Personal Thoughts on the Development of Negative Ion Source Research

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When I entered this field in 1970, working in the ion source group of a Tandem accelerator, much interest was excited by the discovery made a few years earlier [1] of the possibility to generate with high yield negative helium ions, by a two-step charge exchange process in alkali metal vapor. This stimulated us to improve the technique and particularly to increase the lifetime of the charge exchange cells with alkali metals. We then built the heat-pipe type cesium cell, using a capillary structure to recycle the liquid metal from the cell extremities to the oven [2].

Soon another exciting problem occurred: producing intense beams of negative hydrogen ions for neutral beam heating in fusion devices. The method to produce these intense beams seemed obvious: the double charge exchange of proton beams in alkali metal vapor targets. Most fusion research centers built then large size supersonic jets of cesium or sodium vapor, to provide the thin and large area targets necessary for the production of intense negative hydrogen ion beams [3,4]. We built at École Polytechnique in France a supersonic cesium jet with continuous cesium recycling by an electromagnetic pump [5]. This jet target was used in a charge exchange H⁻ source studied at Laboratoire d’Ionoique Generale, at Centre d’Études Nucléaires de Grenoble (C.E.N.G.), France [6].

However the evolution of this field prepared a surprise: the finding that electron-beam generated plasma in low pressure hydrogen contained a large fraction of hydrogen negative ions (approximately 10%). A considerable effort of the international community led to a theoretical model for the “volume production”, based on enhanced dissociative electron attachment to highly vibrationally excited hydrogen molecules [7-9]. Such vibrationally excited molecules can be produced by the same energetic electrons (several tens of eV), which produce the plasma, in a two-step process involving excitation of the molecules to an electronically excited singlet state, followed by radiative decay to one of the vibrationally excited states of the ground electronic state. As a result the so-called volume source of H⁻ ions has been conceived, with its tandem structure: a region containing the energetic electrons, where the plasma and the vibrationally excited molecules are produced, denoted driver region, and a second region, with low temperature plasma, where the negative ions are formed [10,11].

At École Polytechnique we made a large effort to develop the photodetachment diagnostic of the negative ion density and temperature. This allowed us to measure the temperature of the negative ions using the two-laser beam technique [12] and to identify the existence of very high negative ion/electron density ratio (approximately 10) in the weakly magnetized region close to the positively biased plasma electrode [13]. The application of the two-laser beam diagnostic [12]
to this region pointed out the existence of a directed negative ion flow with a velocity which could attain 2C, (C, is the ion acoustic velocity) [14]. Therefore the extraction of negative ions is controlled by this directed flow of negative ions.

In experiments performed at Lawrence Berkeley Laboratory [15] and at FOM (Amsterdam, The Netherlands) [16] laser techniques were applied for the identification of the presence of highly vibrationally excited molecules in the plasma, thus confirming in a qualitative way the theoretical model of volume production. Already in 1970, when studying the negative ion sources for the Tandem accelerator, we learned about the possibility of producing negative ions of the element contained in a solid target, when covered with a cesium film and bombarded with a positive ion beam of argon or cesium. In 1972 the surface production of intense H\(^-\) beams on cesiated surfaces bombarded with hydrogen positive ions or atoms was discovered by Dimov’s group in Novosibirsk [17]; subsequently various practical versions of high current, short pulse ion sources based on the latter principle were developed. These sources have been extensively used in one of the most important applications of negative hydrogen ion sources, namely in the charge exchange injection into accelerators and charge exchange extraction from accelerators, which totally modified the present day high energy accelerators [18]. Other areas and types of ion sources have evolved from surface production on cesiated surfaces. A variety of negative ion species can now be generated and are used in a wide range of applications, such as: material surface treatment (ion implantation and etching) [19], heavy ion probes for plasma diagnostics [20,21].

One of the most intriguing issues appeared to be the introduction of small amounts of cesium in the volume H\(^-\) sources [22]. The consequence is a moderate increase of the H\(^-\) ion current, associated with a tremendous reduction of the extracted electron component. The physical phenomena which enhance the negative ion current and improve the characteristics of volume production are not identified yet. The main phenomena to be considered are the electron cooling and the atomic hydrogen absorption. Some people think that we deal in this case with surface production, but this is also to be demonstrated.

Due to the low negative ion temperature in the plasma of the volume sources, the negative ion beams originating from these sources can be very directional. For this reason, these beams can be used in heating the plasma in fusion devices, but also for other applications using this property, such as exploring the surface of the moon.

Recently the first heating experiments with negative ion based neutral beams were effected on an existing fusion device, JT-60U [23,24]. New fusion devices, such as LHD and ITER are designed including from the beginning the high energy neutral beams based on negative ions [25].

Looking to new directions of study of the negative ion sources, one could consider the advantages both for the accelerator physics and for the fusion plasma diagnostics from modulating the negative ion beam. Basic studies of pulsing the anode voltage or the convertor bias in negative ion sources have been done earlier [26-28]. The possibility to limit the charged particle injection into accelerators only to the time period when this is useful, would improve the optical qualities of the accelerated beam. This justifies further efforts in this direction.

REFERENCES

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Instrum. 54, 56 (1983).


