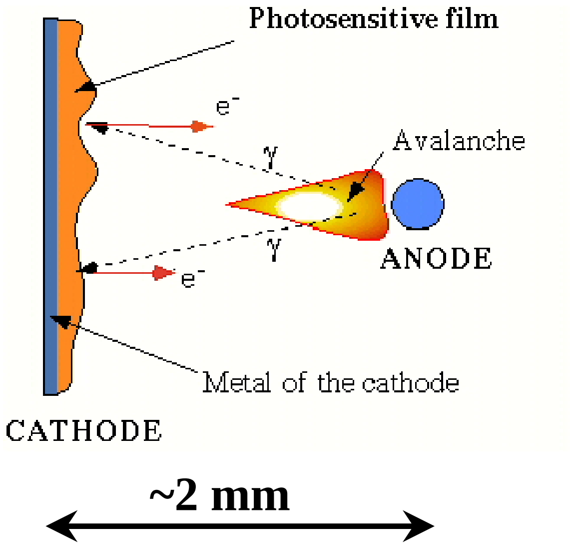
Scope:

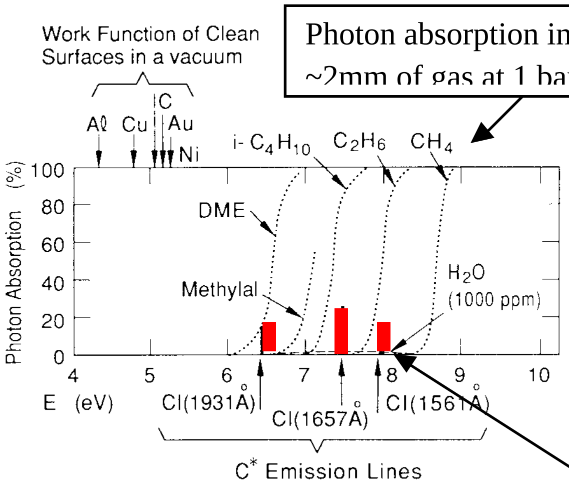


Signature:

The primary pulse is followed by secondary pulses delayed by a long delay (positive ion drift).

Secondary electron emission due to the photon interaction on the cathode surface:



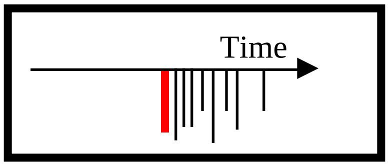


Photon absorption in ~2mm of gas at 1 bar

~1000ppm of H_2O does not absorb these photons at all in a ~2mm path

Necessary condition for electron emission:
a) Gas must be transparent for the avalanche photons
b) γ + Cathode Metal => e^- (photoeffect)
c) γ + Photosensitive film on cathode => e^-

Scope:



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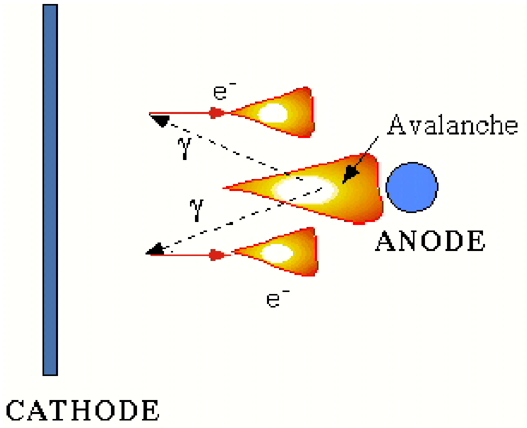
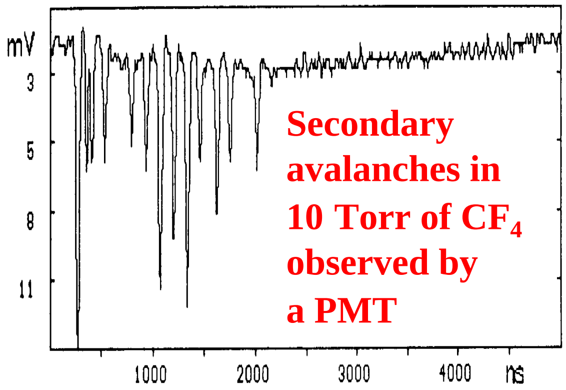
The primary pulse is followed by secondary pulses with a small delay (electron drift).

Secondary electron emission due to the photon interaction in the gas:

A. Pansky et al., NIM A354(1995)262





Secondary avalanches in 10 Torr of CF_4 observed by a PMT

Example:

CF_4 gas scintillates in the UV region:

e^- + CF_4 => $(CF_3^+)^*$ or $(CF_4^+)^*$ => γ (λ ~ 160 nm)

(1200 γ /(MeV.4π) (150-500nm) ~ 16% of that of Xe !!!)

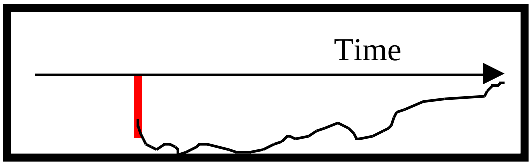
γ (λ ~ 160 nm Û E_γ~7.74eV) + TMAE => $TMAE^+$ + e^-

(J.Va'vra et al., NIM A370 (1996) 352)

<u>Necessary condition for avalanche breeding:</u>

a) Gas, such as Ar or CF_4, creating hard photons in the avalanche.
b) A gas molecule, which can be ionized by such photons.
c) Absence of an effective quenching molecule.

Scope:



Signature:
The pulses start growing in amplitude, time and space.

Photosensitivity of typical photo-cathodes, such as CsI or TMAE, to various emission lines produced in the avalanches by electron collisions

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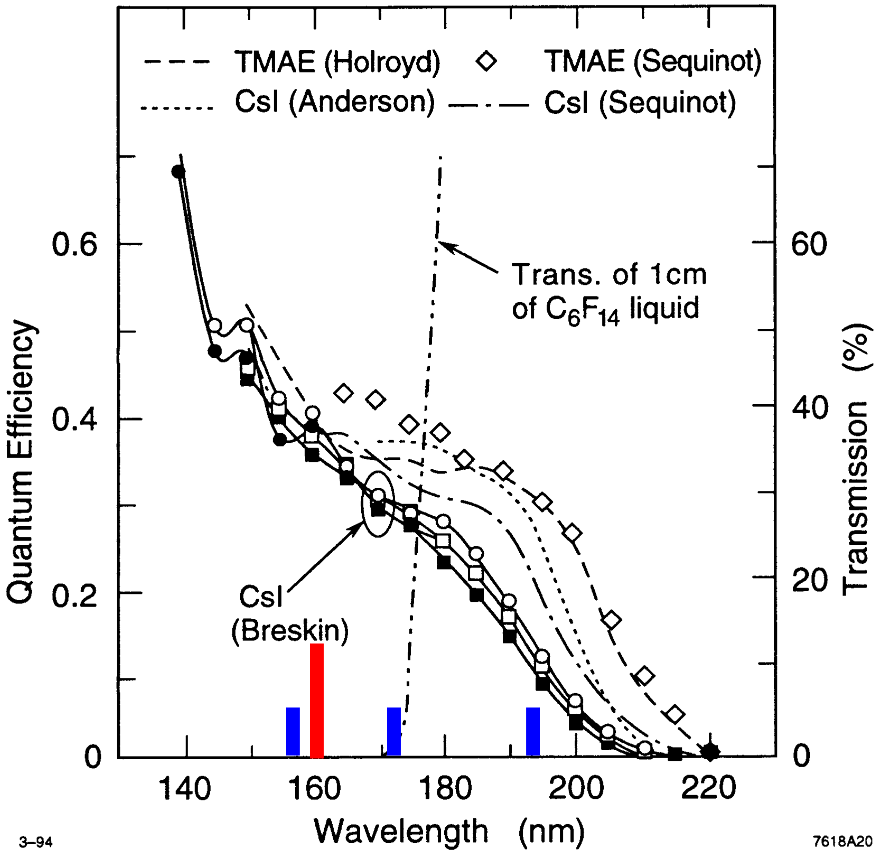
Reflective Q.E. measurements:



- $e^- + C \rightarrow C^* + \gamma$, E_γ ~156, 166, 193 nm
- $e^- + CF_4 \rightarrow (CF_3^+)^*$ or $(CF_4^+)^* \rightarrow \gamma$, E_γ ~160 nm

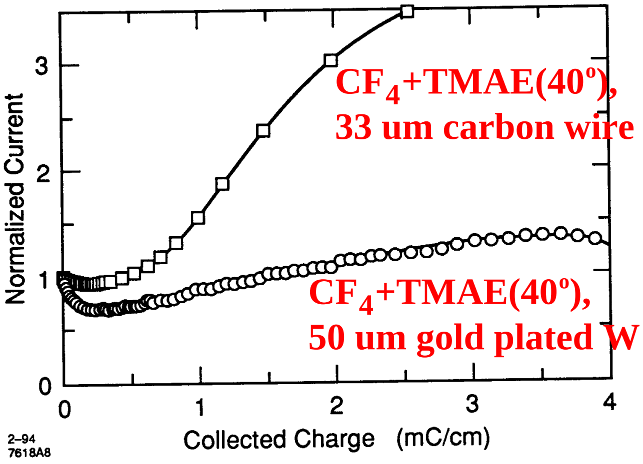
CF_4 gas scintillates in the UV region:

1200 γ /(MeV.4π) (150-500nm) ~ 16% of that of Xe !!!

(A. Pansky et al., NIM A354(1995)262)

Example: Wire aging process in CF_4+TMAE is very “unusual”

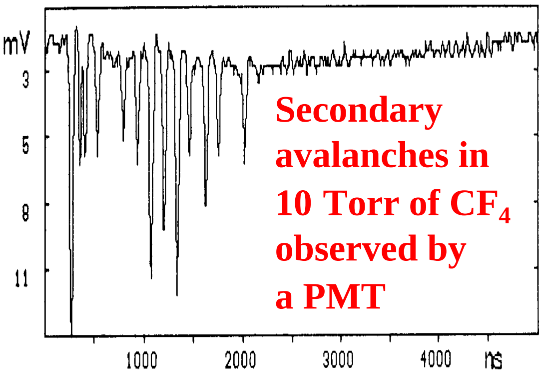
(J. Va’vra et al., NIM A370(1996)352)



CF_4+TMAE(40°), 33 um carbon wire

CF_4+TMAE(40°), 50 um gold plated W

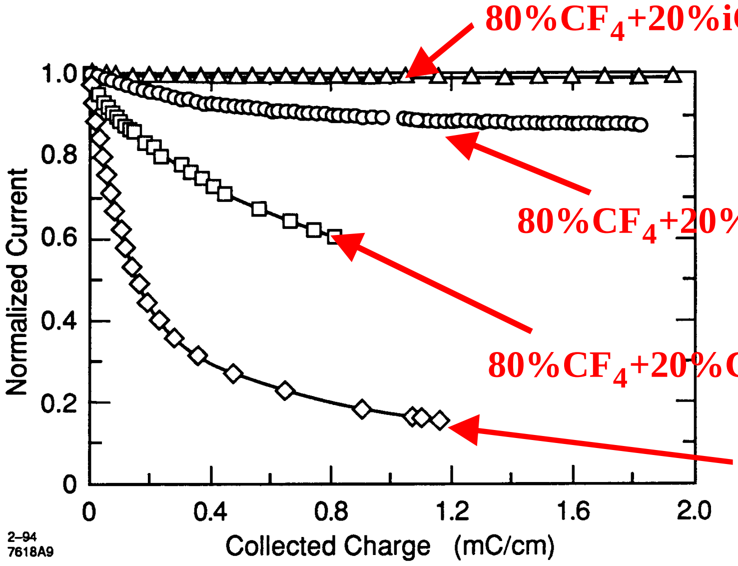
A. Pansky et al., NIM A354(1995)262:



Secondary avalanches in 10 Torr of CF_4 observed by a PMT

- Increase in photo-current is caused by the photo-emission of CF_4 and build up of photosensitive deposits on cathode !

(J. Va’vra et al., NIM A370(1996)352)



80%CF_4+20%iC_4H_{10} (no TMAE); 50 µm wire

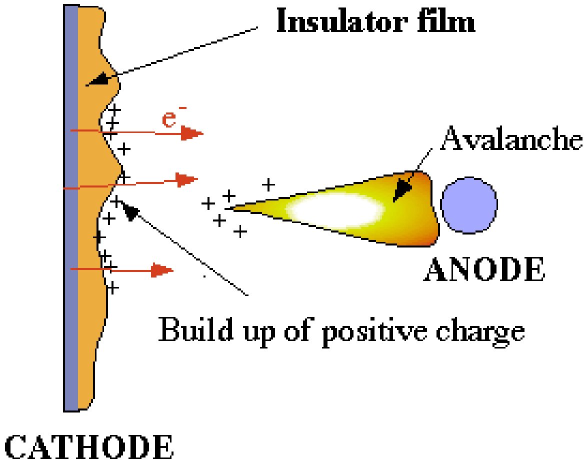
80%CF_4+20%C_4H_{10} + TMAE(15°); 50 µm wire

80%CF_4+20%C_4H_{10} + TMAE(40°); 33 µm wire

C_2H_6 + TMAE(27°); 7 µm wire

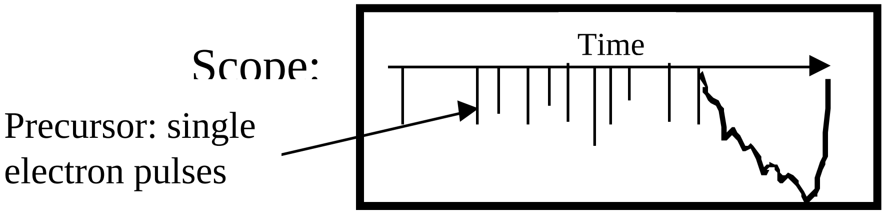
- Addition of more than 20% of iC_4H_{10} stops the photo-emission and one gets a “normal” aging behavior.

Secondary electron emission due to the Malter effect (L.Malter, Phys. Rev. 50(1936)) :



<u>Necessary condition for electron emission:</u>

a) Localized primary ionization deposit.
b) An insulator on the cathode.
c) A rate of the charge build up is higher than its removal rate.
d) Excessive field cathode gradients help to trigger it.
e) **To start the effect, it needs an ignition.**



Signature:
The current starts as <u>single electrons</u> and can grow up to hundreds of nA. <u>The effect is very localized.</u> It is persistent even after the source of radiation is removed.

Methods to create insulating film:

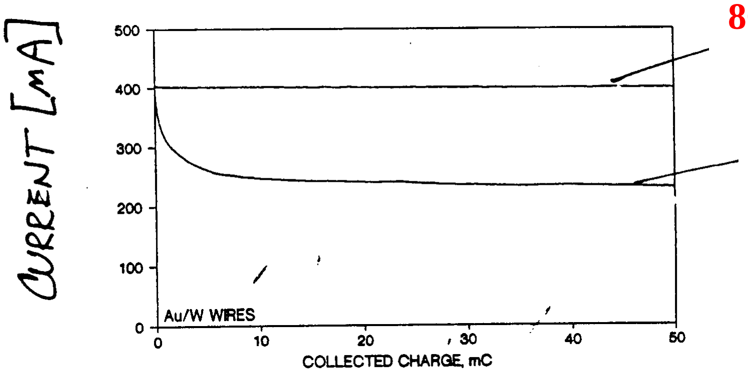
a) Avalanche producing polymers.
b) Glue on electrodes.
c) Gas pollutants.
d) Insulating deposits left from sparks.
e) Corona on sharp point on the cathode.
f) Allowing the Malter currents to go on undetected.
g) Poor plating.
h) Some oxides are highly resistive.
i) Some photosensitive molecules (such as TMAE).
j) Conducting epoxy is not conducting enough.
k) Carbon composite materials may not be conducting enough (HERA-B experience with Pokalon-C).
l) Etching a conducting layer away from the cathode.
m) etc.

Ignition mechanisms:

a) Highly ionizing heavy ions.
b) Fe^{55} X-rays.
c) Sparks.
d) Sharp points on electrodes causing corona.
e) Thin anode wires help the ignition.
f) Background muons aligned with E of a TPC (CRID).

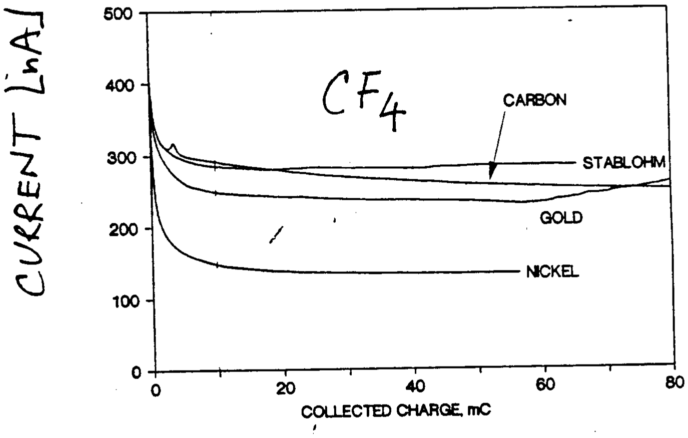
Example of creation of insulation layer on anode - Wire aging in CF_4 gas

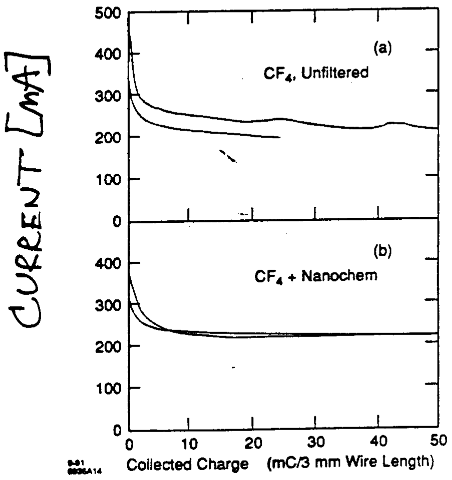
(J. Wise, Ph.D. Thesis)



$80\%CF_4+20\%C_4H_{10}$

CF_4





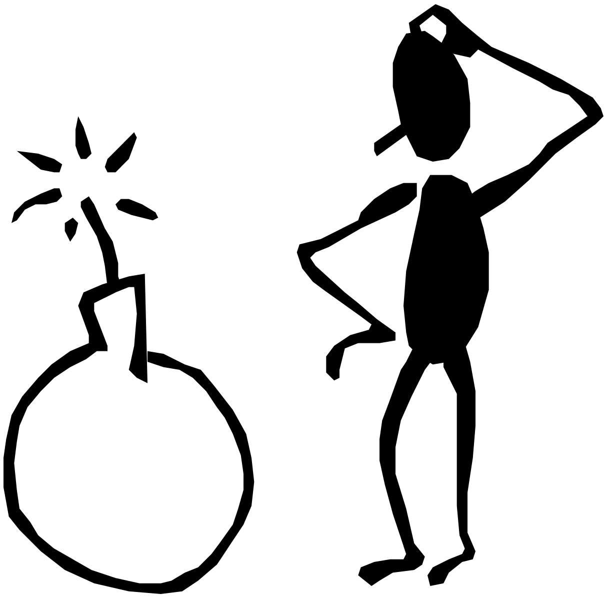
- $80\%CF_4+20\%C_4H_{10}$ is not aging, CF_4 does !!!
- CF_4 alone is aging fast, probably caused by a formation of a non-conducting metal-fluoride. This may be significant from point of view of creating the resistive layer on the cathode and triggering of the Malter effect.
- Nanochem filter did not help – not a purity problem.

