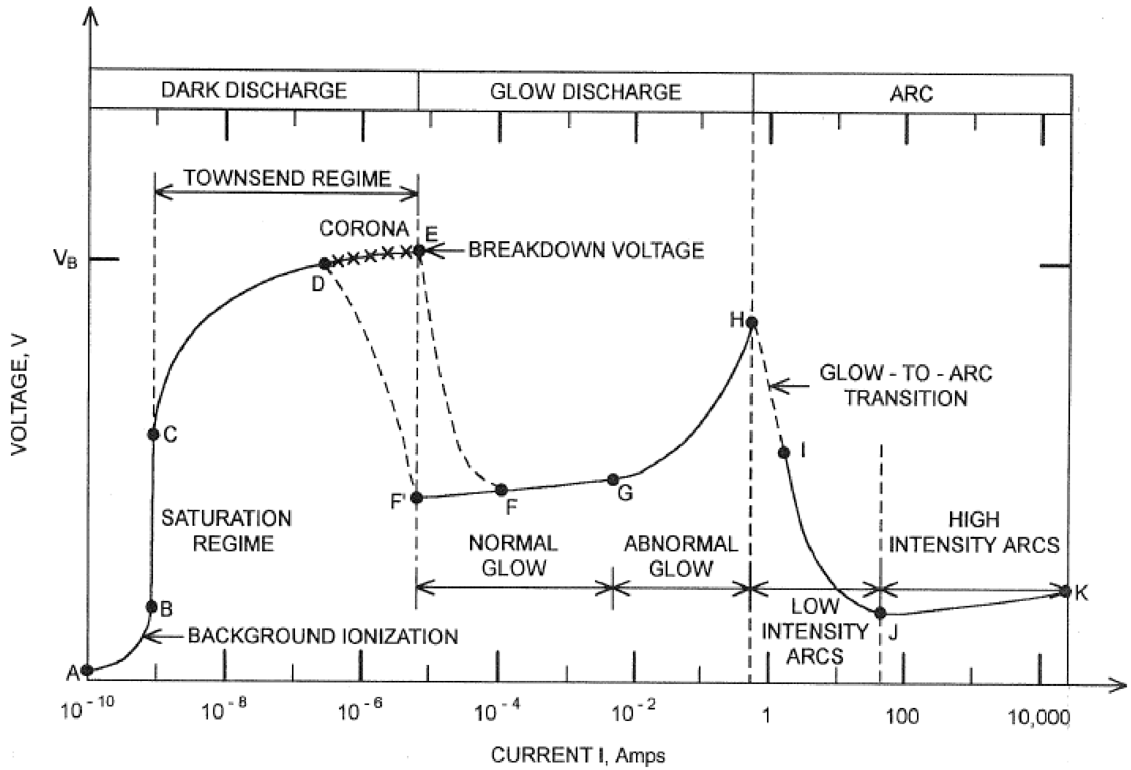
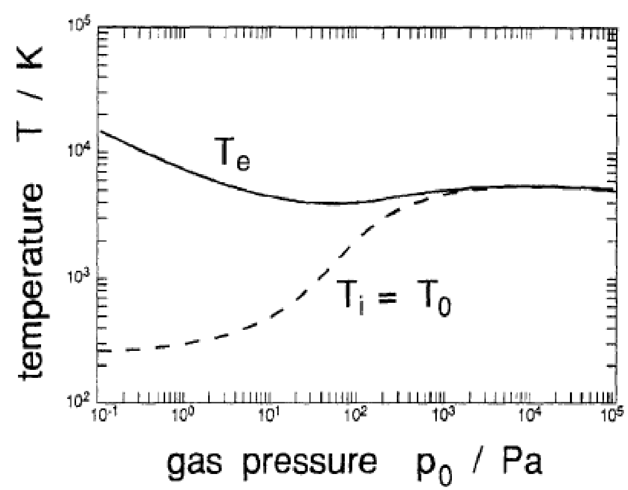
3 types of the stationary discharges:





To generate the non-equllibrium plasma at near-atmospheric-pressures (important for many applications) it is necessary to avoid of „ (e) The filamentary glow to arc transition“

It can be done in the following types ot the non-stationary high-pressure discharges (or their cobinations)

1. ***Impulse discharges - the case of TEA lasers excitation – extremely multiavalanche initiated streamer breakdown***

2. ***Corona discharges (DC or AC)***

3. ***Dielectric barrier discharges (one or several dielectric „barriers" are situated on the lectrode surfaces, or in the gap)***

DEFINITIONS OF THE CORONA DISCHARGES:

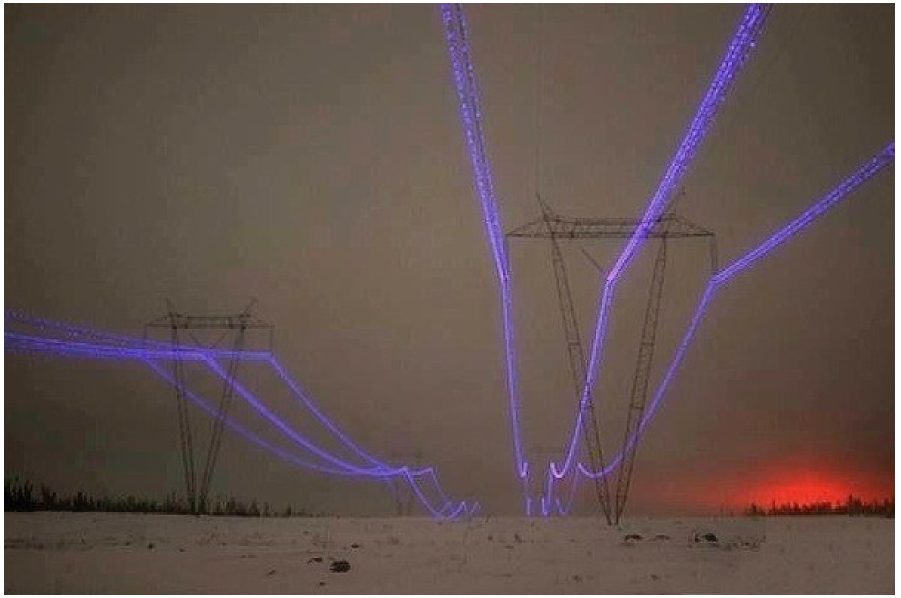
Goldman M, Goldman A and Sigmond R 1985 Pure Appl. Chem. 57 1353–62:

'A corona is self-sustained electrical gas discharge, where the Laplacian electric field confines the primary ionization process to the regions close to high field electrodes or insulators'.

Kogelschatz U and Salge J 2008 Low Temp. Plasmas 2 439:

'Corona discharges are self sustained gas discharges typically operated in air at atmospheric pressure between metal electrodes. At least one of the electrodes is of a geometric form which causes locally high fields. Common configurations are pointed electrodes facing a plane, ...etc. When the voltage is raised in such a configuration current starts to flow at corona onset and increases until the potential for spark is reached. This intermediate range of corona activity is referred to as a partial breakdown of the gap.

The corona is characterized by a faint visual glow in the high-field region occasionally accompanied by luminous streamers propagating toward the other electrode.'



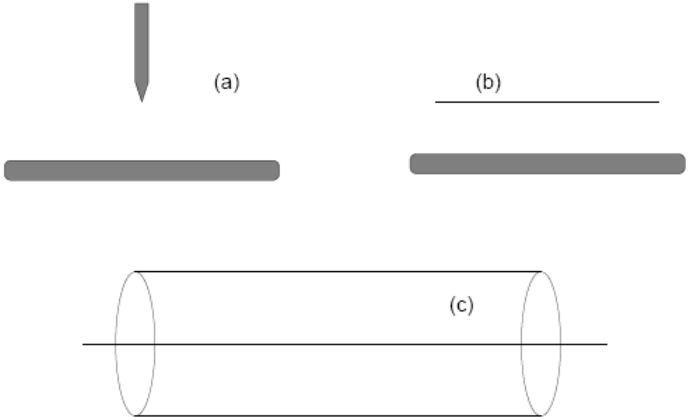
El.corona discharges

- are generated in strongly non-uniform el.fields at near-atmospheric pressures, where the ionization is resticted to a part of the interelectrode space in the vicinity of the electrode with a small radius of the curvature

← **„St. Elmo's fire"**

In 1751, Benjamin Franklin observed a corona discharge on the tip of a grounded metallic rod during the thunderstorm

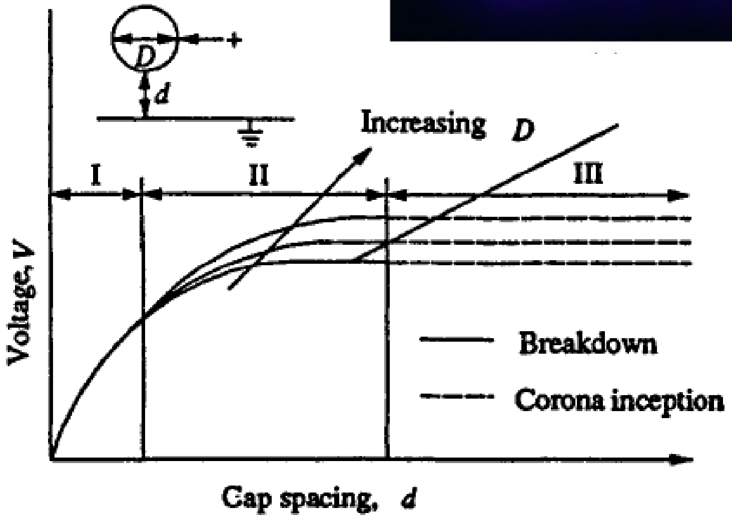
Typical electrode geometries for the corona discharges:
(a) point-to-plane (b) wirw-to-plane (c) coaxial electrodes



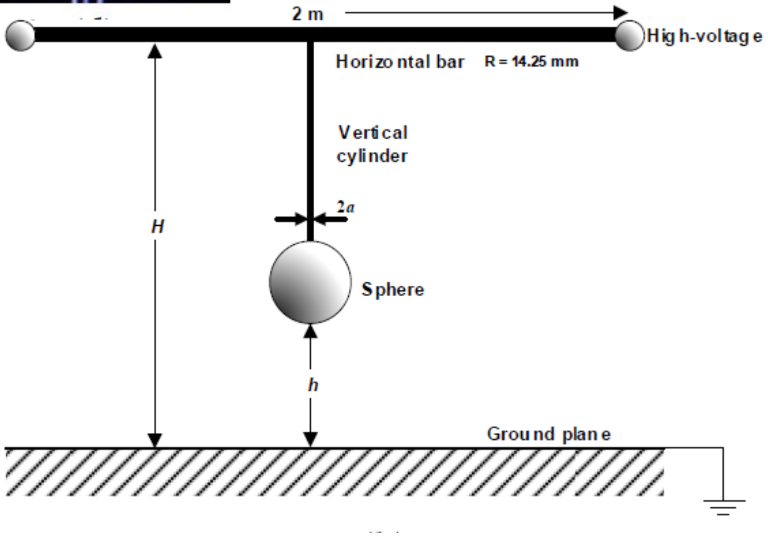
Corona discharge vs. Spark (arc) discharge

(partial breakdown) („breakdown“)

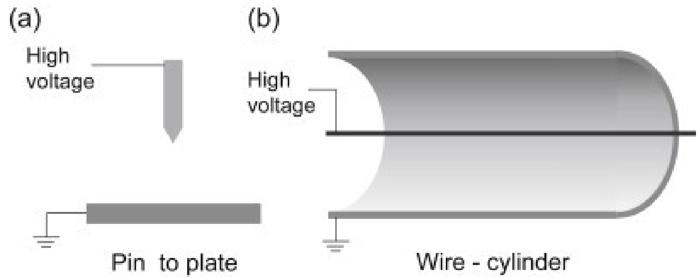
D = 2 cm
d = 15 cm

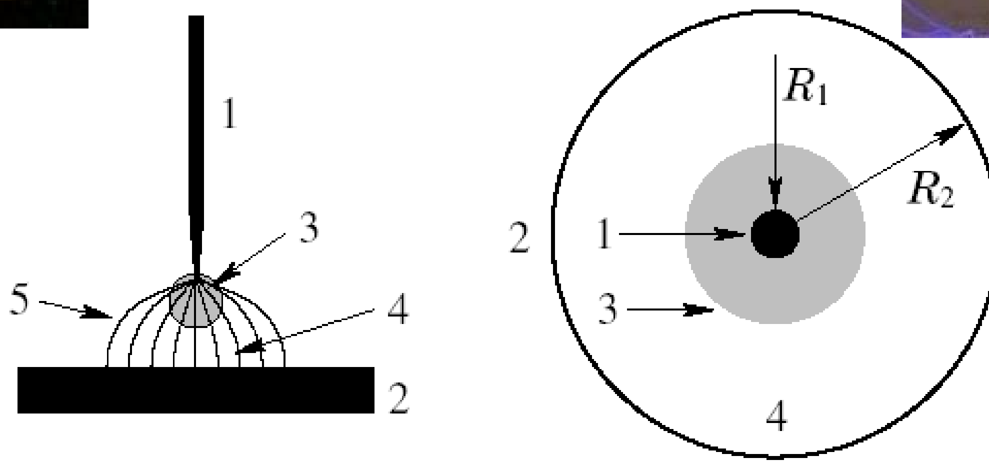


Breakdown and corona inception characteristics for spheres of different diameters in sphere-plane gap geometry



