6. Paschen's curve for atmospheric air

SAFETY MEASURES: Interlocks are provided to prevent high voltage to be switched on while the gates/ doors are open. Despite these measures it is necessary to connect the safety earth stick to the HV parts before touching. (There could be some charge left on the capacitors). Special safety rules for the High Voltage laboratory must be read, understood, signed and always followed to every detail!

6.1 Objectives

The student must gain the following knowledge and comprehension in the following topics:

- Determine the breakdown voltage for atmospheric air in a homogeneous field (Paschen's law) as a function of the product of gap length and pressure, V_b = f(pd) corrected to standard atmospheric conditions.
- Determine the constants $(E/p)_c$ og $\sqrt{K/C}$ (see page 338 in Kuffel) for atmospheric air.

6.2 General Description

For a homogeneous field, there is an unambiguous relation between the product of gap length, d and pressure, p and the breakdown voltage for a certain gas and a certain electrode material, due to the following relations:

$$\Delta W = e \cdot E \cdot \lambda$$

$$\lambda \propto \frac{1}{p}, E = \frac{V}{d}$$

$$\Delta W \propto e \cdot \frac{1}{p} \cdot \frac{U}{d}$$

For a certain gas and a certain electrode material, ΔW is a constant which stands for the energy needed to ionize the gas. Thus:

$$V = f(pd)$$

Fig.1 shows the curve which descripts V = f(pd),   i.e. the Paschen's law.

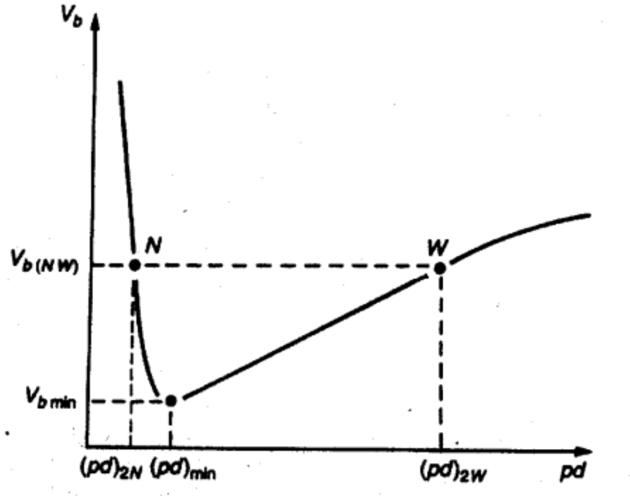


Fig.1 Paschen's law

It can be figured out that for each kind of gas, there is a minimum breakdown voltage V_{min} corresponding a minimum product of pressure and the gap length, $(pd)_{min}$. Table I shows the values of V_{min} and $(pd)_{min}$ of typical gases.

Table 1 Minimum breakdown voltage for various gases

Gas	$(pd)_{min}$ *torr cm*	$V_{b\,min}$ *volts*
Air	0.55	352
Nitrogen	0.65	240
Hydrogen	1.05	230
Oxygen	0.7	450
Sulphur hexafluoride	0.26	507
Carbon dioxide	0.57	420
Neon	4.0	245
Helium	4.0	155

6.3 Laboratory tasks

6.3.1 Test description

Create a setup in the HV laboratory as shown in Figure 2. It is important, that the sphere electrodes in the pressure vessel are cleaned (i.e. dust, greasy fingerprints etc.).

For each value of pd is recorded 5 meaurements. After this the pressure vessel must undergo a completely renewal of the air i.e. exchange the content of air to clean, new air. This can be done by opening the vessel and/or pumping by the vacuum pump. Explain why this step is important and include your explanation in the report. We need the clean air, to eliminate the ionized particles remaining in the air produced by the previous discharges

The experiments are performed with AC power frequency. Breakdown in a homogeneous field will be unaffected of the polarity of the applied voltage and will happen for the peak value of the AC-voltage.