Examples of the Malter effect

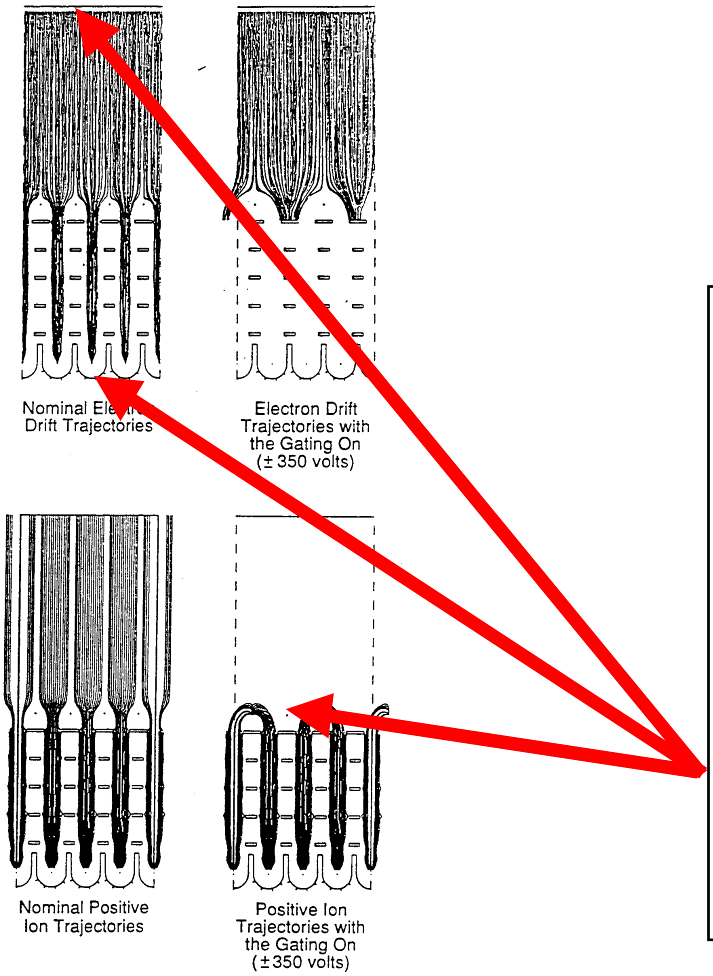
1) The first imaging of this effect ever – CRID experience
   (J. Va'vra, NIM A367(1995)353).

2) Subsequent lab tests (J. Va'vra, NIM A367(1995)353).

3) Attempts to ignite the Malter effect in a CsI-based chamber failed at the Wezmann Inst. – why ?



1) SLD CRID detectors did have the Malter currents under three different conditions (J. Va'vra, NIM A367(1995)353).



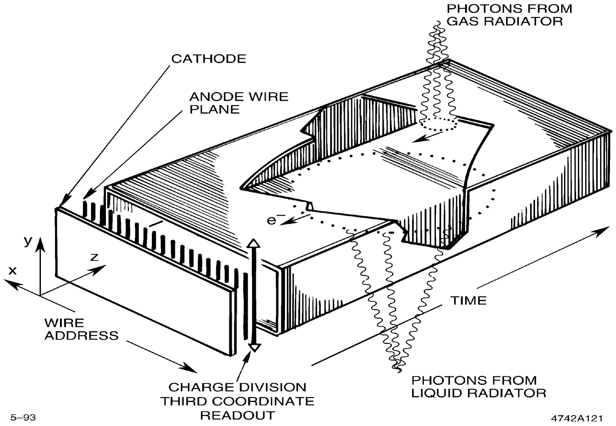
I have observed a Malter effect from all these three cases from:

a) a HV cathode
b) a detector cathode
c) a gatine wire surface, while gating was on.

The first two cases were caused by an ecessive rate of UV calibration fibers. Solved by a reduction of the UV fiber-firing rate. The third case was solved by not gating throughout the entire SLD experiment !!!.

- Luckily, all this was observed during the early period of the SLD operation, and was stopped before damage occurred.
- Nevertheless, during the entire life of SLD, I did worry that some localized charge deposit will trigger the Malter effect, and it would go on without anybody knowing. Therefore, the HV trip threshold were set to an absolute minimum (~300nA). This is still, in principle, too high, by the way.

Tanks to excellent single electron imaging capability of the CRID, we could observe the first imaging of this effect ever (J. Va'vra, NIM A367(1995)353).



Discharging time constant:

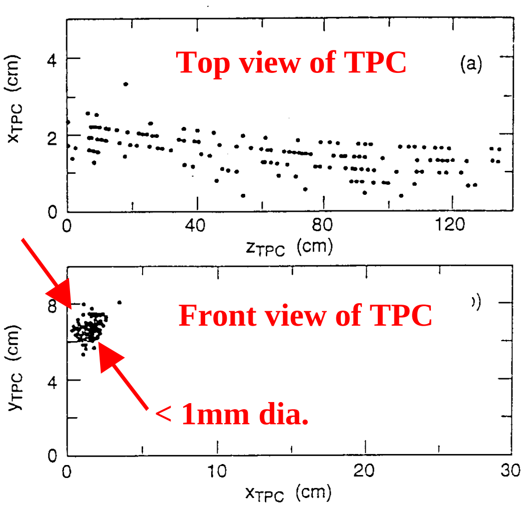
$$RC \sim \varepsilon_r \, \varepsilon_0 \, \rho_{film}$$

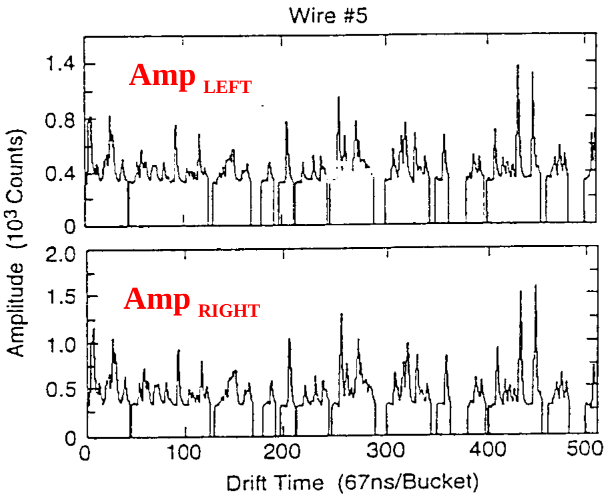
For:

$\varepsilon_r \sim 4$, $\varepsilon_0 \sim 8.87$ pF/m,

$\rho_{film} \sim 2 \times 10^{15}$ Ω cm

=> RC ~ 10-15 min.



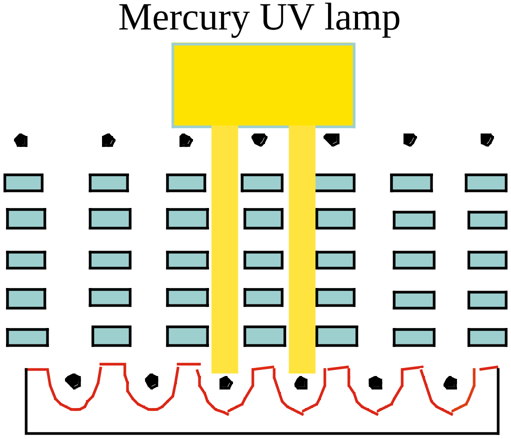


- The UV fibers were creating a continuous photo-electron rate of ~10 Hz/cm of wire length for ~ 2 years, which created conditions to trigger the Malter effect.
- Observed bursts of single electron pulses every ~15 minutes in the location of UV fibers, which were used for calibration.
- Solved by a reduction of the UV fiber rate by ~2000x.

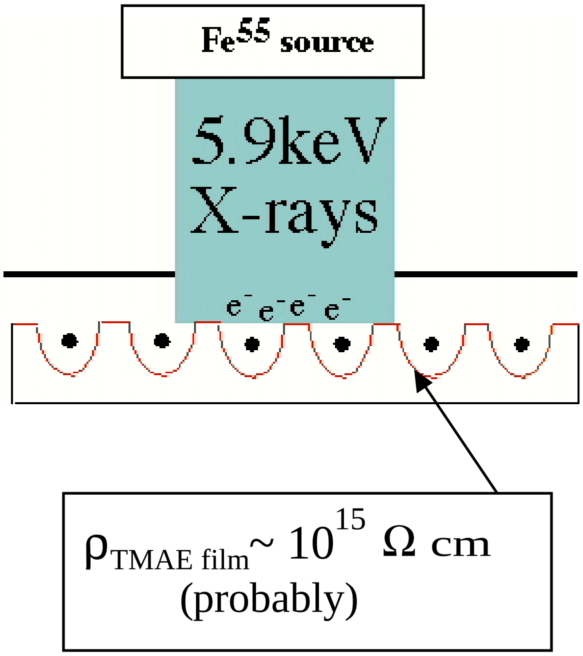
- This taught me that during the Malter effect:
  a) the spot size is actually extremely small,
  b) the signal consists of single electrons, and
  c) in this case, by switching the supply of the charge off, one could switch off the positive feedback mechanism.

2) It was very easy to excite the Malter effect in the CRID detectors in the lab, if they were previously been used in TMAE. (J.Va'vra et al., NIM A367(1995)353)

a) Either with a UV lamp:

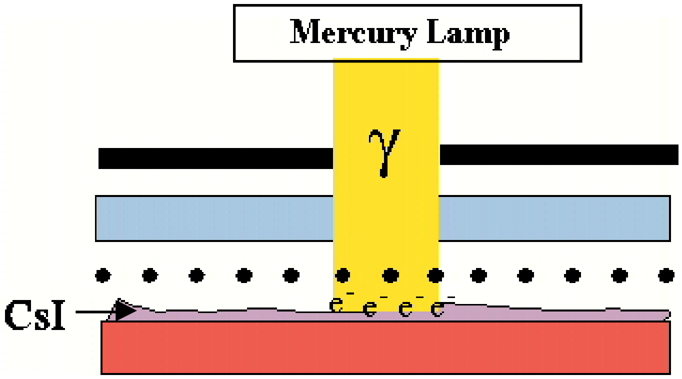


b) Or with an Fe^{55} source:



Answer: a) Resistivity of the "clean" TMAE film is very high
b) 7 μm wire dia. provides a localized ion cloud

3) On the other hand, exactly the same recipe would not work with a CsI-based detector. I was not able to demonstrate it to A. Breskin (J.Va'vra et al., NIM A387(1997)154).



Answer: CsI volume resistivity is much lower:

$\rho_{\text{CsI film}} \sim 10^{10}$ Ω.cm (just after evaporation)

$\rho_{\text{CsI film}} \sim 10^{7}$ Ω.cm (after ~10 min in air)

- Possible explanation: the chamber was exposed to air for ~10 min to transfer it from the evaporation chamber into the detector setup, and thus CsI resistance was substantially lower. If true, one should make the same test again with the photocathode prepared without exposing to air.

Relationship between the maximum rate capabilty and the cathode film resistivity.

- Consider a film on cathode with resistivity ρ_V, relative dielectric constant ε_r.

- Consider the time domain only (neglect gain variation).

- The time constant describing the neutralization of the positive charge is $RC \sim \varepsilon_r \varepsilon_0 \rho_V$.

- Assume the charge is deposited in one spot with a mean time period of T, i.e., with a rate of $r = 1/T$.

- To prevent the charge build up, one needs: $RC < 0.1\ T$. Therefore, the maximum rate is:

$$r_{max} \sim 1/(10\ RC) = 1/(10\ \varepsilon_r \varepsilon_0 \rho_V)$$

- For $\varepsilon_r \sim 4$, $\varepsilon_0 = 8.87$ pF/m, $\rho_V \sim 2.8 \times 10^7\ \Omega$.cm:

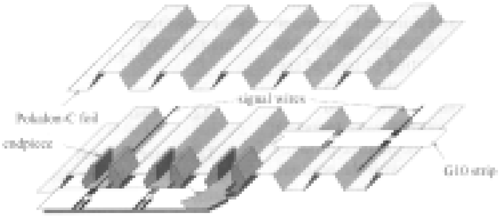
$$r_{max} \sim 10\ \mathrm{kHz}.$$

- For $\varepsilon_r \sim 4$, $\varepsilon_0 = 8.87$ pF/m, $\rho_V \sim 2.8 \times 10^{12}\ \Omega$.cm:

$$r_{max} \sim 0.1\ \mathrm{Hz}.$$

- Wojcicki's group at Stanford was preparing a straw tube-based experiment at BNL. The gas used was CF_4 based mixture. One day, during the night, the gas run out, and the chamber ignited a Malter discharge. The trip setting was a way up (~10µA), and next morning the inner copper conductor was gone, all etched away.

4) Polycarbonate foil doped with graphite ("Pokalon-C") is not conducting enough !!
(Ch. Stegmann, NIM A453(2000)153 and M Hohlmann, NIM A461(2001)21)

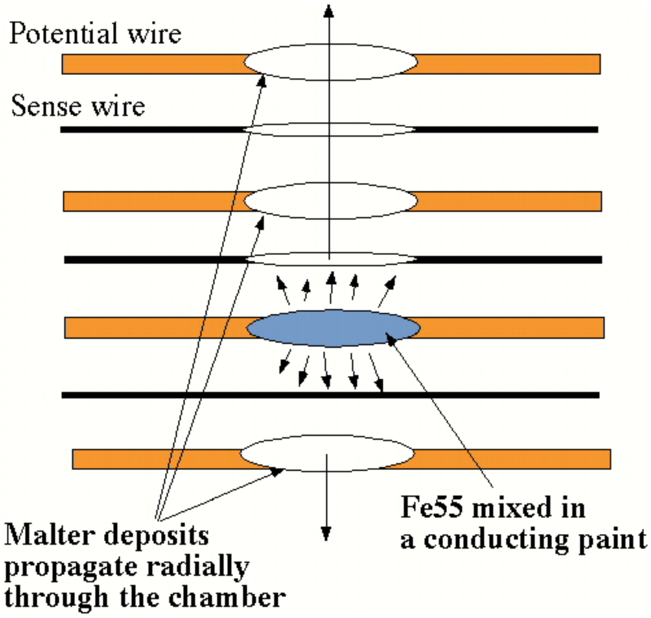


- the chamber died after a few hours of operation at HERA-B
- despite having survived long-term tests in X-ray setup.
- this is probably because the Malter effect can be ignited by a localized large ionization present in the hadron background (slow ions); not present in the X-ray source.

Solved by coating the foil with ~90nm thick Cu/Au layer.

5) Conducting paint is not conducting enough !!

(The 8-wire prototype during OPAL R&D, 1984, unpublished)



Wire deposits have spread from one potential wire to next
=>
the trouble spot can spread like a cancer

- The deposits travel radialy across the chamber causing the overall rapid deterioration. It is important to catch this problem early !!!

How to prevent the Malter effect ?

- Run as low gas gain as possible ($<2x10^4$).
- Pay attention to the anomalous single electron signal activity.
- Segment the HV as much as possible.
- Monitor currents to a nA sensitivity.
- Develop a "clever" software which can look for:
  - a) the single electron activity on a single wire.
  - b) any remnant activity in the chamber, when the beam goes suddenly away.
  - c) based on such software trip the chamber HV.
- Have an access to raw signal waveforms to be able to see the secondary effect.
- Study additives – see later.

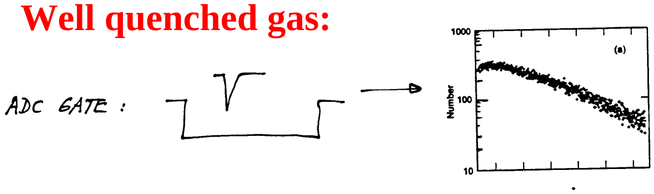
Is there a quantitative method to recognize the presence of the secondary effects ?

- Apart from using a scope….

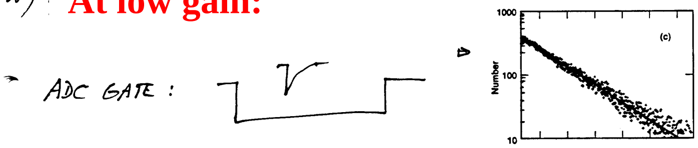
How to recognize the poor quenching in the single electron pulse height spectrum ?

(J. Va’vra et al., NIM A370(1996)352)

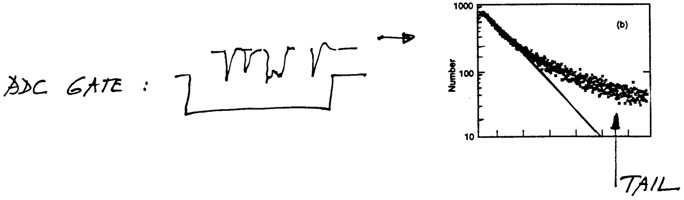
a) **Well quenched gas:**



b) **At low gain:**



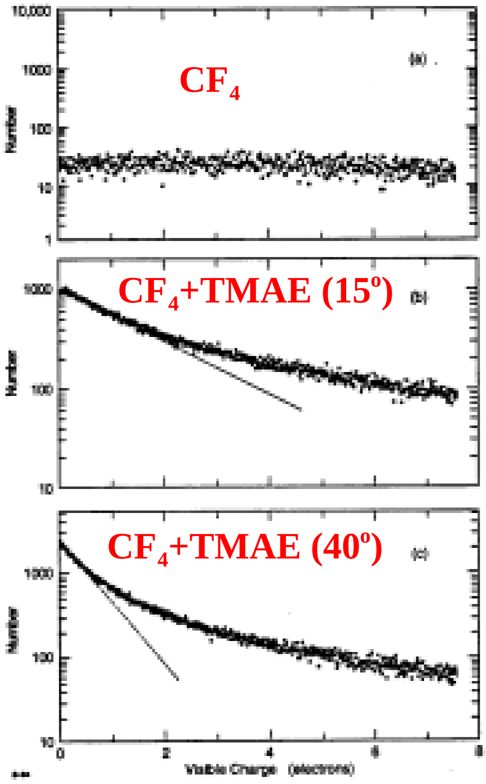
c) **Poor quenching:**

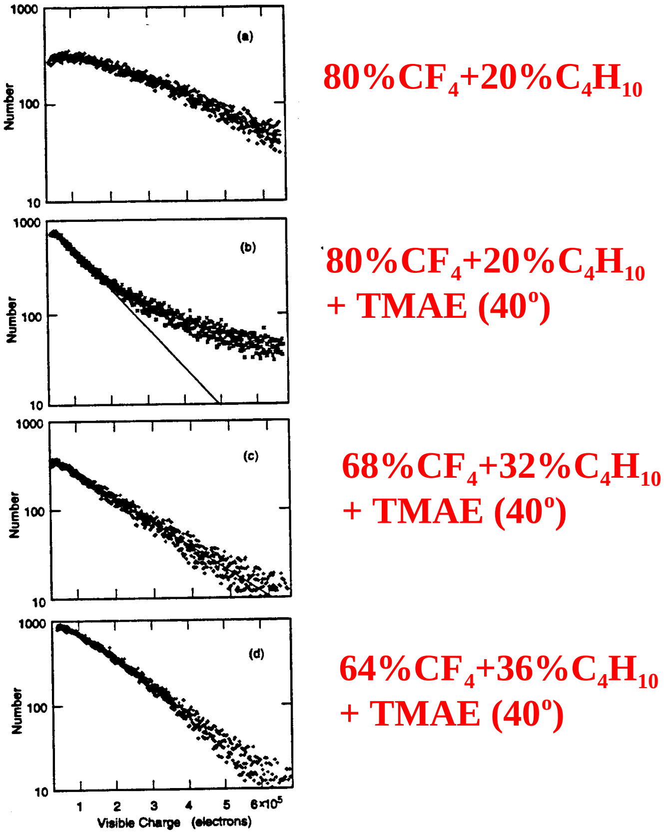


A gas, such as CF_4, is producing many avalanche photons, which may in turn produce secondary electrons at the cathode, which in turn produce secondary avalanches causing an excessive tail in the single electron pulse height spectrum; this can be observed as gains approach 10^5 or more.

One needs to add a large amount of C_4H_{10} to stop the secondary effects in the CF_4+TMAE mixture

(J. Va'vra et al., NIM A370(1996)352)





The CF_4 single electron spectrum is very broad, probably because of the electron attachment in the avalanche at the electric field between ~5-35kV/cm at 1 bar (J. Va'vra, NIM A323(1992)34). Addition of TMAE amplifies the cathode secondary effects caused by the photo-emission of CF_4. Addition of C_4H_{10} helps to stop it. The CsI photocathode present in the GEM holes may cause similar secondary effects – needs to be checked.

