J. Va'vra, DESY workshop, October 2, 2001

WIRE AGING

- The basic processes involved in the aging
- The Early Developments since the 1986

LBL Workshop

J. Va'vra

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REVIEW OF WIRE CHAMBER AGING *

J. VA'VRA

Stanford Linear Accelerator Center, Stanford University, Stanford, California 04305, USA

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.

• Use my 1986 NIM paper as a guidance.

- Color code in this talk:
- things known by the time of the 1986 LBL workshop are in black,
- what happened since then are in red color.

Onion theory:



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

• There are simply too many variables in the problem, and therefore it would appear too naive to expect that one can express the wire aging rate using a single variable such as Q/cm, etc.

The correct variables are cross-sections, electron or photon energies, etc.

• Therefore, it is difficult to understand truly any present aging measurement.

• The aim of this workshop should be modest. It is to find simple practical remedy, even if we might not understand the problem. 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 that magic explanation of what is going on.

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	$1-10 \mathrm{eV}$	5–10 eV (Ar)
Effective Volume	$100 - 1000 \text{ cm}^3$	$10^{-10} - 10^{-8} \mathrm{~cm^3}$
Typical Electron Density	$10^9 - 10^{12} \ { m e/cm^3}$	$10^{14}-10^{17}~\mathrm{e/cm^3/avalanche}$
Typical Power Density	$0.01-10 \text{ watts}/\text{cm}^3$	$10^8 - 10^{12} \text{ watts/cm}^3/\text{avalanche}$
Gas Pressure	0.01 – 10 Torr	≥ 760 Torr
E/p	$10-50~{ m V/cm}{\cdot}{ m Torr}$	$100 - 400 \text{ V/cm} \cdot \text{Torr}$
		(on the surface of the anode)
Type of Electric Field	\mathbf{RF}	DC
Typical Gas Flow	$\sim 1~{\rm Gas}~{\rm Volume}/110~{\rm minutes}$	$\sim 1~{ m Gas}~{ m Volume}/1-8~{ m hours}$

(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. (For example, a role of H₂O, O₂ or oxygen-based additives)

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.
- 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
- Role of the variables, such as gas flow, gas gain, system and gas purity, wire diameter, defects on the electrode surfaces, etc.

Production of γ's by electrons and ions

(γ 's are responsible for the secondary effects)

- Production of γ 's by electrons and ions



1) Photon emission by <u>electron-atom collisions</u>:

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

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

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

+ $Ar => Ar^{+} + Ar^{*} (=> Ar + \gamma)$

2) Photon emission by <u>ion-electron recombination at the cathode</u>: $A^+ + Cathode (e^-) => A + \gamma$ ($E_{\gamma} = E_{ioniz.potential} - E_{work function}$)

3) Photon emission by <u>ion-electron radiative recombination</u> <u>in the gas</u>:

$$e^{-} + A^{+} \implies A^{*} + \gamma$$
 $(E_{\gamma} = E_{e} + (E_{i} - E_{k}))$

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Secondary electron emission

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







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:





Signature:

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:



Example:

CF₄ gas scintillates in the UV region: $e^{-} + CF_4 \implies (CF_3^{+})^* \text{ or } (CF_4^{+})^* \implies \gamma (\lambda \sim 160 \text{ nm})$

 $1200 \gamma / (MeV.4\pi) (150-500nm) \sim 16\%$ of that of Xe !!!

$$\gamma \ (\lambda \sim 160 \text{ nm } \hat{\mathbf{U}} E_{\gamma} \sim 7.74 \text{eV}) + \text{TMAE} \implies \text{TMAE}^+ + \text{e}^-$$

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

Necessary condition for avalanche breeding:

- 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.



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

Secondary electron emission due to the Malter effect:

(L.Malter, Phys. Rev. 50(1936))



Necessary condition for electron emission:

- 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).
- 1) 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).

<u>Relationship between the maximum rate</u> 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 ~ $\epsilon_r \epsilon_0 \rho_V$.
- 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: $r_{max} \sim 1/(10 \text{ RC}) = 1/(10 \epsilon_r \epsilon_0 \rho_V)$
- For $\epsilon_r \sim 4$, $\epsilon_0 = 8.87 \text{ pF/m}$, $\rho_V \sim 2.8 \text{ x } 10^7 \Omega$.cm: $r_{max} \sim 10 \text{ kHz}$.
- For $\epsilon_r \sim 4$, $\epsilon_0 = 8.87 \text{ pF/m}$, $\rho_V \sim 2.8 \text{ x } 10^{12} \Omega.\text{cm}$: $r_{\text{max}} \sim 1 \text{ Hz}$.

