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Transport of e^+ Beams from a Magnetic Field into a Non Magnetic Field

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Transport of e^+ (and e^-) beams which are guided by a magnetic field to a non magnetic field was measured for the first time under several conditions. The transport efficiency when using an einzel lens was more than 80% for energy higher than 1.5 keV.

KEYWORDS: positron beam, electrostatic lens, transport of positron/electron beam

In producing high intensity slow e^+ beams using a linac, the e^+ beams are guided through a flight tube by a parallel magnetic field.[1-4] On the other hand, in some positron-beam apparatus using a radioisotope, the e^+ beams are guided by an electrostatic lens system, because the beam path is rather simple. It is necessary, however, to carry out scattering experiments utilizing the slow e^+ beams in a non magnetic field. In particular, the brightness enhancement by which the e^+ beam characteristics of high brightness and narrow energy width are realized[5,6] is performed in a non magnetic field. No study on the beam transport from a magnetic field into a non magnetic one has been attempted, though such studies are important in the e^+ beam technique. In this letter, transport measurements of e^+ (or e^-) beams are performed in the energy range of 100–2000 eV. It is shown for the first time that the beams guided by a magnetic field are transported with fairly sufficient efficiency into a non magnetic field by means of an einzel lens system.

The transport efficiency of e^+ (or e^-) beams was measured using the experimental arrangement shown in Fig. 1. The e^+ (or e^-) beams were measured at positions ***A*** and ***B*** using a Ceratron, a kind of CEM detector. A magnetic field of 4.5 mT parallel to the flight pipe produced by the coil (a) is used for a beam-guide in the left side of ***A***, but the solenoid coil is not used in the right side except in one case. Position ***B*** is located 180 mm from ***A***. An einzel lens is set between ***A*** and ***B***. The counting rate in the case of the detector set at ***A*** is almost the same inside the solenoid because the draw-in potential of −650 eV for e^+ beams is applied to the entrance of the Ceratron. As an e^+ beam source, a radioisotope ^{22}Na of 50 μCi is used; it has characteristics of the energy and spatial distribution of the e^+ beam similar to those of a linac. Fast positrons are converted to slow positrons by a tungsten-ribbon moderator. Moreover, secondary electrons emitted from the same radioisotope and moderator are used as the e^- beam source. The intensity of e^- beams is two orders of magnitude stronger than that of e^+. The beams of e^+ and e^- in the flight tube uniformly spread about 8 mm in diameter.

The comparison of counts at ***A*** with those at ***B*** is easily carried out using the time spectrum in a TOF system.[7] The ratio of the counting rate measured at ***B*** to that at ***A*** is defined as the transport efficiency from magnetic to non magnetic fields. To examine the characteristics of the einzel lens, a measurement at ***B′*** was carried out without the einzel lens. The efficiency was measured under several conditions. The results are shown in Fig. 2.

The performance of the einzel lens used is investigated in terms of the theory of the electrostatic lens.[8] The calculation program of Canter *et al.*[9] was used for the examination. The Larmor radius $\rho(=mv_\perp/(eB))$ of charged particles increases with decreasing magnetic induction ***B***, where $v_\perp$ is the velocity component perpendicular to the flight tube. Hence, the motion of radial direction comes into existence as a result of the change of the magnetic field. In our case, the radial angle θ is very small, about 0.01 rad, because the average transverse energy $mv_\perp^2/2$ of e^+ beams is about 0.2 eV and that for

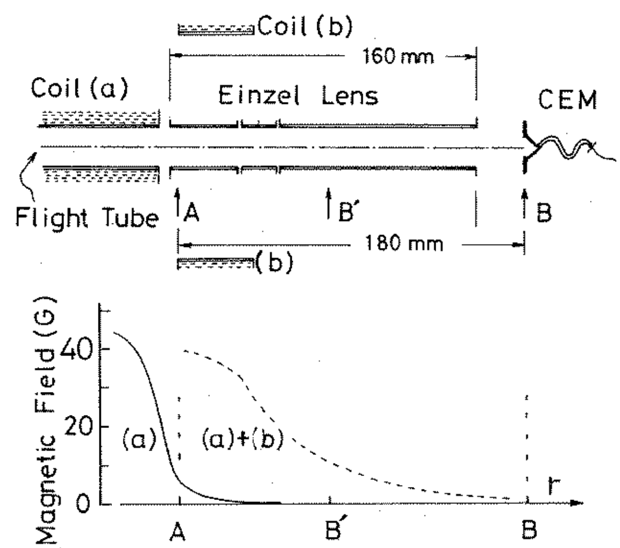

Fig. 1. Schematic diagram of the main part of the experimental setup. Magnetic induction on the axis of the flight tube is shown below.