Molecular dissociation

- This process is a precursor for the polymer production and coating of the electrodes.

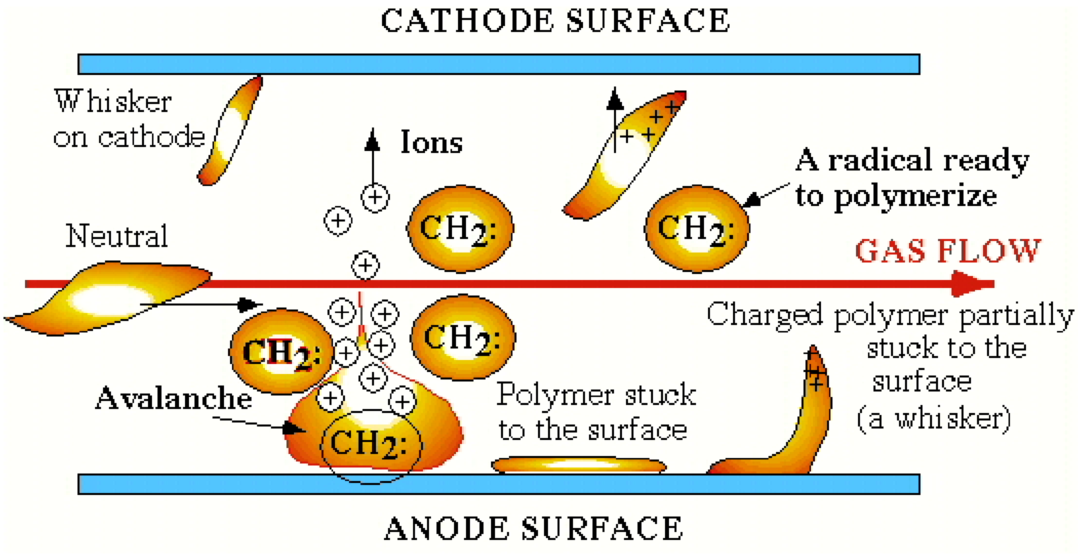
Typical dissociation & ionization energies:

Atom	Thermal dissociation	Dissociation by electron impact	Ionization energy
Ar	**-**	**-**	**15.8 eV**
Xe	**-**	**-**	**12.1**
H_2	**4.5 eV**	**8.8 eV**	**15.43**
O_2	**5.1**	**8**	**12.06**
H_2O	**4.83**		**12.6**
CO_2	**7.8**		**13.77**
CH_4	**4.3**	**4.5**	**12.6**
CF_4	**5.35**	**5.2**	
C_2H_6	**3.6**		**11.5**
Iso-C_4H_{10}	**3.2**	**7**	**10.57**
Methylal	**3.2**		**10.0**
Ethanol	**3.2**		**10.49**
Iso-propanol	**3.2**		**10.15**
DME	**3.2**		**9.98**
TMAE	**2.7**		**5.6**

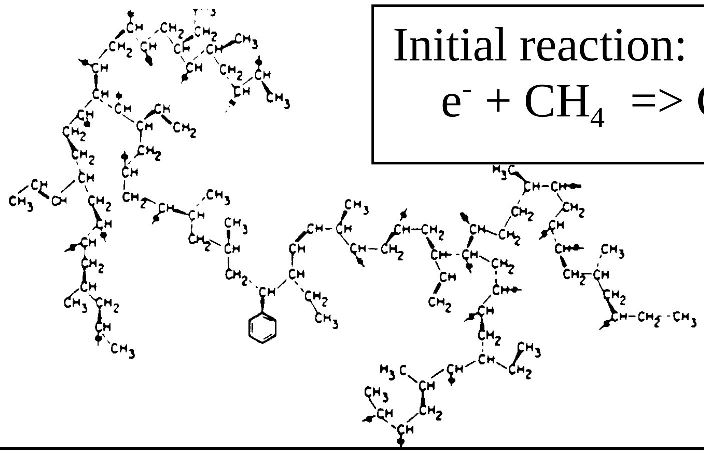
(H. Yasuda, Plasma Polymerization; H. Boeing, Plasma Science and Technology; A. von Engel, Ionized gases; also the Handbook of Chemistry and Physics)

- $E_{\text{Thermal dissociation}} < E_{\text{Electron impact}} < E_{\text{Ionization energy}}$
- $E_{\text{Single bonds}} < E_{\text{Double bonds}}$
- The avalanche is probably too short to create the thermal dissociation, except, possibly, during the Malter effect.
- a) Water is less able to do charge exchange than alcohol.
  b) In gases with TMAE additives, it is always TMAE delivering charge to cathode (TMAE can polymerize).
  c) Adding H_2O to Ar/CO_2 mix guarantee that H_2O delivers the charge (water does not polymerize).

- Polymerization of molecules



Example of polymerization of ethylene:



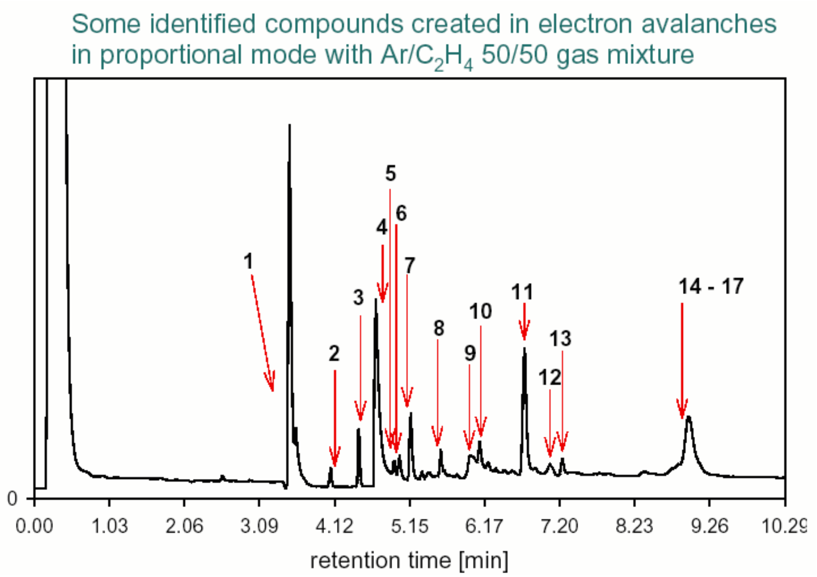
Initial reaction:

$e^- + CH_4 \Rightarrow CH_2: + H_2 + e^-$

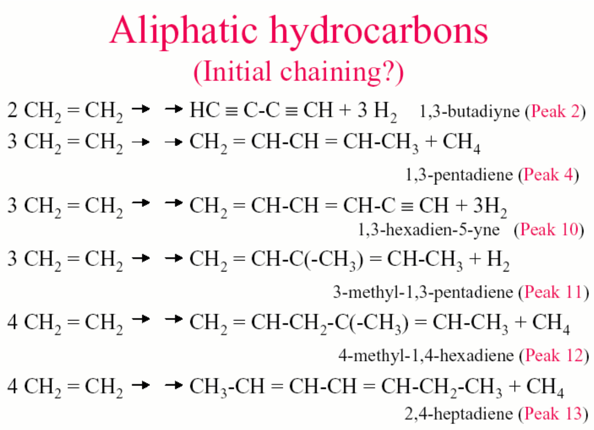
- e^- or γ in avalanche have enough energy to brake covalent bonds, and thus prepare radical formation, such as **CH_2:**.
- **CH_2:** has a large dipole moment and will stick to electrodes.
- **CH_2:** radical is a typical precursor for production of ethylene, a well-known insulator.
- These are major arguments why hydrocarbons cannot be used in high rate applications (I would say above ~0.1-0.5 C/cm).

- Quantitative details of the polymerization are quite complex (K. Kurvinen, DESY Workshop, 2001)

GC analysis of compounds produced in the avalanche:



Some identified compounds created in electron avalanches in proportional mode with Ar/C_2H_4 50/50 gas mixture



Aliphatic hydrocarbons

(Initial chaining?)

$2\ CH_2 = CH_2 \rightarrow\ \rightarrow HC \equiv C\text{-}C \equiv CH + 3\ H_2$ 1,3-butadiyne (Peak 2)

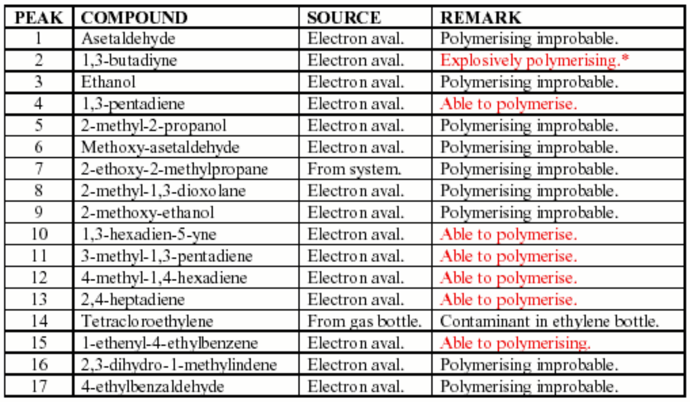
$3\ CH_2 = CH_2 \rightarrow\ \rightarrow CH_2 = CH\text{-}CH = CH\text{-}CH_3 + CH_4$ 1,3-pentadiene (Peak 4)

$3\ CH_2 = CH_2 \rightarrow\ \rightarrow CH_2 = CH\text{-}CH = CH\text{-}C \equiv CH + 3H_2$ 1,3-hexadien-5-yne (Peak 10)

$3\ CH_2 = CH_2 \rightarrow\ \rightarrow CH_2 = CH\text{-}C(\text{-}CH_3) = CH\text{-}CH_3 + H_2$ 3-methyl-1,3-pentadiene (Peak 11)

$4\ CH_2 = CH_2 \rightarrow\ \rightarrow CH_2 = CH\text{-}CH_2\text{-}C(\text{-}CH_3) = CH\text{-}CH_3 + CH_4$ 4-methyl-1,4-hexadiene (Peak 12)

$4\ CH_2 = CH_2 \rightarrow\ \rightarrow CH_3\text{-}CH = CH\text{-}CH = CH\text{-}CH_2\text{-}CH_3 + CH_4$ 2,4-heptadiene (Peak 13)



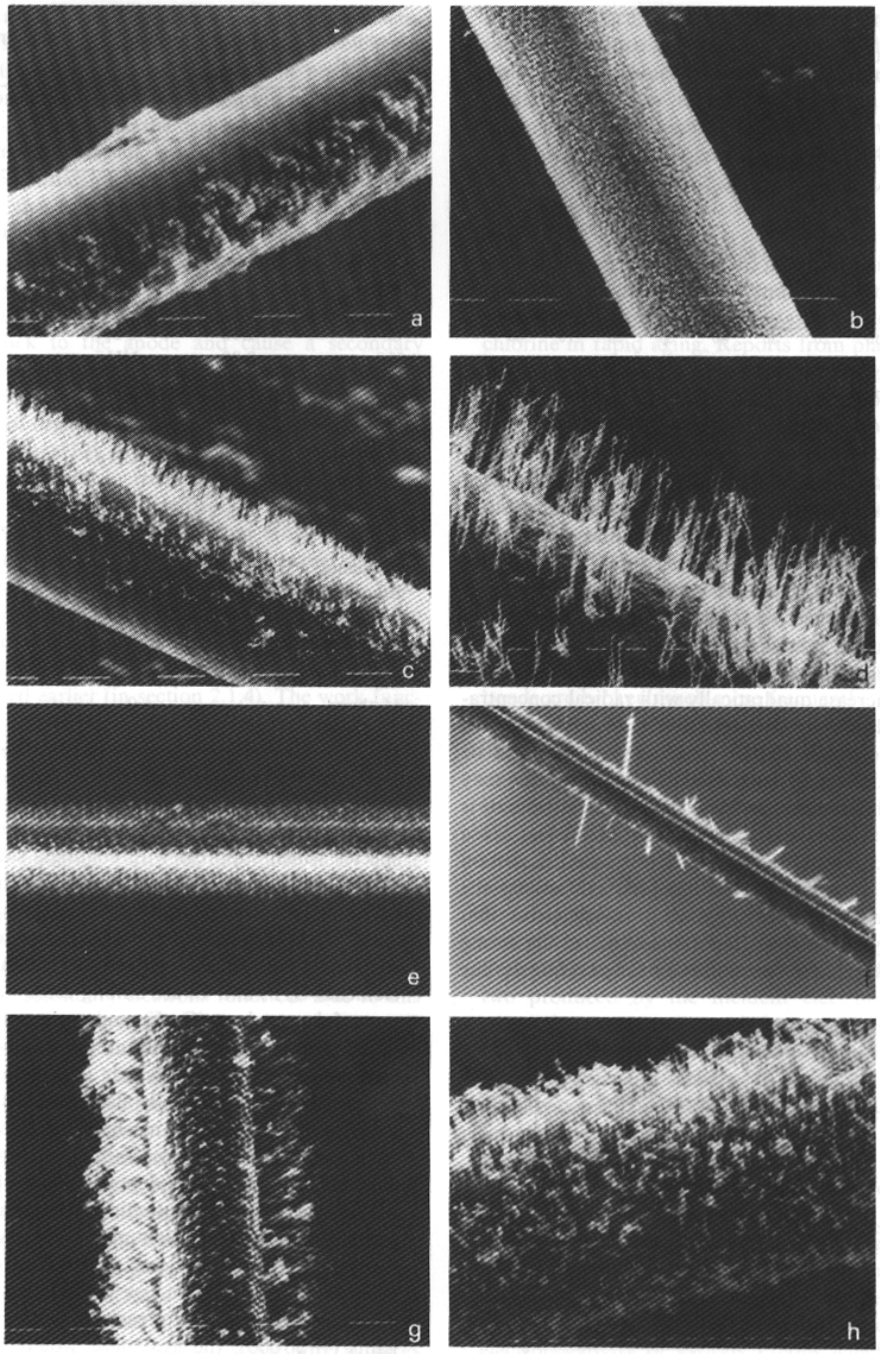
PEAK	COMPOUND	SOURCE	REMARK
1	Asetaldehyde	Electron aval.	Polymerising improbable.
2	1,3-butadiyne	Electron aval.	Explosively polymerising.*
3	Ethanol	Electron aval.	Polymerising improbable.
4	1,3-pentadiene	Electron aval.	Able to polymerise.
5	2-methyl-2-propanol	Electron aval.	Polymerising improbable.
6	Methoxy-asetaldehyde	Electron aval.	Polymerising improbable.
7	2-ethoxy-2-methylpropane	From system.	Polymerising improbable.
8	2-methyl-1,3-dioxolane	Electron aval.	Polymerising improbable.
9	2-methoxy-ethanol	Electron aval.	Polymerising improbable.
10	1,3-hexadien-5-yne	Electron aval.	Able to polymerise.
11	3-methyl-1,3-pentadiene	Electron aval.	Able to polymerise.
12	4-methyl-1,4-hexadiene	Electron aval.	Able to polymerise.
13	2,4-heptadiene	Electron aval.	Able to polymerise.
14	Tetracloroethylene	From gas bottle.	Contaminant in ethylene bottle.
15	1-ethenyl-4-ethylbenzene	Electron aval.	Able to polymerising.
16	2,3-dihydro-1-methylindene	Electron aval.	Polymerising improbable.
17	4-ethylbenzaldehyde	Electron aval.	Polymerising improbable.

- Compounds with double or triple bonds can easily polymerize, something chemists know very well.
- This way of going about the aging analysis is quite ambitious. However, I think that this is a hard way to earn the living….

- Various forms of the polymerization

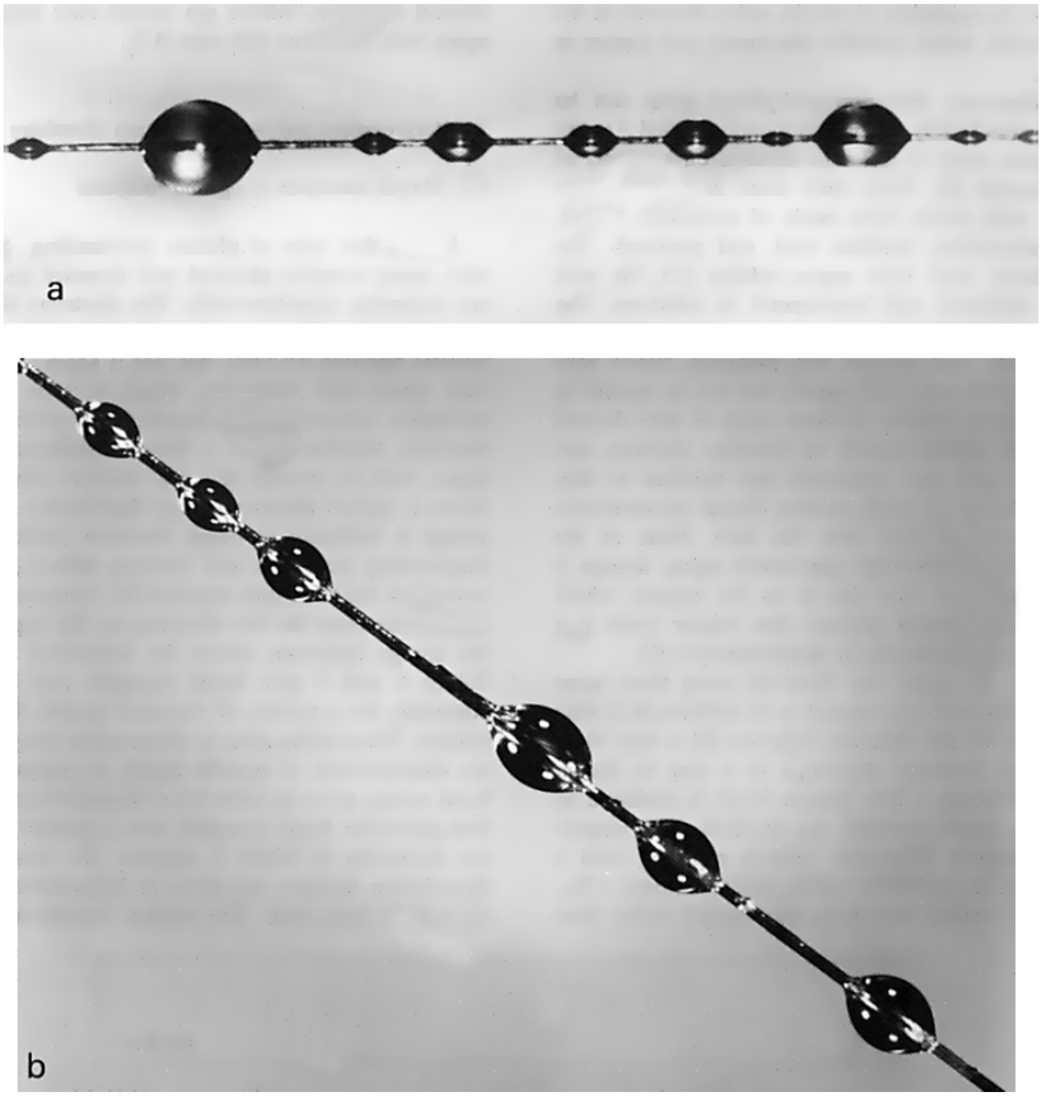
- Solid whisker formation

(taken from J. Kadyk, NIM A300 (1991) 436):



- Film / liquid droplet formation

(taken from (a) J. Va'vra, IEEE Trans.Nucl.Sci. NS-35, 1(1987)487 and (b) C. Woody, IEEE Trans. Nucl. Sci. NS-35, 1(1988)493):



Droplets observed on anode wires in CH_4 + TMAE after obtaining a charge dose ~5-10 mC/cm (until that point, it was a film), and then exposing the chamber to air (at that point, the droplets form).

