Physics Letters B 784 (2018) 33–36

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Nucleus–nucleus potential from identical-particle interference

Ning Wang [a,b,*], Yongxu Yang [a,b], Min Liu [a,b], Chengjian Lin [a,c]

[a] Department of Physics, Guangxi Normal University, Guilin 541004, PR China
[b] Guangxi Key Laboratory of Nuclear Physics and Technology, Guilin 541004, PR China
[c] China Institute of Atomic Energy, Beijing 102413, PR China

ARTICLE INFO

Article history:
Received 3 May 2018
Received in revised form 27 June 2018
Accepted 29 June 2018
Available online 20 July 2018
Editor: J.-P. Blaizot

ABSTRACT

Based on the quantum interference between two-identical-nucleus scattering at energies around the Coulomb barrier, the barrier positions for ^{58}Ni+^{58}Ni and ^{16}O+^{16}O are extracted from Mott oscillations in the angular distributions around 90° for the first time. The angle separation of pairs of Mott scattering valleys around 90° has a direct relationship with the closest distance between two nuclei in elastic scattering. Together with the barrier height from fusion excitation function, the extracted barrier position provides a sensitive probe to constrain the model predictions for the nucleus–nucleus potential barrier.

© 2018 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/). Funded by SCOAP^3.

The study of nucleus–nucleus potential [1–12] is one of the most important topics in nuclear physics. The basic features of the nucleus–nucleus potential are commonly described in terms of an interaction that is a function of the center-to-center distance between the projectile and target nuclei and consists of a repulsive Coulomb term and a short-ranged attractive nuclear component. The total potential possesses a maximum at a distance where the repulsive and attractive forces balance each other. This is referred to as the Coulomb barrier [13–16]. For heavy-ion fusion and scattering reactions, the Coulomb barrier directly influences the behavior of fusion and scattering cross sections, and an accurate extraction of the barrier not only the height but also the position and curvature from fusion cross sections and angular distributions of elastic/inelastic scattering attracted therefore a lot of attentions in many decades. Based on some empirical or realistic nuclear interactions [1–6] together with barrier penetration concept [17,18], coupled-channel methods [19,20], optical models [21–23] or microscopic dynamics equations [24–28], one attends to obtain the information of the nucleus–nucleus potential barrier through reproducing the measured cross sections. Unfortunately, it is found that the data can be reproduced reasonably well with different potentials combining different theoretical models [21,29]. Because of the ambiguity of optical model potential (commonly known as the Igo ambiguity [30]) due to the complicated parameter space and internal structure of the reaction partners, it is therefore of great significance to directly extract the barrier from measured data or to reduce the model dependence as much as possible. The height of the Coulomb barrier (or the distribution of the barrier height) could be extracted from the precisely measured fusion cross sections [31–34] or the back-angle quasi-elastic scattering cross sections [35,36] through a simple and elegant mathematical transformation. Comparing with the barrier height, the extraction of the positions of the Coulomb barrier in heavy-ion reactions at energies around the Coulomb barrier has not yet been explored extensively. Conventionally, the barrier position R_B may be extracted from the classical formula $\sigma_{\rm fus} = \pi R_B^2 (1 - V_B/E_{c.m.})$ for fusion reactions at energies above the barrier height V_B [37]. The extracted result with this conventional method which is model dependent with assumption that all l waves contributing to the fusion cross sections have the same barrier position R_B [37], is sensitive to the selected fusion cross sections in the analysis and the uncertainty is relatively large. For example, with a linear fit of the measured fusion cross sections at above barrier energies for ^{16}O+^{16}O [38], one obtains a value of $R_B = 8.7 \pm 0.5$ fm, whereas a value of $R_B = 9.8 \pm 0.6$ fm is obtained with the data from Ref. [39] for the same reaction. It is therefore required to further investigate the barrier position from heavy-ion fusion/scattering cross sections.