Examples of the Malter effect

- 1) The first imaging of this effect (J. Va'vra, NIM A367(1995)353).:
- Use a device able to detect the single electrons with an excellent imaging capability CRID :



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

- 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.
- 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 too high, by the way.
- 2) <u>It was very easy to excite the Malter effect in the CRID</u> <u>detectors in the lab</u>, if they were previously been used in TMAE. (J.Va'vra et al., NIM A367(1995)353)

a) Either with a UV lamp:



Mercury UV lamp

b) Or with an Fe⁵⁵ source:



Answer: a) "clean" TMAE film resistivity is highb) 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 (J.Va'vra et al., NIM A387(1997)154)



Answer: CsI volume resistivity is much lower: $\rho_{CsI \, film} \sim 10^{10} \,\Omega.cm$ (just after evaporation) $\rho_{CsI \, film} \sim 10^7 \,\Omega.cm$ (after ~10 min in air) 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)



How to prevent the Malter effect ?

- . Run as low gas gain as possible.
- . Pay attention to the single electron signal activity.
- . Segment HV as much as possible.
- Have the HV trip setting as low as possible (<100nA).
- . 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.
- . We will talk about the gas additives later.

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Molecular

dissociation

Dissociation & ionization energies:

Atom	Thermal	Dissociation	Ionization
	dissociation	by electron impact	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 ₂ O	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 ₂ H ₆	3.6		11.5
Iso-C ₄ H 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
ТМАЕ	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)

Generally:

- . $E_{Thermal \ dissociation} < \ E_{Electron \ impact} < \ E_{Ionization \ energy}$
- . $E_{Single\ bonds} \,{<}\, E_{Double\ bonds}$
- . Electrons and photons in a typical avalanche have large enough energy to break the typical molecular bonds.
- . The avalanche is probably too short to create the thermal dissociation, except, possibly, during the Malter effect.
- . Water is less able to do charge exchange than alcohol.

- Polymerization of molecules



Example of polymerization of ethylene:



Necessary condition for polymerization:

- a) e⁻ or $\gamma \Rightarrow$ "Brake a covalent bond" => "Radicals"
- b) "Radicals" may have large dipole moments they stick to electrodes.
- c) "Radicals" are chemically very reactive.

(A typical polymer precursor is radical of ethylene CH₂:).

- 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

- CH₂: 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 :

$$CH_{2}: +H_{2} \implies CH_{4}$$

$$2 CH_{2}: +N_{2} \implies 2HCN + H_{2}$$

$$CH_{2}: +O_{2} \implies CO_{2} + H_{2}$$

$$CH_{2}: +O_{2} \implies CO + H_{2}O$$

$$CH_{2}: +H_{2}O \implies CO + 2H_{2}$$

$$CH_{2}: +CO_{2} \implies 2CO + H_{2}$$

$$CH_{2}: +CO_{2} \implies 2CO + H_{2}$$

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

- In a bond between two atoms, the electrons will be attracted more strongly to the atom with larger electronegativity.

(Taken from my LBL Workshop talk in 1986)

"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, CO₂, H₂O and H₂, which are <u>more stable</u>, and can be removed by a sufficient <u>gas flow</u>.
- 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:

1		
Additive	Chemical formula	Dipole Moment
Water	Н-О-Н	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	$\mathbf{R} \equiv (\mathbf{CH}_3)_2 \mathbf{CH}$	
Methylal:	R-O-R'-O-R	
	$(\mathbf{R} \equiv \mathbf{CH}_3, \mathbf{R'} \equiv \mathbf{CH}_2)$	
Ethers	R-O-R'	1.30 D
	DME: $R \equiv R' \equiv CH_3$	

(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 H₂O, H₂, N₂, NO, N₂O 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)

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

(A. Boyarski's contribution at this workshop)

Gas: 80%He+20%C₄H₁₀+Some additive Source: 100mC Fe⁵⁵ 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 H₂O 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.

Examples:

- 1. SLD drift chamber: 25% Ar+71% CO₂+4% C₄H₁₀+3000ppm H₂0
- 2. BaBar drift chamber: 80% He+20%C₄H₁₀+3500ppm H₂0
 - (~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:

$\mathbf{CH}_2:+\mathbf{H}_2\mathbf{O} \Longrightarrow \mathbf{CO} + 2\mathbf{H}_2.$

- 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 ?

Warning:

- 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 cause a "bad" surface chemistry in RPCs !!!!
- 3. Cannot be used with some photosensitive materials such as CsI or TMAE.

Note:

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

"Good" additive – Alcohols

Why alcohol generally may help:

- 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.
- If alcohol is introduced once the deposits are already made, it tends to stabilize the operation and prevents the Malter. (see A. Boyarski's talk).

Are there some problems with alcohol?

Warning:

- Alcohol and ethers can be broken to formaldehyd CH₂= 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.