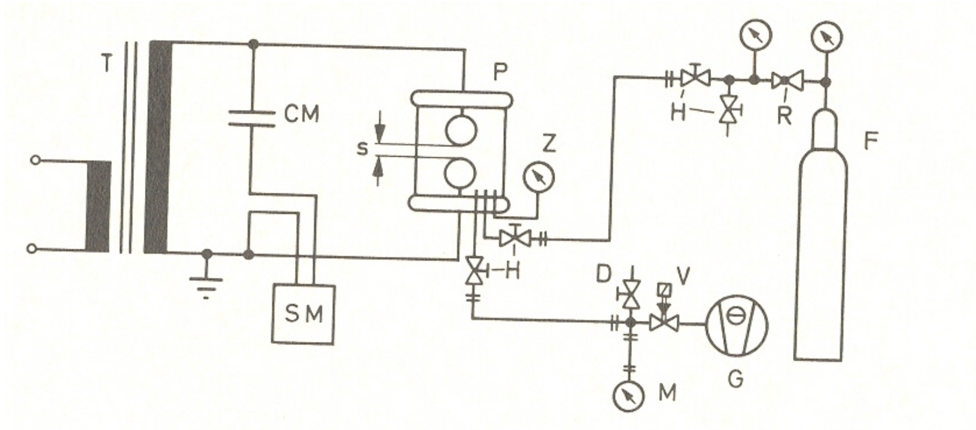


Fig. 2 The principle of the test setup for measuring the breakdown voltages for Paschen's law.

Furthermore, the processes of the gaseous discharge, are of so great rapidness, that the 50 Hz is acting as DC.

Pressures below 1 bar are established by means of the vacuum pump and pressures above 1 bar with the compressor. Take care no condensation water is present in the pressurized air.

The pressure vessel must not be pressurized to more than 3 bars!

6.3.2 Tests

Take 5 measuring points of the breakdown voltage for each value of pd for the gap lengths d=10 mm and d=20 mm, varying the pressure between 0,2 bar and 3 bar. The abscissa should be "covered" with app. 5 measuring points, which each are averages of 5 points for each gap length

Gap length d [mm]	Pressure [bar]	Average breakdown voltage [kV]					Standard deviation [kV]
10	0.2	8.9	7.9	6.9	5.9	5.9	1.3
	0.5	13.22	13.7	16.7	19.2	16.1	2.4
	1	23.1	26.5	28.4	33.8	29.9	3.95
	2	41	39.8	39.1	38.8	34.8	0.8
	3	50.4	55	55.4	51.4	53	2.8
Measurement		1	2	3	4	5	

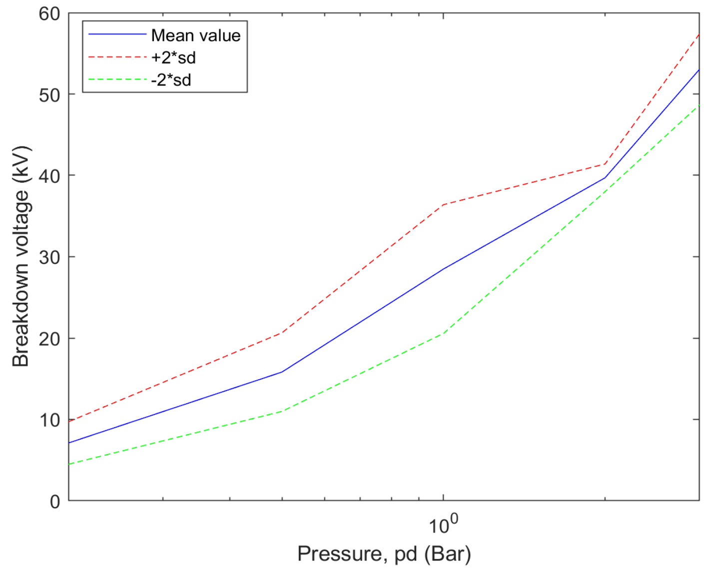
Note the sound and visual appearance of the breakdown phenomena at the varying pressures (lower the light of the lab.)

6.3.3 Calculation and curves

All breakdown voltages should be referred to standard atmospheric conditions, i.e. $p=p_0=1{,}013$ bar and $T=T_0=293$ K.

- Calculate the standard deviation for each measuring point and mark in a semilogarithmic graph as i.e. figure 5.23 in HVE pp. 338. Use the signature ”x” for d=10 mm and the signature ”o” for d=20 mm. The standard deviation is shown with horisontal bars around the measuring points. Draw the Paschen’s law curve below. Compare with figure 5.23 and table 3.3 pp. 83 –

Please draw the Paschen’s law curve.

