Particle sources
-Tutorial-

Study of a Filament Ion Source

This tutorial proposes to study, with very simple estimations, the behavior of a filament ion source.

A filament ion source is composed of a cylindrical plasma chamber with a Tungsten(Wolfram) filament located in the x=0 plane. The cylinder height is L=100 mm, its diameter is D=30 mm. H_2^+ Ions are extracted through a slit with dimensions lz=20 mm and lx=2mm. The source is located at the center of a cyclotron with a 2T magnetic field.

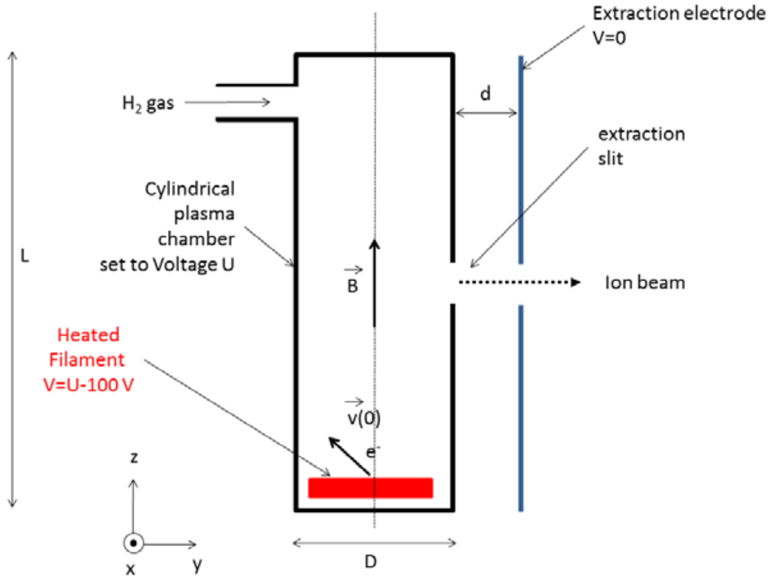

Figure 1: *sketch of the cylindrical ion source*

I study of H_2 ionization and extraction

1) The filament is made of tungsten. Its equilibrium temperature is T=2432°C.
   1.1 Calculate the current density of electrons extracted from the filament.(see p.12 of lecture)
   1.2 The filament geometry is a disk with a diameter D. Calculate the total current of electrons.

2) The difference of potential between the filament and the plasma chamber is -100V.
   2.1 What is the electron energy in the plasma chamber? Calculate the electron velocity.
   2.2 We suppose that the electrons are all extracted along the z direction.
   Calculate the electron density in the plasma chamber.

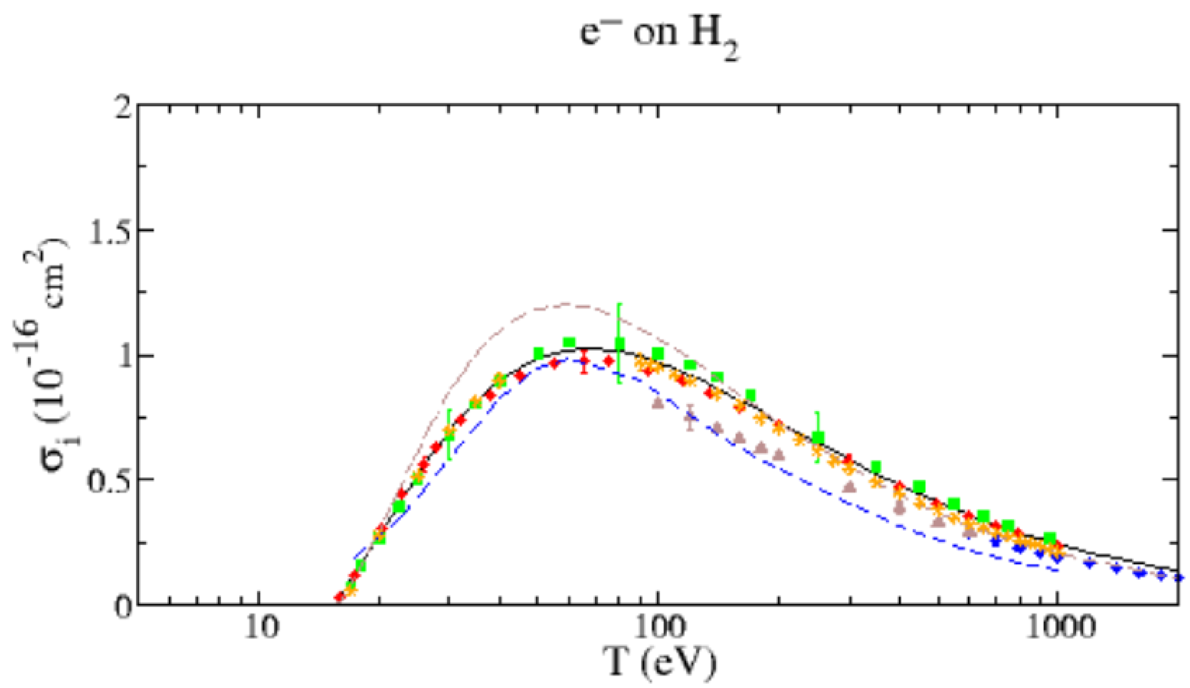

Figure 2: *total H_2 electron impact ionization cross section from NIST database. We consider the black solid curve in this exercise (I-BEB direct).*