In ambient air corona discharge exists for approximately D/d < 0,1 - 0.05





a) *b)*

Obr. 5.8: Korónový výboj v dvoch typických geometriách: *a*) hrot–rovina; *b*) koaxiálne usporiadanie valcových elektród. V týchto geometriách je: 1 – korónujúca elektróda (s malým polomerom krivosti); 2 – elektróda s veľkým polomerom krivosti; 3 – ionizačná vrstva; 4 – vonkajšia oblasť výboja; 5 – elektrické siločiary. Polomery vo valcovej geometrii sú označené R_2 a R_1 (pre korónujúcu elektródu)

„DC" (50 Hz) Positive corona disch.
At the moment when the corona electrode electrode is the anode

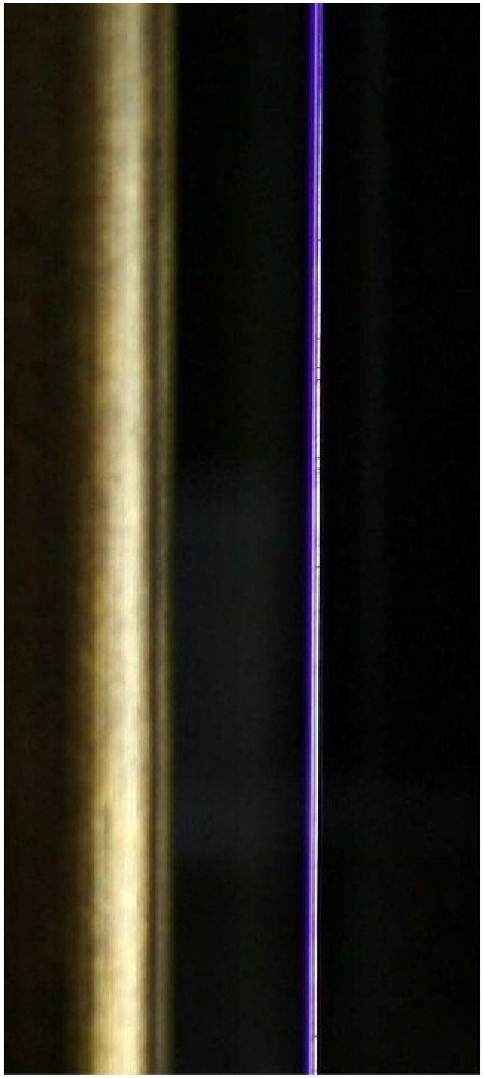
See the positive streamers starting from the uniform glow plasma covering the anode

„DC" Negative corona discharge
At the moment when the corona electrode is the cathode

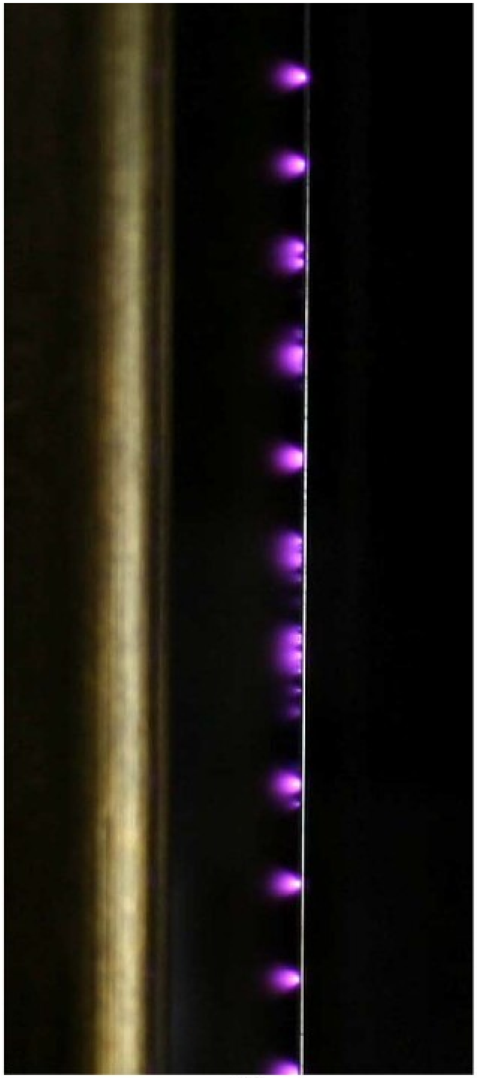
see the so-called neg. corona spots

Corona Discharges in Atmospheric Air Between a Wire and Two Plates

Philippe Bérard, Deanna A. Lacoste, and Christophe O. Laux



(a)

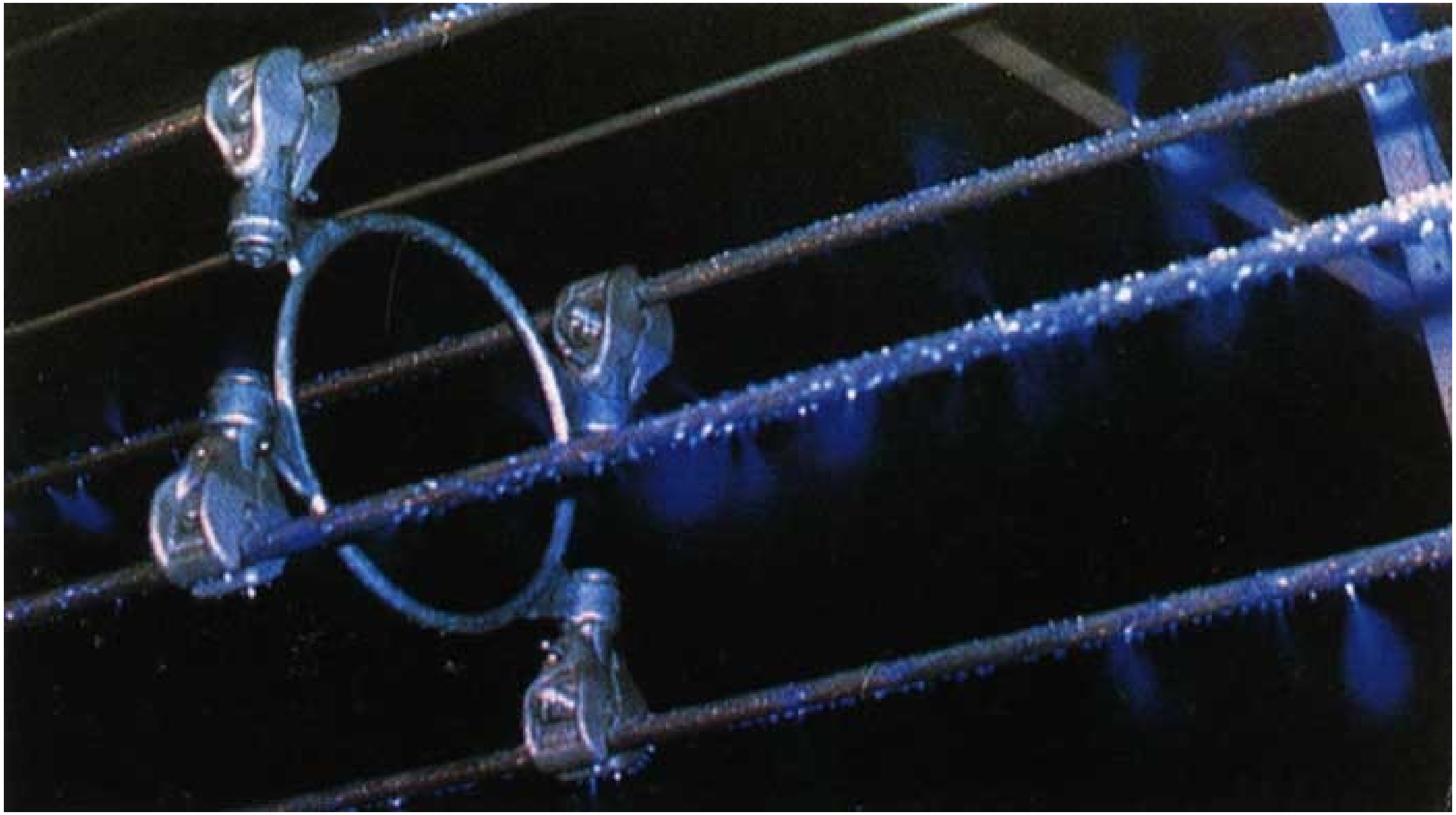


(b)

Fig. 2. Corona discharges between a high-potential wire and two grounded plates in air at atmospheric pressure and ambient temperature. (a) Positive corona ($V = 14.2$ kV, $I = 1.5$ mA). (b) Negative corona ($V = -10.5$ kV, $I = -1.3$ mA).

What is the polarity of the corona ?

- See the primary negative streamers starting from the cathode spots



(e) THE STREAMER BREAKDOWN ALWAYS OCCURS IN THE FOLLOWING SEQUENCE OF EVENTS

(a) The avalanche stage, wherein the streamer initiating charge in a localized region is formed by charges generated in a single avalanche or more often accumulated in a sequence of avalanches

(b) The positive primary streamer initiation: after an initial delay, when the streamer initiating charge partially shields itself from the external field forming a 'critical' region of relatively dense plasma (10^{13}–10^{15} cm−3) resulting in the primary positive streamer starts to propagate.

(c) The positive streamer propagation, where the primary streamer head propagates as a luminous spot of the diameter typically less than 1 mm with the velocity usually in the range 10^7 –10^8 cm s^{-1} followed by a less luminous streamer trail.

(d) The streamer arrival to the cathode, forming an active glow-discharge type cathode spot, which is effectively producing the **glow to arc transition** is often initiated by the growth of secondary streamers

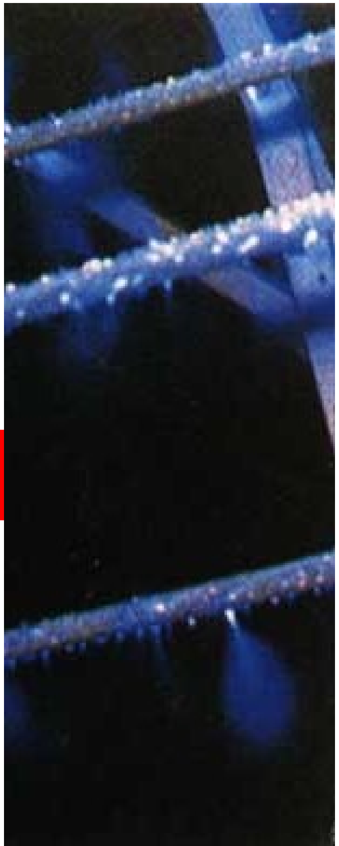
Positive corona :

Negative corona:

Where is the primary positive streamer ? ⟶

← **positive streamer**

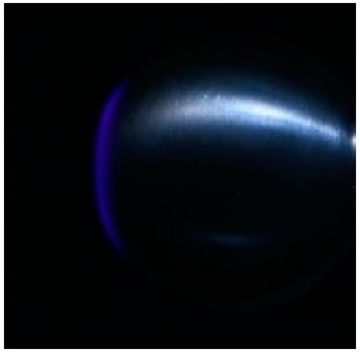
negative streamer →



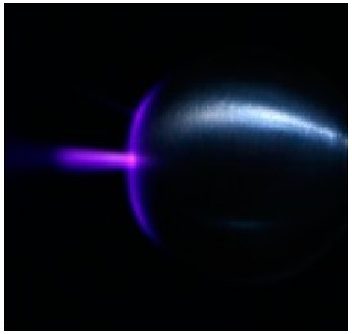
Mechanism of the positive corona:
No single „critical avalanche" !!!

