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Exotic Behavior of Elastic Scattering Differential Cross-Sections of Weakly Bound Nucleus ^{17}F at Small Angles*

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Abstract The differential cross-sections for elastic scattering of ^{17}F and ^{17}O on ^{208}Pb have been measured at Radioactive Ion Beam Line at Lanzhou (RIBLL). The variation of the logarithms of differential cross-sections with the square of scattering angles shows clearly that there exists a turning point in the range of small scattering angles (6°—20°) for ^{17}F having exotic structure, while no turning point was observed in the ^{17}O elastic scattering. The experimental results have been compared with previous data. Systematical analysis on the available data seems to conclude that there is an exotic behavior of elastic scattering differential cross-sections of weakly bound nuclei with halo or skin structure as compared with that of the ordinary nuclei near stable line. Therefore the fact that the turning point of the logarithms of differential cross-sections appears at small angle for weakly bound nuclei could be used as a new probe to investigate the halo and skin phenomenon.

Key words elastic scattering, differential cross-section, halo nuclei

Studies on nuclei far from β stability line have attracted many nuclear physicists in recent years. It has been known that there are neutron and proton halos in weakly bound nuclei such as in ^{6}He, ^{11}Li, ^{14}Be and ^{8}B[1—12]. The appearance of halos and skins is usually identified by the abnormal increase of total reaction cross-sections or by the narrow momentum distributions in the fragmentation of weakly bound nuclei[1—12]. In order to manifest the halo phenomenon clearly it is hoped to search for new probes for identification of the halo and skin phenomenon of weakly bound nuclei. It is believed that low energy nuclear reactions can provide reliable information on the structure of weakly bound nuclei. Here we report a measurement of differential cross-sections of elastic scattering of ^{17}F and ^{17}O on the ^{208}Pb target.

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The experiment was performed using the Radioactive Ion Beam Line in Lanzhou (RIBLL)[13] at the Institute of Modern Physics (IMP), Chinese Academy of Sciences. The primary beam of 70 MeV/A ^{20}Ne from the Heavy Ion Reaction Facility of Lanzhou (HIRFL) bombarded the ^{9}Be target(3.5mm in thickness), which was installed at the beam entrance of RIBLL, to produce the secondary beams. The secondary beams were selected and purified by $B\rho$-ΔE-$B\rho$ technique and transported to the final focus point of RIBLL. With $B\rho$-TOF method, identified particles will hit on a ^{208}Pb target(2mg/cm^2 in thickness) with a mean energy of 141MeV (^{17}F) or 128MeV (^{17}O). The detector arrangement was schematically shown in Fig. 1. Three position sensitive parallel plate avalanche counters (PPAC1-PPAC3) were placed respectively before or after the target. The active area of PPAC1-PPAC3 is 100mm×100mm and their position resolution is 0.5mm. PPAC1 and PPAC2 were employed to determine the track of each incident particle. PPAC3 was used to determine the scattering angles of outgoing particles on the Si detector array with an angle resolution of less than 0.2°, and its detection angle is from 6° to 20° in laboratory system. There are five pieces of silicon detectors(325μm in thickness) in the Si array that were used to detect the residual energy of the products with an energy resolution better than 1%. Because of the momentum dispersion ($\Delta p/p$=±0.1%) of RIBLL, the first excited states both in ^{17}F (at 0.4953keV) and in ^{208}Pb (at 2.614MeV) could not be separated from elastic particles. In other words, the elastic scattering data in this experiment include contributions from inelastic scattering reactions.

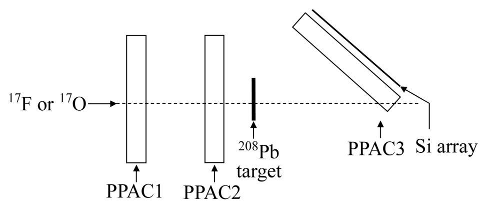

Fig. 1. The schematic figure of experimental setup.

For analyzing the ^{17}F/^{17}O scattering events from the ^{208}Pb target a selected region of TOF and energy (E value on the Si array) were considered to ensure that the events to be analyzed were the elastic scattering products. Then the selected events were analyzed particle-by-particle to deduce its scattering angle. The Si array were so arranged that they covered a wide range of polar angles θ from 6° to 20° and about 20% of the full azimuth. For this reason, a Monte-Carlo simulation of the detector geometry was undertaken in order to estimate geometrical efficiency. Then the differential cross-sections of elastic scattering products of ^{17}F and ^{17}O were calculated at different scattering angles ranged from 6° to 20°.

In order to see the variation of differential cross-sections with scattering angles the logarithms of differential cross-sections ($\ln(\mathrm{d}\sigma/\mathrm{d}\theta)$) are drawn in Fig. 2 as a function of square of the scattering angle (θ^2). The unit of differential cross-sections is mb and the unit of scattering angle is in degree. The horizontal error bar denotes the bin width of θ^2, while the statistical error bar of ($\ln(\mathrm{d}\sigma/\mathrm{d}\theta)$) is smaller than the symbol of the data point.