3) A H_2 molecule is assumed to be fixed in the center of plasma chamber.
   3.1 Using Figure 2, find the electron impact cross section for the H_2 to break into H_2^+ + e^- when it is bombarded with electrons from the cathode.
   3.2 Estimate the mean time $\boldsymbol{\tau_i}$ for this molecule to be ionized by the electron shower

4) The H_2 molecule is thermalized at 300K and is now considered free to move. It is bouncing in the plasma chamber from wall to wall.
   4.1 Calculate the mean distance travelled by the H_2 before it gets ionized by electrons. (see p. 63)
   4.2 We assume that the mean distance travelled by the atom between two bounces is $\boldsymbol{l_B}$=5 cm. How many bounces does the molecule do before being ionized?
   4.3 At each bounce, the molecule has a probability $\boldsymbol{p_s}$ to pass through the extraction slit and get lost for ionization. Estimate the probability $\boldsymbol{p_s}$ by considering the ratio of the slit surface to the plasma chamber surface.
   4.4 What is the mean time $\boldsymbol{\tau_e}$ for a molecule to escape out of the plasma chamber through the slit?
   4.5 Deduce from 4.4 and 3.2 the probability p_i for a H2 to be ionized before it escapes from the extraction slit.

5) Once ionized, the H2+ ion makes a random walk in the plasma and is isotropically diffused toward the plasma chamber wall. So it has a probability $\boldsymbol{p_s}$ to find the extraction slit (see 4.3). If the ion is not extracted through the slit, the ion reaches the plasma chamber wall where it is neutralized. It has then a new fresh chance of being ionized again and extracted. Such a cycle can be repeated indefinitely.
   5.1 Draw a probability tree for the above process for 3 cycles.
   5.2 Derive the actual probability ***Pe*** for a molecule to be extracted as an ion and the complementary probability for an atom to be lost through the extraction slit.

6) The target beam of H2+ to be extracted from the source is 1 mA.
   6.1 What would be the necessary H2 flux rate into the source? Express this number in cubic centimeter per second of H_2 molecules (flux calculated at P=1 atmosphere, perfect gas approximation, P=nkT, PV=NkT, N=number of atoms, n=density of atoms).

II A look at the thermionic electrons trajectories

The electrons are supposed to be emitted from the hot cathode surface following the Lambert's cosine law. The angle θ is taken from the z axis. For a given θ, v(x=0)=v*cos(θ)*ez+v*sin θ.er.

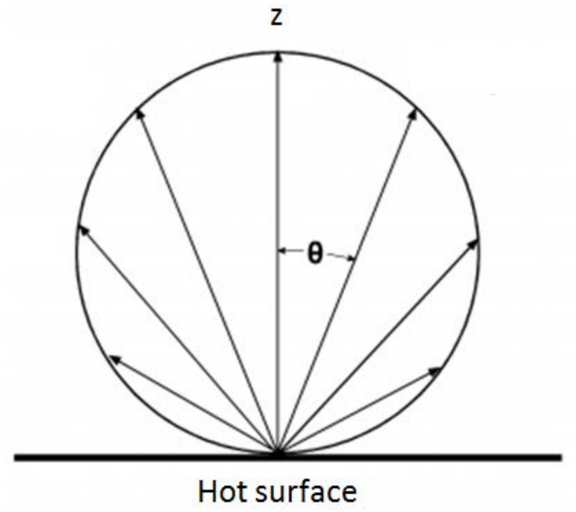

Figure 3: Cosine law

1) Calculate the mean electron angle of emission from the surface θ_m (the statistic weight along θ is cos θ).
2) The electrons are making helices trajectory in the magnetic field.
   2.1 What is the electron cyclotron frequency ω in the magnetic field?
   2.2 Calculate the helix radius r_m for θ_m
   2.3 Give the parametric equation of the electron trajectory as a function of time *t*, electron velocity *v* and angle of emission θ_m.
   2.4 Calculate the helix length until the electron reaches the opposite chamber wall
   2.5 Calculate the instantaneous total number of electrons present into the plasma chamber. Compare it with the same number of electron when θ=0. What is the interest of the magnetic field?
3) A student proposed to heat further the electron by injecting microwave power into the plasma chamber.
   3.1 What would be the microwave frequency to be injected in the plasma chamber to heat further the electrons by ECR resonance?
   3.2 According to the cylindrical geometry, xhat would be the maximum theoretical energy of the heated electrons?
   3.3 When looking at Figure 2, do you think that heating more electrons would help the H2+ beam creation?

constant used

- e = 1.6 x 10^{-19} C
- $k_B = 1.38 \times 10^{-23}\, J.K^{-1}$
- m_e=511 keV/c^2(electron mass)
- c=3×10^8 m/s
- m_{H2}~2.015 g/mol
- N_A=6,02214×10^{23} (Avogadro)