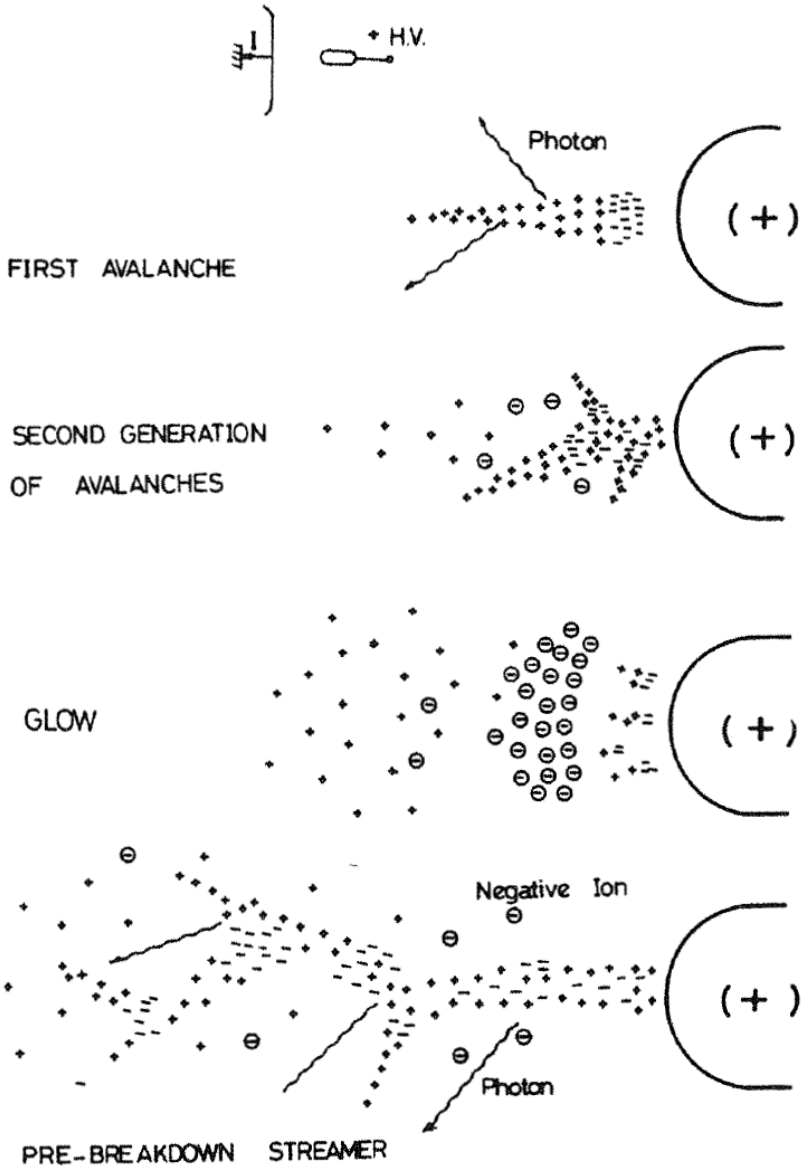
„pre-onset burst pulses"

„glow corona"



„pre-breakdown streamers"





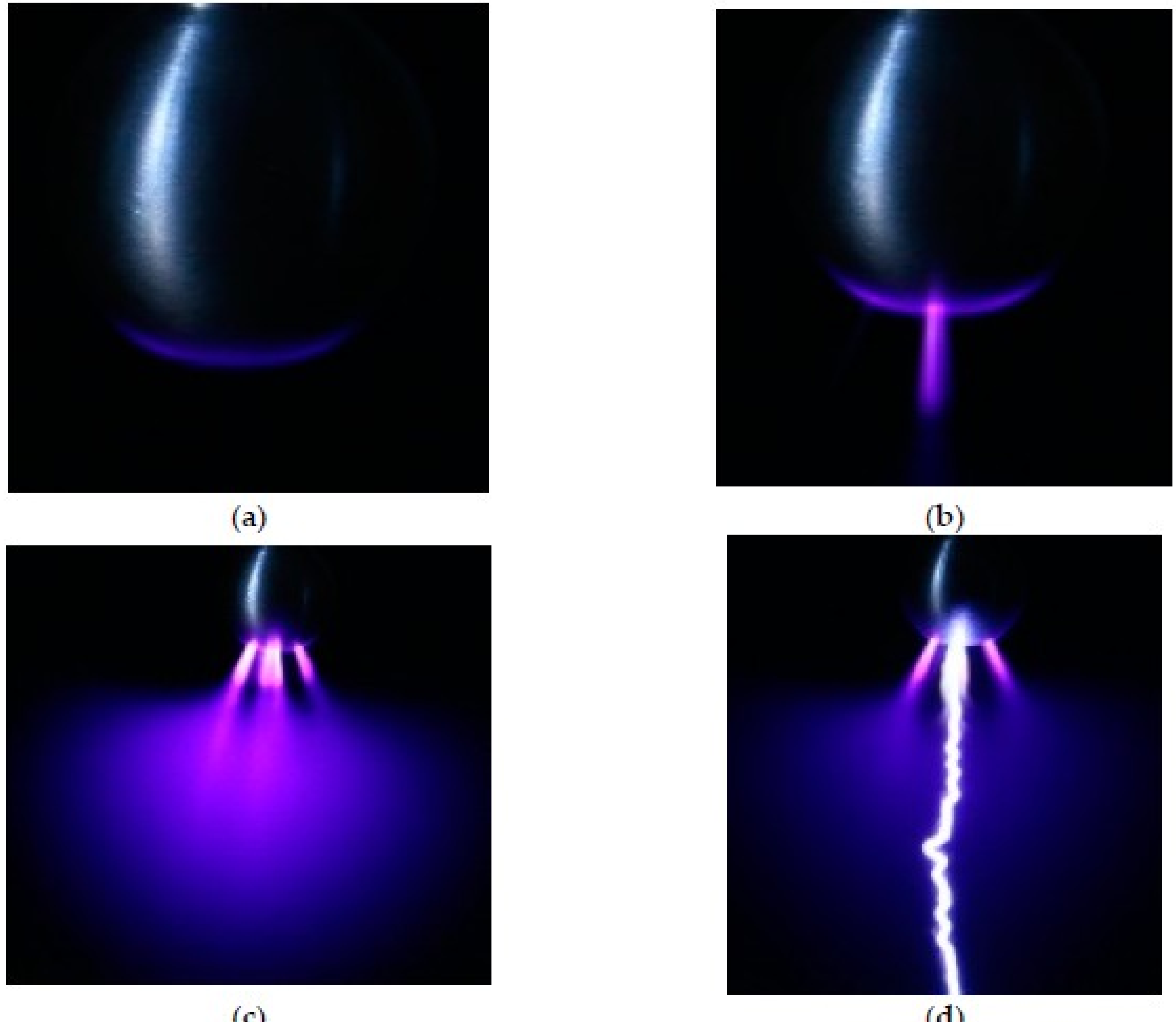


Figure 3. Positive polarity dc corona (sphere diameter of 20 mm, h = 15 cm). (a) Initial corona glow at +55.5 kV; (b) Corona glow and streamer initiation at +56.0 kV; (c) Advanced positive corona combining glow and streamers at +62 kV; (d) Spark breakdown at approximately +80 kV.

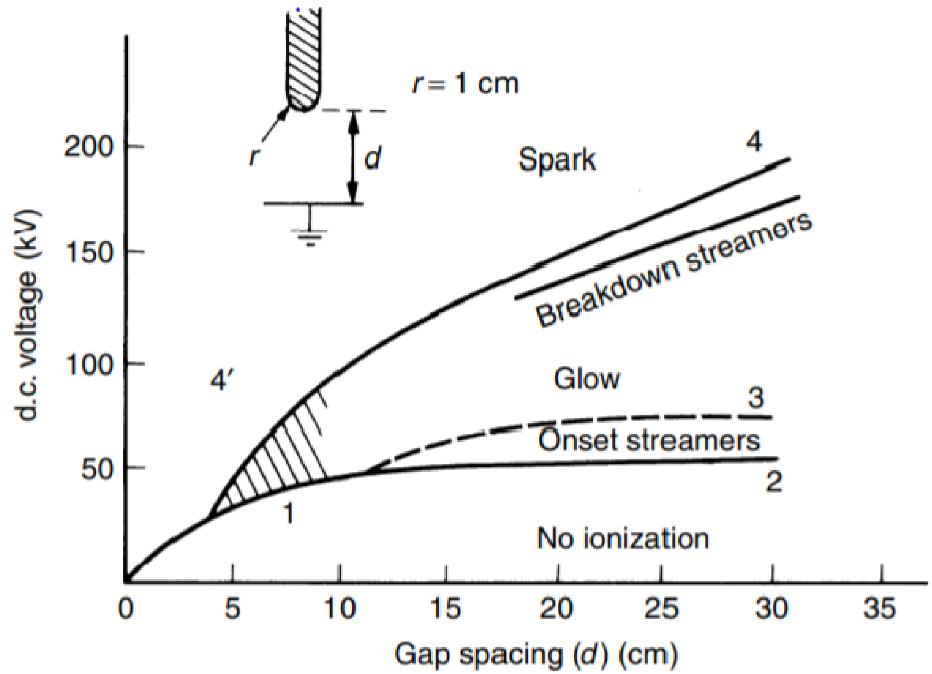


Figure 2.11. Threshold curves for various modes of positive corona in a rod-plane gap with a rod radius of 1 cm [12].

E. Kuffel, W. S. Zaengl, and J Kuffel. *High Voltage Engineering: Fundamentals.* Butterworth-Heinemann, 2000.

The „traditional “ criterion for the streamer onset exp(α,x) ≥ 10^8 is not true since the streamer starts form a multiavalanche glow

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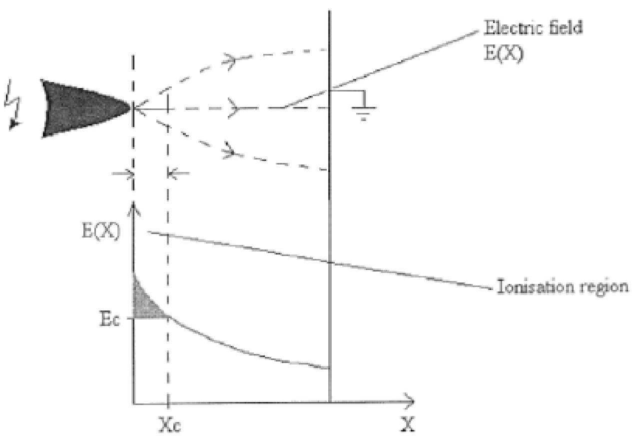
Vernon Cooray

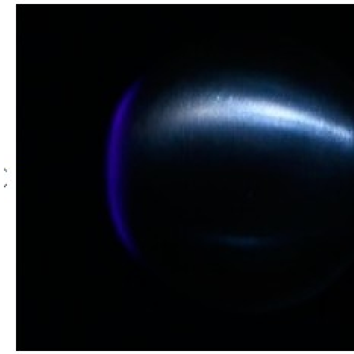
Non uniform gap

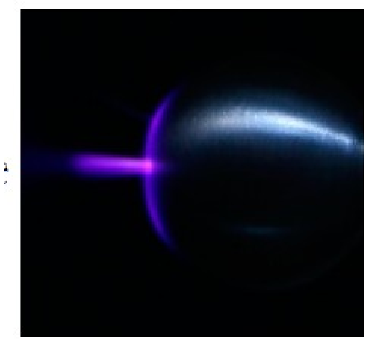


inception criterion: The criterion for the inception of the streamer can be written as

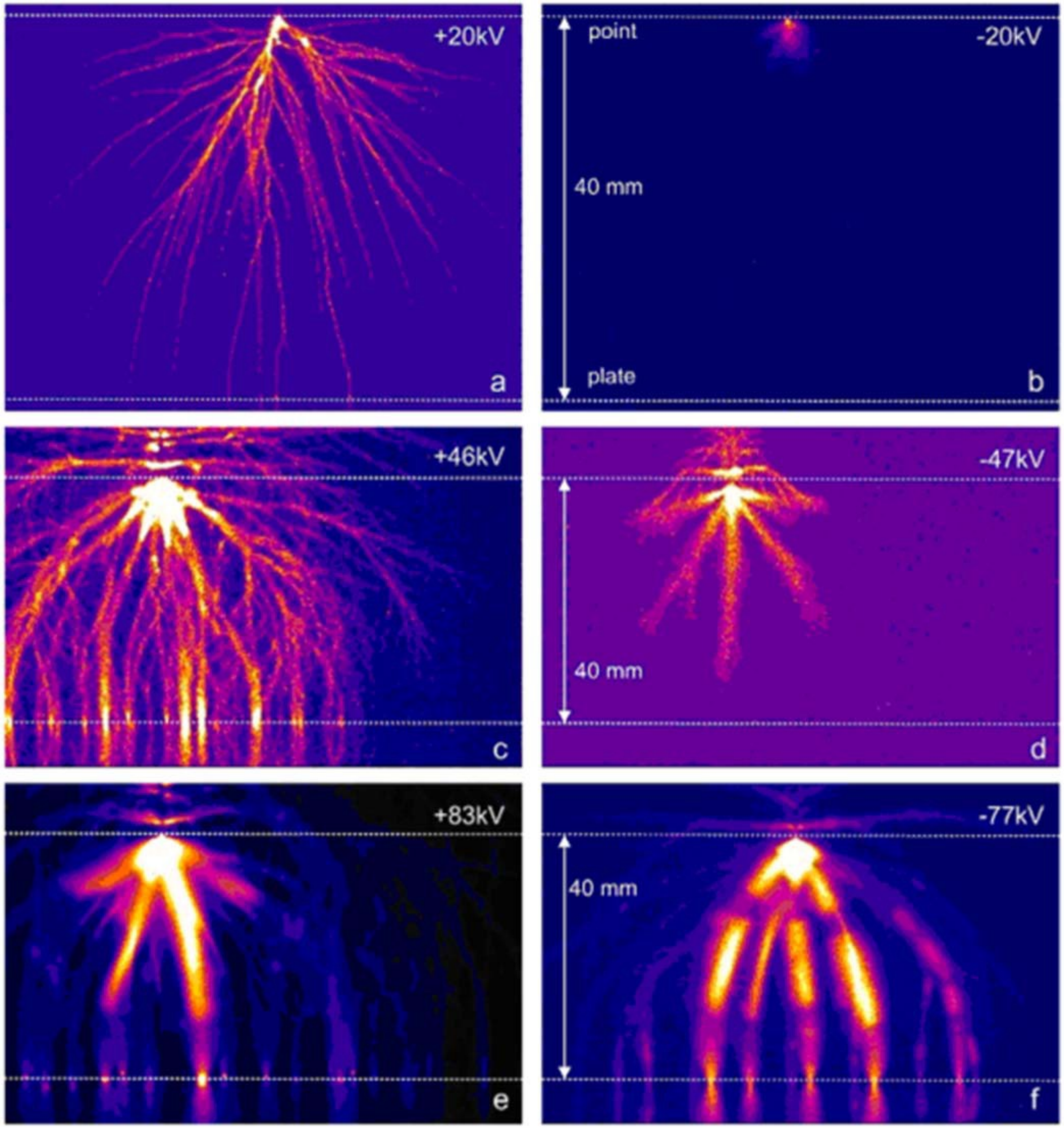
$$\int^{x_c} \overline{\alpha}(x)dx \geq 18$$

where x_c is the axial length of the region within which the electric field is high than 2.6 x 10^4 V/cm.



