Energy and mass-number dependence of hadron-nucleus total reaction cross sections†

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The size of an atomic nucleus is one of the most fundamental quantities that characterize the bulk properties of nuclei. It is well known for β stable nuclei in the ground state thanks to systematic measurements of electron and proton elastic differential cross sections. This helps clarify the equation of state of nuclear matter near the saturation point.[1)]

In this work, we systematically analyze nuclear reaction data that are sensitive to nuclear size, namely, proton-nucleus total reaction cross sections $\sigma_R(p+A)$ and differential elastic cross sections, using a phenomenological black-sphere (BS) approximation of nuclei that we are developing. In this framework, the radius of the black sphere "a" is found to be a useful length scale that simultaneously accounts for the observed $\sigma_R(p+A)$ and first diffraction peak in the proton elastic differential cross section. This framework is expected to be applicable to any kind of projectile that is strongly attenuated in the nucleus. On the basis of a cross-section formula constructed within this framework (BS cross-section formula)[2)] as function of the target mass number A and the proton incident energy T_p, we find that a less familiar $A^{1/6}$ dependence of σ_R plays a crucial role in describing the T_p dependence.

In order to illustrate the A dependence of σ_R, in Fig. 1, we compare the values of the BS cross-section formula with those obtained by using the square-well potential of the same radius "a" within the eikonal approximation for the cases of $^{\mathrm{natu.}}$C and Pb. By noting that a very well scales as $A^{1/3}$, we examine the difference in the A dependence between the two expressions. As a result of expansion in A, the leading term is proportional to $A^{2/3}$, while the subleading term is proportional to $A^{1/3}$ multiplied by an A dependent exponential suppression factor in the eikonal approximation, which causes a different T_p dependence from the solid curve in each panel of Fig. 1. This difference results from the $A^{1/6}$ dependence in σ_R.

By comparing the solid curves in the upper and lower panels of Fig. 1, one can see the relatively weaker T_p dependence for the case of Pb. The cross section itself grows proportional to $\sim A^{2/3}$, while the T_p-dependent term is proportional to $\sim A^{1/6}$, leading to $O(A^{-1/2})$ corrections to the $O(A^{2/3})$ term. Thus, the relative change in the cross section by T_p is suppressed. This is the reason why the slope toward a lower T_p becomes steeper for the case of C than that of Pb. The latest empirical values of σ_R [4)] apparently support the presence of the $O(A^{1/6})$ correction term in σ_R.

A part of this work was already reported in Ref.[5].

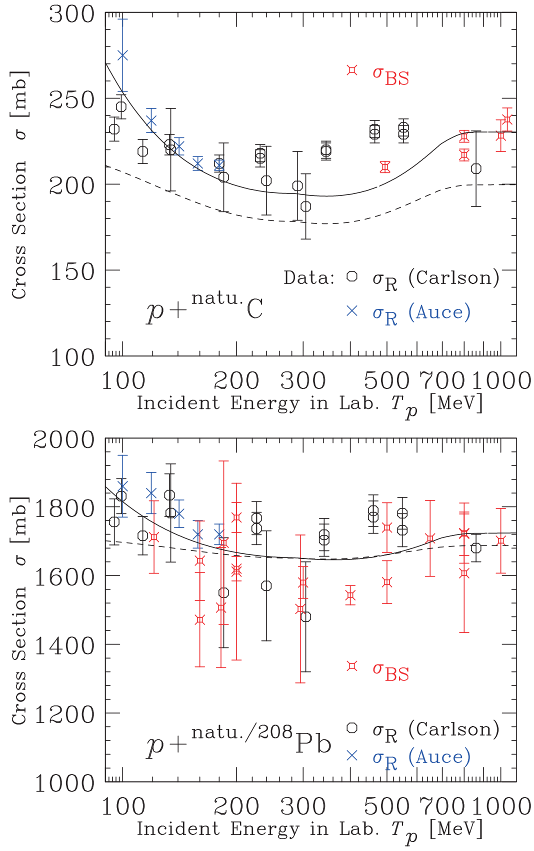

Fig. 1. Comparison of the BS cross-section formula (solid curve) with the eikonal approximation based on the square-well potential (dashed curve) for $\sigma_R(p+^{\mathrm{natu.}}\mathrm{C})$ (upper) and $\sigma_R(p+^{\mathrm{natu./208}}\mathrm{Pb})$ (lower) as a function of T_p. We adopt both the BS radius at 800 MeV and the square-well radius as 2.70 fm for carbon and 7.40 fm for lead. The values of σ_{BS} ($\equiv \pi a^2$), which are represented by squares with crosses, are obtained from the measured peak angle of the first diffraction maximum of the proton elastic scattering. They are consistent with the measured σ_R (○[3)], ×[4)]).

† Condensed from the article in arXiv: 1411.7737

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