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3,374,384

## PROCESS FOR PRODUCING NEGATIVE HELIUM IONS

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The present invention relates generally to a process for producing negative helium ions and relates more specifically to a process for producing metastable helium atoms from positive helium ions and converting the metastable helium atoms thereby produced into negative helium ions.

The prior art has suggested several methods for obtaining negatively charged helium ions. For example, Dukel'skii et al., J. Exptl. Theoret. Phys. U.S.S.R., 30, 792 (1956) [Translation: Soviet Phys. JETP, 3, 764 (1956)], disclosed, that upon passing positively charged helium ions through rarefied gases (e.g., krypton, argon, neon, and helium), negatively charged helium ions are produced. The authors suggested, however, that the production of negatively charged helium ions occurs during a single collision of positive helium ions with atoms of the target gas, such that the positive helium ions simultaneously capture two electrons from the target gas. However, cross sections for the single step collision action disclosed by the author were relatively low, i.e., of the order of magnitude of about  $10^{-19}$  cm.<sup>2</sup>.

Subsequently, Windham et al., "Negative Helium Ions," Physical Review, 109, 1193 (1958) described a device for producing negatively charged helium ions using hydrogen as a target gas. Again, however, relatively low negative helium ion yields were obtained. Also, the Windham et al. results suggest that a single step collision reaction occurred.

Jorgensen et al., Physical Review, 140 A 1481 (1965), likewise discuss inter alia the collision of a beam of positively charged helium atoms with various gas targets (e.g., hydrogen, helium, nitrogen, oxygen, and argon). Once again, the production of negatively charged helium ions is described, but only in relatively low yield. Although the authors suggested that formation of the negatively charged helium ion occurs via a metastable intermediate, in fact, the experimental data published in the article seems to indicate that, at low pressures, a linear relationship exists between the negatively charged helium ions produced and the pressure of the target gas, thereby suggesting that in fact a single step mechanism is involved and not one involving a metastable intermediate.

Lorents et al., "Charge Transfer of He<sup>+</sup> and Ar<sup>+</sup> in Rb and Cs; Near-Resonant Transitions to excited States," Abstracts of Papers, Fourth International Conference on the Physics of Electronic and Atomic Collisions, 328 (1965), measured the total charge transfer cross sections of positive helium ions in rubidium and cesium and surmised that the cross sections were large because the reactions yielding certain excited states of helium, including He(1s, 2s), are nearly resonant. However, the authors did not suggest, teach, or in any way describe any method or means for obtaining negatively charged helium ions.

Briefly, the present invention comprises a process for producing negatively charged helium ions comprising the steps of:

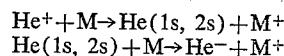
- (a) converting a beam of relatively low energy [i.e., of the order of magnitude of up to several kiloelectron volts (Kev.)] positively charged helium ions into metastable helium atoms; and
- (b) thereafter converting the metastable helium atoms thereby produced into negatively charged helium ions.

It has been discovered that each of these steps can be per-

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formed by a collision reaction between the starting material and the vapor of an alkali atom. Thus, passing a beam of relatively low energy positively charged helium ions into, for example, cesium vapor produces, among other things, metastable helium atoms; and collision of metastable helium atoms with, for example, cesium vapor results, among other things, in the conversion of metastable helium atoms into negatively charged helium ions. The positively and negatively charged helium ions referred to herein are in all instances singly charged (i.e., H<sup>+</sup> or He<sup>-</sup>) and the use of these terms herein should be interpreted accordingly.

The process of the present invention, thus, occurs in accordance with the following reactions:



where M is an alkali atom. Since each of the above-mentioned steps in the conversion process may be carried out using the same alkali atom vapor, the process may conveniently be carried out in a single collision region (i.e., in the same gas cell).

A primary object of the present invention is to provide a method for producing a beam of negatively charged helium ions.

Another object of the present invention is to provide a process of the character described in which positively charged helium ions may be converted via a two-step collision reaction mechanism occurring in a single collision region.

A further object of the present invention is to provide a process of the character described in which the negative helium ions are produced in relatively high yield.

These and other objects, advantages, and features of the present invention will hereinafter appear, and, for purposes of illustration, but not of limitation, exemplary embodiments of the present invention are described hereinafter.

A beam of positively charged helium ions for use in demonstrating the process of the present invention may be obtained from a conventional mass spectrometer ion source. The positively charged helium ions are collimated by appropriate means (e.g., a sector magnetic analyser component of the mass spectrometer ion source) and passed through a collision region (e.g., a gas cell). Alkali atom vapor is then introduced into the collision region and the positively charged helium ion beam interacts with the alkali atom vapor in the collision region, and, in accordance with the previously described steps, negatively charged helium ions are produced.