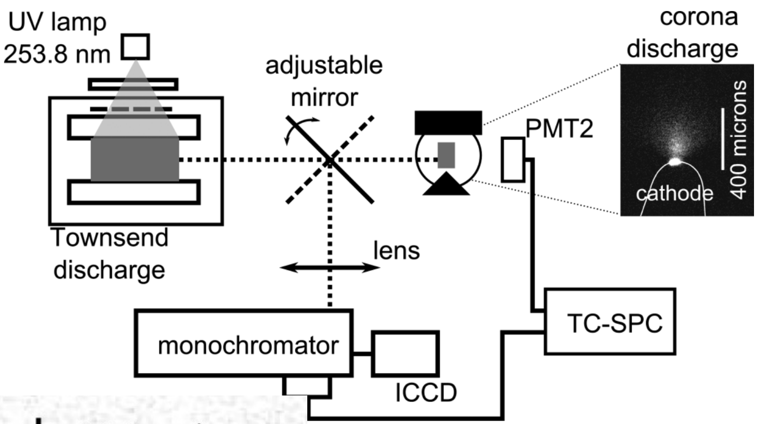


Positive pulse ↓ and negative pulse ↓ coronas in ambient air

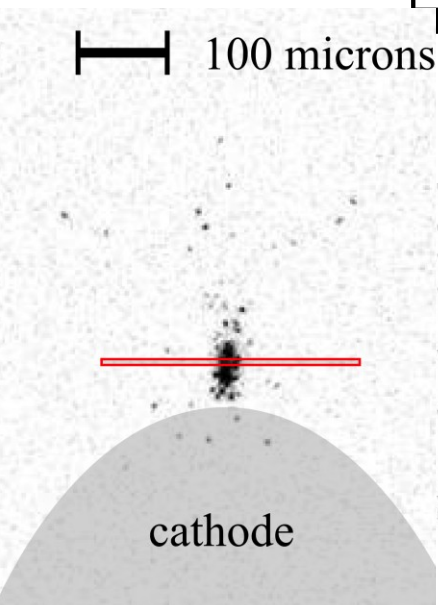


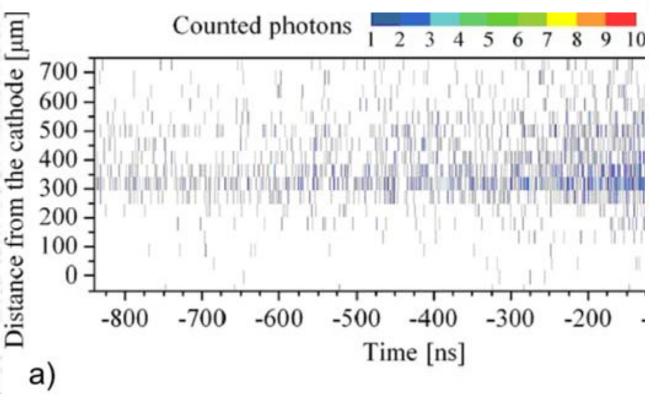
Where is the positive streamer arrival to the cathode generating the cathode spot ???

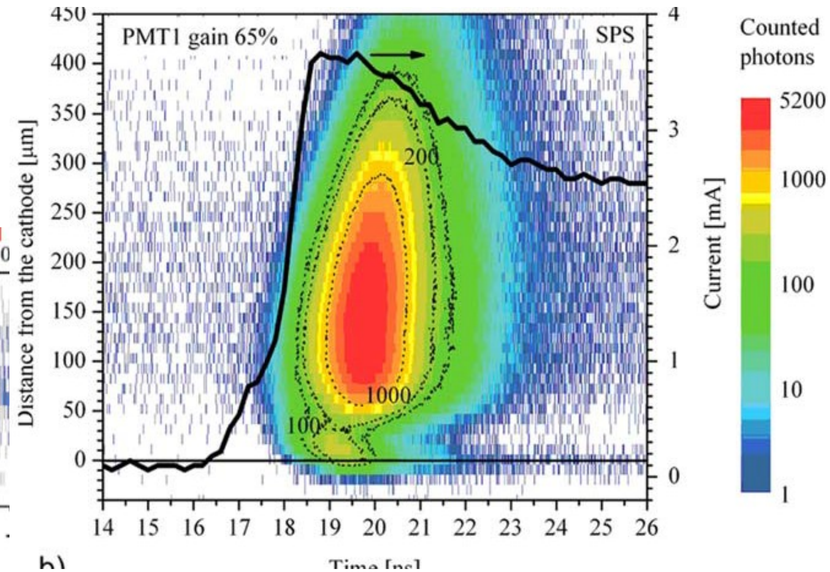
In the negative corona discharge the positive streamer is generated in the immediate vicinity ~ 0.1 mm of the cathode



M. Černák et al.: Plasma Sources Sci. Technol. 29 (2020) 013001



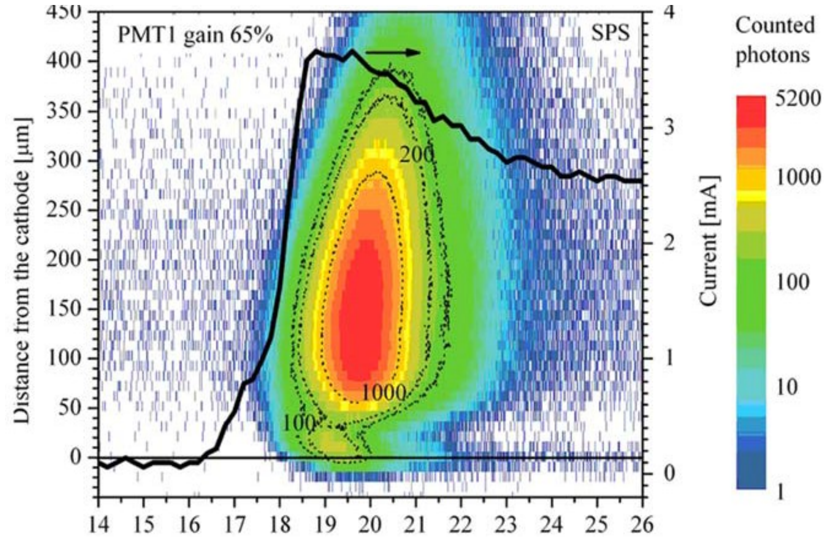




Initial avalanche ionization

Positive and negative streamer formation

„streak camera record"



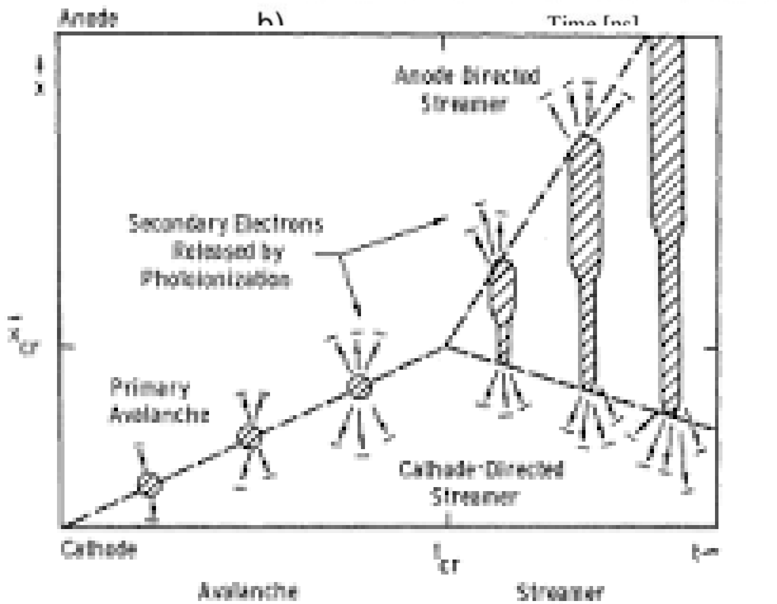
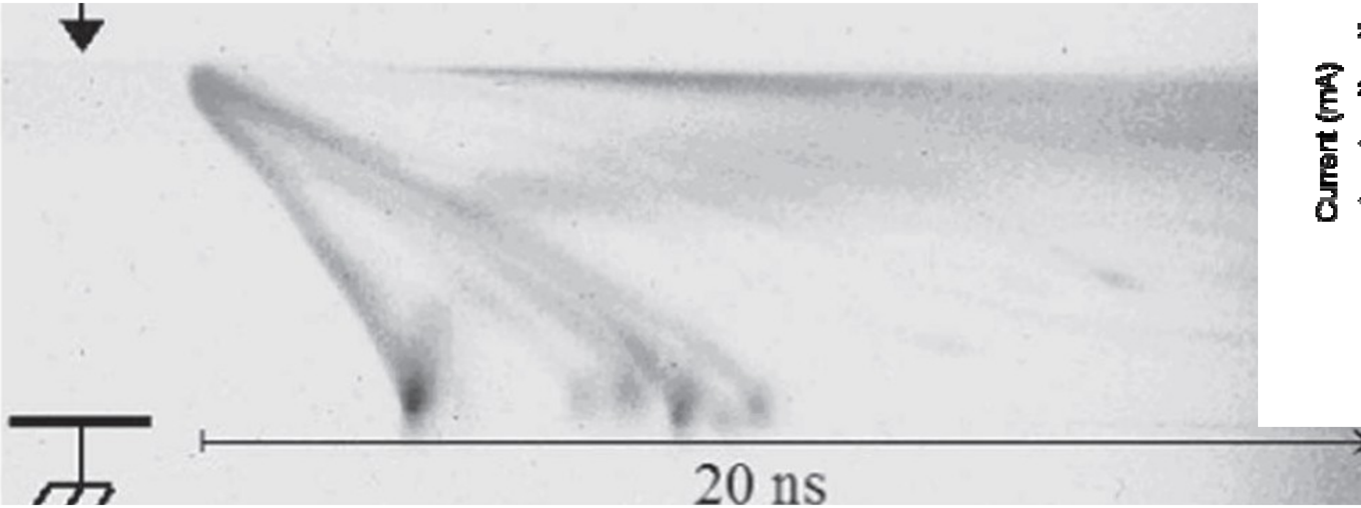
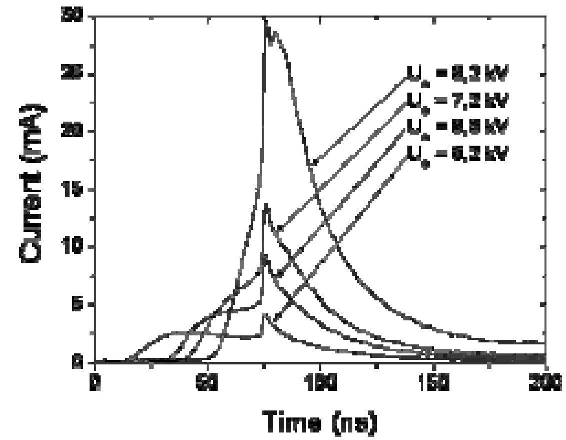


FIG. 6. Schematic representation of the qualitative description of streamer development given by Wagner. (Based on Figs. 22 and 27 of Ref. 11.) Anode- and cathode-directed streamer propagation begins at $t_{critical}$ when the avalanche position equals $x_{critical}$.

