Z52 - Ion Sources and Basis of Mass Spectrometry

Physics Laboratory II – academic year 2017/2018
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Ion sources are widely applied in many areas of research, in particular in atomic physics, solid state physics and nuclear physics. The main goal of this exercise is to study operation principles of ion sources. As a selected example an EBIS (Electron Beam Ion Source) is chosen. Here, the discussed methods of ion production provide a starting point in order to overview interaction mechanisms of atoms with ions, electrons and photons. The available EBIS is designed to produce highly charged ions (HCI). Formation of bare ions is here possible up to Z as high as 18 (Ar). Observation of HCI beams in electromagnetic fields (lenses, Wien filter) is an additional opportunity to study the basic principles of mass spectrometry. Moreover, the facility is equipped with an XFlash detector which is able to register x-rays ($0.5keV$ – $20keV$) associated with the ion production in the EBIS. Analysis of these x-rays gives a survey of radiative atomic processes like characteristic x-ray emission, radiative recombination or resonant dielectronic recombination. In addition, this exercise gives an excellent opportunity to study methods of vacuum formation and diagnostics in experimental chambers used in atomic collision experiments.

Preparatory questions

1. Atomic structure – basic information [1]
2. Vacuum idea – matter density, pressure, units, techniques of vacuum formation and diagnostics [2]
3. Charged particles in electromagnetic fields, Wien filter construction [3] (pp: 19-30)
4. Ionization of atoms in collisions with photons, electrons and protons [5]
5. Construction of ion sources, in particular construction of EBIS [3] (pp: 31-47), [4] (pp: 1-8)
6. Atomic processes in EBIS [4] (pp: 9-14)

Computational assignments

1. The H-like atom model, introduced by Niels Bohr, is still very useful in order to estimate approximate values of many parameters we need in atomic-collision experiments. By using this model one has to show that $En \approx (13,6eV) \cdot Z^2/n^2$, $r_n \approx (5,29 \cdot 10^{-11}m) \cdot n^2/Z$, $v_n \approx \alpha\Delta c\Delta Z/n$, where E_n, r_n, v_n denote the electron binding energy, the radius of the electron orbit, and the electron velocity, respectively, marked with the main quantum number n in H-like atoms with the atomic number Z.
2. Electrons in the mono-energetic electron beam (EBIS) have an energy of $7keV$. Calculate, please, the photon energy which characterizes the radiative recombination transitions (RR). The captured electrons go into the ionized K-shell of Ar. Is the electron-beam energy twice as large, how does the RR-photon energy change?
3. A proton collides with an electron. Calculate, please, the fraction of the kinetic proton energy which is transferred to the electron in the head-on collision.

Apparatus and materials

Information concerning technical details of the EBIS facility is to find in [3, 6].

Experiment

The main goal of this exercise is to study operation principles of ion sources. As a selected example an EBIS (Electron Beam Ion Source) is used. Here, students obtain essential information concerning methods if ion production which again is a starting point in order to overview interaction mechanisms of atoms with ions, electrons and photons.

First, students start the available EBIS (EBIT3 designed and constructed by DREEBIT Co.) [3, 6]. By selecting an input gas (He, Ne, or Ar) the corresponding He^{+q}, Ne^{+q} or Ar^{+q} ions are produced. By tuning the appropriate work parameters of the source [3]. the ion production is optimised and controlled by observation of the current of the extracted ions. EBIT3 is designed to produce highly charged ions (HCI). The fraction of HCI's in the primary ion beam is to be estimated. Finally, observation of bare ions is possible for atoms with Z as high as 18 (Ar).

Second, observation of HCI beams in electromagnetic fields (lenses, Wien filter) is an additional opportunity to encounter the basic principles of mass spectrometry. Students focus the ion beams at various energies ($5keV$ - $15keV$) by electrostatic lenses and separate m/q components (Wien filter) [3]. It is possible to calibrate the Wien filter with the known masses of the input elements used (He, Ne, or Ar) in order to identify other beam species produced in the ion source e.g. ions of the rest gases present in the air like O_2, N_2, H_2O, CO_2. Moreover, this exercise forms an excellent opportunity to study methods of vacuum generation

Figure 1: Experimental set-up

and diagnostics in experimental chambers.

In addition, the facility is equipped with an XFlash 5030 detector (Bruker Co.) ([7, 8, 9]) which is able to register x-rays ($0.5keV - 20keV$) associated with the ion production in the EBIS. Analysis of these x-rays gives a survey of radiative atomic processes like characteristic x-ray emission, radiative recombination or resonant dielectronic recombination. Accumulation of the x-ray data is managed by the TERX system developed for the EBIS facility [10].

Data analysis

Data analysis and final report have to be discussed and fixed after the individual program of the exercise is realized.

Safety rules

Details concerning safety rules one has to find in [3]. (pp: 7-9), [10] (pp: 2-5).

References

[1] A.K.Wróblewski, J.A.Zakrzewski, *Wstęp do fizyki*, PWN, Warszawa 1984.

[2] J. Groszkowski, *Technika wysokiej próżni*, WNT, Warszawa 1978.

[3] *Instrukcja obsługi źródła jonów*, strony 19-30.

[4] G.Zschornack, M.Schmidt and A.Thorn, *Electron Beam Ion Sources.*

[5] L.Vályi, *Atom and Ion Sources.*

[6] http://www.dreebit-ibt.com/product/dresden-ebit.html

[7] *Detektor prom. X*

[8] Detektor-rysunek

[9] Wydajność detektora

[10] M. Keller, *TERX detection system*