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MASSIVE TARGET NUCLEI AS DISC-SHAPED SLABS AND SPHERICAL OBJECTS OF INTRANUCLEAR MATTER IN HIGH-ENERGY NUCLEAR COLLISIONS

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1. INTRODUCTION

E.Rutherford has introduced a method for investigating the constitution of matter by means of beams of electrically charged particles directed onto thin slabs of materials[1].

Almost 80 years ago H.Geiger and E.Marsden, two Rutherford's students, directed a beam of alpha particles onto thin slabs of gold. Using a screen of fluorescent material, they then counted the number of particles scattered at various angles as a result of encounters with the gold atoms[2]. Most of the particles passed straight through the foil or were deflected only at a small angle: the average deflection was smaller than a degree; surprisingly, however, a few particles, about one in tens of thousands, were deflected sharply. In the interpretation of the experimental results E.Rutherford has introduced this method; its importance is not diminished today.

Accurate measurements of the matter distribution in target nuclei or nucleons involve the interactions of probe projectiles with them, and these interactions can be of either an electromagnetic or a nuclear nature.As we know so much more about electromagnetic forces than about nuclear ones, it was tempting to conduct investigations mainly with electron beams, but, unfortunately, information only about the distributions of electrically charged constituents in intranuclear matter or in intranucleon matter could be obtained in this way. The scattering of high-speed charged particles by atoms of matter is one of the most promising methods of attacking this problem. Such measurements were performed in R.Hofstadter's experiments about 30 years ago[3-6]. Latter, the electric structure of the nucleon has been investigated by this method at the Stanford Linear Accelerator Center as well[7,8]. Conclusive information could be obtained very exactly since the relationships between charge and magnetic moment distributions and the electromagnetic potentials due to these are well known from Maxwell's theory.

Similarly, strongly interacting or hadronic probes should tell us something about the nuclear potential between the nucleus or the nucleon and the probe, but it was impossible in general to deduce anything about the intranuclear or intranucleon matter density distributions from hadron-nucleus and hadron-nucleon collisions in a similar way - it was believed by many physicists - since the nuclear equivalent of Maxwell's equations remains to be discovered.

So, as things stand now, in the absence of an adequate nuclear force theory, we propose to employ some nuclear phenomenon occurring plentifully in hadron-nucleus collisions as a physical basis for a new method for probing nuclear properties by means of strongly interacting probes falling on intranuclear matter slabs; nuclear targets can be used as such slabs. The phenomenon should be simply observable and conclusively recognizable; the thickness of the intranuclear matter layer and the location of the hadronic projectile trajectory should be clearly involved in it.

In our opinion, the passage of hadrons through the atomic nucleus, observed in our experiments during about the last 15 years[9-13], satisfies the desired conditions. This nuclear phenomenon is an analogue to the passage of electrically charged particles through materials[13]. The hadron passages through nuclei are accompanied by fast nucleons, with kinetic energies from about 20 up to about 400 MeV, which are emitted from the traversed target nuclei; the number of emitted nucleons corresponds definitely and uniquely to the nuclear matter layer thickness covered in the collisions. Thus, a definite number of emitted fast nucleons corresponds strictly to a definite impact parameter in a definite hadron-nucleus collision[13]. This finding allows one to hope that: a) the massive target nucleus can be treated as a piece of intranuclear matter of a definite thickness; b) a numerous sample of collisions of monoenergetic identical hadrons with identical target nuclei can be treated as a collision of a homogeneous and monoenergetic beam of hadrons with intranuclear matter disc-shaped slabs of various thicknesses; c) the experiments, in which intranuclear matter slabs of definite thicknesses, expressed in nucleons/S, are bombarded by homogeneous monoenergetic beams of hadrons, can be practically performed; S is a surface element of about 10 fm^2. Such experiments should throw a new light on the following: 1. the nuclear matter density distribution inside atomic nuclei[14]; 2. the mechanism of particle production in statu nascendi[15]; 3. the behaviour of hadronic projectiles in passing through intranuclear matter[12,13]; 4. the space-time development of the hadron-nucleus collision process.