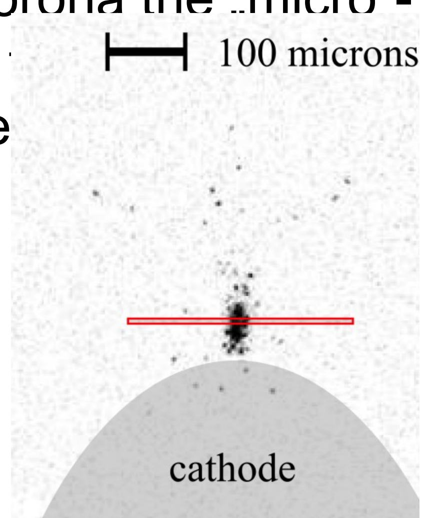
In the POSITIVE corona discharge the arrival of the primary positive streamer to the cathode induce a fast-rising (~ 1 ns) current pulse :

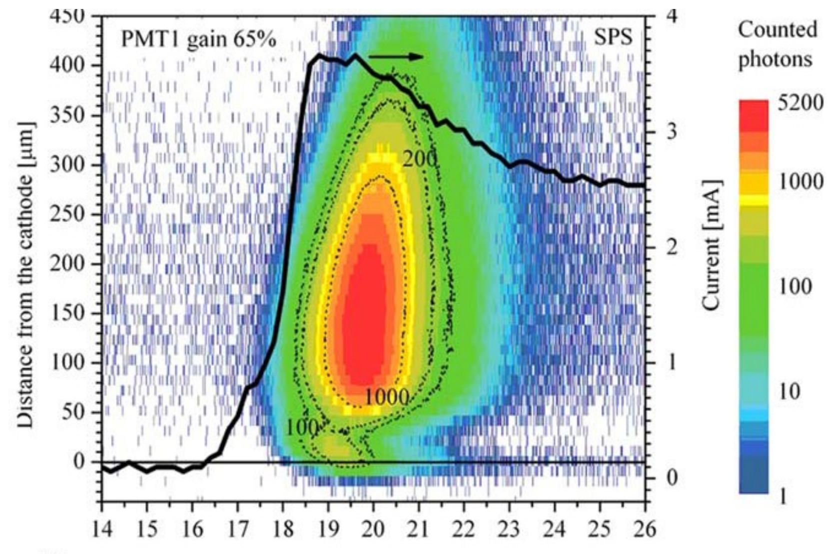




Streak camera record in a 2 cm ambient air gap with an anode radius of 50 µm. The applied voltage and streak are 36.8 kV and 20 ns,

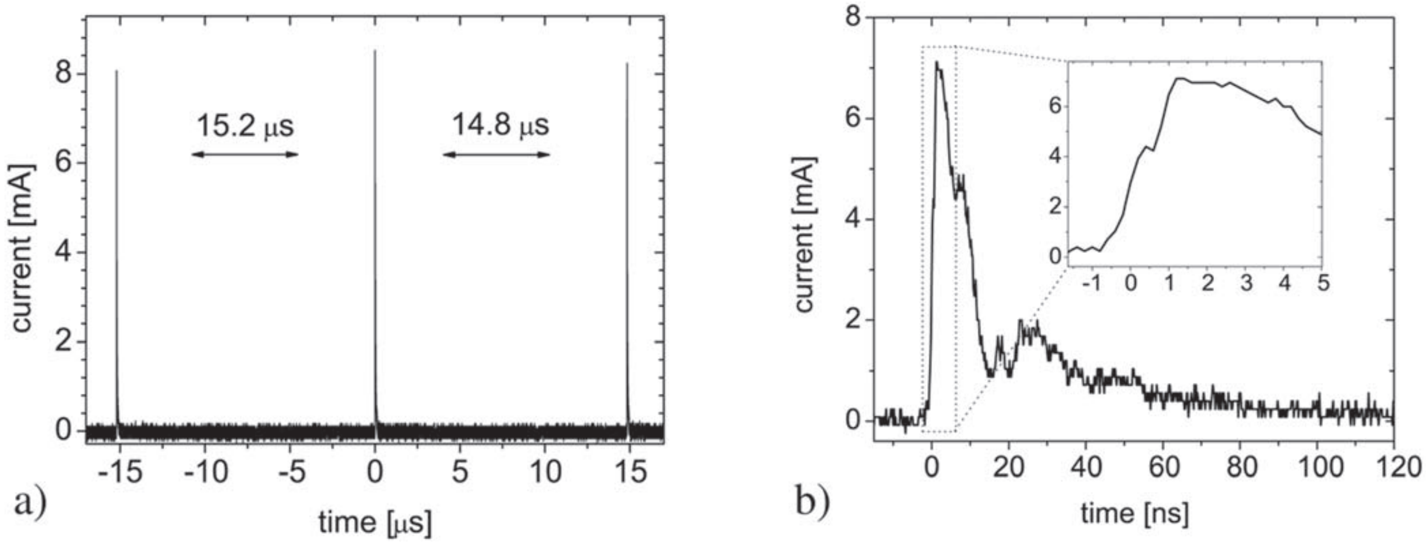
Similarly, in NEGATIVE corona the „micro“-
positive streamer arriving
the cathode induces there
the fast-rising (~ 1 ns)
current pulse





Negative corona discharge – Trichel pulses

Figure (b) shows current peak of 7 mA amplitude generated at the arrival of positive („micro“) primary streamer to the cathode tip. For 10 ns < t < 100 this current peak is followed by a 1 – 2 mA current of a glow discharge. However at some 100 ns the glow discharge is quenched by the formation of negative ion space charge due to the electron attachment. The next current pulse is generated after ~ 15 μs, when the negative ion space chargé drifted away enough from the cathode. The periodic current pulses generated in this way are called **Trichel pulses**.



Záporný korónový výboj – Trichelove impulzy

Takže i keď je na elektrodách jednosmerné napatie, prúd záporného korónového výboja v plynoch, ktoré tvoria záporné ióny (vzduch, O_2, CO_2, H_2O,…) pozostáva z pravidelne sa opakujúcich Trichelových impulzov s frekvenciou od cca 1 kHz až do 1 MHz.

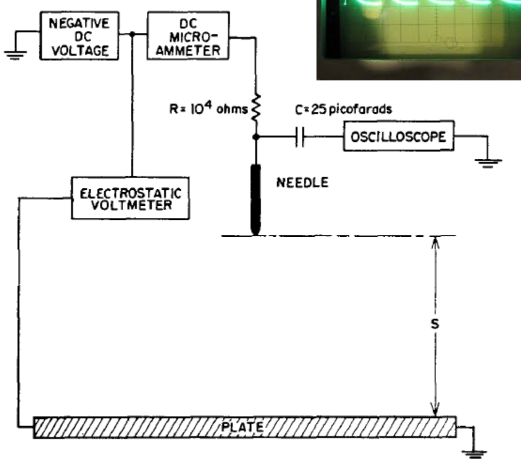
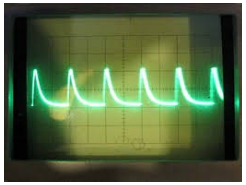


FIG. 1. Schematic diagram of the electrical equipment used to measure the Trichel pulse frequency of negative needle-to-plane coronas in ambient air at atmospheric pressure.



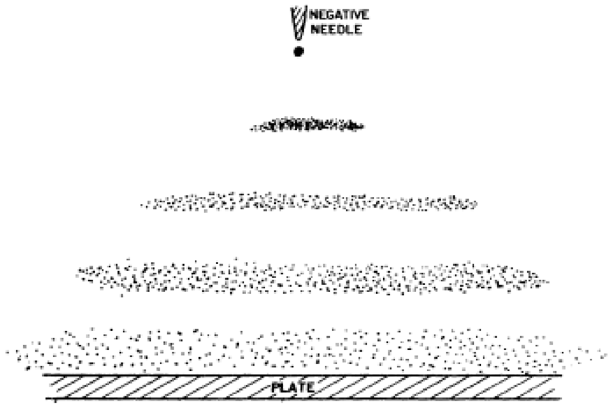


Fig. 8. Qualitative visual representation of our conception of spreading of negative ion cloud in transit across the gap at some voltage above threshold and below sparking. Spreading of charge cloud is due to Coulomb self-repulsion and spatial divergence of applied electric field. Diagram may also represent multiple charge clouds in gap at given time.

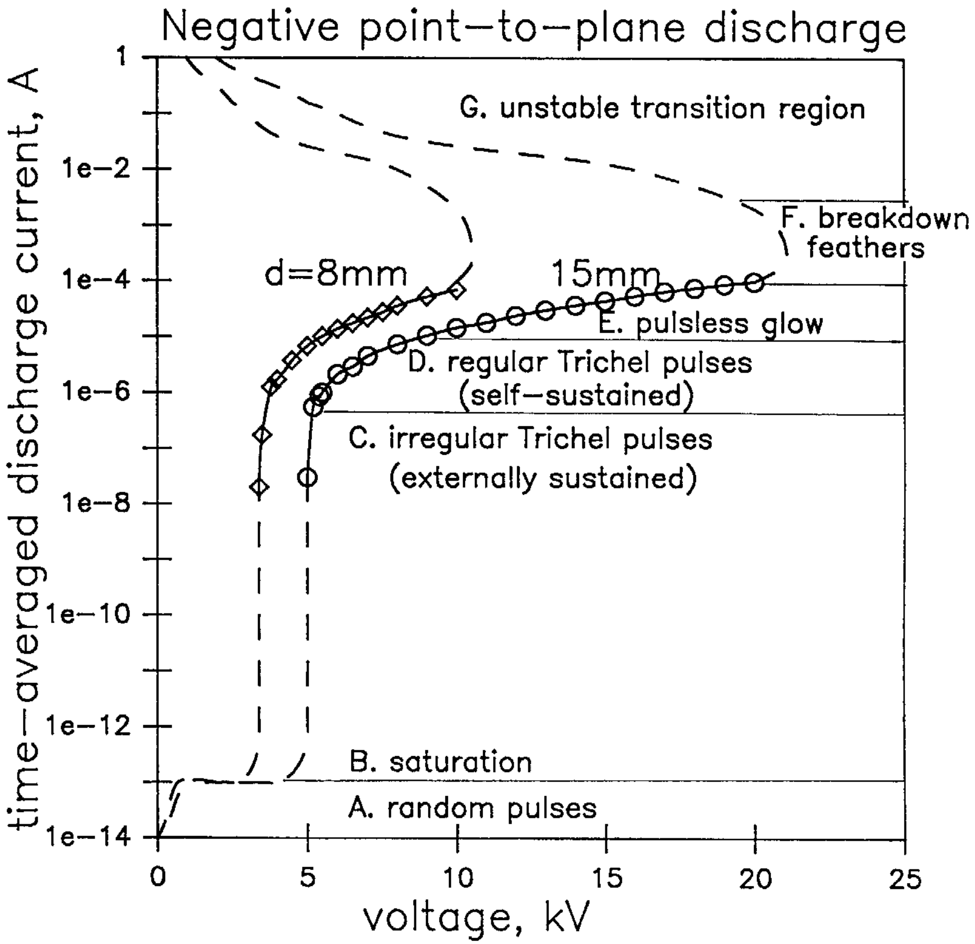
Prečo ?

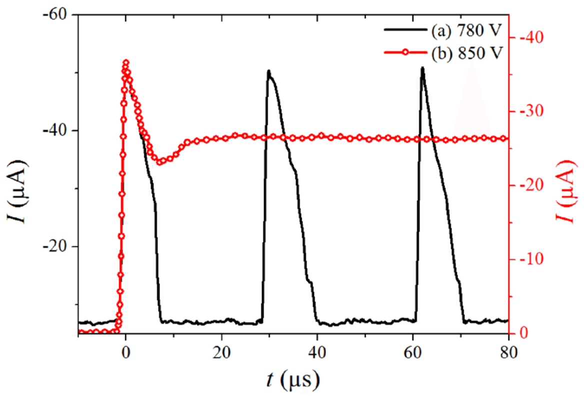
Počas Trichelovho pulzu vzniknú elektróny, ktoré sa pohybujú k anóde. V elektronegatnych plynoch sa však rýchlo zachytia molekulami plynu a vytvorí sa „hustý oblak“ pomalých záporne iónov, ktorý zníži intenzitu el. Poľa při katóde a výboj vyhasne. Nový Trichlov impulz naštartuje až keď sa oblak záporných iónov vzdiali do vzdialenosti L od katódy

W.L. Lama and C.F. Gallo: Study of current pulses

Journal of Applied Physics, Vol. 45, No. 1, January 1974

Stabilný záporný korónový výboj obvykle horí v režime TP. Při výšších napatiach prejde do „pulseless“ tlecieho výboja a následne do iskry