Prevention of the polymerization

Prevention of the polymerization - “good” additives

- **CH_2:** is one of the most significant polymer precursor.
- Adding the following additives tends to eliminate this radical by forming stable, volatile products, which impedes the polymerization process :

$$CH_2: + \boxed{H_2} \;=>\; CH_4$$

$$2\,CH_2: + \boxed{N_2} \;=>\; 2HCN + H_2$$

$$CH_2: + \boxed{O_2} \;=>\; CO_2 + H_2$$

$$\longrightarrow \qquad CH_2: + \boxed{O_2} \;=>\; CO + H_2O$$

$$\longrightarrow \qquad CH_2: + \boxed{H_2O} \;=>\; CO + 2H_2$$

$$\longrightarrow \qquad CH_2: + \boxed{CO_2} \;=>\; 2CO + H_2$$

$$CH_2: + \boxed{CF_4} \;=>\; C_2H_2F_4$$

(Hess’s talk at the 1986 LBL Aging Workshop)

“Good” additive – Oxygen-based molecules

- It is well known in the Plasma Chemistry that atomic oxygen reacts with hydrocarbon radicals and the end-product of this reaction are volatile molecules such as CO, CO_2, H_2O and H_2, which are more stable, and can be removed by a sufficient gas flow.

- H. Yasuda (Plasma Polymerization, page 113):
  Organic compounds with oxygen containing groups –COOH, -CO-, -OCO-, -OH, -O-, -C=O are generally reluctant to form polymers in the plasma environment.

Examples:

Additive	Chemical formula	Dipole Moment
Water	H-O-H	1.85 D
Alcohols:	R-O-H	~1.7 D
a) Methanol	$R \equiv CH_3$	
b) Ehanol	$R \equiv CH_3CH_2$	
c) Iso-propanol	$R \equiv (CH_3)_2CH$	
Methylal:	R-O-R’-O-R $(R \equiv CH_3, R' \equiv CH_2)$	
Ethers	R-O-R’ DME: $R \equiv R' \equiv CH_3$	1.30 D

(Taken from my LBL Workshop talk in 1986)

“Good” additive – Oxygen

Practical examples:

- The rate of removal of organic polymeric material can be often increased in an oxygen plasma by addition of H_2O, H_2, N_2, NO, N_2O molecules.
  (H. Boeing, Plasma Sci.&Tech., page 281)

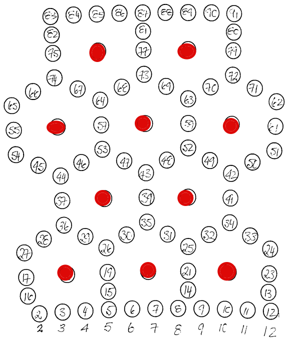
- Cleaning of mirrors of the contaminating films by a glow discharge in oxygen plasma.
  (R. Gillette et al., Vac. Sci. Tech., 7(1070)534)

- Recovery from the Malter effect deposits by Oxygen !!!
  (A. Boyarski – BaBar R&D study)

Example of a "Good" additive – Oxygen - recovery from the Malter effect deposits

(A. Boyarski's contribution at this workshop)

Gas: 80%He+20%C_4H_{10}+Some additive
Source: 100mC Fe^{55} X-ray source
Test chamber has the BaBar chamber drift cell structure:



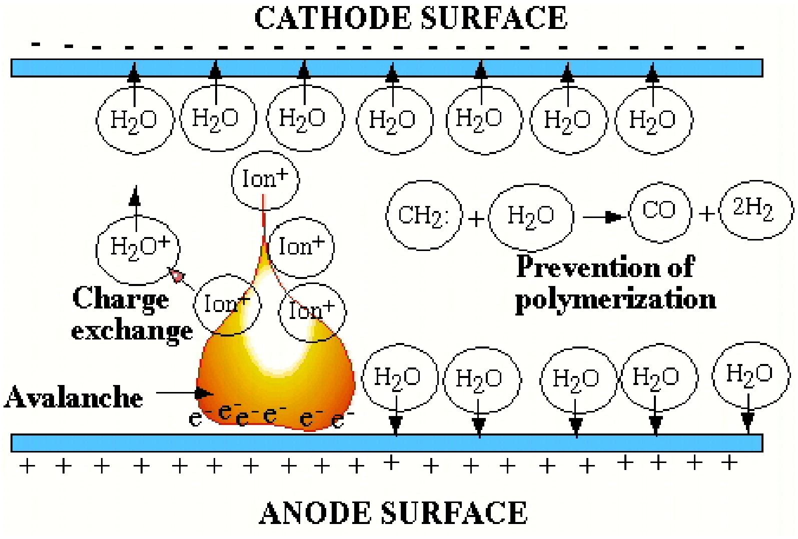
Observations:

1. Start with a damaged chamber – Malter at very low current.
2. Additives such as H_2O or alcohols were shown to stabilize the operation, but not cure it. When the additive were removed, the chamber would suffer from the Malter at very low currents again.
3. However, when 200-1000ppm of O_2 was added, a damaged chamber could be "cured" by allowing a high current operation successively. When the O_2 was removed, the chamber could still operate at high currents, as if it were new (>25nA/cm).
4. Single electron rate is a precursor of the Malter effect.
5. Some evidence of the cathode film heating during the Malter.

This is certainly one of the most significant experimental results of the workshop.

Note: These results were confirmed recently by Ch. Lu, Princeton.

“Good” additive – Water



Examples:

1. SLD drift chamber: 25%Ar+71%CO_2+4%C_4H_{10}+3000ppm H_20
2. BaBar drift chamber: 80%He+20%C_4H_{10}+3500ppm H_20
   (~85% of the gas recirculates through O_2 palladium getter)

Why water generally may help:

1. Water prevents the start of the polymerization, if introduced right from the beginning through the reaction:

$$CH_2: + H_2O \Rightarrow CO + 2H_2.$$

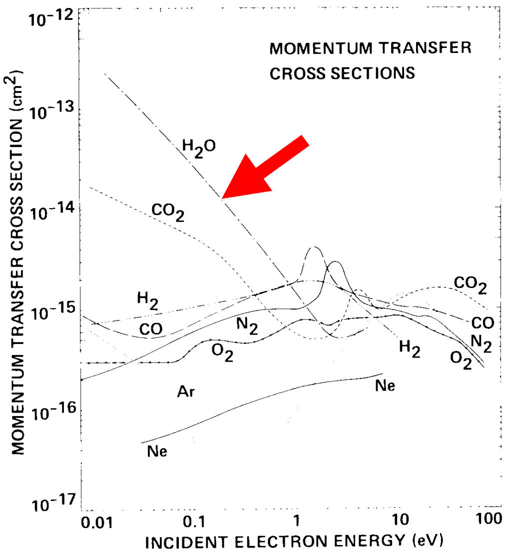
2. If water is introduced once the deposits are already made, it tends to stabilize the operation and prevent the Malter.
3. Water molecule will perform the charge exchange with the avalanche hydrocarbon ions, which will tend to avoid their polymerization during the cathodic recombination.
4. Water does not polymerize.
5. Water will help to increase the conductivity of the insulator.

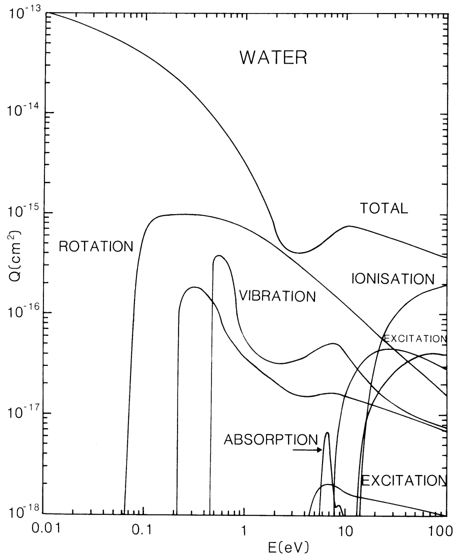
Are there some problems with water ?

1. The choice of water is best suited to metal-only-designs, such as classical large wire chambers. In applications involving dielectrics operating at high electric surface gradients, such as the anode wire supports or GEM amplifying structure, large amount of water may cause a surface breakdown !!!
2. Can produce HF in gases such as CF_4, $C_2H_2F_4$, etc. This can etch the glass or gold.
4. Cannot be used with any photosensitive materials such as CsI, or TMAE, not to speak about bi-alkali types.

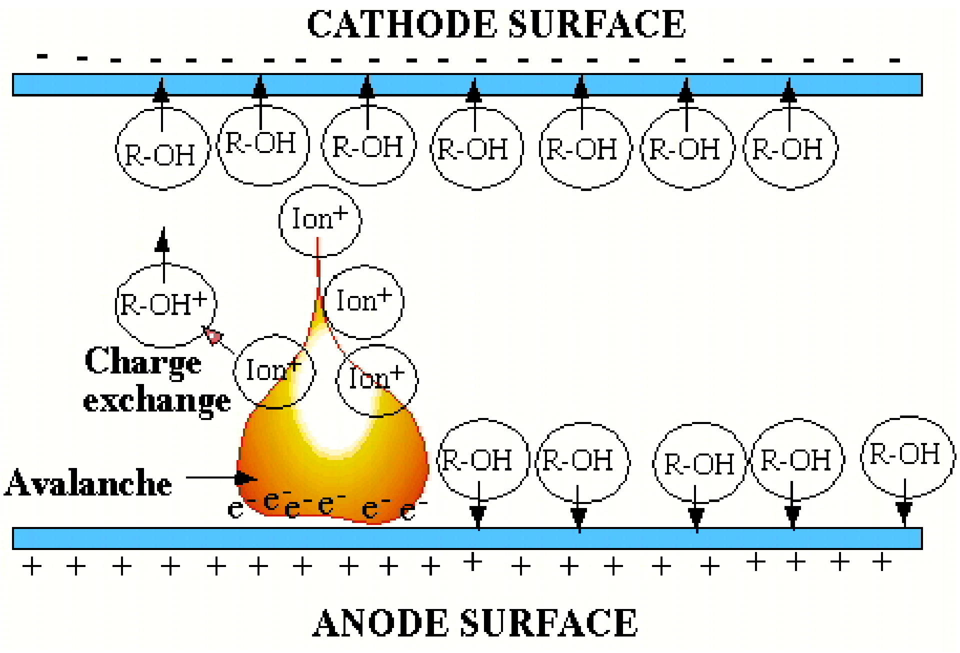
Note:

Large water dipole moment cools electrons only below ~1eV:





“Good” additive – Alcohols



Why alcohol generally may help:

1. Alcohol molecules have large dipole moments, and therefore they will be attached directly on the electrodes.
2. Alcohol molecule will perform the charge exchange with the avalanche hydrocarbon ions, which will tend to avoid their polymerization during the cathodic recombination.
3. If alcohol is introduced once the deposits are already made, it tends to stabilize the operation and prevents the Malter. (Tests of A. Boyarski at SLAC).

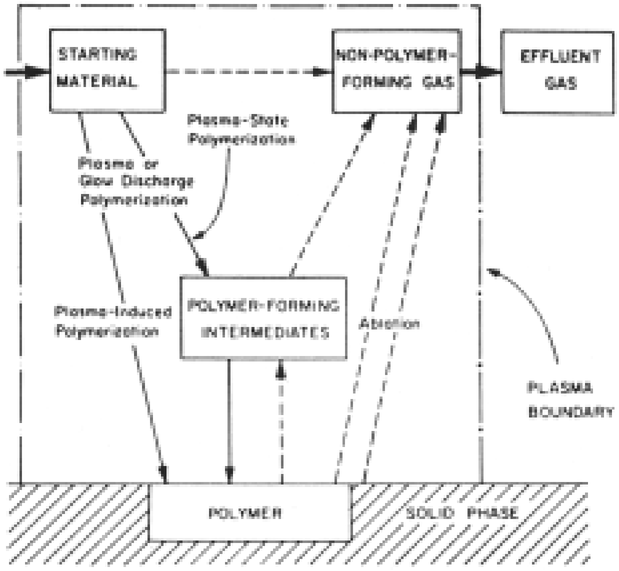
J. Va'vra, October 2, 2001

Are there some problems with alcohol ?

Warning:

1. Alcohol and ethers can be broken to formaldehyd $CH_2 = O$, which can polymerize. They have large dipole moments (2.8D), so they will stick to electrodes !! However, the rate of this polymerization is slower compared to the rate of the ordinary hydrocarbons, and therefore the addition of the alcohol can be judged as beneficial.
2. Various dissociation byproducts, such CH_2O_2, C_2H_4O or $C_2H_4O_2$, can react with aluminum and nickel and create the oxides, which have high resistivity.
3. Alcohols are solvents. Can cause swelling and expansions of some plastic materials such as Mylar or Kapton.

- Competition between etching and polymerization (Yasuda, DESY workshop, 2001):



	Etching	Polymerization	
Ar	0	-	
O_2	+++	-	←
H_2O	+	-	
CO_2	+	-	
CH_4	0	polymerize	
CF_4	+++	-	←
CF_4+H_2	0 (HF)	polymerize	
CF_4+CH_4	0 (HF)	polymerize	
CF_4+CO_2	++	-	←

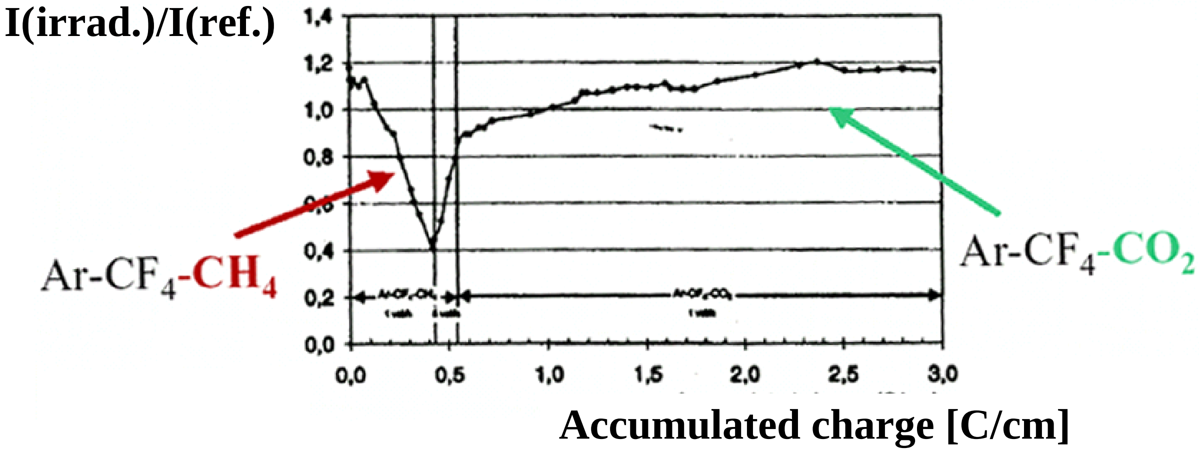
- CF_4-based gases are used for both etching and deposition processes, the distinction being made by the gas and its concentration with which CF_4 is mixed. Addition of oxygenated species to CF_4 plasma tends to shift the chemistry to etching, addition of hydrogenated species shift it to polymerization.

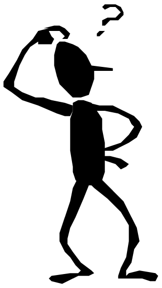
- My comment: Not very quantitative, nevertheless useful.

- Example of a competition between etching and polymerization:

(Capeans, DESY workshop, 2001)

HERA-B outer tracker honeycomb muon detector study:

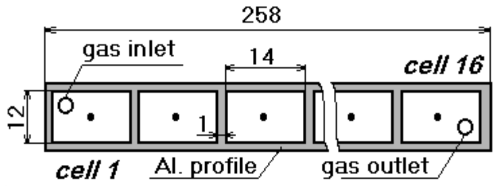


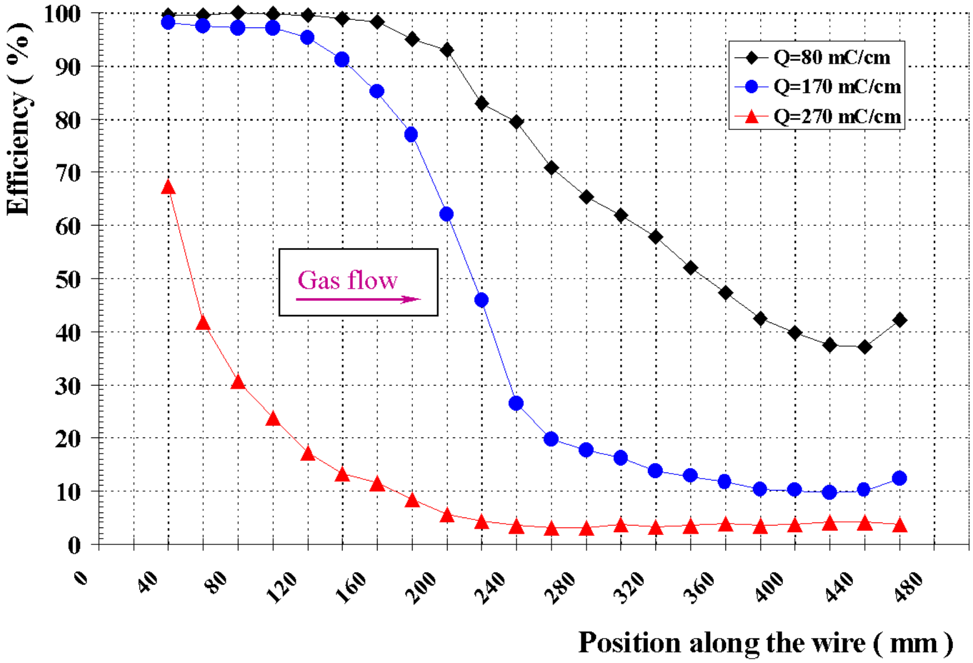


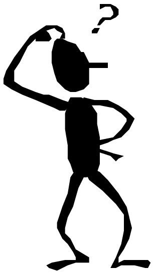
- HERA-B outer tracker honeycomb chambers which were initially subject to aging with Ar/CF_4/CH_4 gas; after switching to Ar/CF_4/CO_2 gas, the chambers recovered.
- This result is consistent with the Plasma Chemistry prediction.

- Evidence for the long-lived molecular fragment spieces ? (Titov, DESY workshop, 2001)

HERA-B muon detector study:





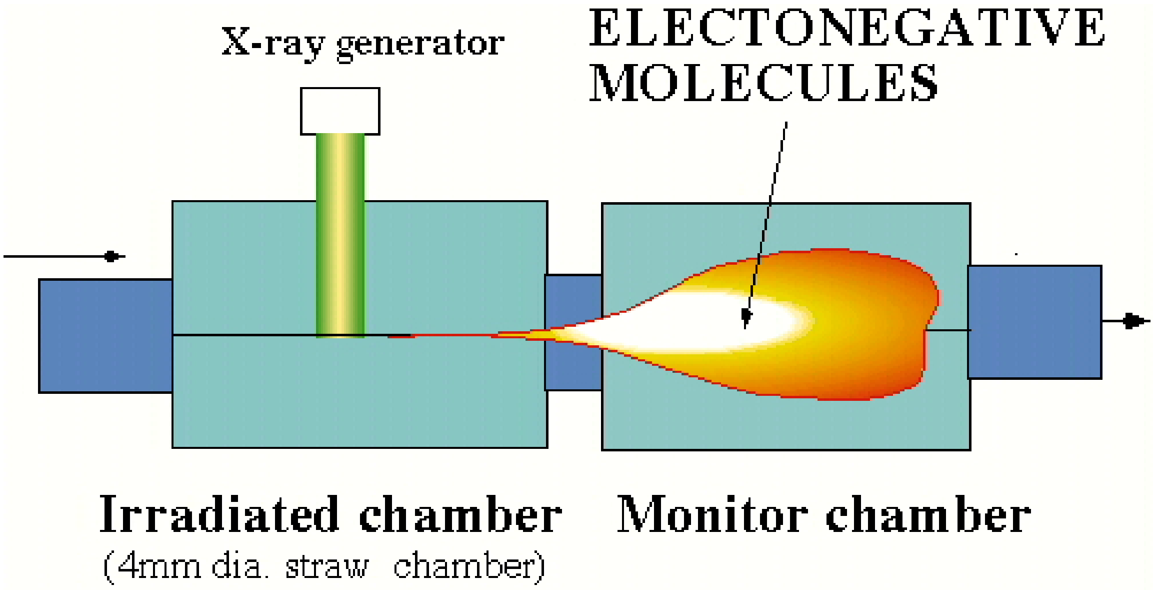


- Ar/CF_4/CH_4 (67:30:3)+500 ppm of H_2O.
- It would appear that there is an accumulated aging effect in the direction of gas flow. This may be evidence that the CF_4 molecular fragments are long lived.

