PHYSICAL REVIEW C VOLUME 48, NUMBER 2 AUGUST 1993

Dark sphere with a bright interior: A nucleus viewed by intermediate energy alpha particles

Anders Ingemarsson
The Svedberg Laboratory and Department of Radiation Sciences, Uppsala University, Box 533, S-75121 Uppsala, Sweden

Göran Fäldt
Department of Radiation Sciences, Uppsala University, Box 535, S-75121 Uppsala, Sweden

(Received 29 January 1993)

Effective optical potentials for intermediate energy alpha particles are discussed. It is shown that the strong refraction substantially reduces the absorption in the center of the nucleus.

PACS number(s): 24.10.Ht

When intermediate energy alpha particles are elastically scattered by nuclei, the diffractive pattern in the angular cross section distribution is followed by an exponential falloff. Numerous analyses have shown that the large-angle behavior sensitively depends on the real part of the optical potential at very small radii. As discussed in the review article by Batty *et al.* [1] there is, however, no simple explanation for this sensitivity.

Recently, we investigated noneikonal corrections to the Glauber model at intermediate energies [2] for protons, antiprotons, and alpha particles. The result of this investigation induced us to consider the possibility that alpha particles are not as strongly absorbed as one would naively expect from the depth of the imaginary part of the optical potential. According to Wallace [3] a Glauber calculation with first-order noneikonal corrections is equivalent to a zeroth-order calculation "effective" potential, U_{eff}, given by

$$U_{\text{eff}}(r)=V(r)+\frac{1}{2kv}\left[2+r\frac{d}{dr}\right]V(r)^2 \quad (1)$$

where $V(r)$ is the sum of the optical and Coulomb potentials.

In order to illustrate the difference between the effective and nominal potentials, we have arbitrarily chosen an optical potential which reproduces the elastic scattering of 172.5 MeV alpha particles from ^{58}Ni [4]. In Fig. 1 we show the real and imaginary parts of these potentials. The solid curves are the real and imaginary parts of the Woods-Saxon potential $V(r)$, of Ref. [4]. The dashed curves are the real and imaginary parts of the effective potential $U_{\text{eff}}(r)$ when the Coulomb potential is included in $V(r)$, and the dotted curves are the real and imaginary parts of the effective potential $U_{\text{eff}}(r)$ when the Coulomb potential is excluded. There is a dramatic difference between the potentials, especially for the imaginary part. We also note that the Coulomb potential has quite a large effect on the result. For the effective imaginary potential we observe an increase in the surface region, which is mainly due to the second part of the correction in Eq. (1), i.e., the term involving the derivative of the square of $V(r)$. The drastic decrease for small values of r is due to the first term of the correction, which for the imaginary part is proportional to the product of the real and imaginary parts of the potential $V(r)$. The large effect on the absorptive potential for small radii is due to the fact that the real part of the potential is considerably larger than its imaginary part.

It was shown in Ref. [2] that inclusion of first-order noneikonal corrections in Glauber model calculations gave better agreement with phase-shift calculations. The agreement is, however, not satisfactory for alpha particles, and the shape of the effective potential in Eq. (1) should only be trusted qualitatively. Qualitatively, however, it is possible to test the predictions of Eq. (1) by calculating the exact phase shifts in an optical model calcu-

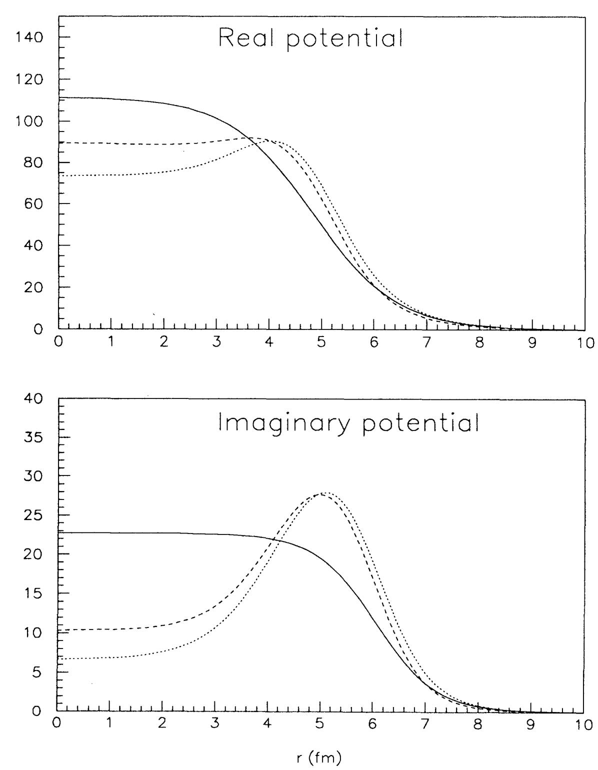

FIG. 1. The solid curves are the real and imaginary parts of the potential $V(r)$ used in the calculations. The dashed and dotted curves are the effective potentials $U_{\text{eff}}(r)$ calculated from Eq. (1) with and without Coulomb potential.