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Electrolytic processes in insulators

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

- Electrolytic process in CsI

- 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 $\rho \sim 1.3 \times 10^9 \ \Omega.cm$
- Cesium is very conductive $\rho \sim 2x10^{\text{-5}}~\Omega.cm$

- Electrolytic process in the CsI photocathode

Example of a damage by an operation with gas gain: (P. Krizan et al., NIM A387(1997)146):

- This is still, to my knowledge, not understood

- 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.

Potential trouble with the Linseed oil:

- 1) A current in "Fatty acids" is modulated by a presence of
- water. (Organic Fatty acids have a form: R-COOH)
- 2) Unsaturated bonds may cause a lower resistivity.

- <u>If there is no water</u> then R-COO⁻ just shares a charge:
 <u>The current slowly decays</u> as R-COOH is consumed.
- 2) <u>If there is water</u> then R-COO⁻ will share a charge and convert back to the fatty acid R-COOH.
 => <u>The current will continue</u>.

Note:

<u>Bakelite:</u> "It is the phenol-formaldehyde polymer." <u>Current is also carried via ions :</u> Phenol impurities => (H⁺) + (Ion⁻)

- Indeed that is what is observed:

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

- Adding water sharply increases the current (similar result obtained by Ch. Lu, Princeton).
- Reversal of the voltage does not return the current to the original high value !!
- There is an evidence of an accumulation of some substance on the surface of the Linseed oil (probably related to R-COO).

- BaBar RPC:

Model of BaBar RPC problems:

- a) <u>Too much water</u>, in some chamber, which is distributed non-uniformly throughout the edges and supports.
- b) <u>Not enough water</u>, in some chambers, which will stop the charge transfer through the Linseed oil film layer, and this will cause a charging up effects. The Linseed oil will become some sort of shutter, which prevents a flow of charge.
- c) <u>Unsaturated bonds</u>, i.e. non-polymerized Linseed oil, which makes it less resistive. This effect is non-uniform throughout the chamber due to a non-uniform distribution of the Linseed oil. Adding oxygen will help to polymeryze the Linseed oil which would increase its resistivity.

Note: None of this is proven in the real BaBar chambers yet !!

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Surface chemistry of the electrodes

Example: Belle RPC: (Gas: 30%Ar+8%C₄H₁₀+62%C₂H₂F₄) (D. Marlow, View Wire Chamber Conference, 2001)

Trouble:

Freon + Water + Plasma => "Hydrofluoric acid"

(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.

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Miscl. dependencies

(Wire diameter, gas flow, gas recirculation, gas tube material, gas gain, wire material, etc.)

- 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.

- Aging rate as a function of gas molecule

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

- To be able to measure a finite result, choose molecules where the aging is reasonably fast.

- Wire aging is faster with molecules, which has smaller dissociation energy (for example, the TMAE molecule is more fragile that the TEA molecule).

- Aging rate as a function of tubing material

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

- 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 gas gain

(M. Danilov et al., IEEE, Lyon, France, 2000)

- HERA-B muon detector:

- subdivide chambers into groups of these gains:

 $\sim 8x10^3$, $\sim 4x10^4$, $\sim 6x10^4$, $\sim 10^5$, $\sim 2x10^5$.

- Current densities: ~100nA/cm up to 400nA/cm.
- Gas flow: ~2 volumes per hour.

Results in the HERA-B environment:

- No aging effect observed in 65%Ar+30%CF₄+3%CO₂+ 1000ppm of H₂O gas up to ~400mC/cm, in all five different gain groups.
- 2) <u>Large aging rate</u> in 67% Ar+30% CF₄+3% CH₄+500ppm of H₂O, which depends on <u>gas gain</u> and area of irradiation.

Authors conclude:

=> Accumulated charge alone cannot explain data consistently.

- Is a gas recirculation safe ?

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

Gas: 50%Xe+30%CO₂+20%CF₄

- Good aging result observed in the "Irradiated chamber": no detorioration 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 suprizes.

List of No, No...

- . No halogens in the gas
- . No oil traces in the gas
- No RTV to seal the chambers
- . Avoid all soft glues
- . No PVC or Tygon gas tubing
- . No sparking with a large capacitance
- . 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

(Taken from my LBL Workshop talk in 1986)

Last few words of "wisdom".

- It is cheaper to spend money on electronics (better amplifiers, highly segmented HV power supplies with a low trip levels, etc.) than to rebuild the chambers.
- . Run as low gas gain as physics allows.
- Run as low HV trip level as possible.
- Use clever software to search for any anomalous activity in the chamber.
- Use gas additives right from the beginning, do not wait when you detect a trouble.

• I think there was a tremendous progress compared to the early days of wire aging.