For microscopic particles, such as photons, nucleons, heavy nuclei and so on, the quantum effect especially quantum interference between two-identical-particle have been evidently observed, which verifies the wave properties of microscopic particles, such as the positions of the sources of waves and de Broglie wavelength. In the double slit interference experiment of light as shown in Fig. 1(a), the slit separation d has a relationship with the linear separation Δy between fringes on screen (detector):

$$d \simeq \lambda L/\Delta y \qquad (1)$$

* Corresponding author.
E-mail address: wangning@gxnu.edu.cn (N. Wang).

https://doi.org/10.1016/j.physletb.2018.06.073
0370-2693/© 2018 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/). Funded by SCOAP^3.

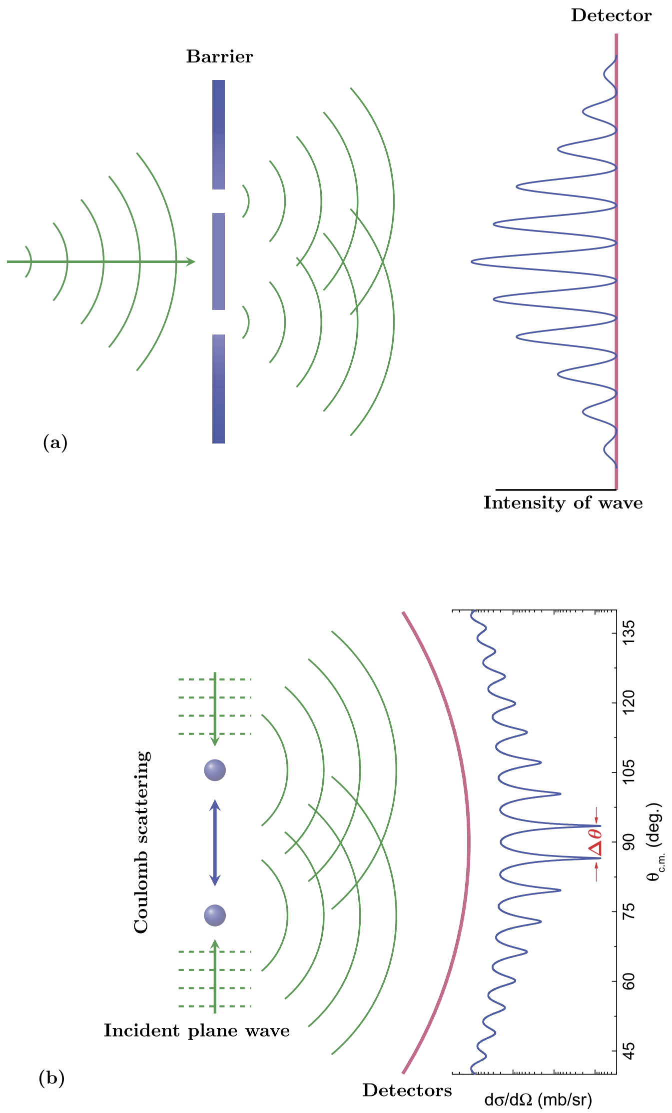

Fig. 1. (Color online) (a) Schematic view of the double slit interference of light. (b) Schematic view of a Mott scattering between two identical nuclei.

where λ is the wavelength of light, L is the distance between the slit and the screen. It is known that the slit separation should be comparable with the wavelength of light in order to form the evident fringes on the screen. Although the direct double slit interference experiment for heavy nuclei is difficult since the slit separation should be at the femtometer scale, the quantum interference was clearly observed from the angular distribution of elastic scattering between identical projectile and target nuclei as shown in Fig. 1(b), which is known as the Mott scattering [40–42]. Mott proposed an analytical formula for describing the differential cross section in the center-of-mass system for pure Coulomb scattering of identical particles [40]:

$$d\sigma/d\Omega = \frac{Z^4e^4}{16E^2_{c.m.}}\{\csc^4(\frac{\theta_{c.m.}}{2}) + \sec^4(\frac{\theta_{c.m.}}{2}) + 2\frac{(-1)^{2I}}{2I+1}\csc^2(\frac{\theta_{c.m.}}{2})\sec^2(\frac{\theta_{c.m.}}{2})\cos[\eta\ln(\tan^2(\frac{\theta_{c.m.}}{2}))]\}, \quad (2)$$

where Z is the charge number of nuclei, $\theta_{c.m.}$ is the center-of-mass scattering angle, $E_{c.m.}$ is the center-of-mass energy and I is the intrinsic spin of particles. $\eta = \frac{Z^2e^2}{\hbar v}$ is the Sommerfeld number which is $\frac{1}{2}$ the ratio of the characteristic distance of closest approach given by $Z^2e^2/E_{c.m.}$ and the reduced wavelength $\lambdabar$ [41]. According to Eq. (2), the Mott oscillations can be seen most clearly around 90°. The separation $\Delta\theta$ around 90° could have a direct relationship with the closest distance between the two nuclei in scattering.

