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JUAS 2015

Wednesday March the 18th 2015
Duration : 1h30

Particle sources
Examination

¡ PLEASE READ THIS TEXT FIRST !

- The examination text is long, but the questions have easy answers
- The exercises require simple calculations.
- before rushing into the lecture : check the list of constants and formulas at the end of the text!!!
-the lecture questions (part 1) are likely to be 50% of the evaluation

1. General lecture questions

1.1 What is the physics behind the Child-Langmuir law (current density limit) ?

1.2 Cite a method to produce a negative hydrogen ion.

1.3 Why does a photoemission gun require a very high level of vacuum?

1.4 Will you use a Duo-plasmatron to make a continuous working high intensity proton beam? Why?

1.5 On what type of electrostatic accelerator are negative ion sources of interest?

1.6 Why is the amount of multi-charged ions produced in an Electron Beam ion source limited?

1.7 What kind of ion source will you use to separate iso-mass radioactive ions?

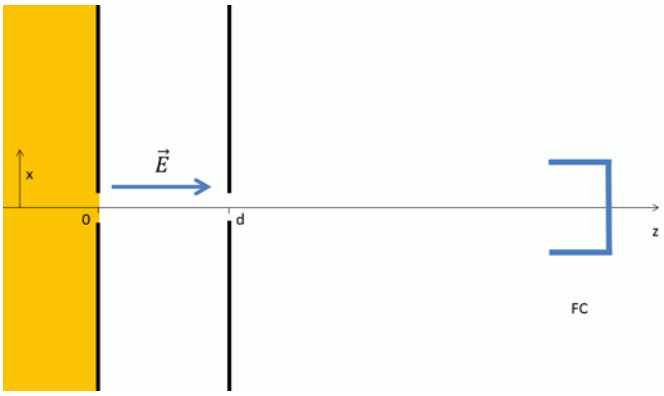
1.8 Above which photon energy is the pair production dominant with respect to the other processes?

1.9 What is the cyclotronic frequency of an electron rotating in a 1 Tesla magnetic field (result in Hz not in rad.s^{-1}!).

1.10 What is the Shottky effect?

2. Beam divergence:

A student is working on a 1+ proton source. The ion beam is emitted from a very small hole located on the beam line axis. The source is set to a high voltage U. A flat extraction electrode is placed in front of the source hole at a distance d. The extraction electrode is set to 0 V. The uniform electric field E is strictly along the beam pipe axis $\vec{z}$. The extraction electrode is equipped with a very small hole located on the axis $\vec{z}$. The ions are emitted from the source with an unknown thermal energy kT. In the following, in order to simplify calculations, the problem is restricted to the 2 dimensions x and z. The ions are supposed to be emitted from the point O ($x = 0$ and $z = 0$).



2.1 Express the electric field E in the accelerator gap as a function of U and d.

2.2 Use the equation of motion to express the velocity of one ion as a function of the distance z in the gap ($z \in [0, d]$). The initial condition for the velocity at $t = 0$ and z=0 is $\vec{v}_0 = v_T\vec{x}$. The initial conditions for the position at $t = 0$ are , $x = 0$ and $z = 0$. Write the velocity v_z at $z = d$ as a function of U, d, m, e (e = electric charge). Write the velocity v_x at $z = d$.

2.3 We assume that the ions are still on the axis ($x = 0$) when they reach $z = d$. Afterward, the ions propagate freely toward a Faraday Cup (FC) located 1 meter away. the student measures the ionic current in the FC as a function of the High Voltage (HV). Data is reported in the table 1. Why does the current measured in the FC increase with the HV at low voltage? Why does it stop increasing above 20 kV?

Table 1: student's measurement

HV (kV)	5	10	15	19	20	25	30
I (mA)	2.5	3.5	4.3	4.9	5	5	5

2.4 The FC diameter is 2.5 cm. Find an estimate of the ion perpendicular velocity v_T (in m/s) and derive the ion thermal energy kT (in eV, see p. 62).

3. Beam separation in a dipole (see. p. 66 and add-on p. 18)

An ion beam with a mass M, electric charge state number Z, is accelerated by an electric potential U. The ion beam must pass through a magnetic dipole with a bending radius ρ and a magnetic intensity B. We remind that :$B\rho = \sqrt{\frac{2}{e}}\sqrt{\frac{MU}{Z}}$

3.1. A 1+ ion source set to 20 kV is using the silane gas (SiH_4) to produce a $^{28}Si^{1+}$ beam. The beam from the source is filtered through a magnetic dipole with a bending radius ρ =1 m. What is the magnetic field required to pass the beam through the dipole?

3.2. When the magnetic dipole is ramped up, the operator notices the presence of another beam for the magnetic field intensity $B = 0.02042\ Tesla$. What chemical species is this beam?

4. Charge breeding *(see p. 113) (electron impact see p. 55)*

A $^{39}K^{2+}$ ion beam with a kinetic energy of 40.005 keV is injected into a charge breeder which plasma chamber is set to an electric potential of 20 kV. The plasma potential is assumed to be null for convenience. The plasma length is 0.3 m.

4.1. At what kinetic energy does the ion pass through the charge breeder? Calculate the ion velocity. Show that the time for an ion to travel through the plasma is $t = 60.3\ \mu s$.

4.2 The mean electron kinetic energy is $E_e = 300\ eV$. Calculate the electron velocity and compare it to the ion's one.

4.3 Calculate the electron impact cross section for a potassium ion passing from the charge state 2+ to the charge state 3+. See Table 1 for ionization potential.

Table 1: ionization potential of Potassium (K)

Charge state	neutral	1+	2+	3+
Ionization potential (eV)	4.028	31	49	68

4.4 The plasma electronic density is $n_e = 10^{12} cm^{-3}$. Calculate the number of collision that the set of electrons will have with the ion when it passes "slowly" through the plasma during the time t. (collsion formula: see the toolbox at the end of exam text). Make sure to have cm in all quantities!

Toolbox

- e = 1.6 x 10^{-19} C
- $k_B = 1.38 \times 10^{-23}\ J.K^{-1}$
- $\epsilon_0 = 8.85 \times 10^{-12}\ F.m^{-1}$
- m_e=511 keV/c^2(electron mass)
- m_p=938.2 MeV/c^2(proton mass)
- m_A=931.49 MeV/c^2(atomic mass unit)
- c=3×10^8 m/s
- Number of collisions : $\Delta N = n\sigma v\Delta t$; n=density of projectiles, σ cross section , v velocity of projectiles, t duration when collisions are considered
- $\vec{E} = -\overrightarrow{grad}V$