The subject of this paper is to show how it is possible in hadron-nucleus collisions to treat massive target nuclei as spherical objects and disc-shaped slabs of intranuclear matter of definite thicknesses bombarded by hadronic beams.

2. NUCLEAR TARGETS AS SPHERICAL OBJECTS AND DISC-SHAPED SLABS OF INTRANUCLEAR MATTER

In a numerous sample of collisions of a hadron with a definite spatially unpolarized massive atomic nucleus, the target can be treated as a spherical object of intranuclear matter with a definite maximum thickness $\lambda_{max} = D$, where D is the nucleus diameter, the mean thickness $\langle\lambda\rangle$, and the thickness $\lambda(b)$ at the distance b from the nuclear centre or, in other words, at the impact parameter b. It is convenient to express these thicknesses and the distance b in nucleons/S, where S is an area which can be as large as $\pi D_0^2 \approx 10$ fm^2, D_0 is the nucleon diameter; such a length unit is similar to that in g/cm^2 used frequently in measurements of the thicknesses of the layers of materials with inhomogeneous densities; the thickness of the earth atmosphere layers is usually expressed in g/cm^2 in cosmic ray physics.

The thickness $\lambda(b)$ can be recognized in any of the hadron-nucleus collisions because the relation exists[12,13]:

$$n_N = \lambda(b)\, S(1 - e^{-\lambda(b)/\langle\lambda_{tot}\rangle}) \qquad (1)$$

between the number n_N of the "fast" nucleons emitted from the target nucleus and the length $\lambda(b)$. The mean free path $\langle\lambda_{tot}\rangle$ is related to the well-known total cross section σ_{tot} for the collision of a hadron with a nucleon as

$$\sigma_{tot} = \frac{1}{\langle\lambda_{tot}\rangle}, \qquad (2)$$

σ_{tot} is the total hadron-nucleon cross section in S/nucleon units.

The mean thickness $\langle\lambda\rangle$ can be determined in a numerous sample of hadron-nucleus collisions from the relations[12]:

$$\langle n_p\rangle = \frac{Z}{A}\langle\lambda\rangle\, S(1 - e^{-\langle\lambda\rangle/\langle\lambda_{tot}\rangle}) \qquad (3)$$

or

$$\langle n_N\rangle = \langle\lambda\rangle\, S(1 - e^{-\langle\lambda\rangle/\langle\lambda_{tot}\rangle}), \qquad (4)$$

where $\langle n_p \rangle$ and $\langle n_N \rangle$ are the mean multiplicities of the emitted fast protons and nucleons, Z and A are the charge and mass numbers, respectively.

The maximal thickness λ_{max} in nucleons/S can be obviously determined from the maximal number of emitted fast nucleons in the sample of collisions and the latter from the multiplicity n_N distribution of nucleons.

In addition, the thicknesses λ_{max}, $\langle\lambda\rangle$, and $\lambda(b)$ in nucleons/S and $\langle\lambda\rangle$ in protons/S can be evaluated[14] for various nuclei from the well-known data[3-6].

Any spherical object can be treated as consisting of a sample of axially centred disc-shaped slabs of various radii and thicknesses; the target nucleus can be treated as a sample of axially centred such disc-shaped slabs of intranuclear matter. A numerous sample of hadron-nucleus collisions can be regarded as a collection of subsamples of the collisions of hadrons with slabs of intranuclear matter of definite thicknesses $\Delta\lambda(\Delta b)$. True, in any of collisions the target nucleus is destroyed, but new identical nucleus is involved in any of them. Thus, any of the subsamples of collisions with a definite multiplicity of emitted nucleons can be regarded as an interaction of a homogeneous beam of identical hadrons with a slab of intranuclear matter of a definite thickness.

As an example, the quantities λ_{max}, $\lambda(b)$, and $\langle\lambda\rangle$ are presented in the figure for the xenon nucleus; thin lines c show the lens-shaped xenon target nucleus, the thicknesses $\lambda(b)$ are given in nucleons/S units; and the impact parameter b, in fm. The thick line represents the b-dependence of the target nucleus thickness $\lambda(b)$ in nucleons/S; the value of $\langle\lambda\rangle$ is shown for the corresponding value of $b(\langle\lambda\rangle)$.