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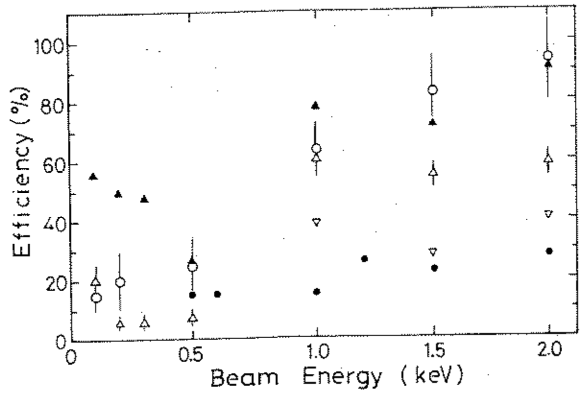

Fig. 2. Transport efficiency vs beam energy. ○, for e^+; △, e^-; ▲, e^- in magnetic field (a)+(b); ●, e^+ at B' without the einzel lens; ▽, e^- with 3 mmϕ hole at the detector. Error bars are shown only for the main results, ○ and △.

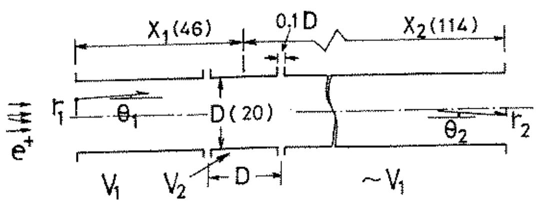

Fig. 3. Schematic diagram of the einzel lens.

e^- is about 0.8 eV for the present condition[7] of the solenoid current. For example, in the case of the incident e^+ beam energy of 1500 eV, the radius $r_1=5$ mm, and the geometrical size of the lens $X_1=46$ mm and $X_2=114$ mm (X_1 and X_2 are denoted in Fig. 3), the beams with the radial angle θ_1 between ± 0.025 rad are collected on the 8 mm diameter entrance of the detector. The trajectory of e^+ (or e^-) particles is not simple even in a uniform magnetic field, because of the complicated spatial distribution and transverse energy distribution within the beam. The complete check of the applied condition by the calculation is very complicated and not important for the present purpose since only the high efficiency of the beam transport is necessary on the whole. The conditions for good efficiency agree roughly with those predicted by the lens theory. The conditions were as follows. The potential distribution within the lens was nearly symmetrical. The potential ratio V_2/V_1 was about 2, where V_1 and V_2 were the potential for the side lens and that for the center, the value of V_2 was about 4 keV for the beam of 2 keV and 1.5 keV.

The following conclusions were obtained from the experimental results.

1. The beam-transport efficiency from a magnetic field into a non magnetic one for e^+ of energy higher than 1500 eV was higher than 80%. The efficiency for e^- was considerably lower than that for e^+. This difference is explicable based on the fact that the transverse energy of e^- beams is larger than that of e^+, as mentioned above.
2. By the additional magnetic field of the coil (b) the transport efficiency increases.
3. The focus effect was not achieved easily.
4. To obtain high-transport efficiency for beams of energy lower than 1 keV, the kinetic energy within the lens should be increased by the applied potential to the lens.
5. The lens system should be located close to the solenoid coil.

In conclusion, in the range of several keV where the re-emission phenomenon of positrons takes place efficiently, e^+ beams are easily transported from a magnetic field into a non magnetic one with sufficient efficiency using an einzel lens. By applying the present technique to the intense slow e^+ beam production using an electron linac, we can resort to the conventional simple method of the e^+ beam guide using solenoid coils, and then transport the e^+ beam from a magnetic field into a non magnetic one. This has a further advantage in comparison with the method of beam transport method by an electrostatic lens system since only the present beam transport can be done after the pulsed e^+ beam is stretched into a DC mode using a Penning trap method.[10,11]

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