- Is the gas recirculation safe ?

(M. Capeans et al., NIM A337(1993)122)

Gas: 50%Xe+30%CO_2+20%CF_4



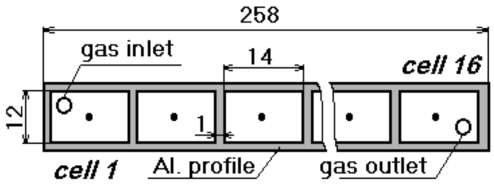
- Good aging result observed in the “Irradiated chamber”: no deterioration in pulse height observed up to ~0.9 C/cm.
- However, they see evidence for neutral, stable, highly electronegative species in the “Monitor chamber”, which are created in the avalanche plasma in the “Irradiated chamber”.
- These avalanche by-products are responsible for poor pulse height resolution of the “Monitor chamber”.

- This may have consequences for dE/dx operation of a chamber downstream of the irradiated area.
- One may also question if the gas-recirculation may bring some unforeseen surprises in the aging rates.

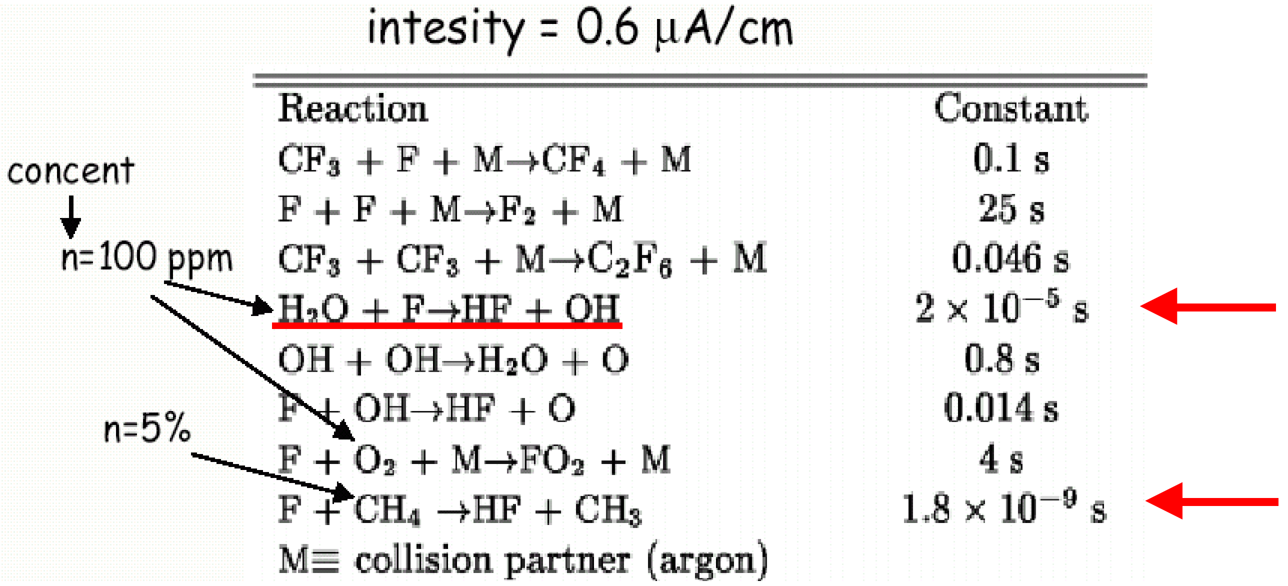
- Chemistry in the CF_4 gas mixtures.

(J. Schreiner, M.Titov, DESY workshop, 2001):

HERA-B muon detector study:

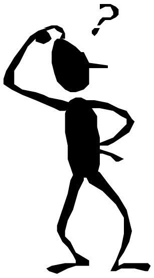


Attempt to estimate rate of the chemical reactions:



intesity = 0.6 µA/cm

Reaction	Constant
$CF_3 + F + M \rightarrow CF_4 + M$	0.1 s
$F + F + M \rightarrow F_2 + M$	25 s
$CF_3 + CF_3 + M \rightarrow C_2F_6 + M$	0.046 s
$\underline{H_2O + F \rightarrow HF + OH}$	2×10^{-5} s
$OH + OH \rightarrow H_2O + O$	0.8 s
$F + OH \rightarrow HF + O$	0.014 s
$F + O_2 + M \rightarrow FO_2 + M$	4 s
$F + CH_4 \rightarrow HF + CH_3$	1.8×10^{-9} s
$M \equiv$ collision partner (argon)	



- $Ar/CF_4/CH_4$ (67:30:3)+100 ppm of H_2O.
- Creation of HF molecule is worrying, since it can attack gold, tungsten, etc. One must control the water content with CF_4 gas!!

- Ar/CF_4/CO_2 gas mixtures.

(DESY workshop, 2001):

1) HERA-B muon detector:

- Ar/CF_4/CO_2 (65:30:5) + 1000ppmH_2O:
- No loss of performance up to ~0.7 C/cm

2) LHC-B full scale MWPC prototype:

- Ar/CF_4/CO_2 (40:50:10):
- No loss of performance up to ~0.25 C/cm

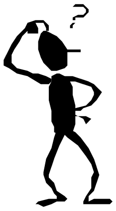
3) CMS Cathode Strip Chamber:

- Ar/CF_4/CO_2 (30:50:20) & Ar/CF_4/CO_2 (40:50:10):
- No loss of performance up to ~0.4 C/cm

- However, there appears to be some evidence of gold etching and cracking, which may be a sign that CF_4 reacts with water creating HF.

- $Xe/CF_4/CO_2$ gas mixtures.

(A. Romaniouk, DESY workshop, 2001):

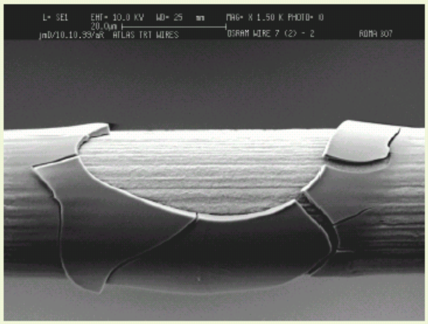


Straws for ATLAS transition radiation detector:

OSRAM wire, 3 % Au

Standard mixture +1.2% H_20 and 1.5%O_2

0.5 C/cm



OSRAM wire, 3 % Au

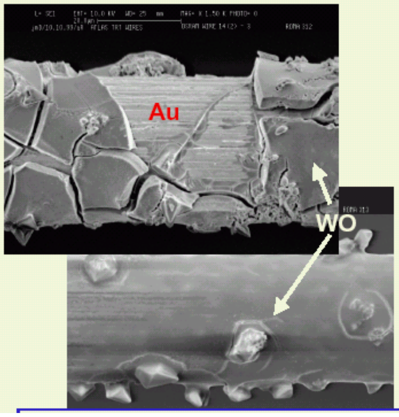
Standard mixture +1.2% H_20 and 1.5%O_2

0.5 C/cm

OSRAM wire, 3 % Au

Standard mixture +1.2% H_20 and 1.5%O_2

Total dose: *0.5 C/cm*

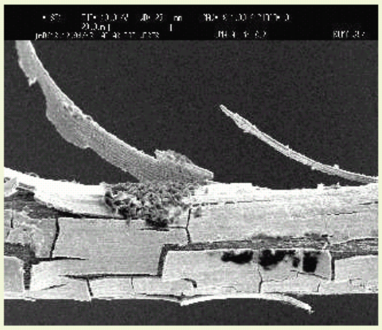


Luma wire, 5 % Au,

Ni-substrate

Standard mixture +1.2% H_20 and 1.5%O_2

Total dose: ~3 C/cm

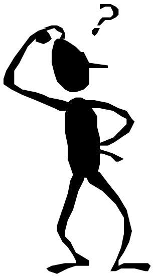


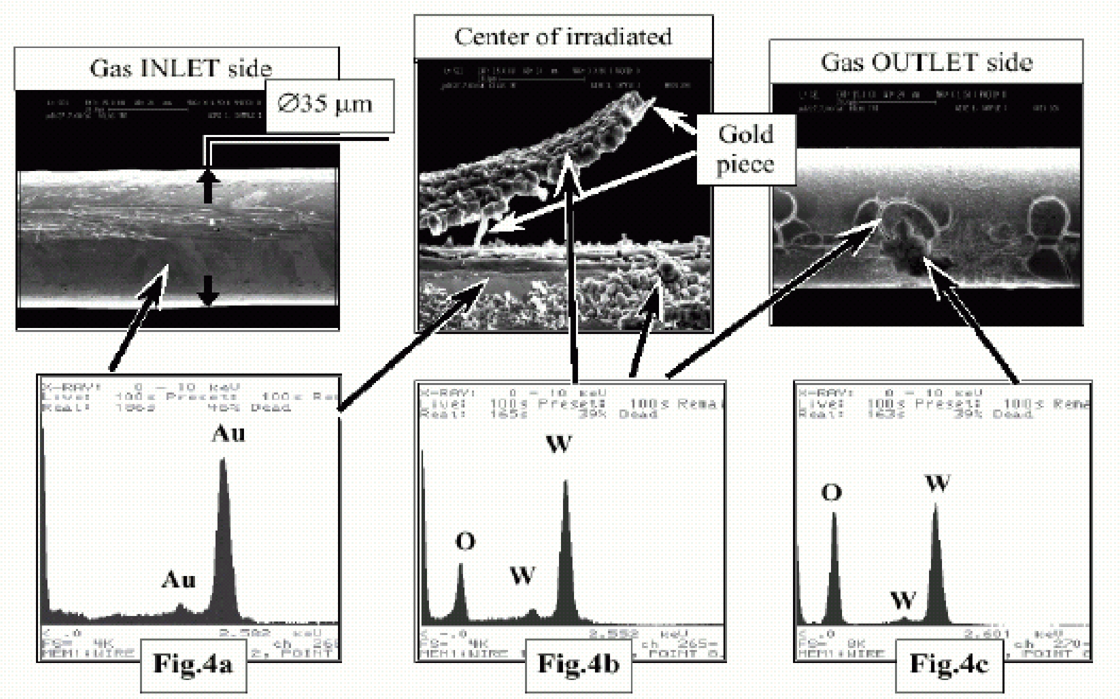
!!

- Test performed at a <u>astronomical current density</u> of ~5μA/cm !!!
- The damage is probably caused by HF; the presence of H_2O and O_2 seems to speed up the rate of damage. No damage observed if H_2O is below 0.1% up to ~20C/cm !!

- $Xe/CO_2/C_2H_2F_4$ gas mixtures.

(A. Krivchitch, DESY workshop, 2001):

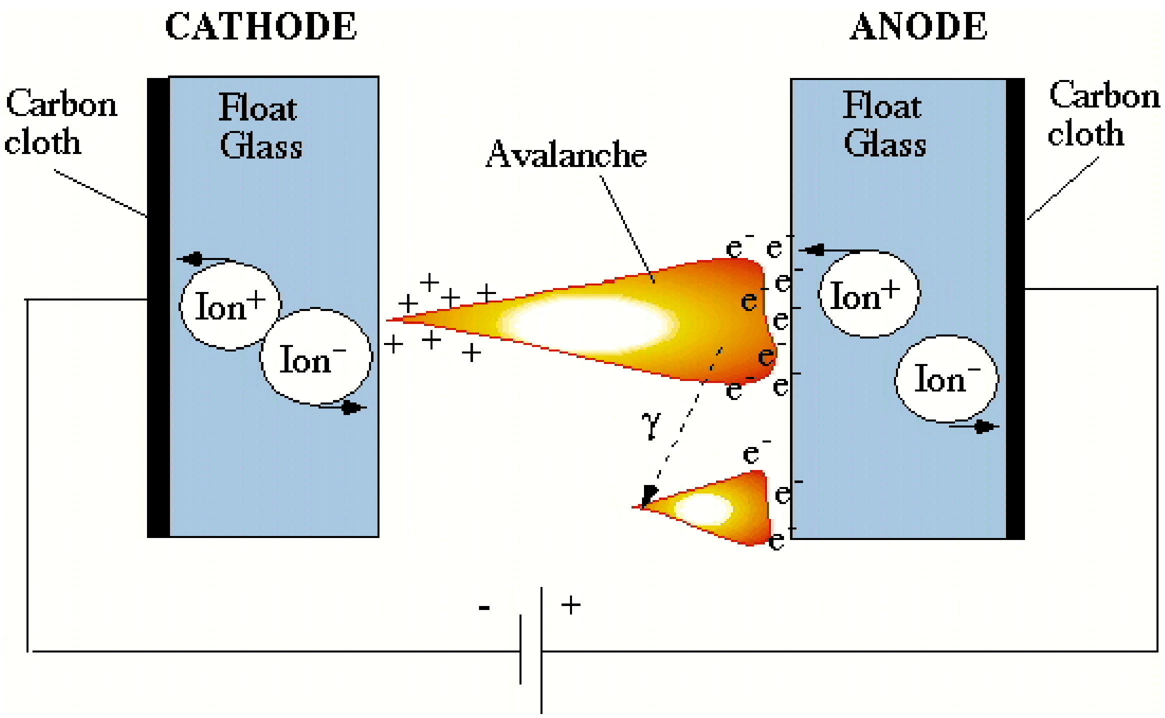




- Test performed at a <u>astronomical current density</u> of ~3µA/cm !!!
- Anode wire deposits found ~13cm downstream the irradiated area.
- Wire swelling observed after ~9C/cm in $Xe/CF_4/CO_2$ (70:20:10).
- Critics claim that the experiment has large amount of water.
- M.Titov thinks that these people did not control the water.

Example: **Belle RPC:** (Gas: 30%Ar+8%C_4H_{10}+62%$C_2H_2F_4$)

(D. Marlow, View Wire Chamber Conference, 2001)



Trouble:

$$C_2H_2F_4 + H_2O + \text{Plasma} \Rightarrow HF$$

(As a result, the glass surface corroded, which created emission points, triggering chamber currents, which lowered voltage across the gap.)

Fix:

Replace the Polyflow tubing with a copper tubing to reduce the water contamination.

- Summary of worries with CF_4 gas.

- Cannot be used if a water content is large because of HF.
- Mixing with the hydrocarbon gases may also produce HF.
- Creates electronegative long-lived molecular fragments
- Avalanche produces hard UV photons, which can cause the secondary effects on nearby electrodes such as mesh.
- Fluorine creates non-conducting metal fluorides, which could help to trigger the Malter effect.

- Ar/CO_2 gas mixtures.

(M. Kollefrath, W. Mohr, DESY workshop, 2001):

ATLAS muon drift tube detector (3bar operation):

- Ar/CO_2 (93:7):
  - **21 tubes tested**
  - **Rate: 0.8-12.5 kHz/cm**
  - **Source: Am^{241} (60keV)**
  - **All tubes are 100% efficient after ~1.3C/cm**

- Ar/CO_2 (97:3):
  - **47 tubes tested**
  - **Rate: 1.8 kHz/cm**
  - **Source: Cs^{137} (60keV)**
  - **All tubes are 100% efficient after ~0.6C/cm**

- The Freon-less mixture may do just fine…. And they should, in my opinion, allow additives such as water or alcohol. In this case, H_2O will deliver the charge, which is good because water cannot be damaged at the cathode.
- A sensitivity to Si deposits reported.

- Si deposits.

- **According to Plasma Chemistry, Si has higher tendency to form polymeric structures than C** (Yasuda, DESY workshop, 2001)**.**

- **Therefore one should be careful not to pollute the system with Si.**

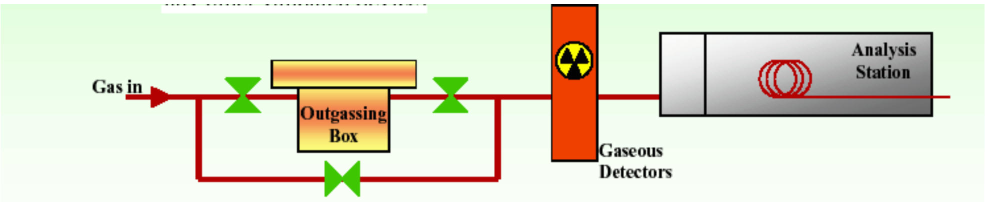
- **CF_4-based gases have some ability to remove them (SiF_4).**

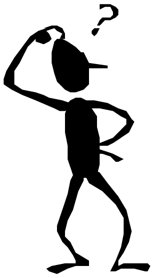
Examples of Si sources:

- O-rings with Si-based grease.
- Valves sealed with Si-based grease.
- G-10 boards inside the active region of a chamber.
- Molecular sieves not protected by appropriate mechanical filters.
- General pollution of a system.
- Copper tubing can be contaminated because Si-based oil can be used during its production.

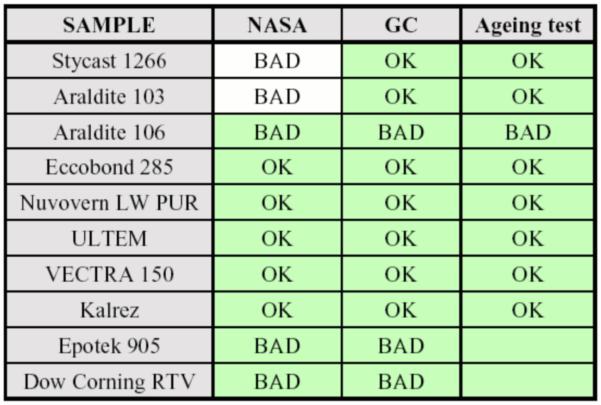
- Importance of cleanliness.

