ELECTRON ATTACHMENT TO MEDIUM-ENERGY IONS*

M. B. Sampson, W. W. Eidson, F. J. Bartis
Department of Physics, Indiana University
Bloomington, Indiana

A method is proposed for changing the charge state of energetic ions such as are obtainable from medium-energy accelerators. The method consists of superimposing on the ion beam an electron beam of the same laboratory velocity. Thus, small center-of-mass velocities can be obtained even though large velocities are present in the laboratory system. The feasibility of the method has been estimated from published cross sections for radiative recombination. The practicality of the method is being investigated in a simple experiment using 8.78 MeV alpha-particles from ThC' and 1.2 keV electrons. So far, no positive results have been obtained, but this may be due to technical difficulties in superimposing the two beams, and/or the physical limitations imposed by space charge. Possible applications of this technique to future ion source and accelerator design will be discussed.

Introduction

In August 1964, we started looking for a practical method for attaching electrons to fast ions. We began our work with a simple idea in mind. Ions which have energies of several million electron volts pass much too rapidly through matter to capture electrons. In order to increase the probability of electron capture, we superimpose on the ion beam an electron beam with the same laboratory velocity. Thus, small center-of-mass velocities can be obtained even though large velocities are present in the laboratory. Since the radiative capture cross section is known[1] to increase rapidly as the relative velocity decreases, we felt that the above method might produce a reasonable amount of recombination even though the electron density in a beam is quite low compared to that in matter.

It is interesting to note that a series of experiments similar to ours was performed by Barnes and Davis[2] in 1930. They observed that as much as 90% of their 5.3 MeV Polonium alpha particles underwent single electron capture and about 80% double electron capture at zero relative velocity. Webster,[3] however, was unable to reproduce their results.

Although there is an obvious discrepancy between the results of Barnes and Davis[2] and those of Webster,[3] we have been motivated by possible applications of electron capture by fast ions in future accelerator and ion source design. It is clear that if the results of Barnes and Davis are correct it would be practical to bend, neutralize, and re-accelerate ions several times with a tandem electrostatic accelerator.

Apparatus and Procedures

Since the crux of the above scheme is the neutralization process, we have tried to repeat the earlier work. Our apparatus consisted essentially of a natural ThC' alpha-particle source, an electron gun, and an analyzing magnet. An electron accelerating potential of 1200 volts was necessary to match velocities with the 8.78 MeV alpha particles from the ThC' source. In one approach, the electrons were extracted from a Duoplasmatron[4] source and electrostatically deflected into the alpha beam. Use of the duoplasmatron was discontinued due to the large energy and angular spread of its electron beam. In another method, an electron beam from a Pierce[5] gun was focused through the center of an annular alpha source; but, again, the large angular divergence of the electron beam proved to be unmanageable. Finally, a fine, spiral filament and anode assembly was placed directly in the alpha beam. This arrangement seemed to provide the best electron optics.

After the beams were superimposed, an axially-symmetric magnetic field was applied in order to spatially confine the electron beam. At the current densities used (10-20 ma/cm^2 at the end of the drift path) space charge, very slight misalignment, and stray magnetic fields all tend to remove the electrons from the path of the alpha particles. Unfortunately, the axial magnetic field does not correct the components of velocity perpendicular to the axis but only causes the electrons to spiral. Use of this field was found necessary, however, to provide sizable electron currents at the end of the drift path. Collection efficiency was often as high as 25% of the total emission from the cathode.

After drifting with the electrons for one meter (50 nanoseconds), the alpha particles are separated into the various charge states by an analyzing magnet: He^{++} (no capture), He^{+} (single electron capture), He^{0} (two electron capture). After this charge-state analysis, the alpha particles strike a silicon surface barrier detector, whose output is amplified by a charge sensitive amplifier and fed into a 1024-channel multichannel pulse-height analyzer. We employed two detectors so that we could simultaneously compare the He^{0} rate (straight-through the magnet) with either the He^{++} or He^{+} when the magnet field was appropriately adjusted to deflect the He^{++} or the He^{+} through an angle of 10°. Some effort was made to shield the electron beam from the fringing field of the analyzing magnet.

Results

At no time during any of our experiments were we able to detect the presence of neutral 8.78 MeV alpha particles with any statistical significance. The background (counting rate in the He^{0} counter with magnet on, electron beam off) was zero for all practical purposes, but unfortunately, so was the rate with the electron beam. Due to limitations in the maximum field in the analyzing magnet, we could not bend the He^+ ions, but intend to remedy this in the future to search for He^+ directly. An indirect approach, attempting to detect a decrease in the He^{++} counting rate, failed to find any statistically significant deviations.

Discussion

The failure of our experiments to detect an appreciable recombination can be due to either or both of two causes: 1) The recombination cross section is simply too small to detect appreciable electron capture with electron currents presently available. 2) Technical difficulties of alignment and energy spread prevent us from obtaining optimum conditions of velocity matching and superposition.

The theoretical calculations of Bates et al.[1] suggest that, although the electron densities are low in our experiments, a detectable recombination should be present in an ideal arrangement in which the electron and alpha velocities are matched over a long drift path. A simple calculation utilizing only the coulomb attraction between the alpha particles and a matrix of electrons at rest with respect to the alpha particles indicates that most of the alpha particles should capture a single electron during our one meter drift path.

We believe that the major problem, preventing us from observing the expected recombination, is the production of a parallel, mono-energetic electron beam. Stray fields and space charge[6] can easily destroy the beam. On the other hand, solenoidal magnetic or electrostatic focusing lenses make the beam spiral or change energy, respectively, so that zero energy relative to alpha particles is quite difficult to maintain.

The single electron capture by a He^{++} nucleus should be a much more likely process and experiments are being continued to attempt to measure this. Further improvements in the beam geometry and the electron optics are also planned.

References

*Supported by the Indiana University Foundation.

1. Bates, Buckingham, Massey, and Unwin, Proc. Roy. Soc. 170A, 322 (1939).

2. Davis and Barnes, Phys. Rev. 34, 152 (1929); Barnes, Phys. Rev. 35, 219 (1930); Barnes and Davis, Phys. Rev. 37, 1368 (1931).

3. H. C. Webster, Proc. Camb. Phil. Soc. 27, 116 (1930).

4. On loan from the Oak Ridge Technical Enterprises Corporation, Oak Ridge, Tennessee.

5. J. R. Pierce, Theory and Design of Electron Beams, Sec. Ed. (Van Nostrand, New York, 1954).

6. Simpson and Kuyatt, N B S J. Res. 67C, 279 (1963).