Appropriate electrostatic or magnetic means (e.g., a conventional electrostatic analyser) may be employed to separate the beam of negatively charged helium ions produced by the process of the present invention and means (e.g., a conventional Faraday cup) may be used to measure the current of negatively charged helium ions thereby produced.

Of the alkali atoms, cesium and potassium have been shown to be effective in carrying out the process herein disclosed. However, the other alkali atoms could be expected to be effective since the characteristic believed to be most important insofar as the process of the present invention is concerned is the ionization energy of the operative material. In view of the similarity of the electronic structures and the ionization energies of the various alkali atoms, it would be expected that substantially any alkali atom could be used in practicing the present invention.

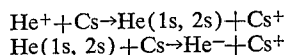
It is believed that the intermediate metastable helium atoms produced by the first step of the process of the present invention are in either the singlet or the triplet state. The ionization energies of the alkali atoms are such

that the reactions producing the singlet and triplet metastable helium atoms are nearly resonant. It is believed that the negatively charged helium ions produced in the second step of the reaction are in the (1s, 2s, 2p)<sup>4</sup>P<sub>5/2</sub> state and are, therefore, probably formed predominantly from triplet metastable helium atoms rather than from singlet metastable helium atoms in which the electron spins would have to be realigned during the second step of the process. These theoretical suggestions are presented as applicant's best estimate of the mechanism by which the conversion process of the present invention occurs, but the discussion is not intended to limit the process of the present invention to any specific mechanism.

The process of the present invention may be illustrated by the following example.

#### EXAMPLE I

Collimated beams of positively charged helium ions of varying energies were obtained from a conventional mass spectrometer ion source and were passed through a collision region. Initially, the current of positively charged helium ions was itself measured by means of a conventional electrostatic analyser and Faraday cup. Thereafter, cesium vapor was admitted to the collision region and the following reactions occurred:



The electrostatic analyser was then adjusted so as to measure the negatively charged helium ion current. The following table lists the ratio of negatively charged helium ion current to the incident positive helium ion current for positive helium ion beams of various energies at the optimal cesium vapor thickness of about 3 micron centimeters. Within the preferred positively charged helium ion energy range of up to about 3000 electron volts, the He<sup>-</sup>/He<sup>+</sup> ratios achieved approached  $5 \times 10^{-3}$  (i.e., 0.5%). Thus, under optimal conditions, the yields that may be achieved with the process of the present invention approach about one half of one percent. The preferred positive helium ion energy range for obtaining optimal yields is about 1300 to 2400 electron volts.

Table I

| MAXIMUM He <sup>-</sup> YIELD VS. He <sup>+</sup> ENERGY IN<br>He <sup>+</sup> -Cs COLLISIONS |                                          |
|-----------------------------------------------------------------------------------------------|------------------------------------------|
| He <sup>+</sup> energy, ev.:                                                                  | (He <sup>-</sup> /He <sup>+</sup> ) max. |
| 600                                                                                           | $.75 \times 10^{-3}$                     |
| 900                                                                                           | $2.8 \times 10^{-3}$                     |
| 1300                                                                                          | $4.84 \times 10^{-3}$                    |
| 1600                                                                                          | $4.67 \times 10^{-3}$                    |
| 2000                                                                                          | $4.83 \times 10^{-3}$                    |
| 2400                                                                                          | $4.66 \times 10^{-3}$                    |
| 3000                                                                                          | $3.16 \times 10^{-3}$                    |

#### EXAMPLE II

In the same manner as Example I, negatively charged helium ion currents were obtained using potassium as the target alkali atom. The following reactions occurred:

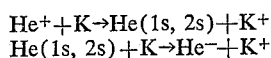


Table II reports the He<sup>-</sup>/He<sup>+</sup> current ratios achieved using potassium as the alkali atom target. The data of Table II verify that relatively high yields of negatively charged helium ions are obtained using potassium as the target alkali atom, the optimal potassium vapor thickness being about 6 micron centimeters. However, optimal yields of negatively charged helium ions occur at somewhat higher He<sup>+</sup> energies. Again, using potassium as the target alkali atom, yields approaching the level of one half of one percent are obtained. The optimal energy range for the beam of positive helium ions is higher in the case of potassium (peak negative ion yields at above 3000 electron volts) than in the case of cesium (optimal

negative ion yields with positive ion energies lying in the range of about 1300-2400 electron volts).