(M. Copeans, DESY workshop, 2001):

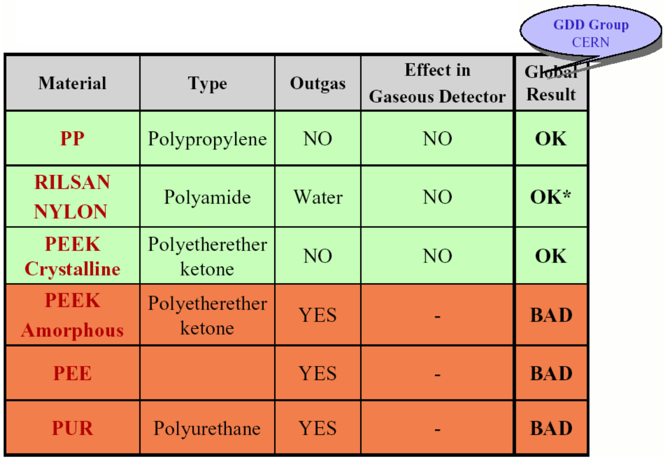




Examples:



SAMPLE	NASA	GC	Ageing test
Stycast 1266	BAD	OK	OK
Araldite 103	BAD	OK	OK
Araldite 106	BAD	BAD	BAD
Eccobond 285	OK	OK	OK
Nuvovern LW PUR	OK	OK	OK
ULTEM	OK	OK	OK
VECTRA 150	OK	OK	OK
Kalrez	OK	OK	OK
Epotek 905	BAD	BAD	
Dow Corning RTV	BAD	BAD	



Material	Type	Outgas	Effect in Gaseous Detector	Global Result
PP	Polypropylene	NO	NO	OK
RILSAN NYLON	Polyamide	Water	NO	OK*
PEEK Crystalline	Polyetherether ketone	NO	NO	OK
PEEK Amorphous	Polyetherether ketone	YES	-	BAD
PEE		YES	-	BAD
PUR	Polyurethane	YES	-	BAD

List of No, No… (Taken from my LBL Workshop talk in 1986)

- No oil traces in the gas
- No RTV to seal the chambers
- Avoid all soft glues
- No PVC or Tygon gas tubing
- Do not allow even one single delivery of bad gas
- Avoid soldering fumes polluting electrodes
- Avoid glue-curing fumes polluting electrodes
- Avoid a combination of dielectrics and alcohol
- Avoid a combination of plastic materials and alcohols
- Make the gas system with the semiconductor industry quality

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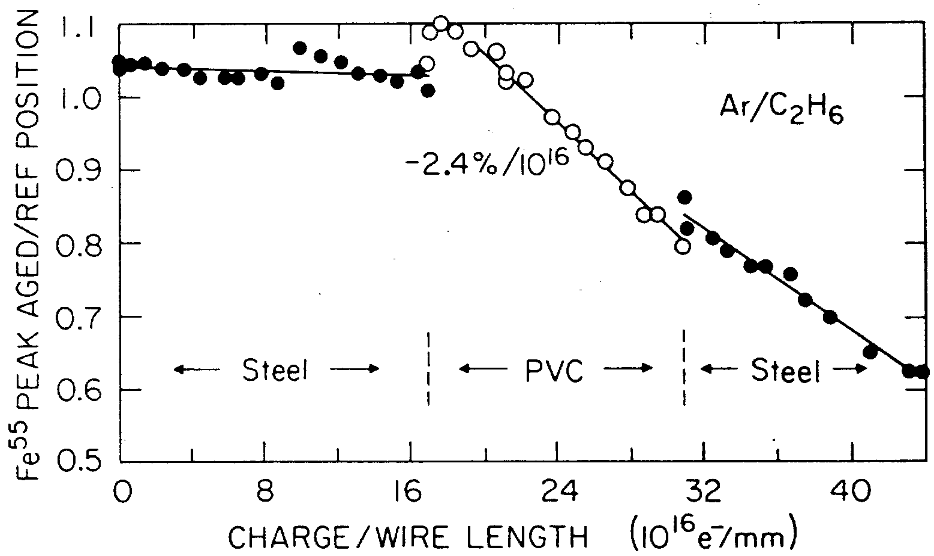
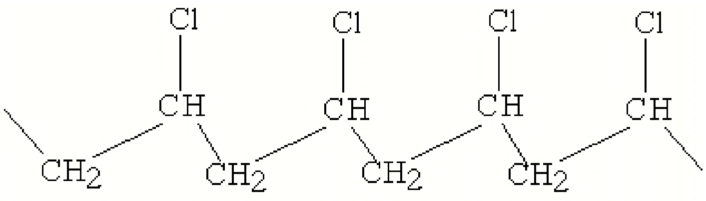
- Many good things were already said in 1986 LBL workshop

- Aging rate as a function of tubing material

(Kothaus, Test results, LBL workshop, Berkeley, 1986)



PVC:

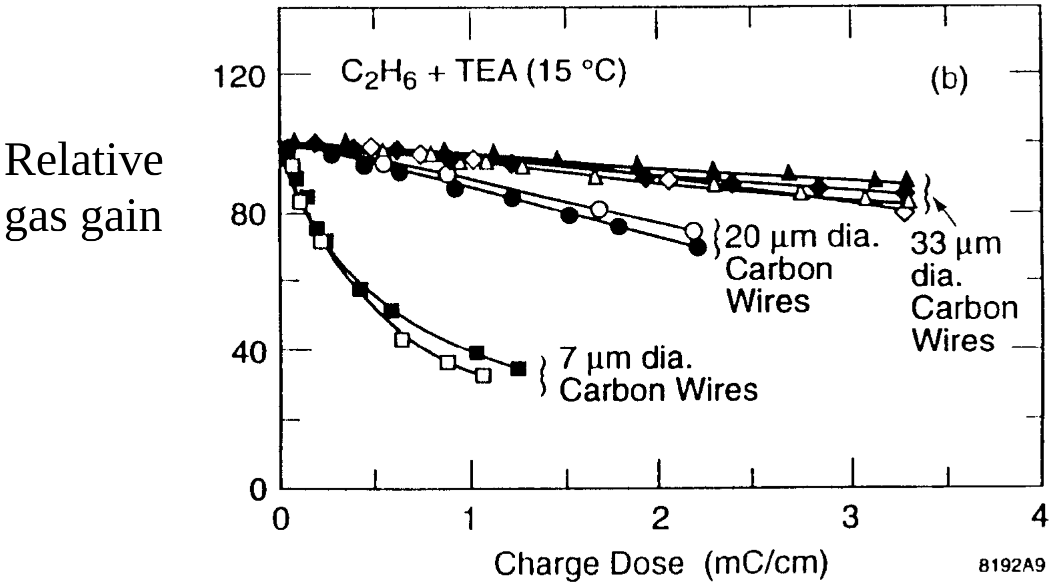


- Clearly, the tubing choice does matter. One can cause permanent damage by a wrong choice even for a limited period.

- Aging rate as a function of wire diameter

(J. Va'vra, NIM A387(1997)183)

- To be able to measure a finite result, choose molecules where the aging is reasonably fast.
- Both of these molecules leave a smooth film on the surface



- Smaller the wire diameter, larger the wire aging rate.

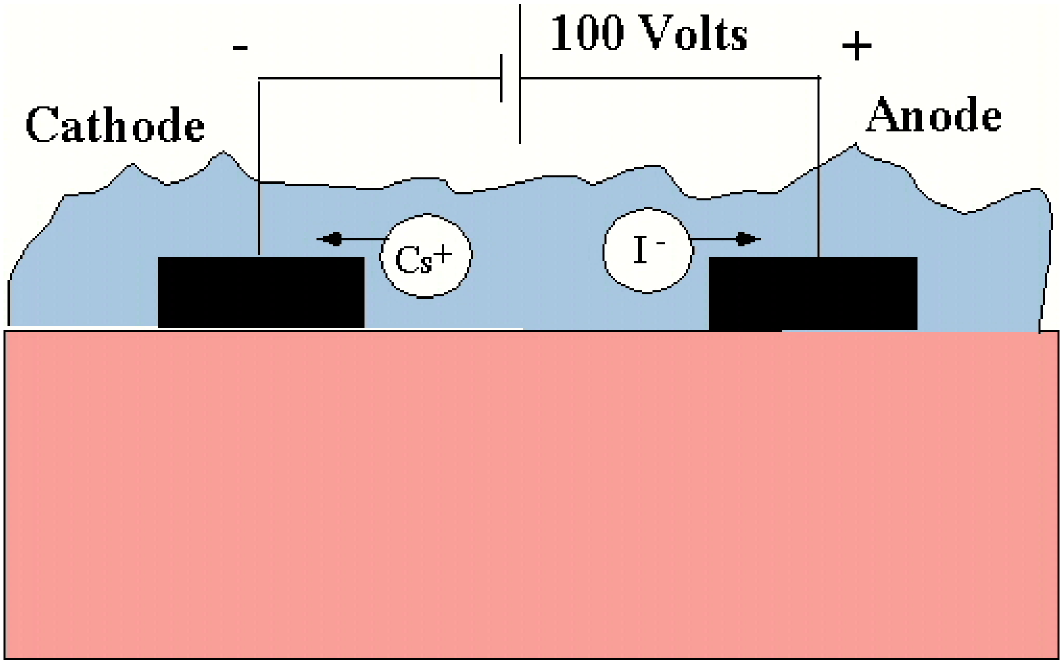
J. Va’vra, October 2, 2001

Electrolytic processes in insulators

- Current in Glass, Alkali Halides (CsI), Bakelite and the Linseed oil is of an ionic origin.

- Electrolytic process in CsI:

(J. Va’vra, DESY workshop, 2001)



- The current in alkali halides is of an ionic origin, i.e., for example in the CsI, it is carried by the Cs^+ and I^- ions.
- One can clearly observe this effect visually.

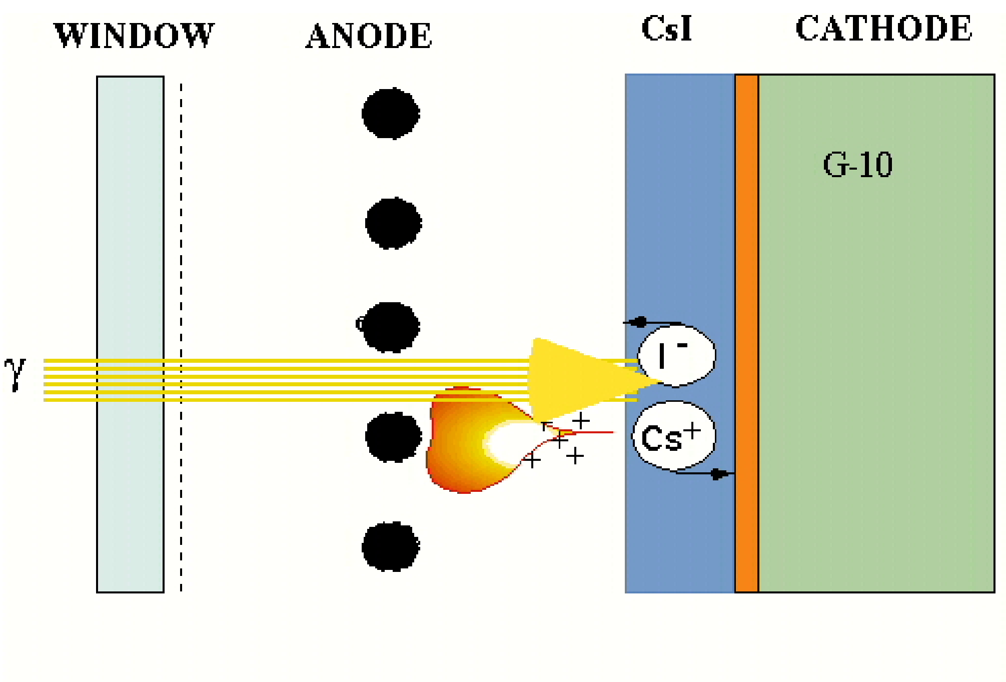
(J. Va’vra et al., NIM, A387(1997)154)

- When all ions move to their respective electrodes the current will stop. This is the major difference from metals where the current is made of electrons.

- Electrolytic process in the CsI photocathode

- A high flux of UV photons causes a photocurrent, which brings iodine ions to the cathode surface and the cesium ions in contact with the pad electrodes.

(J. Va'vra et al., NIM, A387(1997)154)



This will alter the chemistry of the surface and may alter the quantum efficiency and the resistivity of the photocathode.

- Iodine is very resistive $\rho \sim 1.3 \times 10^{9}$ Ω.cm
- Cesium is very conductive $\rho \sim 2 \times 10^{-5}$ Ω.cm

- Electrolytic process in glass

(G. Cicognani, P. Convert, A. Oed and J. Pannetier, ILL, Grenoble, France)

- Long-term instability of the ionic glasses:
  The conductivity in standard glasses is ensured by the movement of the alkaline ions, and for that reason they are called ionic conducting glasses. Typical resistance of these materials is 10^{12}-10^{16} Ωcm. However, during the long-term operation, the alkali ions migrate towards the cathode by the electric field and leave a depleted layer close to anode. This leads to a permanent increase of the surface resistance. The ionic glasses therefore suffer from long-term instabilIty.

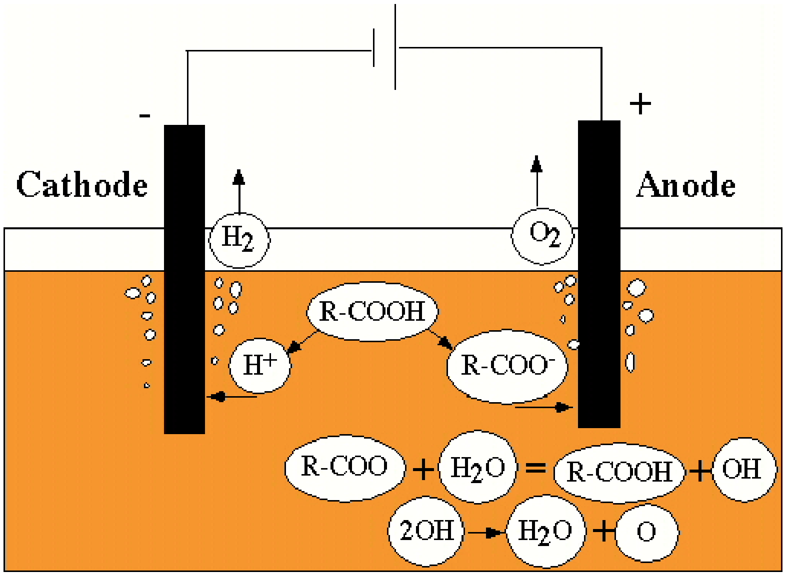
Note:

From BaBar DIRC experience we know that Alkali ions can leave the glass by "vacuum effect" of ultra pure water (sodium leaching).

- Electrolytic process in Linseed oil

Linseed oil: "It is a mixture of the glycerides of linolenic, linoleic, oleic, stearic, and palmitic acids with high degree of unsaturation of its fatty acid radicals." It is pressed from seeds.

Model of conductivity of the Linseed oil:
A current in Linseed oil is modulated by a presence of water, and a level of "organic fatty acids (R-COOH). Its volume resistance may not be uniform !!!



1) If there is no water then $R\text{-}COO^-$ just shares a charge:
=> The current slowly decays as R-COOH is consumed.

2) If there is water then $R\text{-}COO^-$ will share a charge and convert back to the fatty acid R-COOH.
=> The current will continue.

- Source of water: Bakelite, gas tubing, etc.

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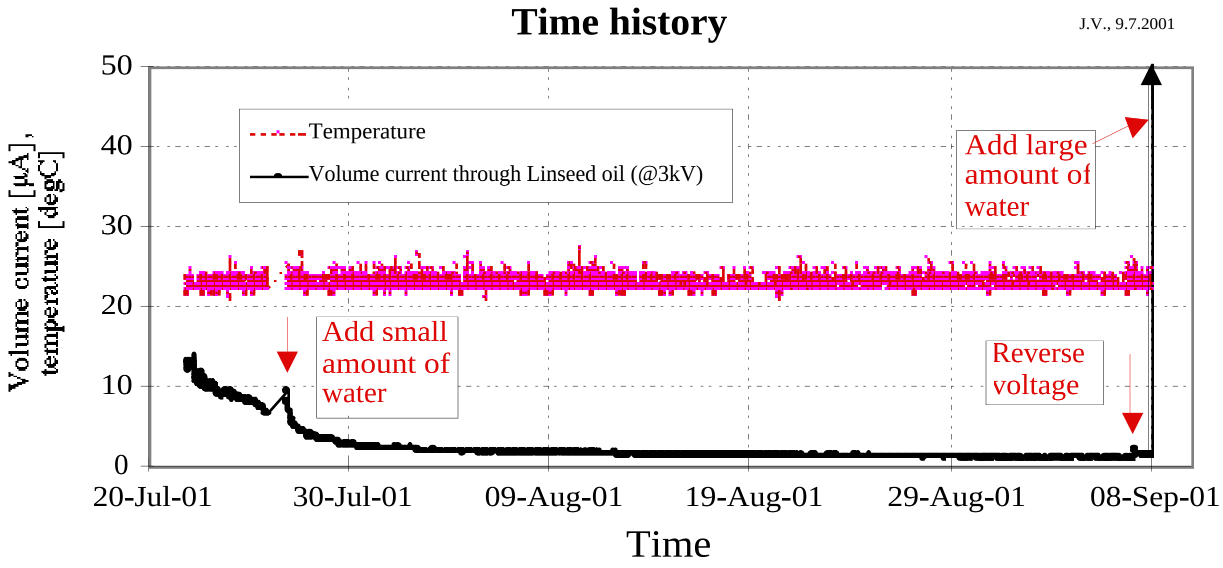
- Indeed that is what is observed:

Experimental evidence that the current through the Linseed oil decays if we do not add water:



- Total charge in this experiment: <u>~11.4 Coulombs</u>.

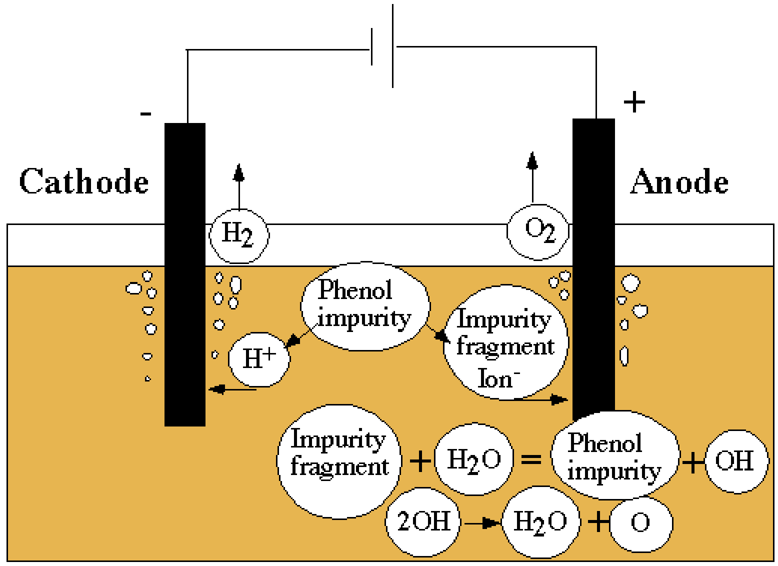
- Adding water sharply increases the current.

- There is an evidence of accumulation of some substance (probably related to R-COO).

- Electrolytic process in Bakelite

Bakelite: "It is the phenol-formaldehyde polymer, almost non-conducting. Its conductivity comes from the phenol impurities"

Potential trouble with the Bakelite:
A current in Bakelite is modulated by a presence of water, and a level of Phenol impurities. Its volume resistance may not be uniform !!!



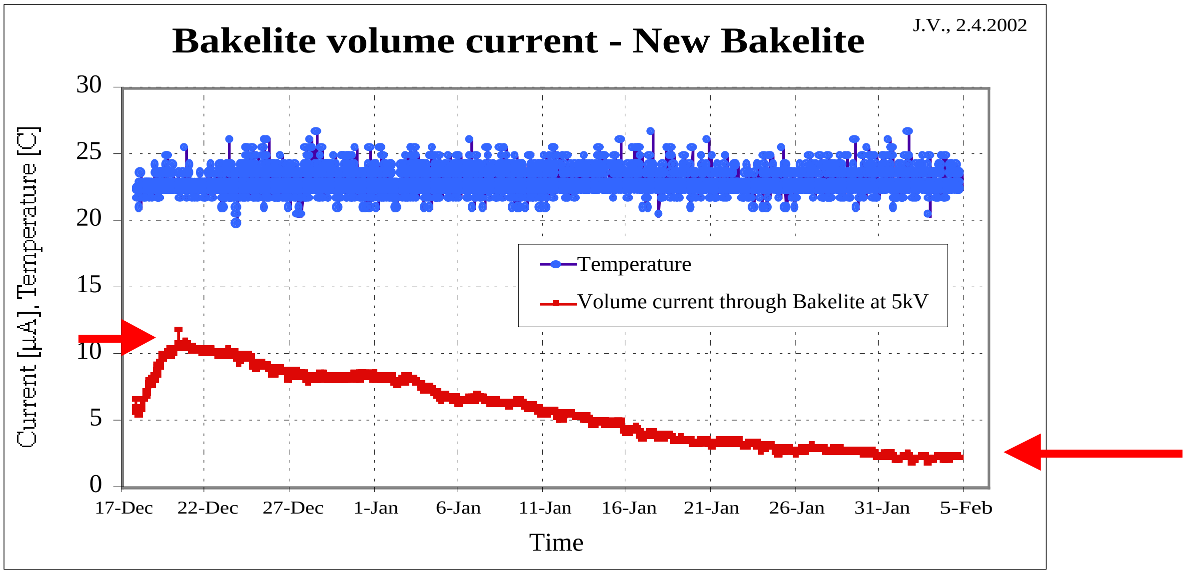
1) Presently, I do not know the molecular structure of the "phenol impurity."