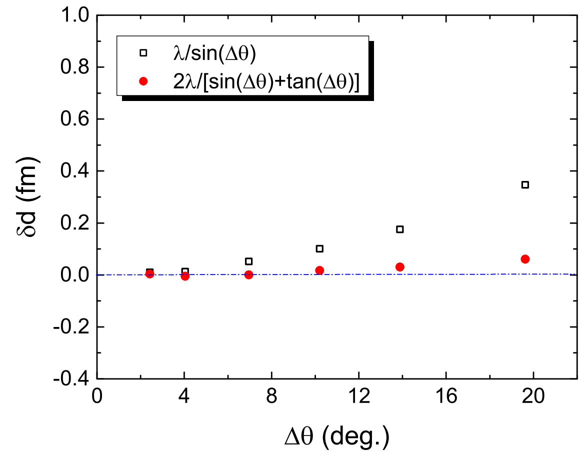

Fig. 2. (Color online) Discrepancies between the calculated closest distance based on the separation of Mott oscillations around 90° and the expected value $d = Z^2e^2/E_{c.m.}$ for a series of reactions at sub-barrier Coulomb scattering.

We first systematically investigate the Mott oscillations for a series of elastic scattering reactions at energies below the Coulomb barrier. From light to heavy systems, the separation $\Delta\theta$ of Mott oscillations around 90° [see Fig. 1(b)] decreases with the masses of nuclei due to the decrease of the corresponding de Broglie wavelength $\lambda = h/\sqrt{2\mu E_{c.m.}}$, where μ is the reduced mass of the system. Similar to Eq. (1), we note that the closest distance d between two heavy nuclei in pure Coulomb scattering approximately satisfies $d \approx \lambda/\sin(\Delta\theta)$. In Fig. 2, we show the discrepancies betweem the calculated closest distance with the separation $\Delta\theta$ and the expected value $d = Z^2e^2/E_{c.m.}$. One can see that the closest distances are described very well with $d \approx \lambda/\sin(\Delta\theta)$ for heavy nuclei. However, this approximation is not good enough for light systems, and the discrepancies increase rapidly with the value of $\Delta\theta$ and even larger than 0.35 fm for ^{16}O+^{16}O. To improve the accuracy, we propose a modified expression:

$$d \simeq \frac{2\lambda}{\sin(\Delta\theta) + \tan(\Delta\theta)}. \quad (3)$$

From Fig. 2, one can see that for all investigated systems the accuracy of the calculated closest distances with Eq. (3) are significantly improved. Experimentally, the Mott oscillations of ^{58}Ni+^{58}Ni at an incident energy of $E_{c.m.} = 80$ MeV which is lower than the Coulomb barrier by about 20 MeV, were precisely measured in Ref. [42] and the separation of Mott oscillations around 90° is $\Delta\theta = 2.42° \pm 0.03°$. The obtained closest distance according to Eq. (3) is 14.12 ± 0.17 fm which is consistent with the expected value of 14.11 fm from $d = Z^2e^2/E_{c.m.}$.

With Eq. (3), we further investigate the Coulomb barrier of ^{58}Ni+^{58}Ni. The Mott oscillations around 90° in the quasi-elastic scattering were also measured at an incident energy of $E_{c.m.} = 100$ MeV [42] which is generally at the Coulomb barrier. Considering that the elastic cross sections at energies around the Coulomb barrier are dominant in the quasi-elastic scattering and the adding of the inelastic cross sections does not change significantly the angle separation around 90° according to the coupled-channel calcula-

Download English Version:

https://daneshyari.com/en/article/8186183

Download Persian Version:

https://daneshyari.com/article/8186183

Daneshyari.com