Exercises DC and RF discharges

Exercise 1: Paschen curve and guarding ring

In a DC or RF discharge we want the plasma to be contained between the electrodes. To prevent the discharge to strike between the side of the powered electrode and the cylinder wall of the reactor, a so-called guarding ring is placed around the powered electrode. This ring is grounded. The geometry is sketched below. The question to be answered now is at what distance this ring should be placed.

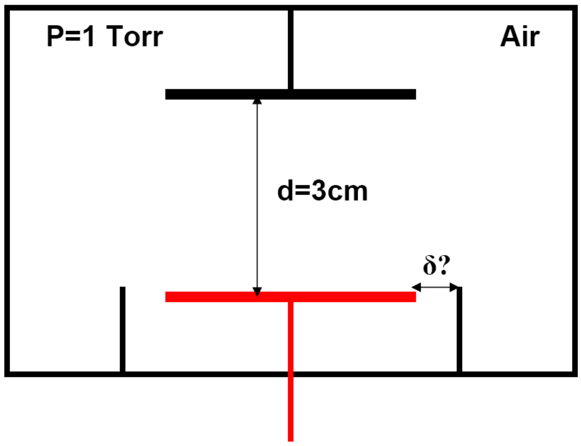

Figure Ex1.1: Discharge geometry with grounded top electrode, grounded cylinder wall, and grounded guarding ring. The bottom electrode is powered.

Suppose the electrode distance is 3 cm, the pressure is 1 Torr, and the gas is air, so assume that the the Paschen curve given in figure 1.2 of the lecture notes applies. For convenience it is reproduced below.

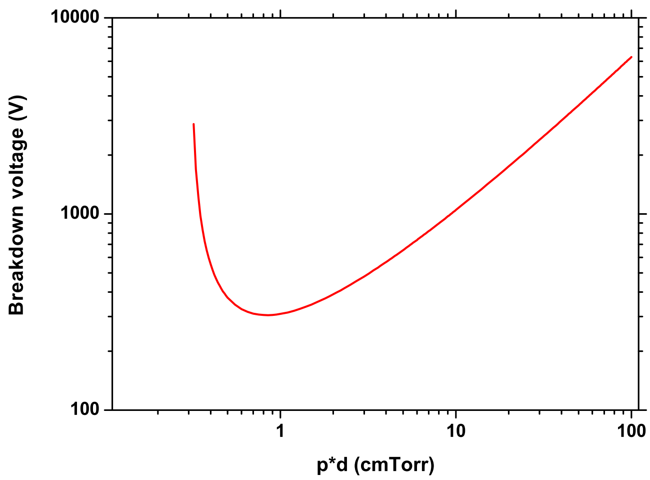

Figure Ex1.2 Paschen curve for breakdown in air. The secondary electron emission coefficient is set to 10^{-2}.

(a) What is (approximately) the voltage needed to create a plasma in between the electrodes?

Answer: The conditions are already given in Torr and cm. The product p×d is 3 cmTorr. According to the Paschen curve the required voltage at this value is about 500 V.

(b) At what other product of $p \times d$ would this be the right voltage for the generation of a discharge?

Answer: There is another point giving 500 V on the left branch, 500 V also holds for a p×d value of 0.4 cmTorr.

(c) How must we choose the distance δ between the powered electrode and the guarding ring to make sure that the conditions for discharge generation are never met.

Answer: If we put the ring at a distance corresponding to a p×d value in between 0.4 and 3 cmTorr the voltage for breakdown between the electrode and the ring is reached before that for breakdown between the electrodes. Obviously, the p×d product for the ring must be less than 0.4, giving a higher breakdown voltage. At 1 Torr pressure this means that the ring should be closer than 0.4 cm.
Remark: Of course we would also have no problem without the ring and a large distance between the electrode and the wall. In that case we are at the right of the 3 cmTorr point, requiring a higher voltage for breakdown. Often the distance between the electrodes is larger, however.

Exercise 2: DC discharge with unequal electrodes

In the lecture notes the potential distribution in a DC discharge is discussed for electrodes with equal areas. We actually looked at the current densities, and thus took 1 m^2 for the size of the electrodes. In the discussion of the RF reactor the electrodes were not assumed to be equal in size, mainly because the grounded cylinder wall also acts as grounded electrode. Of course this will also hold for a DC discharge in the same geometry. In this exercise we will look at the influence of the size of both electrodes. The grounded electrode has area A_{grnd}, the powered electrode A_{pow}, and the ratio $A_{pow}/A_{grnd}=\alpha$. As in the lecture notes, the powered electrode is at a large negative potential, and he electron current contribution to that electrode can be neglected.

(a) What is the current to the powered electrode and to the grounded electrode, expressed in the electron density, electron temperature, area, and plasma potential?

Answer: For the powered (small) electrode, we may neglect the electron current. This leaves only the Bohm contribution of the ions (current from plasma to electrode):

$$I_{pow} = eN_eA_{pow}\exp(-1/2)\sqrt{\frac{kT_e}{M_+}}$$

The electron contribution at the grounded electrode cannot be neglected. The potential drop over the sheath is V_{plasma}, so (again from plasma to electrode:

$$I_{grnd} = eN_eA_{grnd}\Big[-\exp(-1/2)\sqrt{\frac{kT_e}{M_+}} + \frac{1}{4}\sqrt{\frac{8kT_e}{\pi m_e}}\exp\Big(\frac{-eV_{plasma}}{kT_e}\Big)\Big].$$

(b) The currents must be equal and opposite. This condition gives an expression for the plasma potential.

Answer (skipping eN_e and introducing α):

$$I_{pow} + I_{grnd} = 0$$

$$(1+\alpha)\exp(-1/2)\sqrt{\frac{kT_e}{M_+}} = \frac{1}{4}\sqrt{\frac{8kT_e}{\pi m_e}}\exp\Big(\frac{-eV_{plasma}}{kT_e}\Big)$$

Yielding:

$$V_{plasma} = \frac{kT_e}{2e}\Big[1 - \ln\Big(\frac{2(1+\alpha)^2\pi m_e}{M_+}\Big)\Big]$$

(c) Check that α=1 gives the expression from the lecture notes.

Answer: For α=1 we get:

$$V_{plasma} = \frac{kT_e}{2e}\Big[1 - \ln\Big(\frac{8\pi m_e}{M_+}\Big)\Big].$$

(d) What happens when α goes to zero?

Answer: The value for α=0 becomes:

$$V_{plasma} = \frac{kT_e}{2e}\Big[1 - \ln\Big(\frac{2\pi m_e}{M_+}\Big)\Big].$$

This is precisely the floating potential, as can be seen from the condition for zero current through a sheath:

$$\exp\Big(-\frac{1}{2}\Big)\sqrt{\frac{kT_e}{M_+}} = \frac{1}{4}\sqrt{\frac{8kT_e}{\pi m_e}}\exp\Big(\frac{-eV_{plasma}}{kT_e}\Big)$$

This answer is obtained because the current density at the large grounded electrode that is needed to generate the current flowing through the discharge becomes smaller and in the limit of an infinite area (at a fixed size of the powered electrode) goes to zero.