2) If this model is right, the volume current through Bakelite should diminish if we do not add water.

- Bakelite may be a large reservoir of water.

If the electrolytic model applies to the Bakelite, its long-term current capability must stop as we consume ions.

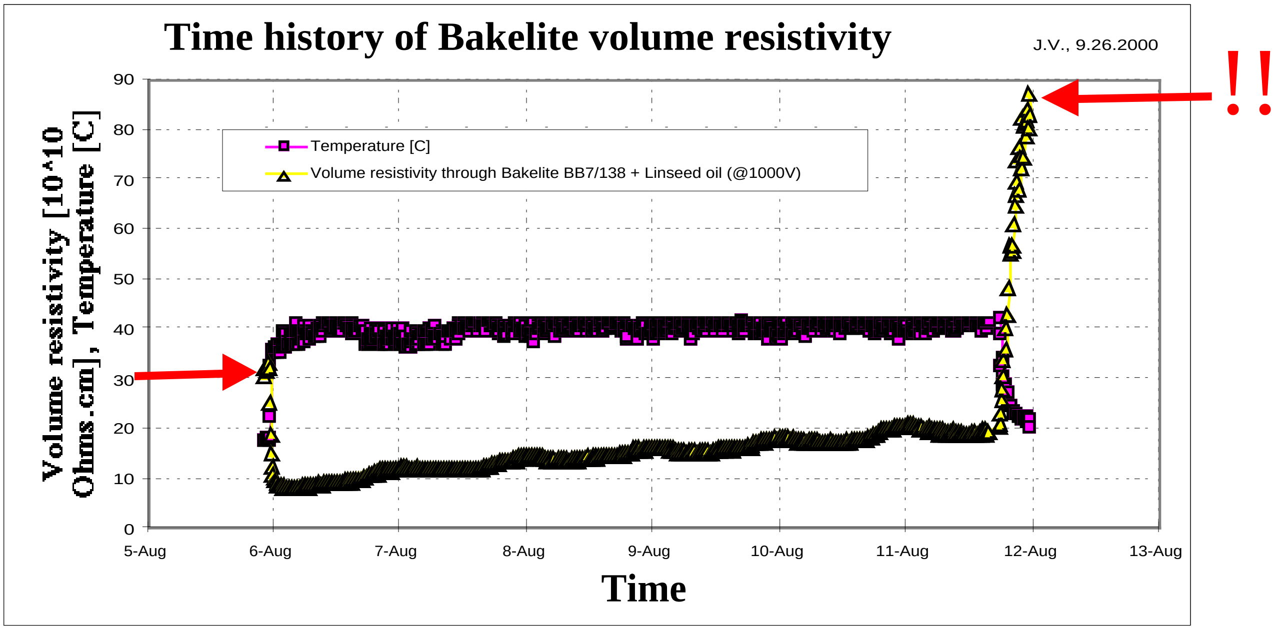
- Bakelite from the new BaBar RPC chamber (LHC equivalent).



- Total charge in this experiment: ~20.7 Coulombs (at 5kV).
- Total charge density is: ~0.63 Coulombs/cm^2 (test continues).

- I predict that it will take ~1 Coulombs/cm^2 to increase the Bakelite resistance by a factor of 10 (this is in air !!!).

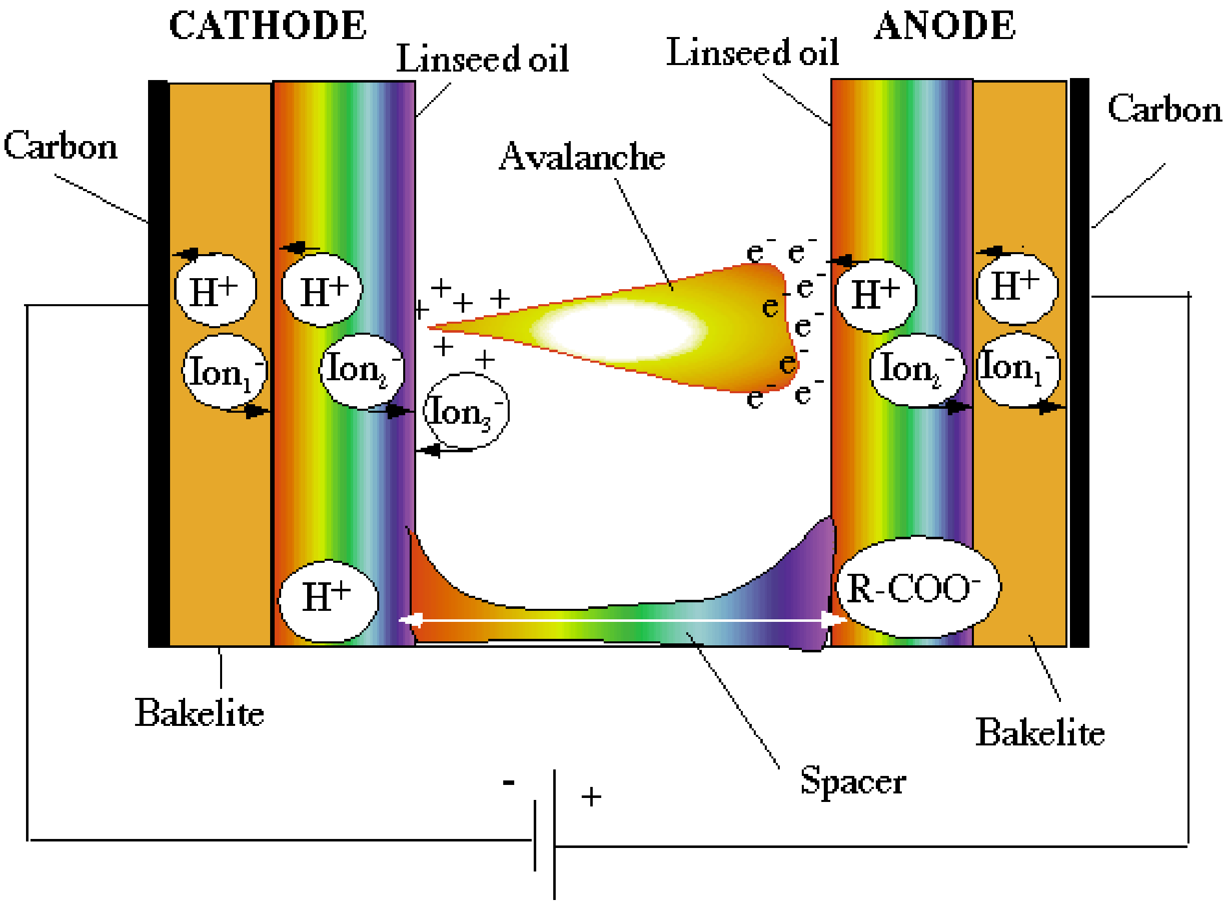
Another effect can be due to dry gas, which was simulated as follows: ρ_{Volume}(old Bakelite+Linseed oil) = f (Time, ~ 40°C):



- Total charge in this experiment: ~0.5 Coulombs.
- Total charge density is: ~0.015 Coulombs/cm^2.

- Volume resistance of Bakelite, covered by the Linseed oil, increased by a factor of ~3 after a week at 40°C (the charge dose was insignificant).
- Combining two effects, one the charge dose and one dry gas, may create an insulator from the Bakelite !!!

- Ionic model of BaBar RPC:



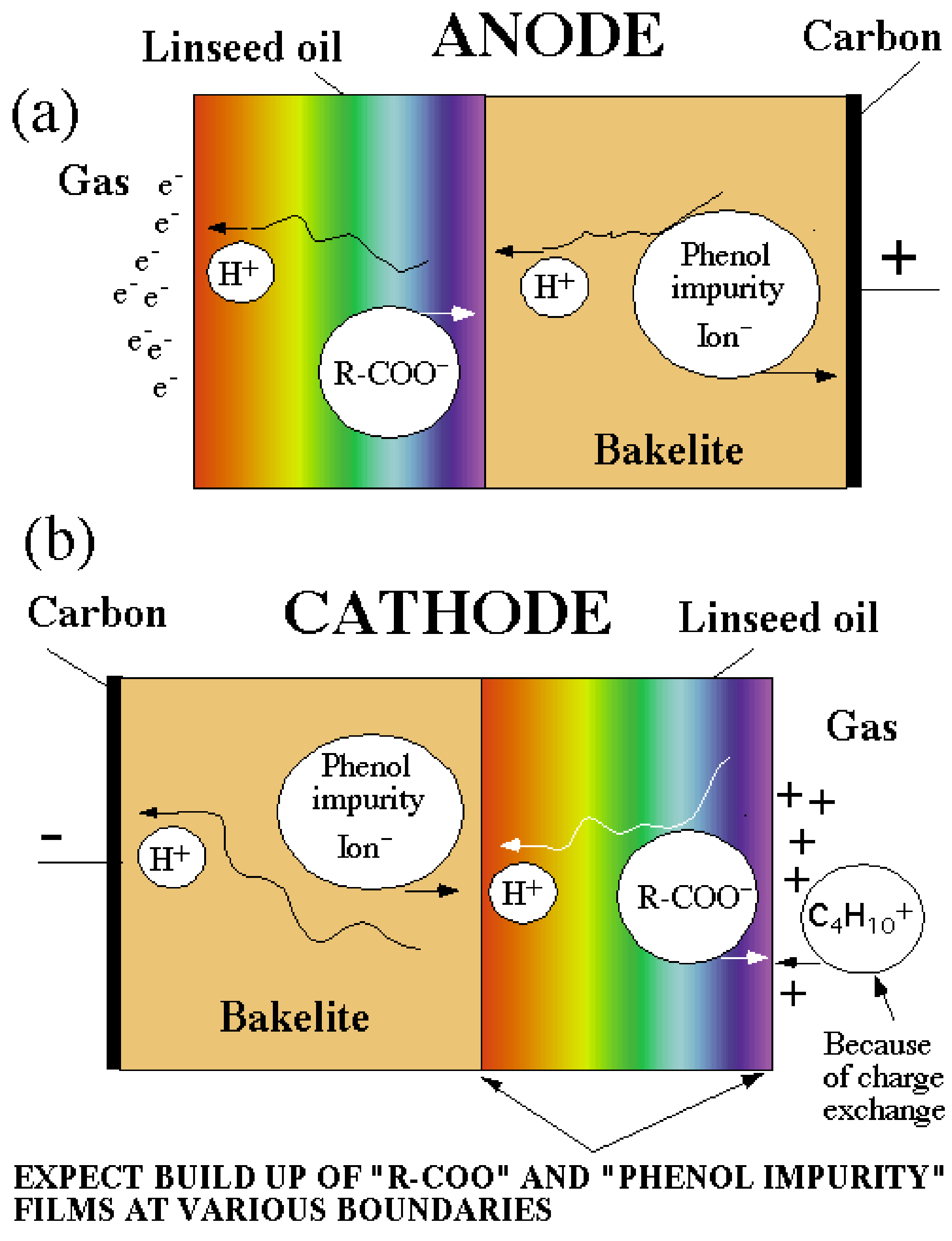
- There are several ions involved in the current flow. The charge exchange has to work to prevent the charging at various boundaries. If a resistivity buildup occurs at some boundary, there may be a charging effect.

- Within the context of the electrolytic model, water modulates the conductivity of both Linseed oil and the Bakelite.

- During the Marcelo's remediation procedure by running RPCs in pure argon, apparently some portion of the current goes through the buttons. This is what fixes the RPC, according to this presentation.

BaBar RPC ionic currents in electrodes:

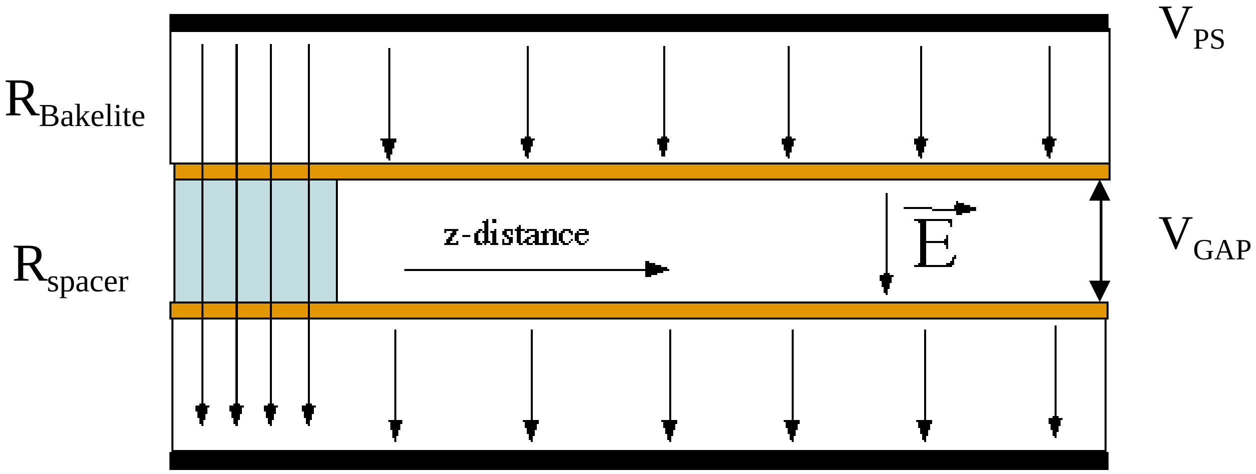
(Assuming the electrolytic model)



- There is a build up of molecular layers at various boundaries, depending where the current goes.

Requirements for well-working RPC:

- Stability of resistance of various components.
- No tangential gradients allowed.
- The current through the spacer should be small, but not zero, otherwise we will have charging !!!!



$$\mathbf{V_{GAP} = V_{PS} / (1 + 2\, R_{Bakelite}/R_{Lexan\ spacer}) \sim V_{PS}}$$

$$\mathbf{\text{if}\ \ R_{Lexan\ spacer} >> R_{Bakelite}}$$

Example – “nominal” design:

$R_{Bakelite} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim 2.5 \times 10^{11}\ \Omega.\text{cm} \times (0.2\text{cm}/100\text{cm}^2) \sim 5\text{x}10^{8}\ \Omega$

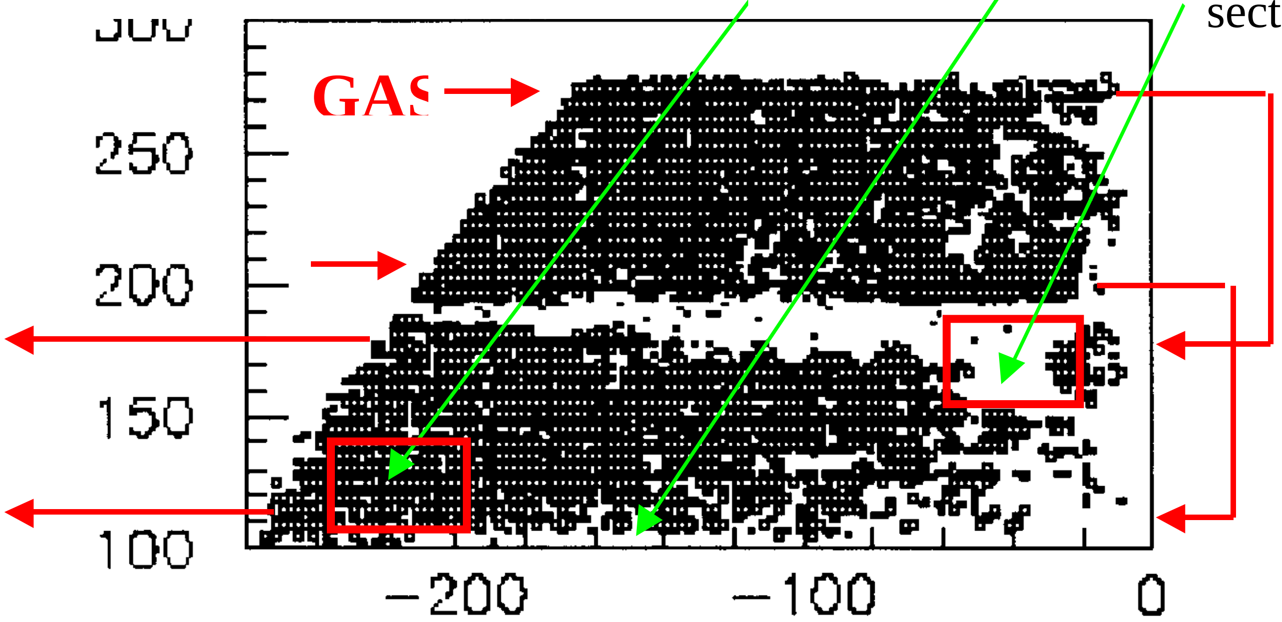
$R_{Lexan\ spacer} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim 10^{12}\ \Omega.\text{cm} \times (0.2\text{cm}/1\text{cm}^2) \sim 2 \times 10^{11}\ \Omega$

$$\Rightarrow \mathbf{V_{GAP} = V_{PS} / (1+2*5*10^{8} / 2\text{x}10^{11}) \sim V_{PS}*0.995 \sim V_{PS}}$$

Choice of sections of chamber for the study

EC FWD WEST TOP – LAYER 7:

Radiography of the RPC made by Davide:

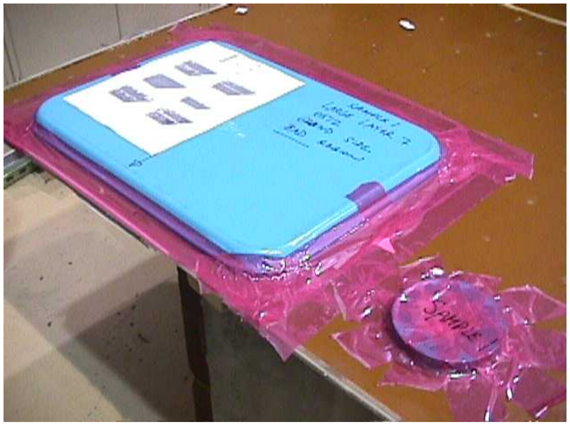


Good section

A lot of partially cured Linseed oil found here

Bad section

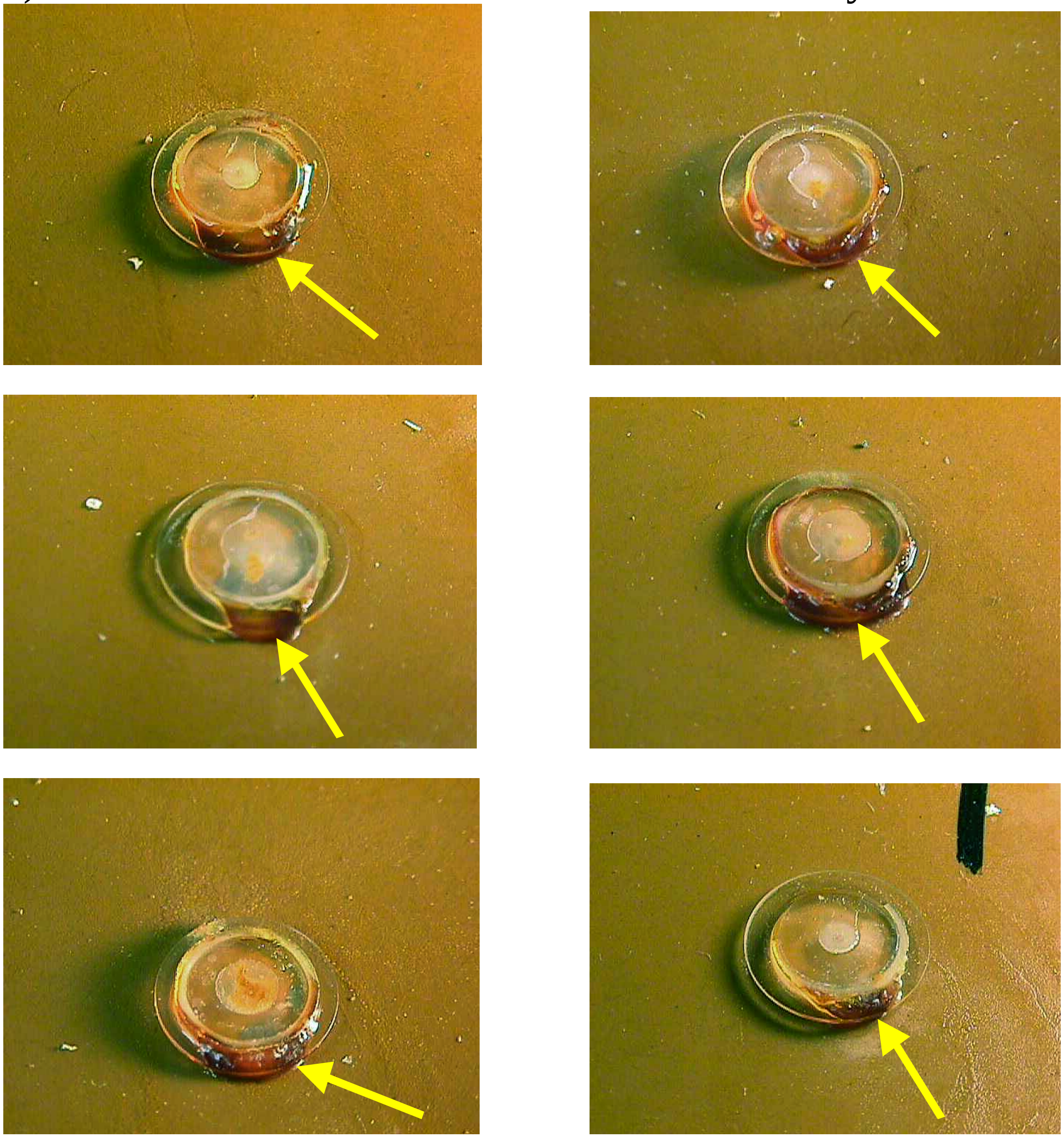
Cut four pieces altogether: (a) from anode & cathode, (b) good & bad section:



A recent discovery on 12.20.2001:

The buttons from a “bad” section are looking noticeably worse.

a) Buttons from a “bad” section of the RPC Layer 7:



- Practically every button has a “dark looking” bridge across.