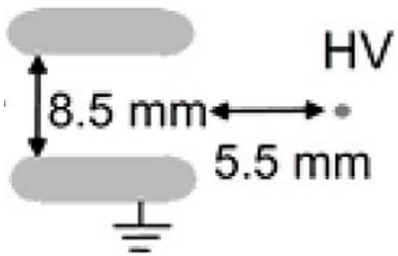


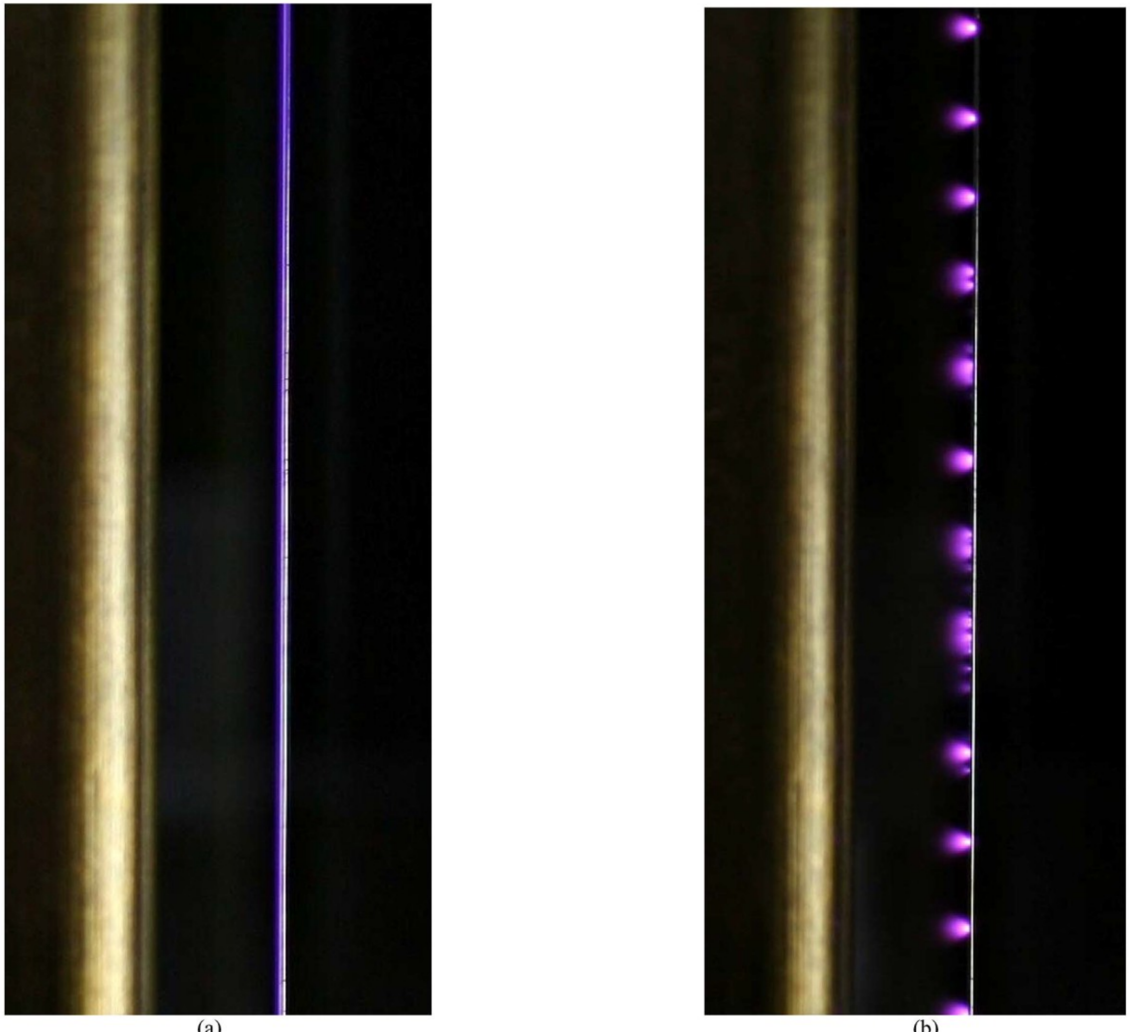


„POZITÍVNE“ APLIKÁCIE KORÓNOVÝCH El. VÝBOJOV

Stabilné kladné a záporné korónové výboje obyčajne horia v režime

glow (+) a Trichel pulses (-)





Corona discharges between a high-potential wire and two grounded plates in air at atmospheric pressure and ambient temperature. (a) Positive corona (*V* = 14.2 kV, *I* = 1.5 mA). (b) Negative corona (*V* = −10.5 kV, *I* = −1.3 mA).

Korónové výboje sa najčastejšie využívajú jako zdroj iónov v Aplikovanej elektrostatike, napr.

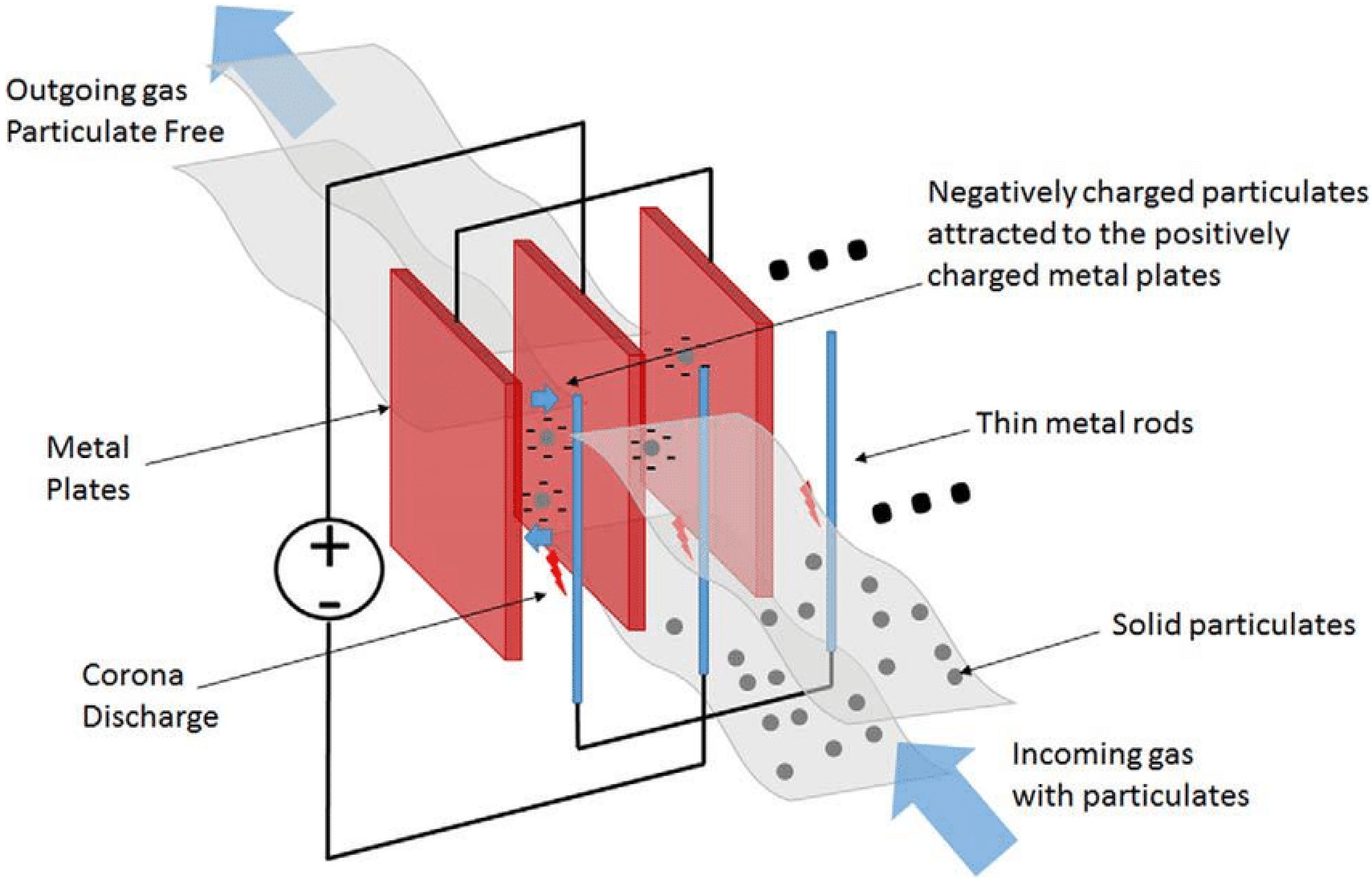
1. **Elst. odlučovače**
2. **Elst. nanášanie práškových materiálov**
3. **Elst. separátory**
4. **Eliminácia statického el. náboja**

Pri týchto aplikáciach má, v porovnaní s kladným, záporný korónový výboj nasledovné výhody:

1. **Nižšie zápalné napatie**
2. **Vyššie el. prúdy pri rovnakej geometrii elektród a napatí**
3. **Do iskry prechádza pri vyššom napatí**

Elektrostatické odlučovače

https://en.wikipedia.org/wiki/Electrostatic_precipitator

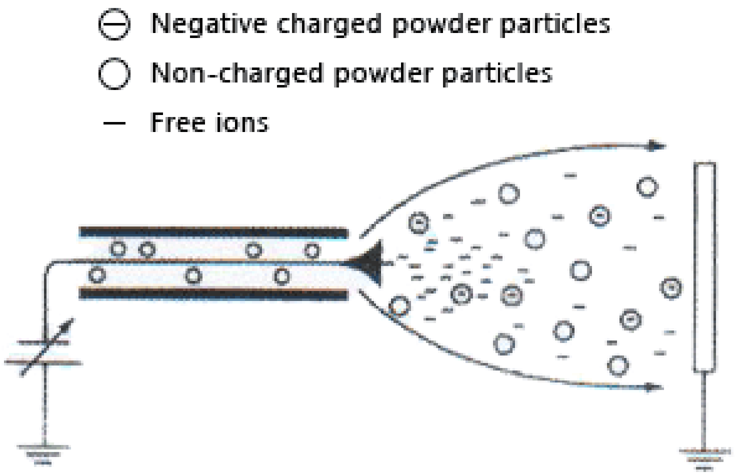

Outgoing gas
Particulate Free
Negatively charged particulates
attracted to the positively
charged metal plates
Thin metal rods
Metal
Plates
Solid particulates
Corona
Discharge
Incoming gas
with particulates

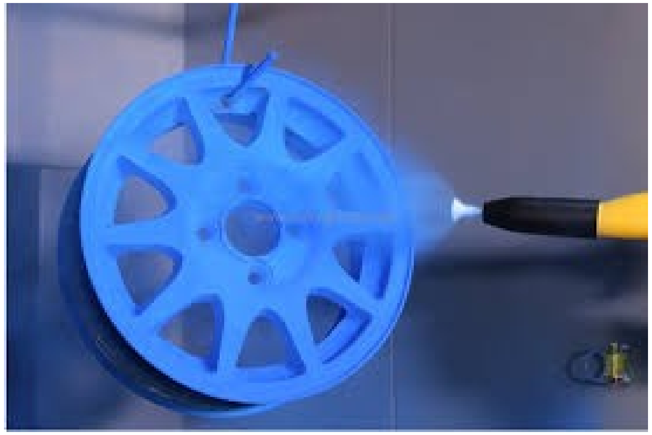
[redacted]

https://www.botonair.com/commercial-kitchen-esp-hood/

Exhaust range hood is one of the important part of the ventilation system. Our hood style ESP is a special hood inside with electrostatic filters. The function is not only to extract the cooking smoke and grease vapor, but also to filter the cooking fumes and grease particles by electrostatic precipitator. ESP hood combines kitchen canopy exhaust hood with electrostatic filtration system which can be installed directly over the cooking appliance.