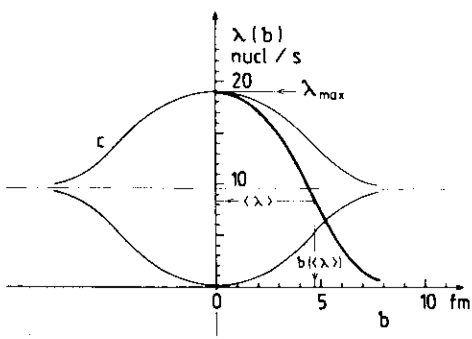

Fig. The thickness of the intranuclear matter layer, $\lambda(b)$, in the xenon nucleus versus the collision impact parameter b (the thick line); the thickness is in nucleons/S units; and the impact parameter, in fermis. Thin lines c represent the contour of the nucleus as a lens-shaped piece of intranuclear matter.

3. CONCLUSIONS AND REMARKS

In reviewing many methods used to determine the properties of the ground state matter of finite nuclei, it gets clear that strongly interacting probes should be necessarily involved. But, it was extremely difficult to obtain model-independent quantitative information in this way since the nuclear equivalent of Maxwell's theory remains to be discovered.

So, we should look for some other possibilities. The discovery of the hadron passage process through atomic nuclei and its recognition as a nuclear analogue of the electromagnetic process, i.e. the passage of charged particles through a material, open up a new possibility: experiments, similar to the Rutherford-Geiger-Marsden one, can be carried out in which a beam of hadrons traverses the slabs of intranuclear matter. In hadron-nucleus collisions the dependence of the output on the thickness of the intranuclear matter layer involved in the collision reaction contains new experimental information. Preliminary results have been obtained in this way and published in a series of papers[15-17] devoted to the particle production process[15], matter distribution in the xenon nucleus[16] and hadron mean free path in intranuclear matter[17].

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REFERENCES

1. Rutherford E. - Philosophical Mag., 1911, 21, p.669.
2. Geiger H., Marsden E. - Proc. Roy. Soc., 1909, A82, p.495.
3. Hofstadter R. - Rev. Mod. Phys., 1956, 28, p.214.
4. Hofstadter R. - Ann. Nucl. Sci., 1957, 7, p.231.
5. Hofstadter R. - Nuclear and Nucleon Structure, Frontiers in Physics. W.A.Benjamin, New York, 1963.
6. Elton L.R.B. - Nuclear Sizes, Oxford Univ. Press, 1961.
7. Kendall W., Panofsky W.K.H. - Sci. Amer., 1971, 224, No.6, p.60.
8. Friedman J.I., Kendall W. - Ann. Rev. Nucl. Sci., 1972, 22, p.203.
9. Strugalski Z., Pluta J. - Sov. Journ. Nucl. Phys., 1974, 27, p.504.
10. Strugalski Z., Pawlak T., Pluta J. - JINR Commun., E1-82-718, E1-82-719, E1-82-841, Dubna, 1982; E1-83-234, Dubna, 1983; E1-85-888, Dubna, 1985.

11. Strugalski Z. - Proc. 20-th Intern. Cosmic Ray Conf., August 2-15, 1987, Moscow Univ., Vol.5, p.46, "Nauka", Moscow, 1987.
12. Strugalski Z. et al. - JINR Commun., E1-88-211, Dubna,, 1988.
13. Strugalski Z. - JINR Commun., E1-88-639, Dubna, 1988.
14. Pawlak T. et al. - JINR Commun., E1-86-643, Dubna, 1986.
15. Strugalski Z. - JINR Commun., E1-81-576, E1-81-577, Dubna, 1981.
16. Strugalski Z. et al. - JINR Commun., E1-86-642, Dubna, 1986.
17. Strugalski Z., Mousa M. - JINR Commun., E1-87-695, Dubna, 1987.

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