PHY682

Electron and Ion Sources

Homework

# Problem 1 - Child–Langmuir Law

Let us assume two parallel conducting plates separated by the distance *d*, and with a constant potential difference *V* between the two plates.



Figure 1: Two parallel conducting plates separated by the distance *d* and powered by a voltage difference *V* will, for a proper value of *V* , accelerate charged particle initially at rest at one of the plates.

Charged particles injected with initial velocity *v* = 0 will be accelerated toward the opposite plate when the sign of the voltage difference is set appropriately.

1. Assuming a steady state flow, the current will be constant (**J** = *ρ***v**) and the energy of a particle at a given position is given by 1*/*2*mv*2 = -*qφ*(*z*) where q, m, v and z are respectively the charge, mass, velocity and position of the particle. Using Poisson’s equation (*d*2*φ/dz*2 =

*−ρ/*0), and posing Φ = *−qφ*, show that

 (1)

Then Demonstrate:

 (2)

Considering now the special case *d*Φ*/dz* = 0 at *z* = 0, we get *C* = 0, integrate again to find an expression of the current density function of the voltage known as the *Child’s Law* or *Child-Langmuir Law* and gives the maximum current that can be extracted for a given voltage and plate separation.

1. Assuming a beam of Argon (A=40) of charge 1+ and a circular aperture of 5mm and a distance d to be 1cm. What would be the value of V in kV that allow to extract 1euA, 1mA, and 1A respectively.
2. The voltage breakdown in vacuum is assumed to be 10kV/mm. i.e above this value, the system cannot hold voltage even under very good vacuum (practical limit). Are the values found in b) for V realistic? What electron emission mechanism can come into play if the voltage is increased beyond the value above (i.e reaching close to 108V/m)

# Problem 2 – Charge Exchange

FRIB seeks to accelerate Uranium ions with the charge 33+ through the superconducting linac . First the uranium beam has to go through the front end beam line of the FRIB which is about 40 m long extending from the ion source to the Radio Frequency Quadrupole. In this section the beam energy is 12keV/u.

Make an estimate of the required average vacuum in the beam line if beam losses due to vacuum are required to be less than 10% for uranium.

Use the Salzborn-Muller charge exchange cross section fit for this estimate:

with the ionization potential of the neutral atom (residual gas) and q the charge state. Use the following model for transport/attenuation of the ion beam:

𝑤𝑖𝑡ℎ 𝑛 𝑡ℎ𝑒 𝑑𝑒𝑛𝑠𝑖𝑡𝑦 𝑜𝑓 𝑡ℎ𝑒 𝑟𝑒𝑠𝑖𝑑𝑢𝑎𝑙 𝑔𝑎𝑠 𝑖𝑛 𝑐𝑚−3

Use the first ionization potential for nitrogen (). For plot the transmission of the ion

beam versus pressure in the range of Torr to Torr. What is the minimum pressure to operate the beamline to ensure above 99 % transmission?

# Problem 3 – Negative Ion Sources

An Aarhus ion source is used with Tandem accelerator to produce negative ion beams and is shown below. Xenon gas is injected and ionized by a discharge and Xe+ accelerated to a cesiated sputtering cathode made of graphite biased to a high negative potential. Energetic Xe+ sputters the target and release negative carbon ions of the target material



The source is equipped with a target made of a carbon metallic compound having a work function of 5 eV. Cesium is injected into the source to cover the target surface with an atomic layer of cesium in order to lower its work function following:

With and respectively the first ionization potential and electronic affinity of Cesium in eV. The first ionization potential and electron affinity of cesium can be found at: <https://www.nuclear-power.com/caesium-affinity-electronegativity-ionization/>

1. Calculate the work function of the cesiated carbon compound.

Xe gas with a pressure of 13.3 Pa (0.1 Torr) is used for the discharge during which up to 600 A of Xe+ ions is accelerated and sputter the target to release C- ions. The production efficiency of C- ions can be calculated using

where is the probability for an ion to be emitted with a velocity and is the velocity distribution. The probability can be expressed as follows:

with a the decay factor and the sputtering angle.

b) Assuming the decay factor (a) is 3.3x10-5 eV s/m and that the ejection angle = 0 (normal to the target surface) for a C- velocity of 6x103 m/s. Calculate the production efficiency assuming that the velocity distribution is a Dirac delta function centered around . The target as well as the entire source assembly can be assumed to be at room temperature (300 K). Note: A metal surface with low work function is critical for negative ion production because of the exponential dependency.

After exiting the target surface, the C- ions are accelerated to 2 keV. The target is flat and is on the opposite side of an aperture for ion extraction, placed 2 cm away from the target. The C- current can be expressed as

where A is the sputter yield, the residual gas density (xenon in this case), L the transport length and the cross section for electron detachment.

c) Calculate the negative C- ion current (in nA) for the ejection angle of = 0 that reaches the opposite side of the target using the following constant: A=0.5 and