Elst. nanášanie práškov



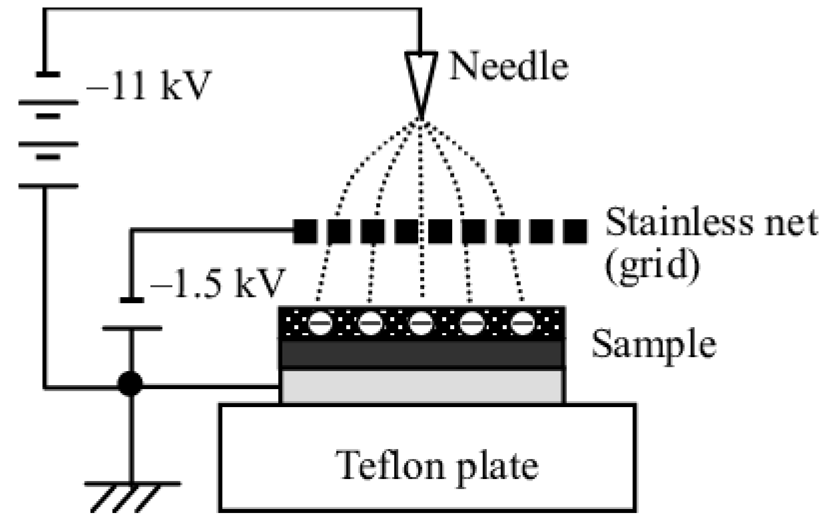


https://en.wikipedia.org/wiki/Electrostatic_coating

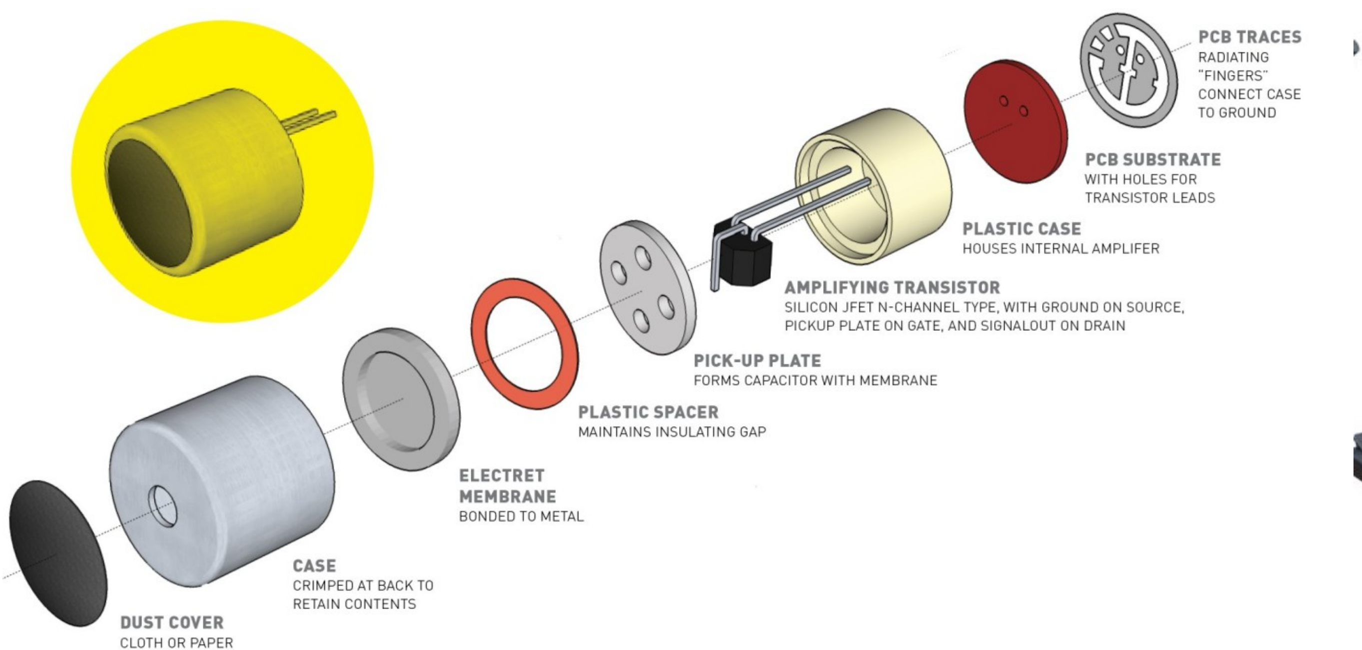
Elektrostatický separátor

Elektrostatický bubnový separator umožňuje oddeliť vodivé a nevodivé prášky a častice

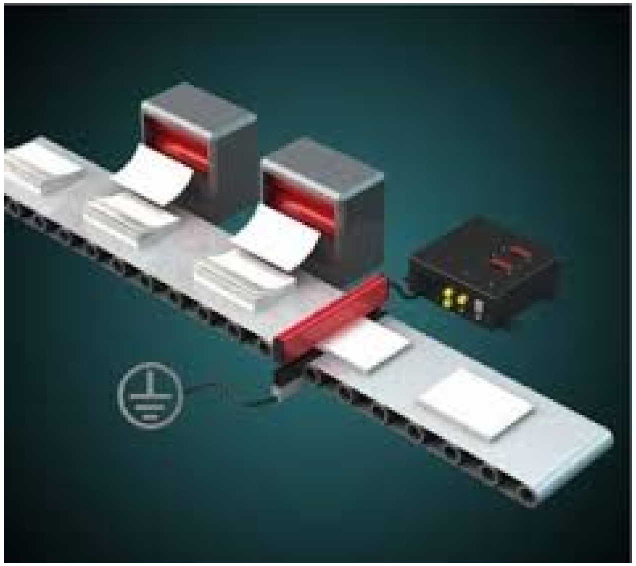
ELEKTRETY sú polymérne materiály s permanentným elektrickým nábojom. Obvykle sa pripravujú nabitím povrchu polymérnych materiálov korónovým výbojom



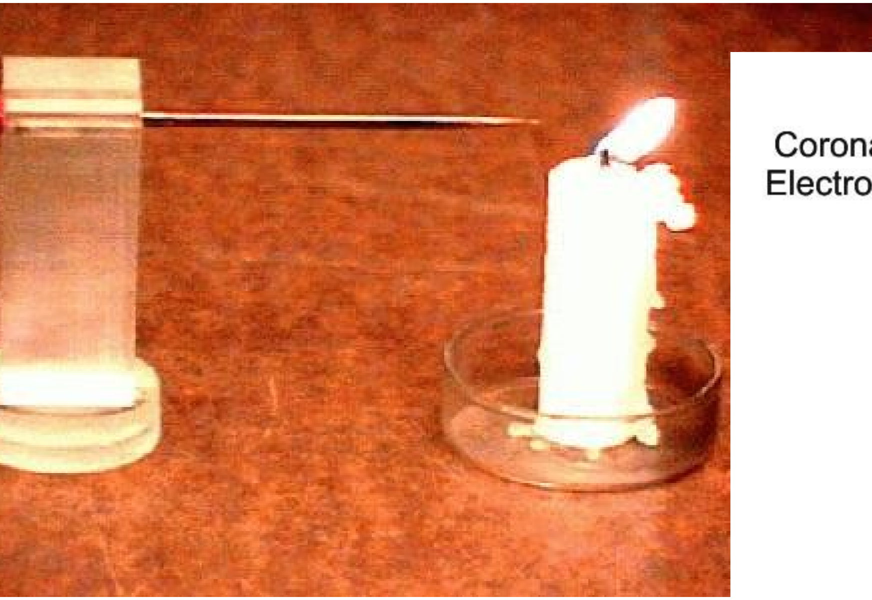
Používajú sa hlavnene pri výrobe miniatúrnych mikrofónov, ale i na elst. čistenie vzduchu a v medicíne

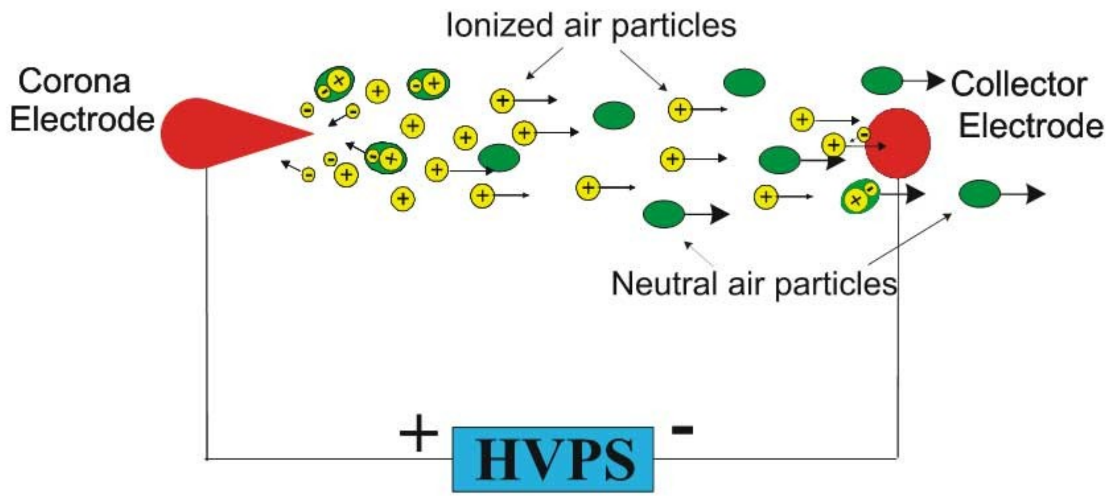


Korónujúce elektródy (static dischargers) **sa umiestňujú na krídla lietadiel, aby vybíjali náboj vznikajúci trením o vzduch. Podobne sa používaju napr. i na vodivých komínoch, pri výrobe folii, papiera, atď**

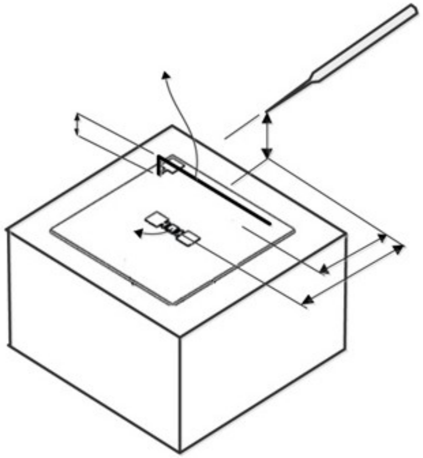


Elektrický (iónový, korónový) vietor





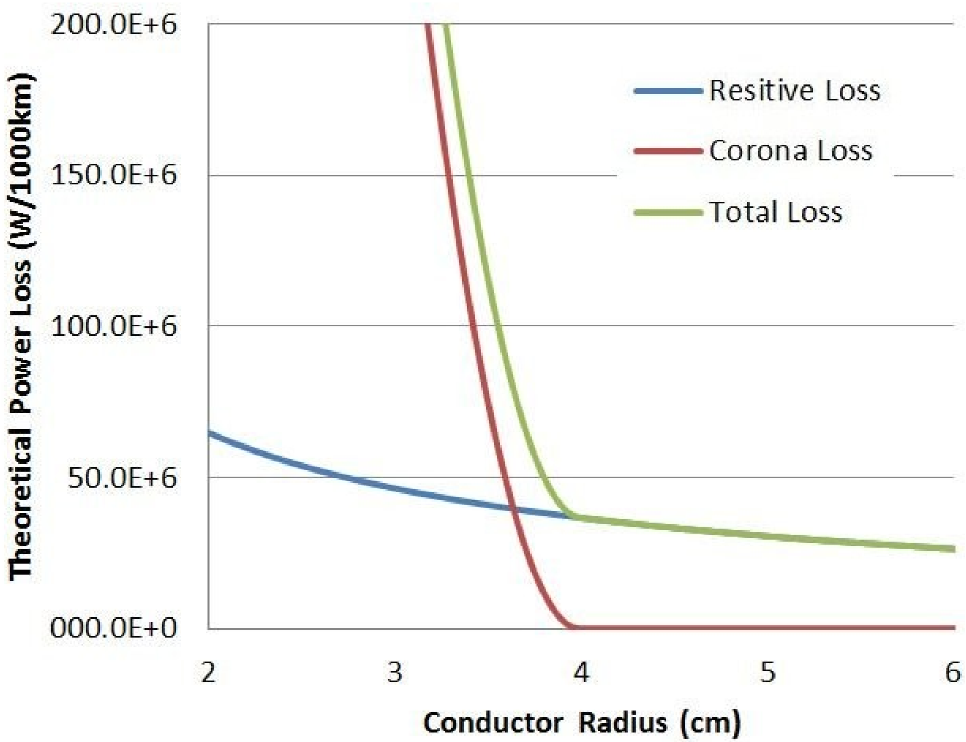
Može byť využitý na chladenie el. súčiastok
„Enhanced cooling for LED lighting using ionic wind", International Journal of Heat and Mass Transfer 57 (2013) 285–291

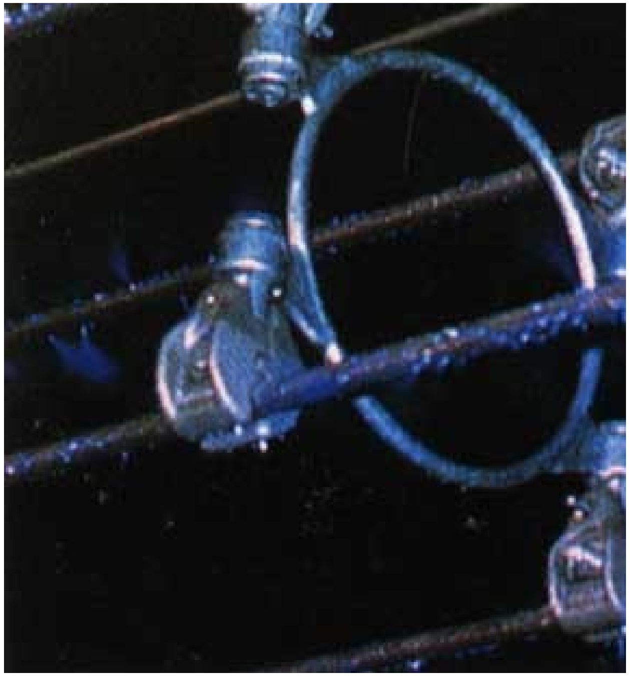


<u>Vzniká i pri striedavej 50 Hz koróne ?</u>

[redacted]

