Fusion and industrial plasma technologies - Exercises

Dr. H. Reimerdes - SPC/EPFL

Problem Set 6 - April 1, 2025

1 Multi-choice questions

1.1 A low temperature plasma is principally heated by:

( ) the ions which gain energy from the electric field and transfer it to the electrons.

( ) the electrons which gain energy from the magnetic field and transfer it to the gas.

( ) the electrons which gain energy from the electric field and transfer it to the gas.

( ) the ions which gain energy from the magnetic field and transfer it to the gas.

1.2 Neutral species can be transported to the walls and electrodes by:

( ) drift in the electric field of the plasma (Bohm's criterion).

( ) collisions with electrons.

( ) orbiting the magnetic field.

( ) diffusion in a density/concentration gradient of that neutral species (Fick's law).

1.3 Townsend's first coefficient is called alpha, and his second coefficient is called gamma, because:

( ) Townsend did not know the Greek alphabet.

( ) Townsend originally thought that ion collisions also ionised the gas (his beta coefficient).

( ) Townsend intended to include an effect due to beta radiation.

( ) the coefficients were not named by Townsend, but by somebody else with the same name.

1.4 A condition for breakdown can be described as follows:

( ) All electrons must reach the anode.

( ) Every electron leaving the cathode must create another to replace it.

( ) All ions must reach the cathode.

( ) Every ion must cause a secondary emission event.

1.5 If the external source of ionisation is removed when the voltage is less than the breakdown voltage,

( ) the current will fall to zero.

( ) the electron ionisation rate will increase to compensate.

( ) the ions will ionise the gas as well as the electrons.

( ) the current will remain steady but not increase.

1.6 For vacuum breakdown, the optical emission spectrum is different from the gas breakdown because:

( ) the gas atoms are strongly perturbed by the electric field (Stark shift).

( ) the atoms being excited are not the same as the gas atoms.

( ) the gas ions radiate at different wavelengths from the gas atoms.

( ) there is no gas to absorb the emitted light (optically thin).

1.7 For breakdown experiments using the same gas but different electrode materials,

( ) the measured Paschen curve is always the same.

( ) Townsend's first coefficient alpha is always the same.

( ) Townsend's second coefficient gamma is always the same.

( ) the theoretical Paschen curve is always the same.

Exercise 1 - Recombination, momentum and energy transfer in binary collisions

Consider a collision between two hard spheres, with the target one at rest.

a) What is the maximum energy transfer fraction in an elastic collision (i.e in a head-on collision)? Compare electron-atom and ion-atom collisions (see slide 9).

b) What is the average energy transfer fraction in an elastic collision? What is the average momentum in the original direction, assuming a target particle with infinite mass?

c) What is the maximum energy transfer in an inelastic collision? Show that an electron can transfer almost all of its energy in an inelastic collision, in contrast to elastic collisions. Why is it more difficult to break-down molecular gases (see slide 13) ?

d) Since opposite charges attract, why don't the electrons and positive ions simply recombine to form neutral atoms? In fact, why do plasma exist? Show that 2-body association and recombinations are forbidden in the plasma volume.

Exercise 2 - Comparison of reaction rates in gas and in plasma

a) Calculate the electron temperature in K of an electron temperature of 1 eV.

b) A plasma medicine technique requires a flux of oxygen molecular ions (ionisation energy 12 eV) in air. Using the Arrenhius rate (ignore the temperature dependence of the pre-exponential factor), compare the rate of ionisation by gas heating at 1000 K with the ionisation rate by electrons at temperature 2 eV. If the degree of ionisation due to the plasma in the air is as low as 10^{-8}, which is the most efficient method of oxygen ion production - the hot air, or the weak plasma? (see slide 14)

Exercise 3 - Derive Paschen's law from Townsend's breakdown criterion (see slide 41)

Exercise 4 - Paschen's law applied to modern satellite solar panels (see slide 42)

Calculate the minimum breakdown voltage in air (A= 15 cm^{-1} Torr^{-1}, B= 365 V/(cm Torr)) and the corresponding pressure for parallel iron electrodes ($\gamma \sim 0.01$) 1 cm apart. A modern satellite solar panel can generate potentials up to 400V. Is this a problem for slip rings?