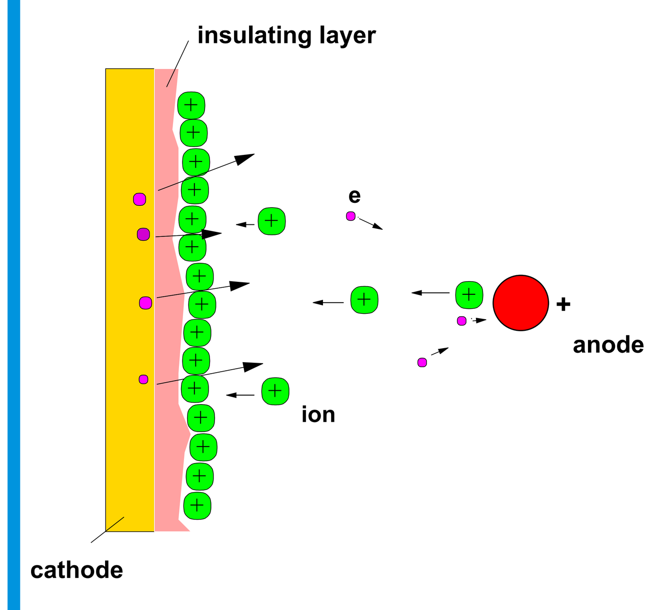
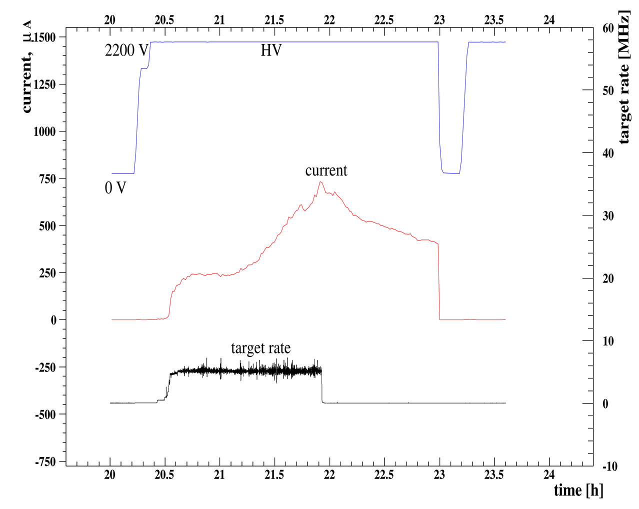
# Observations on Cathode Aging (Malter-Effect) in Honeycomb Drift Chambers under High Irradiation

## Details of Aging Test




*Model of Malter-effect*

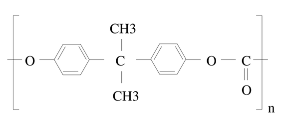
| | |
|---|---|
| Lab. test or result from exp.: | prototype test under exp. conditions, Lab.tests |
| Name of the detector : | HERA-B Outer Tracker |
| Signif. degradation of performance: | persistent Malter currents |
| Most critical change: | fast reexcitation after first occurence of Malter-effect |
| Anode wire materialr: | 25 µm Au-coated W |
| Cathode material: | uncoated conductive polycarbonat (POKALON-C) |
| Electric field on anode wire: | 340 kV/cm |
| Electric field near the cathode: | 1.7 kV/cm |
| Particle rate (in Hz/cm): | up to $4 \cdot 10^5$ |
| Anode current (in nA/cm): | up to $10^3$ |
| HV applied: | 2250 V |
| Gain (per primary electron): | $2.5 \cdot 10^4$ |
| Type of radiation (eg: beam particle, etc.): | hadrons, electrons, X-rays |
| No. of primary electrons per ion. event: | $10^2 ... 10^4$ |
| Approximate total charge dose (in C/cm): | 4 (X-rays), $10^{-3}$ (hadrons) |
| Gas composition (including additives): | $CF_4/CH_4$, 80/20 |
| Gas flow rate (in detector volumes/hour): | 1 |
| Gas flow condition: | open honeycomb cells in gas-box |
| Gas impurities: | not analyzed |
| Gas pressure: | 1 bar |
| Length and material of gas tubing: | 1 to several meters; material copper, Teflon, later stainless steel |
| Materials in the gas system: | Noryl, Araldite AW106+hardener Hv953 (Ciba-Geigy), FR4, E-solder 3025 (IMI) (not complete) |




*Example of time evolution of current in HERA-B prototype chamber, showing Malter-effect*

## Factor I: Cathode Surface

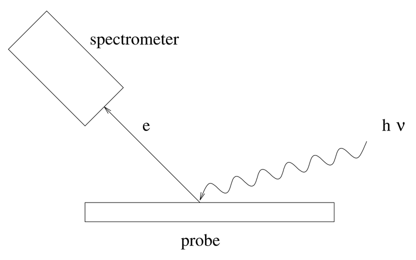
General condition for Malter discharges:
insulating layer on cathode, existing or building up under irradiation, after charging-up by positive ions, leading to sufficient electron emission for sustaining a stationary (corona) discharge for sufficiently high electron amplification.
Confirmation of this model for the case of cathode foil from POKALON-C, a polycarbonate based on Bisphenol-A, loaded with 6% of soot, with formula:



