Production of zero energy radioactive beams through extraction across superfluid helium surface

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Abstract

A radioactive ^{223}Ra source was immersed in superfluid helium at 1.2 - 1.7 K. Electric fields transported recoiled ^{219}Rn ions in the form of snowballs to the surface and further extracted them across the surface. The ions were focussed onto an aluminium foil and alpha particle spectra were taken with a surface barrier spectrometer. This enabled us to determine the efficiency for each process unambiguously. The pulsed second sound wave proved effective in enhancing the extraction of positive ions from the surface. Thus we offer a novel method for study of impurities in superfluid helium and propose this method for production of zero energy nuclear beams for use at radioactive ion beam facilities.

Key words: Impurities in superfluid helium, Radioactive snowballs, Second sound wave, Radioactive ion beams

A novel experimental method using radioactive impurities is applied for the extraction of positive ions across the superfluid helium surface, to determine the efficiencies of transport and extraction processes. The positive ions are transported in the form of snowballs [1,2] in superfluid helium and again reduced to the ionic form when they are extracted from the liquid surface. Our experiments represent the first basic research for producing zero energy radioactive nuclear beams (RNBs) by stopping fast ions in superfluid helium.

Recoiled ^{219}Rn was released into superfluid helium at 1.2 - 1.7 K following the alpha decay of ^{223}Ra from a thin source placed at the bottom of the experimental cell and covered with superfluid helium 5 mm in depth. The positive ions were transported to the surface and focussed onto a thin aluminium foil placed 55 mm above the surface through static electric fields. An alpha particle spectrometer, a surface barrier Si detector was deployed 3 mm above the foil.

The range of alpha particles in the liquid helium was about 0.4 mm and there were no alpha particles detected in the spectrometer without electric fields. Alpha particles appeared in the spectrometer after the electric fields were applied all the way to the foil. Fig. 1 shows alpha particle spectra measured at 1.60 and 1.22 K at helium vapour pressures of 760 and 95 Pa, respectively. We interpret the peaks in the spectra through the measured energy and the calculated energy loss between the place of decay and the spectrometer. The alpha peaks marked as “Rn”, “Po” and “Bi” are from ^{219}Rn, ^{215}Po and ^{211}Bi decays on the foil, while the peaks labelled “Rn*” and “Po*” are from ^{219}Rn and ^{215}Po decays at the surface of liquid helium. The observed alpha particle spectra demonstrate that ^{219}Rn ions have been extracted out of the liquid helium and collected on the foil in front of the spectrometer. It is confirmed for the first time that positive ions are in-

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Table 1
Measured efficiencies at 1.60 K.

Overall	0.0720(4)%
Snowball formation	1.5%
Snowball transportation to liquid surface	70%
Ion extraction out of liquid	36%
Ion transportation in He vapour	20%

deed extracted from the superfluid helium surface with identification, which was made possible through highly sensitive radioactivity detection.

The absolute overall efficiency of 0.0720(4)% was determined from the intensity of the peak Rn and the ^{223}Ra source strength. This splits up into four factors: snowball formation, transport in the liquid, ion extraction out of the liquid surface and transport in the vapour. The efficiencies are shown in Table 1. The efficiency of 20% for transport in the vapour was obtained by stopping the recoils at approximately 5 mm away from the source in the experimental cell at a temperature of 5.08 K with an amount of helium gas equivalent to about 10000 Pa at room temperature. From the peak Rn*, the efficiency for an ion to form a snowball and reach the surface without being extracted, is deduced to be 0.64(9)%. The efficiency for ion extraction out of liquid helium is then deduced to be 36%. The efficiency to transport the snowballs to the surface was deduced from separate measurements to be approximately 70%. These numbers give an efficiency for snowball formation of only approximately 1.5% which determines the relatively low overall efficiency. It is known, however, that the snowball formation probability can reach up to 20% with higher electric fields for the site of snowball formation [4].

The extraction of positive ions transported to the surface of superfluid helium in the form of snowballs has been one of the hitherto unclarified issues [6]. A higher surface temperature eases the extraction but on the other hand the transportation takes more time and is ineffective. We solved this problem by applying a pulsed second sound wave created from a circular heater around the radioactive source. The current pulses that excited the heater were 20 - 50 ms wide and were repeated every 50 to 500 ms. The decay rate of ^{219}Rn from the foil increased by 10 - 30% depending on heater power.

Radioactive ions have been used earlier to study transportation process [7] and properties of impurities [3–5]. We propose to apply this method as a new tool for the cases where the electric current or charge measurements have limited sensitivity.

Cold RNBs are required in the studies of exotic nuclear states and nuclear astrophysics [8]. RNBs are produced in high energy nuclear reactions and therefore the degradation of their energies through traditional

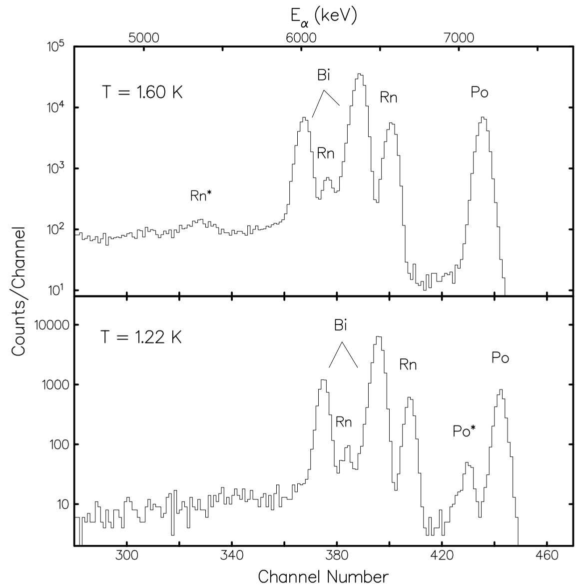

Fig. 1. Alpha particle spectra for superfluid helium temperature of 1.60 and 1.22 K. See text.

Ion Guide Isotope Separator On-Line (IGISOL) methods [9] may not be the best choise. Production of cold RNBs based on the method described in this work is practised under the appellation, Jyväskylä Snowball Project, at the University of Jyväskylä, Finland for use at the next generation RNB facilities.

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