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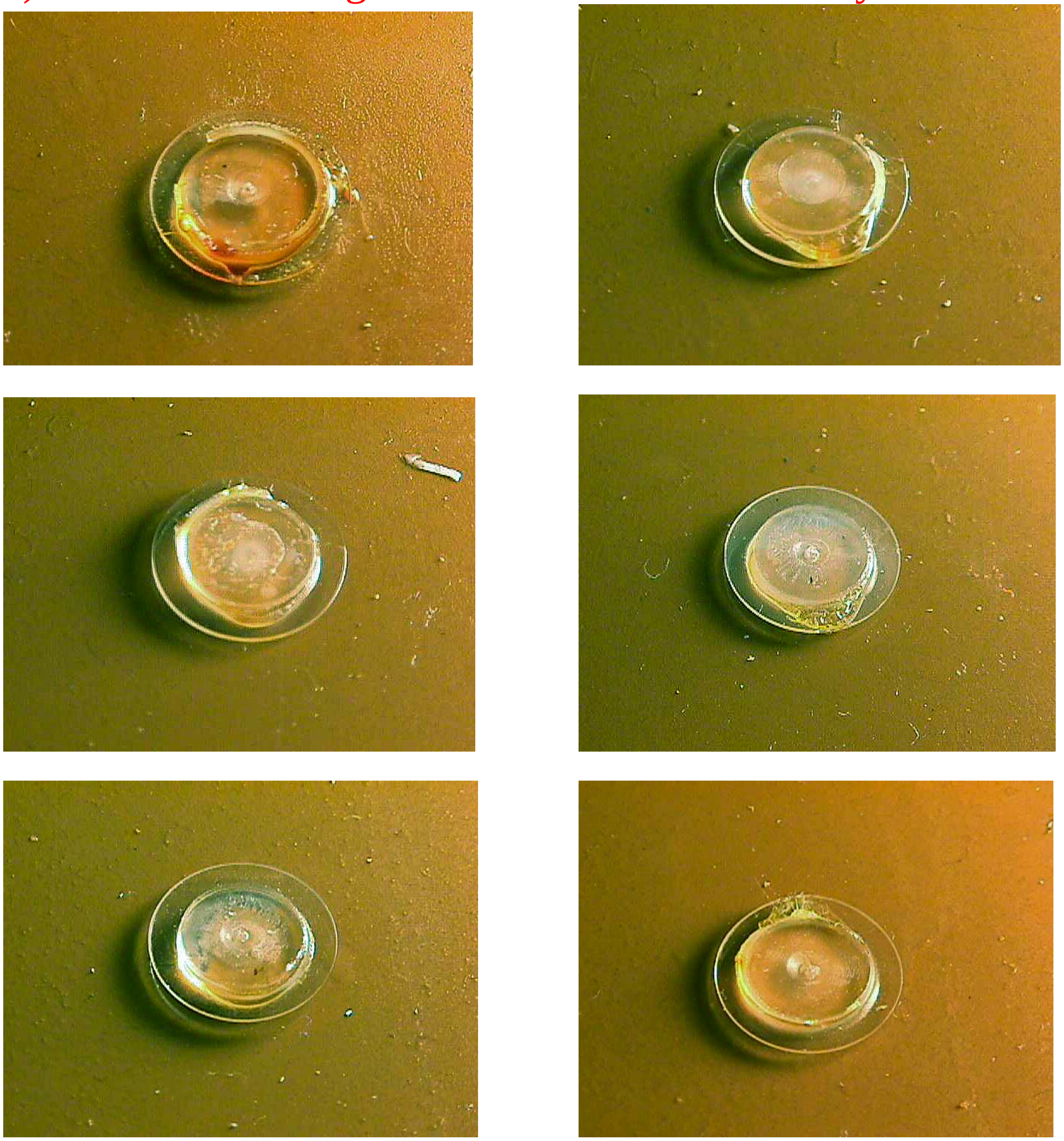
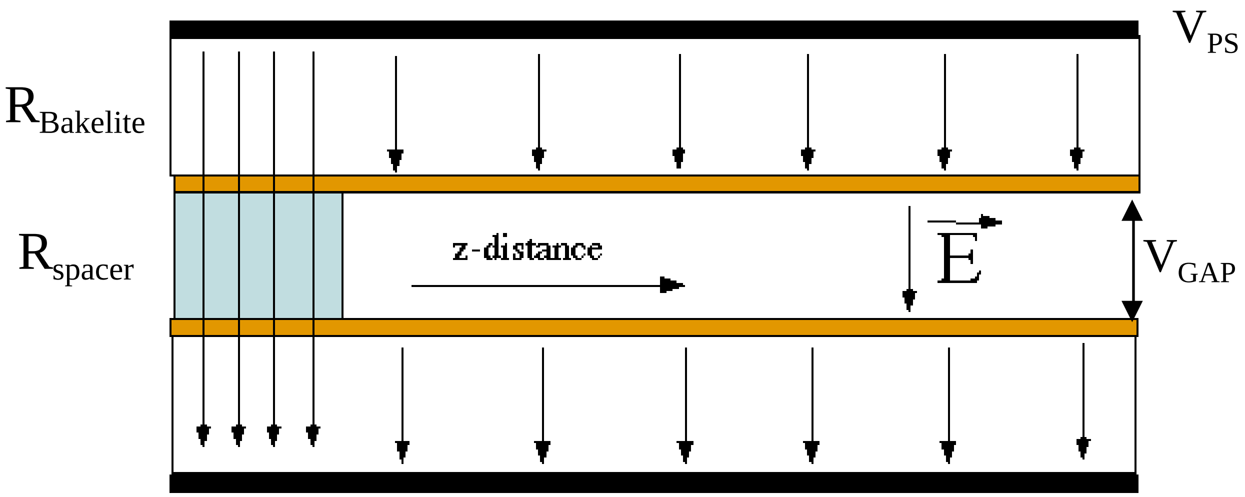
a) Buttons from a “good” section of the RPC Layer 7:



- Although there is some excess of Linseed oil, there is not as much of it, so it does not bridge the gap, and it is not as dark looking as in the “bad”section of RPC.

1) Good region of Layer 7:



$$\mathbf{V_{GAP} = V_{PS} / (1 + 2\, R_{Bakelite} / R_{Lexan\ spacer}) \sim V_{PS}}$$

$$\mathbf{if\ \ R_{Lexan\ spacer} >> R_{Bakelite}}$$

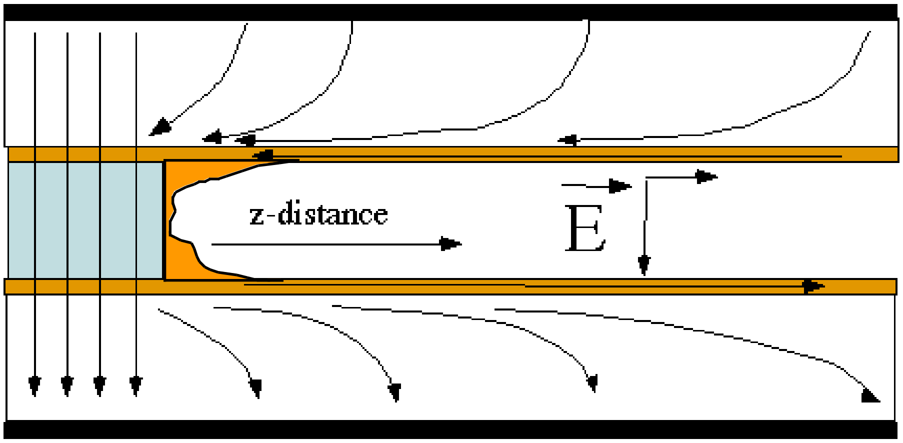
In this case, the chamber will work OK:

$R_{Bakelite} = \rho_V\,(t_{gap}\,/\,Area) \sim 2.5 \times 10^{11}\ \Omega.cm \times (0.2cm/100cm^2) \sim 5 \times 10^8\ \Omega$
$R_{Linseed\ oil\ blob} = \rho_V\,(t_{gap}\,/\,Area) \sim \mathbf{1.7 \times 10^{11}\ \Omega.cm} \times (0.2cm/0.1cm^2) \sim 3.4 \times 10^{11}\ \Omega$

$$=> \mathbf{V_{GAP} = V_{PS} / (1 + 2 * 5 * 10^8 / 3.4 \times 10^{11}) \sim V_{PS} * 0.99}$$

2) Bad region of Layer 7:

Buttons are shorted by a "gui" Linseed oil and we assume that there is an excess of Linseed oil on the surfaces – a reasonable assumption:



A button is shorted by the "brown gui Linseed oil blob":

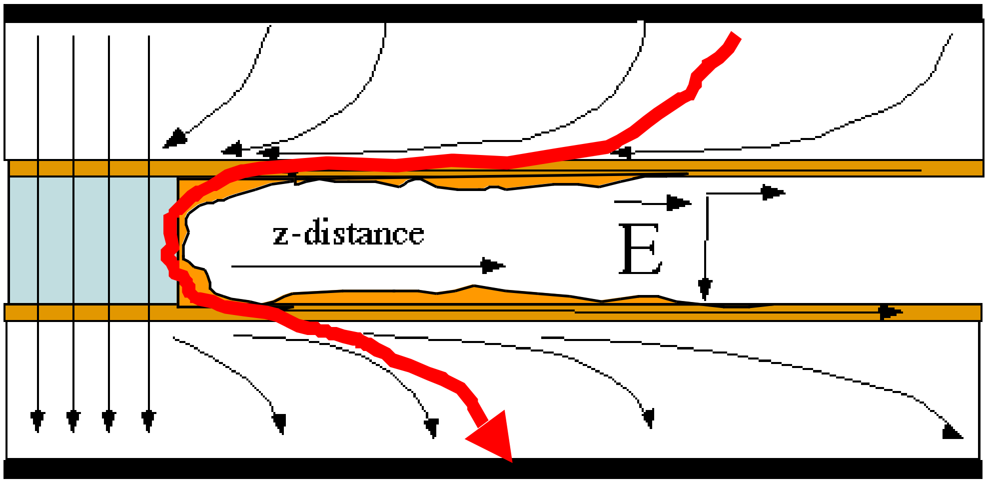
$R_{Bakelite} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim 2.5 \text{ x } 10^{11}\ \Omega.\text{cm x } (0.2\text{cm}/100\text{cm}^2) \sim 5\text{x}10^8\ \Omega$

$R_{\text{Linseed oil blob}} = \rho_V\,(t_{gap}\,/\,\text{Area}) \sim \mathbf{2.5*10^8\ \Omega.cm} \text{ x } (0.2\text{cm}/0.1\text{cm}^2) \sim 5 \text{ x } 10^8\ \Omega$

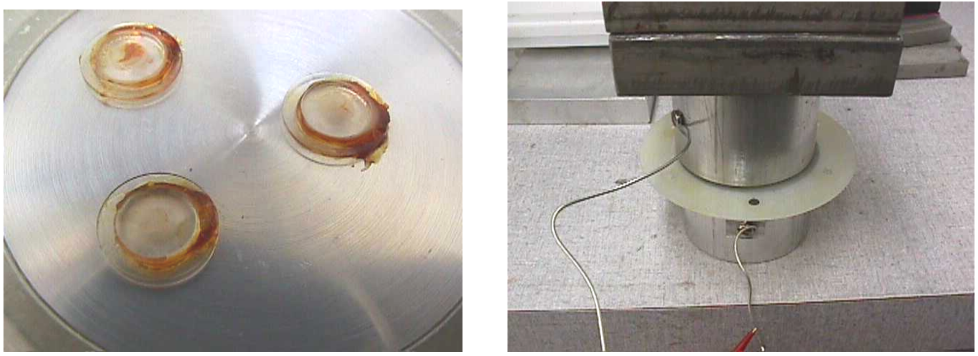
$$\Rightarrow \mathbf{V_{GAP} = V_{PS} / (1+2*5*10^8 / 5\text{x}10^8) \sim V_{PS} * 0.33}\quad \mathbf{!!!!!!!!}$$

=> The chamber may not work with such buttons.

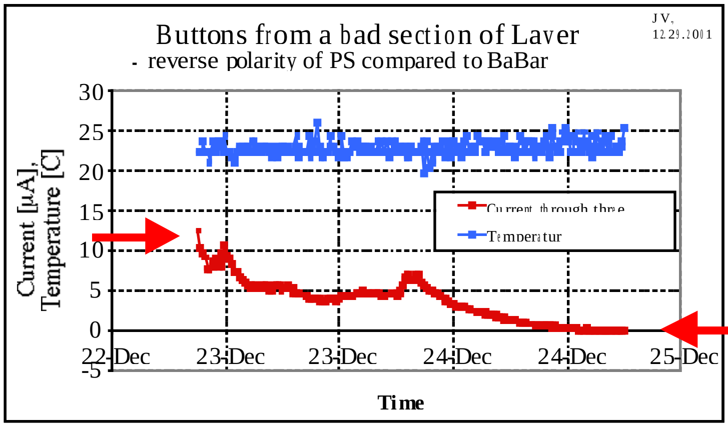
3) However, things are more complicated because it is a 3-D problem, involving the surface resistance of the Linseed oil and volume resistance of the Bakelite:



- <u>Test:</u> Curing of the “gui” brown Linseed oil on the buttons from a bad region of Layer 7:



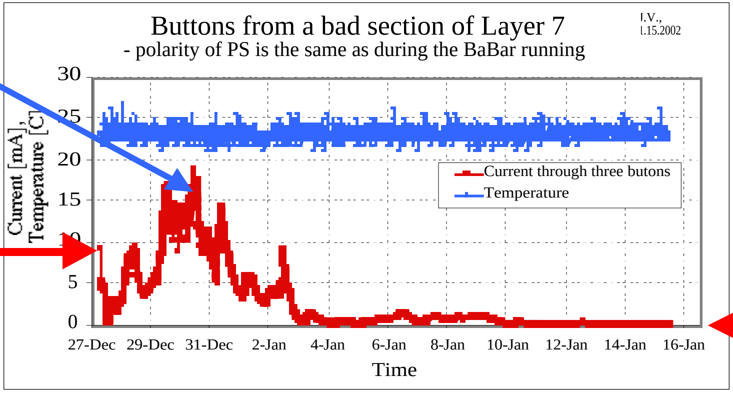
1) Reverse polarity during curing (the 1-st three buttons):



Total charge:
~0.2 C/button

2) Do not reverse polarity during curing (the 2-nd three buttons):

Peaks due to daily p
humidity (61-74%) I
very raining period



Total charge:
~1.7 C/button

- Resistance increased by a factor >400; RPC would work again !!
- Develop a hard film on the electrode difficult to scratch away.
- This result supports the electrolytic model.

Last few words of "wisdom".

- It is cheaper to spend money on electronics than to rebuild the chambers, i.e., better amplifiers, highly segmented HV power supplies with a low trip levels, etc.)
- Run as low gas gain as physics allows.
- Run as low HV trip level as possible, segment HV power supplies.
- Use clever software to search for any anomalous activity.
- Use gas additives right from the beginning, do not wait when you detect a trouble. Make sure though that these additives do not produce unwanted chemistry with your gases or electrodes.
- I would tend to avoid the CF_4-based gases for the moment.
- The Ar/CO_2 mix may not be that bad for high rates, but be careful of Si deposits.
- Use flat cathode surfaces to reduce the surface gradient.
- Use an oscilloscope more often.
- The electrolytic model of the ionic current conductivity in the Linseed oil and the Bakelite were proposed. In this model, the

electrical conductivity of the Linseed oil and Bakelite is modulated by amount of water. The primary source of water is Bakelite, which is very hydroscopic. Within the context of the electrolytic model, if no water is present, a buildup of R-COO molecules will create non-conducting films impeding the charge flow.

- Inefficiency regions in the BaBar Layer 7 are primarily caused by the dark brown "gui" Linseed oil blobs around the buttons, which are "shorting" the gap, together with the excess of oil in the active region (assumption only at this point). These blobs have very small volume resistance, much lower than the "fresh" Italian Linseed oil. This resistence is consistent with the resistance of the brown stuff taken from the very bottom of the Layer 7. It is not understood why the dark brown "gui" Linseed oil has such a low resistance at present ($\rho_V \sim 2.5 \times 10^8\ \Omega$.cm). It is possibly either due to some chemical reaction with a Freon molecule or due to porosity of the stuff due to a release of the gases during the electrolysis.

- In a chamber where the buttons are either shorted or near-shorted, changes in the Bakelite volume resistance by a factor of 2-3 do matter. Such change can occur either by drying the Bakelite surfaces or by a huge charge of about ~0.5 C/cm^2.

- The curing of the shorts was attempted by sending a large current through the buttons. The current diminishes (a factor of >400) after a certain charge (0.2-1.5C/button), <u>independently of the polarity of the current</u>. This would be consistent with the electrolytic model. There is evidence that a hard film developed on the aluminum electrode during the test, which is difficult to scratch away. Almost like cooking without a Teflon surface.

- If the Lexan buttons or Bakelite would become a perfect insulators, the chamber could charge up and stop working. A solution to add water has to be done very carefully to avoid the problems mentioned above.
- The Marcello's "Argon curing treatment" is a convenient way to introduce the uniform current throughout the chamber. Some portion of this current goes through the buttons, and this portion does the fixing of the bad RPCs. Its effect is to increase the chamber overall button resistance, and also the uniformity of the Bakelite resistance. It seems to me that the polarity does not matter.
- To explain the problems of the BaBar Layer 18, one clearly needs more studies. However, a possible explanation is related to the changes of the Bakelite/Linseed oil resistance under the influence of very large charge doses, and influence dry gas creating a very thin water-free layer. We should remove this chamber very carefully from BaBar this summer to allow this test, meaning not to allow too much exposure to water.