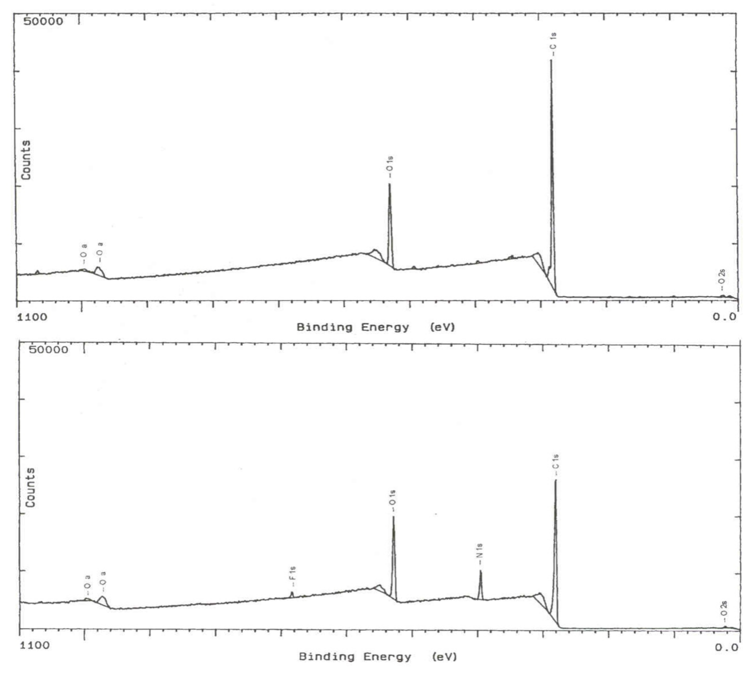

Investigation of surface properties:

1. Direct resistivty measurement (voltage drop for given current through foi):
   - unsuccessfull, irregularities connected to surface roughness

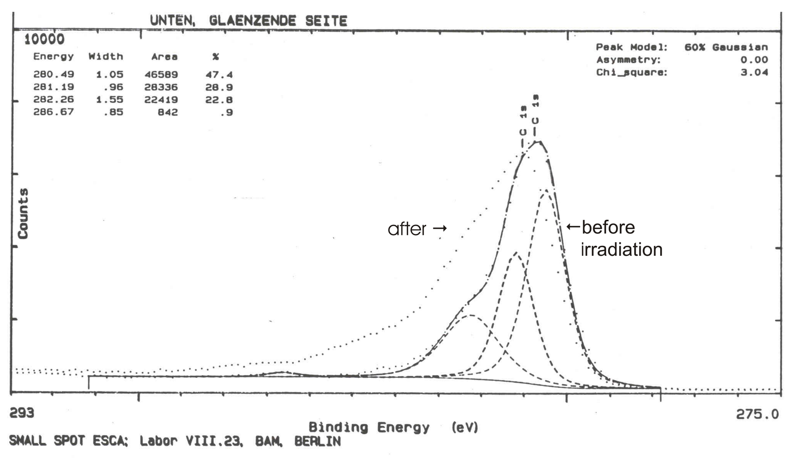
2. Chemical analysis of surface by (photo)electron spectroscopy (ESCA), principle:




Results and observations:
- charging-up of surface (positively)
- no soot seen (to depth  10 nm)
- on used foil: C-O-groups from Bisphenol-A (as seen on fresh foil) covered by plasma condensats, containing C-F and C-N groups.

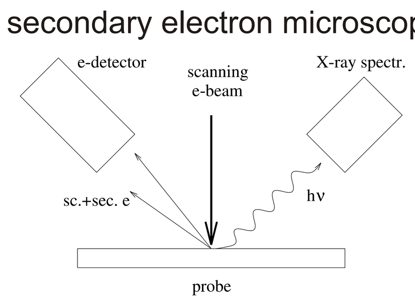



*Esca spectra of POKALON-C cathode foil before (upper spectrum) and after (lower spectrum) irradiation (from region showing Malter-effect): N and F in organic bounds appear (besides expected CO groups).*




*High resolution spectra from the same places show broadening of C-peak for irradiated foil, characteristic of plasma polymers.*

3. Scanning secondary electron microscopy (SEM), Principle:




Observation:
- Reversible loss of contrast, if primary electron energy diminished below 900 eV ( penetration depth below 100 nm).
- This effect is characteristic for 75 µm POKALON-C foil without treatment.
- Prevented by mechanical scraping, plasma-etching, conductive coating. Also not observed on 15 µm POKALON-C foil, ATLAS-straw foil.