Table II

| MAXIMUM He <sup>-</sup> YIELD VS. He <sup>+</sup> ENERGY IN<br>He <sup>+</sup> -K COLLISIONS |                                          |
|----------------------------------------------------------------------------------------------|------------------------------------------|
| He <sup>+</sup> energy, ev.:                                                                 | (He <sup>-</sup> /He <sup>+</sup> ) max. |
| 1300                                                                                         | $1.4 \times 10^{-3}$                     |
| 2000                                                                                         | $2.5 \times 10^{-3}$                     |
| 2600                                                                                         | $3.9 \times 10^{-3}$                     |
| 3000                                                                                         | $4.7 \times 10^{-3}$                     |

Because of the higher beam intensities that can be achieved at higher positive ion beam energies, the optimal positive helium ion energies for carrying out the process of the present invention may be higher than those indicated by the exemplary experimental data reported in Examples I and II. Accordingly, the precise preferred positive ion ranges given herein are not meant to be critical, and other appropriate positive helium ion beam energies may be satisfactorily employed, so long as the beams are of relatively low energy (i.e., of the order of magnitude of up to several kev.).

The yield of negative helium ions obtained with the process of the present invention is influenced by the density of the target alkali atom vapor in the collision region and by the length of the collision region. These variables are conveniently expressed in product form as a vapor thickness for the gas. For example, at a pressure of 5 microns of mercury and with a collision length of 5 microns, the vapor thickness is 25 micron centimeters. In accordance with the present invention and where cesium is employed as the alkali atom, optimal yields of negatively charged helium ions are obtained at a vapor thickness of about 3.3 micron centimeters. Where potassium is employed as the alkali atom, optimal yields of negatively charged helium ions are obtained at a vapor thickness of about 6 micron centimeters. Other vapor thicknesses may be employed although negative ion yields will probably be somewhat diminished.

The process of the present invention for producing negatively charged helium ions in relatively high yields has utility in various atomic and nuclear physics basic research activities. In particular, the negative particles produced by the process of the present invention are well suited for use with conventional tandem-type accelerators, which require an input of negatively charged particles.

If the positive helium ions successively pick up two electrons from alkali atoms having electronic polarization (produced, for example, by optical pumping or by selection by deflection in a strong inhomogeneous magnetic field), the resulting negative helium ions would be polarized. If <sup>3</sup>He<sup>+</sup>, with a nuclear spin of 1/2, is employed, the electronic angular momentum would couple to the nuclear angular momentum to produce a nuclear polarization. Appropriate hyperfine transitions could be induced to enhance the nuclear polarization.

The process of the present invention may also be employed to carry out the conversion from positive ionic state to negative ionic state of <sup>3</sup>He, as well as of the more common <sup>4</sup>He helium isotope. Yields of <sup>3</sup>He<sup>-</sup> would be of the same magnitude as those of <sup>4</sup>He<sup>-</sup> at corresponding velocities. Thus, the term helium as used in the appended claims should be understood to generically encompass the normal helium isotope (<sup>4</sup>He) as well as the lighter helium isotope (<sup>3</sup>He).

Although the subject invention has been described as a two-step reaction in which all of the collisions occur in the same collision region (i.e., in the same gas cell), each of the discrete steps could be carried out separately and sequentially.

In accordance with the present invention, a two-step process is provided in order to convert relatively low energy positively charged helium ions into a beam of negatively charged helium ions in relatively high yield.

While the process of the present invention has been

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described with reference to certain preferred embodiments, it will be obvious to one skilled in the art that various changes, alterations, and modifications may be made in the reactants and reaction conditions for the process, without departing from the spirit and the scope of the appended claims.

What is claimed is:

1. A process for producing negatively charged helium ions comprising the steps of:

passing a beam of relatively low energy positively charged helium ions through the vapor of an alkali atom in order to produce metastable helium atoms; and

passing said metastable helium atoms through the vapor of an alkali atom in order to convert said metastable helium atoms into negatively charged helium ions.

2. A process, as claimed in claim 1, wherein the same alkali atom is employed for each step and wherein each step is carried out in the same collision region.

3. A process, as claimed in claim 2, wherein the alkali atom is cesium.

4. A process, as claimed in claim 3, wherein the positively charged helium ions of said beam have energies lying in the range of up to about 3000 electron volts.

5. A process, as claimed in claim 4, wherein the optimal vapor thickness of the cesium in the collision region is about 3 micron centimeters.

6. A process, as claimed in claim 2, wherein the alkali atom is potassium.

7. A process, as claimed in claim 6, wherein the optimal vapor thickness of the potassium in the collision region is about 6 micron centimeters.

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8. A process for producing negatively charged helium ions comprising passing a beam of positively charged helium ions having energies in the range of up to several kiloelectron volts through the vapor of an alkali atom and thereafter separating the negatively charged helium ions thereby produced.

9. A process, as claimed in claim 8, wherein the alkali atom is cesium and wherein the positively charged helium ions of said beam have energies of up to about 3 kiloelectron volts, the optimal vapor thickness of said cesium vapor being about 3 micron centimeters.

10. A process, as claimed in claim 8, wherein the alkali atom is potassium and wherein the optimal vapor thickness of said potassium vapor is about 6 micron centimeters.

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