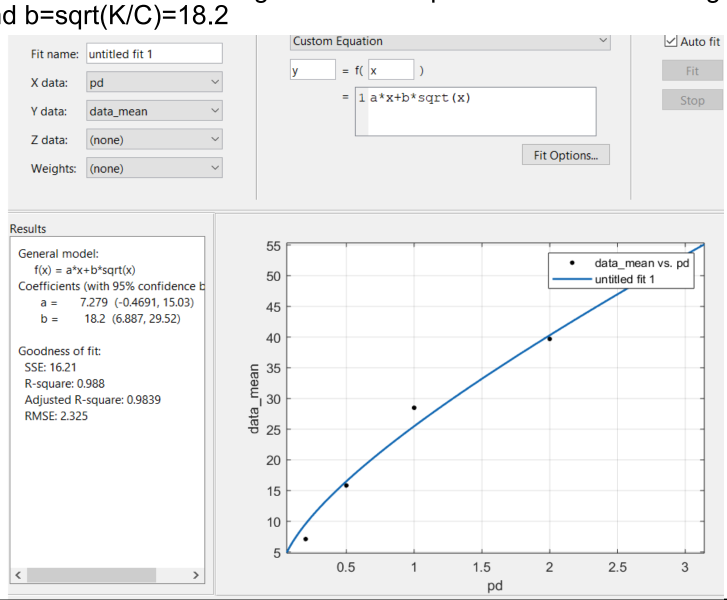


In comparison with the figure 5.23 from the book our measurements look similar in pressure below 1 bar but over that the breakdown voltage for figure 5.23 is higher. But our measurements is only a small

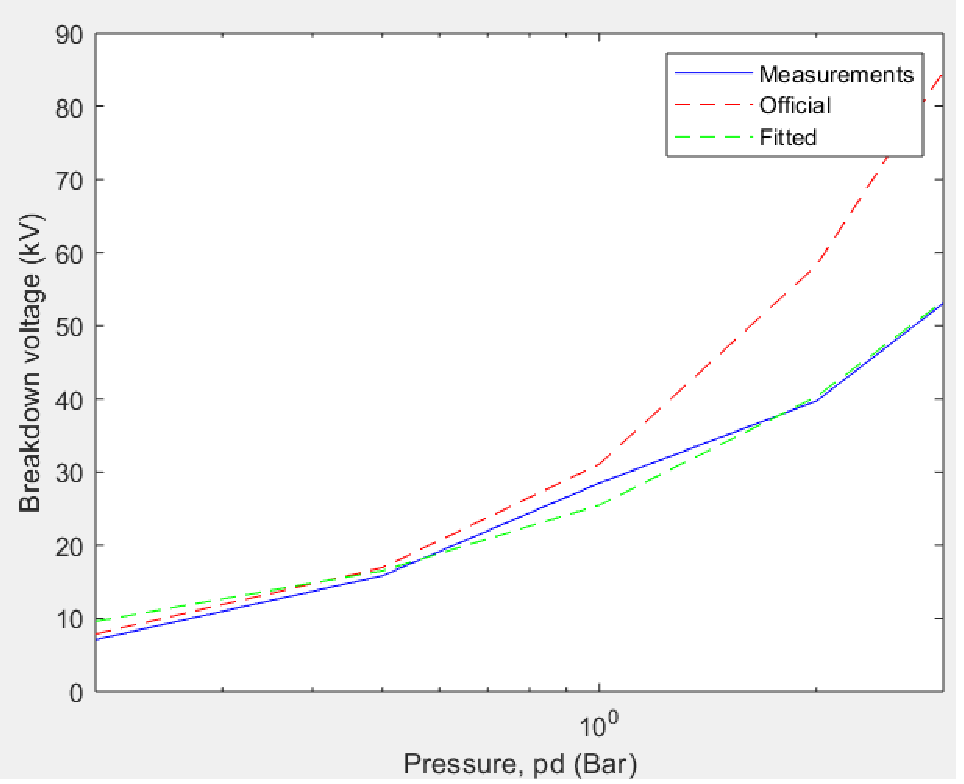
COMMENT ! part of the figure. From 0.2 to 3bar.

- By means of MATLAB and the routine FMINS you should determine the optimum values of (E/p)c and $\sqrt{K/C}$, see eq. 5.102 and 5.103 in HVE pp. 338. These should be compared with the standard values for air; (E/p)c = 24,36 kV/cm and $\sqrt{K/C}$= 6,72 kV/cm½ .The fitted curve based on 5.102 with your own values for (E/p)c and $\sqrt{K/C}$ should be drawn in the same graph as the measurements together with the ”official” one from figure 5.23 – COMMENTS PLEASE !

To do this optimization the "curve fitting tool" has been used from matlab. As it can be seen on the picture below the equation from 5.102 has been inserted and the X data is our pd values while the y data is the mean of the breakdown voltages from each pd value. From this we get that a=(E/p)c=7.279 and b=sqrt(K/C)=18.2



The fitted curve from above is drawn in the graph below together with the official one from figure 5.23 and from the measurements based on the test values



It can be seen that the fitted curve is very similar to the measurements which it should because the same values have been used. The difference is that the measurement line has obviously 5 points while the fitted is more smooth. In comparison with the official from the figure in the book, all three are very similar in pressure below 1 bar. After this value the official ones breakdown voltage is way higher than the measured.