lation. Figure 2 shows the imaginary part of the phase shifts calculated with (stars) and without (open circles) the real part of the potential. As can be seen, the optical model calculation supports our conclusions based on the shape of the effective potential of Fig. 1. The absorption of partial waves with large angular momentum increases, whereas the absorption of partial waves with small angular momentum decreases. As a result the alpha particles can penetrate the nuclear surface barrier, and the cross section becomes sensitive to the value of the potential in the central region.

The results we have reported imply that there is a considerable variation in the absorption inside the nucleus. The absorption is determined by the imaginary part of the local wave number, which for weak potentials is proportional to the imaginary part of the optical potential. However, in our application the potential is so strong that this linear relationship is no longer valid. Instead it becomes necessary to use the exact expression for the local wave number, as given by Wallace [3]. When expanded in powers of the potential one obtains, when lowest nonvanishing corrections are retained, the expression given in (1). It follows that the mean free path of alpha particles, which is inversely proportional to the imaginary part of the local wave number, becomes much larger in the center of the nucleus than in the surface region. This effect is the main reason why alpha particles could be a good probe for investigating the interior of the nucleus.

Our result is an excellent illustration of the fact that the eikonal approximation is not always a reliable guide. When we add a real part to an imaginary potential, or an imaginary part to a real potential, both the real and imaginary parts of the phase shifts drastically change. Our result also questions the assumption that the shape of the imaginary part of the optical potential should be unaffected by its real part. We find that the final result for the phase shifts is a delicate balance between the real and imaginary parts of the potential. Furthermore, the Coulomb potential plays an important role. It also follows, that it is questionable to assume, that the exponential falloff of the cross section for large scattering angles is due to refraction alone, and not to absorption, since the effect of a very strong real potential is to decrease the absorption in the nucleus.

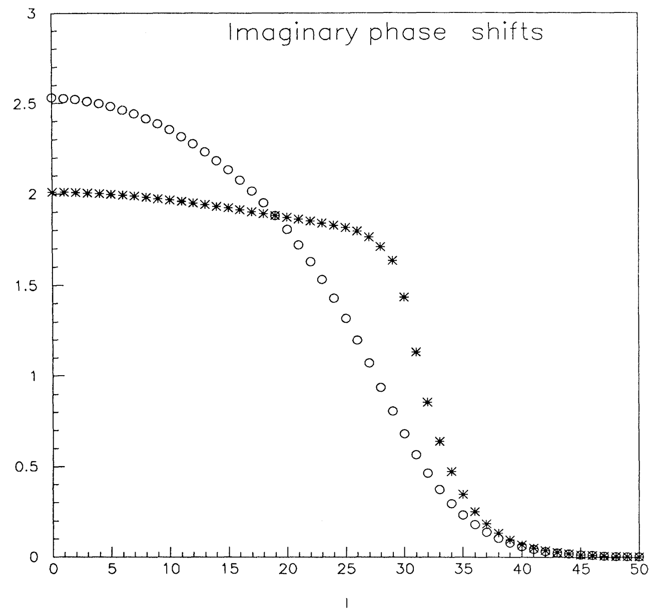

FIG. 2. The imaginary part of the phase shifts calculated with ($*$) and without ($\circ$) the real part of the potential $V(r)$.

We wish to thank R. J. Lombard for stimulating discussions.

[1] C. J. Batty, E. Friedman, H. J. Gils, and H. Rebel, Adv. Nucl. Phys. **19**, 1 (1989).
[2] G. Fäldt and A. Ingemarsson, Phys. Rev. C **46**, 1974 (1992).
[3] S. J. Wallace, Ann. Phys. (N.Y.) **78**, 190 (1973).
[4] J. Albinski *et al.*, Nucl. Phys. **A445**, 367 (1985).