Explanation: charging up of surface (in case of 75 µm foil too low conductivity in upper layer).

*SEM-pictures of 75 µm POKALON-C foil for electron energies 1 keV, 0.9 keV, return to 1 keV: the contrast disappears (reappears) with threshold -like behaviour (lefthand side).*

*SEM-pictures of partially etched 75 µm POKALON-C foil (0.6 → 1.0 keV): the contrast (re)appears in the non-etched region only (upper and lefthand edge of pictures below).Lefthand edge of pictures below).*

## Factor II: Beam

The charging-up of an (insulating) cathode surface is related to the local ionisation current density, which in turn very strongly depends on beam conditions.

Malter-effect not clearly observed

| Place | Several lab's | HMI Berlin | FZ Rossendorf | FZ Rossendorf | Zeuthen |
|---|---|---|---|---|---|
| Beam/energy | X-rays/ 35 keV | $e^-$ / 2.5 MeV | /28 MeV | p/13 MeV | /4.5 MeV |
| Irr. dosis | Up to 5 C/cm | 10 mC/cm | 3 mC/cm | 5 mC/cm | 150 mC/cm |
| Remarks | Reexcitation possible | Not seen | Not reproducibly seen | Seen after increasing HV | Not seen |

Malter-effect observed and confirmed

| Place | HERA-B | PSI | PSI | FZ Karlsruhe |
|---|---|---|---|---|
| Beam/energy | Hadrons/undefined | Hadrons/350 MeV | p/70 MeV | /100 MeV |
| Irr. dosis | few mC/cm | few mC/cm | 3 mC/cm | 10 mC/cm |

Conclusions:
- Only sufficiently energetic (> ~100 MeV) hadrons excite Malter discharges in new chambers
- heavily ionizing nuclear fragments have to play a prominent role.

X-rays produce more diffuse primary ionization; the total ionization current cannot be enhanced sufficiently due to space charge limitation
- local current density stays too low.

Reexcitation possible (in already sick chambers and chamber build from aged foil).

$j_+^{max}$ may reach values much higher than mean current densities
$j_+^{max} \approx$ 3.4 mA/cm$^2$ >> $\langle j_+ \rangle \approx 1$ cm
(see box "parameters and relations").
The lifetime of ion layers extends over many orders of magnitude: practically no charging - up, if surface resistivity comparable to bulk resistivity of POKALON - C, otherwise nearly unlimited for insulating surface layers.

**Parameters and Relations**

Change of surface charge density $n$ :

$$\frac{dn}{dt} = j_+ - j_-,$$

$$j_+ = \frac{Q}{\Delta t \, \Delta z \, 2\pi r_a}, \quad j_- = E_{SC} / \rho = n / (\varepsilon\rho)$$

$Q$ – charge / particle hit
$\Delta t$ – duration, $\Delta z$ – extension along chamber for ion cloud hitting cathode at radius $r_a$,
$E_{SC}$ – electric field of surface charge,
$\rho$ – resistivity,
$\varepsilon$ – permittivity of surface layer

**Numerically :**

$Q \simeq 10^6 \div 10^8 \, e$ (for MIPs / HIPs),
$\Delta t \simeq 1 \, \mu s$, $\Delta z \simeq 30 \, \mu m$,
(from diffusion of ions and electrons),
$r_a = 2.5$ mm,
$\Longrightarrow j_+ = 34 \, \mu A / cm^2 \div 3.4 \, mA / cm^2$
$\Longrightarrow \tau = \varepsilon\rho \simeq 3 \cdot 10^{-13} \, s \div 3 \cdot 10^3 \, s$
(for POKALON – $C$ / pure polycarbonate)

## Factor III: Gas

The influence of gas mixture including impurities from leaks and outgassing was not studied systematically. The following observations are to be considered as indications.

$CF_4/CH_4$ (80/20): Strong Malter effect, not affected by addition of $H_2O$ (up to 0.5%), but partially cured by ethanol (the latter excluded, however, for its negative influence on glue stability).

$Ar/CF_4/CH_4$ (74/20/6) (Voltage lowered to 1600 V): Malter effect observed, partly superseded by strong anode aging.

$Ar/CF_4/CO_2$ (65/30/5) (Voltage lowered to 1700 V): typically effect difficult to reproduce . Observed in experimental area only, no special aging tests.

The change to a gas not containing hydrocarbons nor impurities from outgassing of Araldit seems to remove the memory effect, probably because plasma polymerisation is inhibited.

Gas flow effects: In case of (plasma)chemical processes to be expected, if diffusive exchange of neutral species involved. Indeed it was observed that Malter-currents grow, if gas flow is enhanced to very high values.

The ultimate remedy: conductive coating

(Higher insurance against occasional Malter effect by gas $Ar/CF_4/CO_2$ )

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