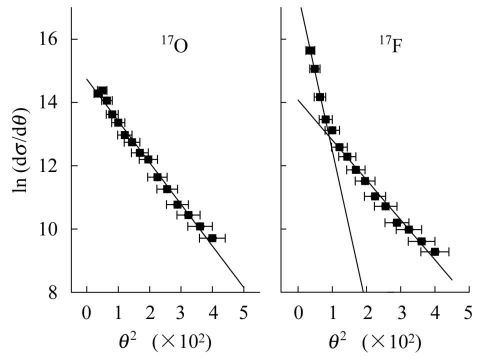

Fig. 2. The logarithms of differential cross-sections ($\ln(\mathrm{d}\sigma/\mathrm{d}\theta)$) via the square of scattering angles (θ^2) of ^{17}F and ^{17}O in this experiment.

It is seen in Fig. 2 that the logarithm of the differential cross-sections for ^{17}O vary approximately along a straight line. This is quite different from those of ^{17}F which can not be fit by a single straight line. However the data of ^{17}F can be fit by two straight lines where a turning point appears near the small angle $\theta\approx$12°. It is well known that the separation energy of the last proton in ^{17}F is very low $S_\mathrm{p}=0.60$MeV[14]. For ^{17}O the last neutron is bound with an energy of $S_\mathrm{n}=4.14$MeV[14]. It also has been known that there is an exotic structure in ^{17}F with the weak binding of the last proton[6, 9, 10]. The measurement of the reaction cross-section[9] shows clearly an abnormal increase of ^{17}F indicating the existence of large proton skin[9, 10]. Here the data of the elastic scattering of ^{17}F demonstrate the existence of a turning point at a small angle, and this may be used as a new probe of exotic structure of a weakly bound nucleus.

In order to test this suggestion we have also quoted the data of previous experiments by other groups and plotted them in Fig. 3. The beam energies for the elastic scattering of ^{16}O[15] and ^{6}He[16] on ^{208}Pb were 10.6MeV/u and 4.5MeV/u, respectively. It is seen from Fig. 3 that there exists obviously a turning point at small angle $\theta \approx 17°$ for the halo nucleus ^{6}He while no turning point is observed clearly for ^{16}O in the range up to $\theta \approx 20°$. This agrees well with our observations shown in Fig. 2.

In summary, the differential cross-sections for the elastic scattering of ^{17}F and ^{17}O on ^{208}Pb have been measured at small angles at RIBLL. The logarithm of the differential cross-sections show different behavior as a function of the square of scattering angle. The data of ^{17}O in the range of small angles θ=6°—20° vary approximately along a straight line but those of ^{17}F can not be fit with a single straight line. However the data of ^{17}F can be fit by two straight lines with a turning point appearing at a small angle. It is thus suggested that the turning point could be used as a new probe to investigate the structure of the weakly bound nucleus with halo or skin structure. The data of elastic scattering of ^{16}O[15] and ^{6}He[16] on the ^{208}Pb target from other groups support this view. This idea might be useful for future investigations of exotic structure of weakly bound nuclei.

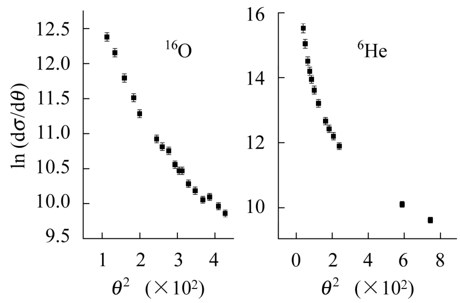

Fig. 3. The logarithms of differential cross-sections (ln(dσ/dθ)) via the square of scattering angles (θ^2) of ^{16}O and ^{6}He from Refs. [15, 16].

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小角度范围内弱束缚核 ^{17}F 弹性散射微分截面的奇异行为*

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摘要　在兰州放射性束流线(RIBLL)上完成了 ^{17}F/^{17}O+^{208}Pb的弹性散射微分截面角分布测量. 分析了 ^{17}F/^{17}O弹性散射产物微分截面的对数($\ln(\mathrm{d}\sigma/\mathrm{d}\theta)$)随散射角平方($\theta^2$)的依赖关系. 结果表明, 在所测量的角度范围内(6°—20°), ^{17}O的这一依赖关系可以用一条直线很好地拟合, 而 ^{17}F的这一依赖关系需要两条不同斜率的直线才能拟合. ^{17}F数据拟合中的这种斜率改变可能起因于 ^{17}F的奇异结构. 对其他实验组数据的分析支持以上的结论, 即在一定的角度范围内, 弱束缚核与稳定核相比, 弹性散射产物微分截面的对数与散射角平方的依赖关系有明显的差异, 这可以作为深入研究"晕核"和"皮核"的一个新探针.

关键词　弹性散射　微分截面　晕核

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