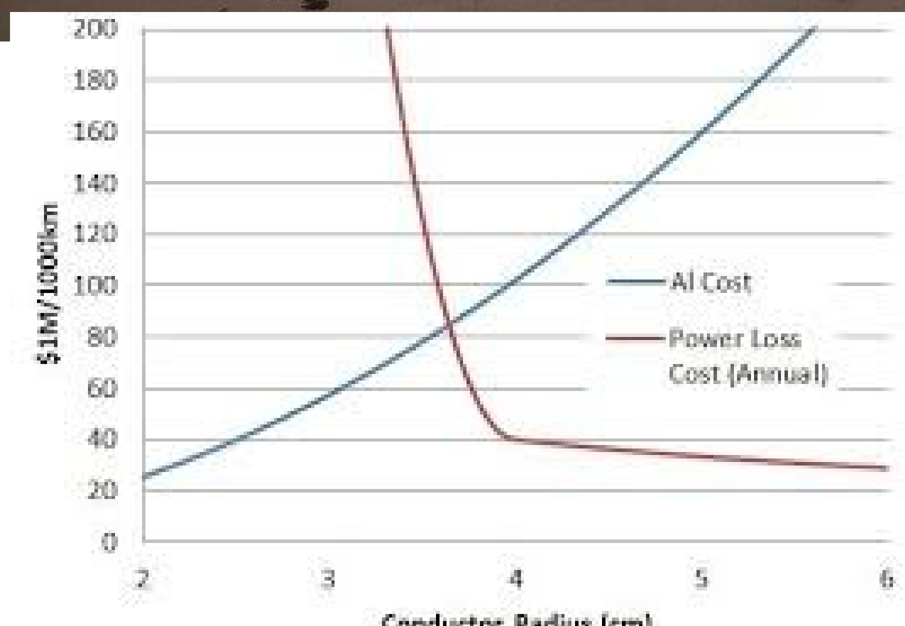
Straty na vedeniach VN v dosledku korónových výbojov



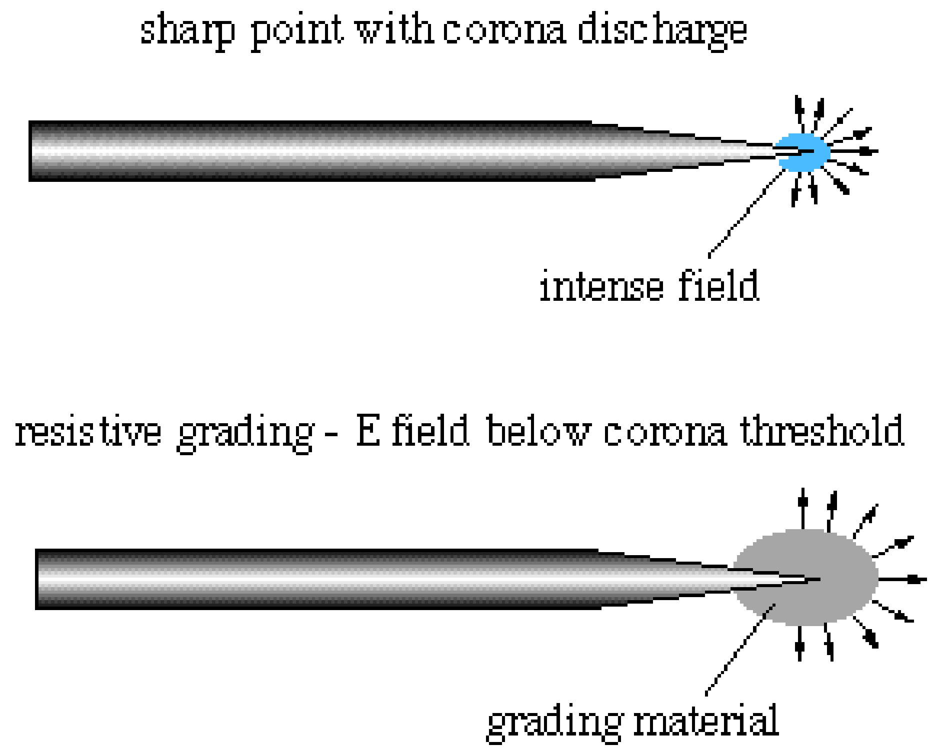


Straty korónovým výbojom v 1GW/765 kV prenosnej sieti sú asi 2.5 % a 1000 km dĺžky, čo je porovnateľné s ohmickými strátmi

http://large.stanford.edu/courses/2010/ph240/harting1/

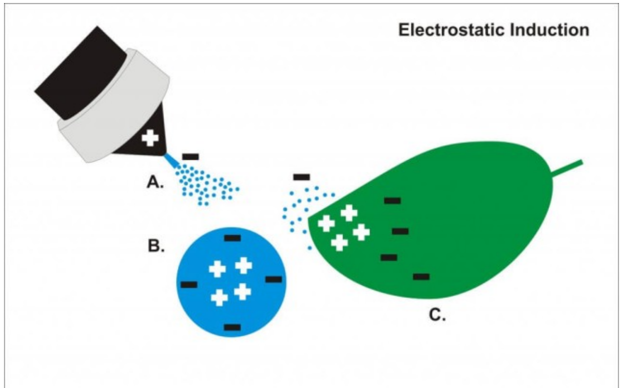

$1M/1000km
200
180
160
140
120
100
80
60
40
20
0
2
3
4
5
6
Conductor Radius (cm)
Al Cost
Power Loss Cost (Annual)

Prečo nie je dobrým riešením pokrytie (izolácia) vodičov vedenia VN, 50 Hz polymérnym izolačným materiálom ?

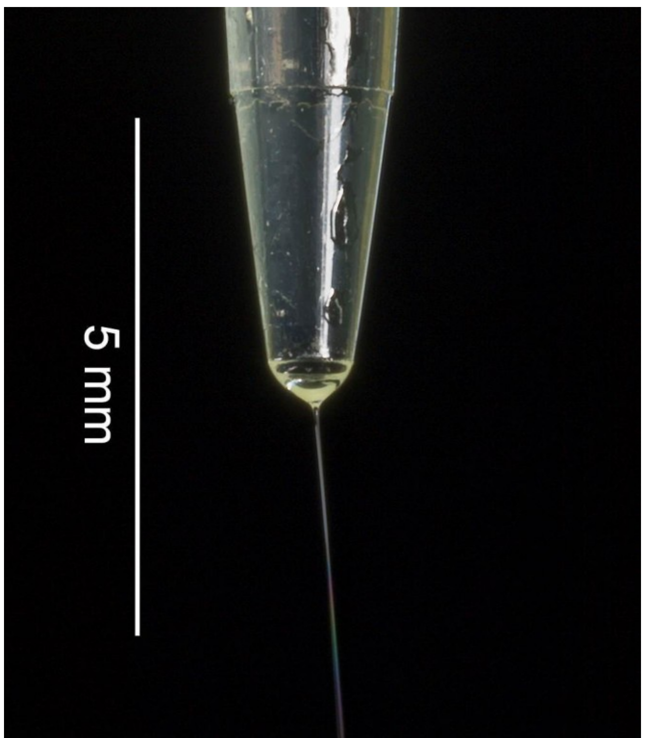


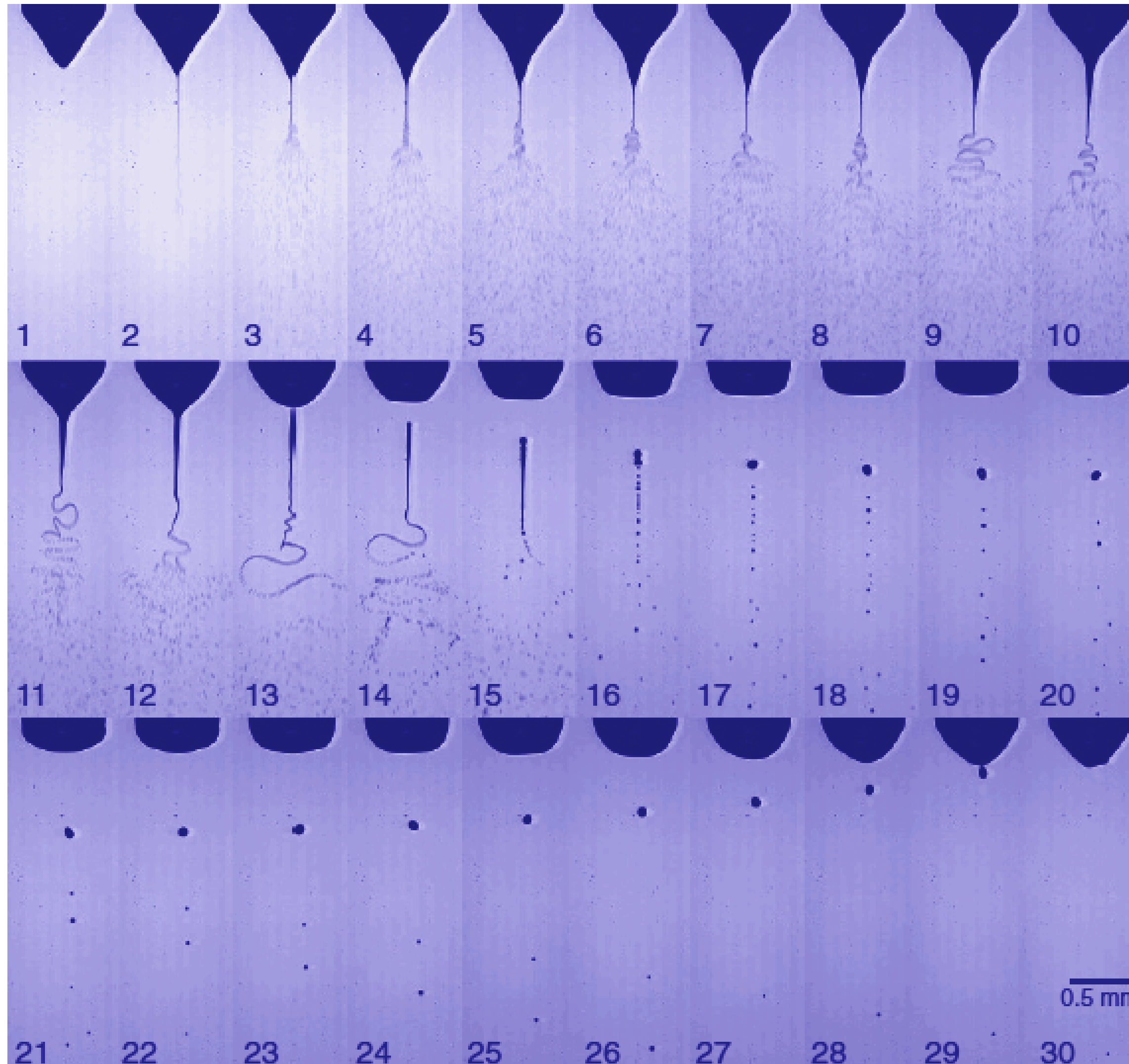
Vzniká DBD v „dielectric voids" na rozhraní kovu a polyméru, ktorý následne degraduje

Korónový výboj sposobuje problémy pre elektrostatickom rozprašovani a zvlákňovaní



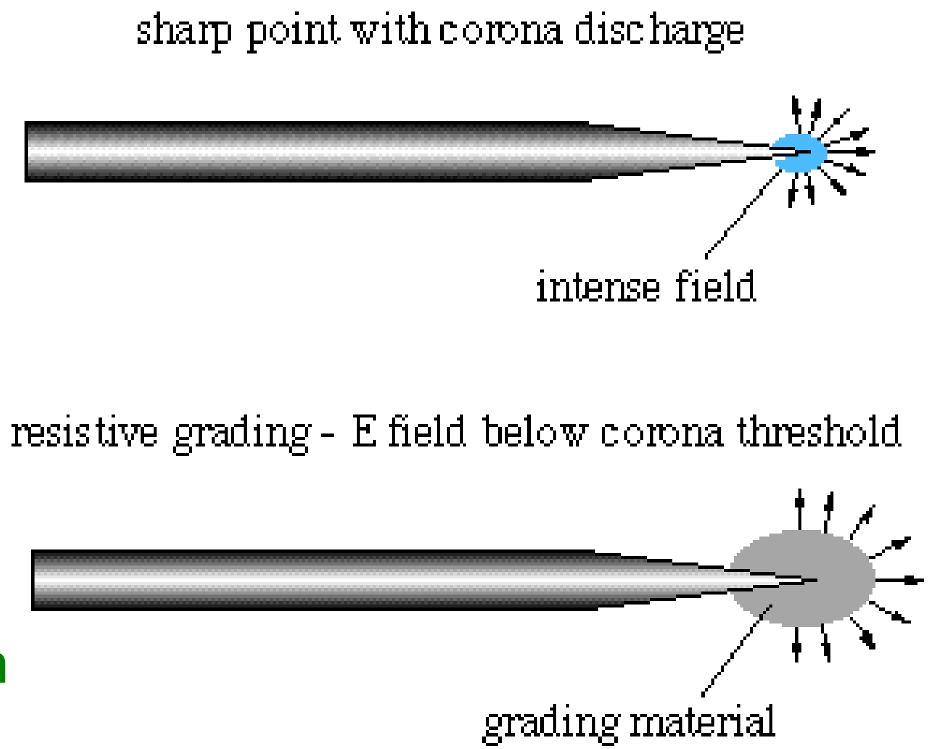
Taylor cone:





http://ecfuchs.com/?page=electrospray

Stabilizácia korónou



Vzniká DBD v „dielectric voids“ n následne degraduje