Mass Number Dependence of Inelastic Cross Section for High-Energy Proton-Nucleus Collision

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M.Teranaka, Department of Physics, Osaka City University

T.Ogata, Department of Physics, Kwansei-Gakuin University

In this report, a new interpretation is given for the cross section in high-energy proton-nucleus collision induced by proton-nucleon inelastic interaction in nucleus through the hypothesis of contracting space mentioned in our previous report.

The inelastic interaction cross section for proton-nucleus(mass number A) is expressed through the analysis of nuclear emulsion exposed to 200 GeV proton beam at FNAL by taking account of the content for the elements contained in emulsion as follows *

$$\sigma_A = \sigma_p A^{2/3+0.1\pm0.01}$$

It is valid to take the inelastic cross section p-p interaction for σ_p from the following reason: Almost all events obtained by means of the following-track-scanning method have more than two thinly ionizing tracks, which means the energy loss of more than 0.3 GeV for the incident proton. If the events were induced by p-nucleon elastic interaction, the squared value of four momentum transfered to target nucleon, t, are obtained more than $0.5(\mathrm{GeV}/c)^2$. Since the distribution of t for elastic p-p interaction is expressed by formula e^{-bt} with $b \simeq 12$, the rate of events induced by elastic p-nucleon interaction is estimated to be less than one percent of whole obtained events, considering that the distribution of elastic p-p interaction is nearly same as that of p-nucleon.

No matter how contracted the target nucleon may be for the first incident p-nucleon inelastic interaction in nucleus, it is naturally considered to be recognized as one event of proton-nucleus collision by observing from the outside of nucles, that is, the number of event is measured by one proton-nucleon collision unit.

When the existence probability of incident proton(without means surviving

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*The Collaboration of Osaka City UNiversity and Kobe University Groups
O. Kusumoto, S. Konishi, H. Okabe, M. Teranaka : Osaka City University;
G. Fujioka, H. Fukushima, H. Yamazaki, M. Igarashi, K. Kobayakawa,
M. Miyagaki, Y. Tsuzuki, : Kobe University ;
M. Ohta : Kinki University ; J. Yokota : Science Education Institute
Osaka Prefecture

proton) at λ is expressed as P, the decrease of P for the distance between and $\lambda + d\lambda$ is shown as follows,

$$dP = -e^{-2\gamma\lambda} P\, d\lambda. \qquad (1)$$

In the ordinary space without the contracted nucleon, dP is equvalent to the increase of interaction probability, dI, between λ and $\lambda + d\lambda$.
Since the summation of interaction cross section between λ and $\lambda + d\lambda$ is expressed as $\sigma_p P\, e^{-2\gamma\lambda} d\lambda$, the increase of interaction probability measured by the scale of ordinary nucleon size at $\lambda = 0$ is expressed as $\sigma_p P \cdot e^{-2\gamma\lambda} d\lambda / \sigma_p$.

However, this dose not mean the interaction probability measured by the scale of the contracted nucleon size in one proton-nucleon collision unit.

Therefore, the increase of interaction probability for the distance between λ and $\lambda + d\lambda$ measured by the scale of nucleon size contracted at λ, dI, is obtained as follows

$$dI = \frac{\sigma_p\, e^{-2\gamma\lambda}\, P\, d\lambda}{\sigma_p\, e^{-2}} = P\, d\lambda \qquad (2)$$

In other words, it means that the ordinary nucleons with the existence probability obtained from formula (1) come into the target nucleon at λ and the mean free path length is show same as the ordinary one for the distance of $d\lambda$.

Therefore, σ_A / σ_p is given as following formula:

$$\frac{\sigma_A}{\sigma_p} = A^{2/3} I = A^{2/3} \int_0^{\bar{L}_A} P\, d\lambda = A^{2/3} \int_0^{\bar{L}_A} e^{-\frac{1}{2\gamma}(1 - e^{-2\gamma\lambda})}\, d\lambda \qquad (3)$$

This integral cannot be analytically obtained by the elementary function. Since the value of γ is considerably small compared with $\bar{L}_A$, the following integral is given as very good approximation:

$$\frac{\sigma_A}{\sigma_p} \simeq A^{2/3} \int_0^{\bar{L}_A} e^{-\{e^{-(2\gamma \bar{L}_A/2)} \cdot \lambda\}}\, d\lambda \qquad (4)$$

In the case of nucleus with large mass number,

$$\frac{\sigma_A}{\sigma_p} \simeq A^{2/3} e^{\gamma L_A} = A^{\frac{\gamma \cdot \eta \frac{4}{3} A^{1/3}}{\ln A}} \sim A^{2/3 + \gamma} \qquad (5)$$

The above experimental A-dependence agrees well with the caluculated result.

The results of σ_A/σ_p for various elements deduced from the counter experiment obtained by Ashmore et al[1] at 24 GeV incident proton energy are shown in Fig. 1. The measurements were performed by the scintillator with minimum subtended angle of 15 mrad. In this condition, it is considered that the proton-nucleus events induced by the inelastic p-nucleon interaction occupied about 94 % of whole events considering the distrbution of e^{-bt} and cross sections of 30 mb and 10 mb for the inelastic and elastic interactions, respectively. Therefore, these value of 0.94 X σ_A/σ_p are plotted upon A in Fig. 1.

σ_A/σ_p for Al, Cu and Pb target were given by Ogata(one of the reporters) The good agreement between the caculated and these experimental results is shown in Fig. 1, except the points of Cu at 200 GeV.

The observation for high-energy proton-nucleon inelastic interaction in nuclear matter is compared with that for the double-slit diffraction of photon by the following conceptual diagram:

observation for photon impinged onto screen
↓
photon → double-slit → partition of existence for position

high energy proton → nuclear matter ↓ contracting space → partition of existence for extent of space

observation for high-energy proton-nucleon inelastic interaction ↓ partition of existence for extent of space

As the value of r_o is obtained from 1.2 to 1.5 fermi in expression of of $r_oA^{1/3}$ for nuclear radius, the increasing A-dependence for cross section has been explained by the increasing of nuclear size. However, since the value the values of r_o are given as 1.5 and 1.2 for the middle and large mass number, respectively, it is impossible to explaine the increasing factor $A^{0.1}$ from the consideration of nuclear structure. The interpretation should not be misconceived by using of the mean value of r_o.

In the limited case of A = 1, the concept of the interaction probability in formula (3) is not presented in the ordinary nucleon space taking no account of the inside collision for one nucleon. However, it is meaningful to obtain the value of I for A = 1 under the consideration of this model. The value of I for A = 1 is obtained as 0.707 from the formula (4), that is,

1) A. Ashmore et al, Phys. ReV. Letters, 5 (1960), 576

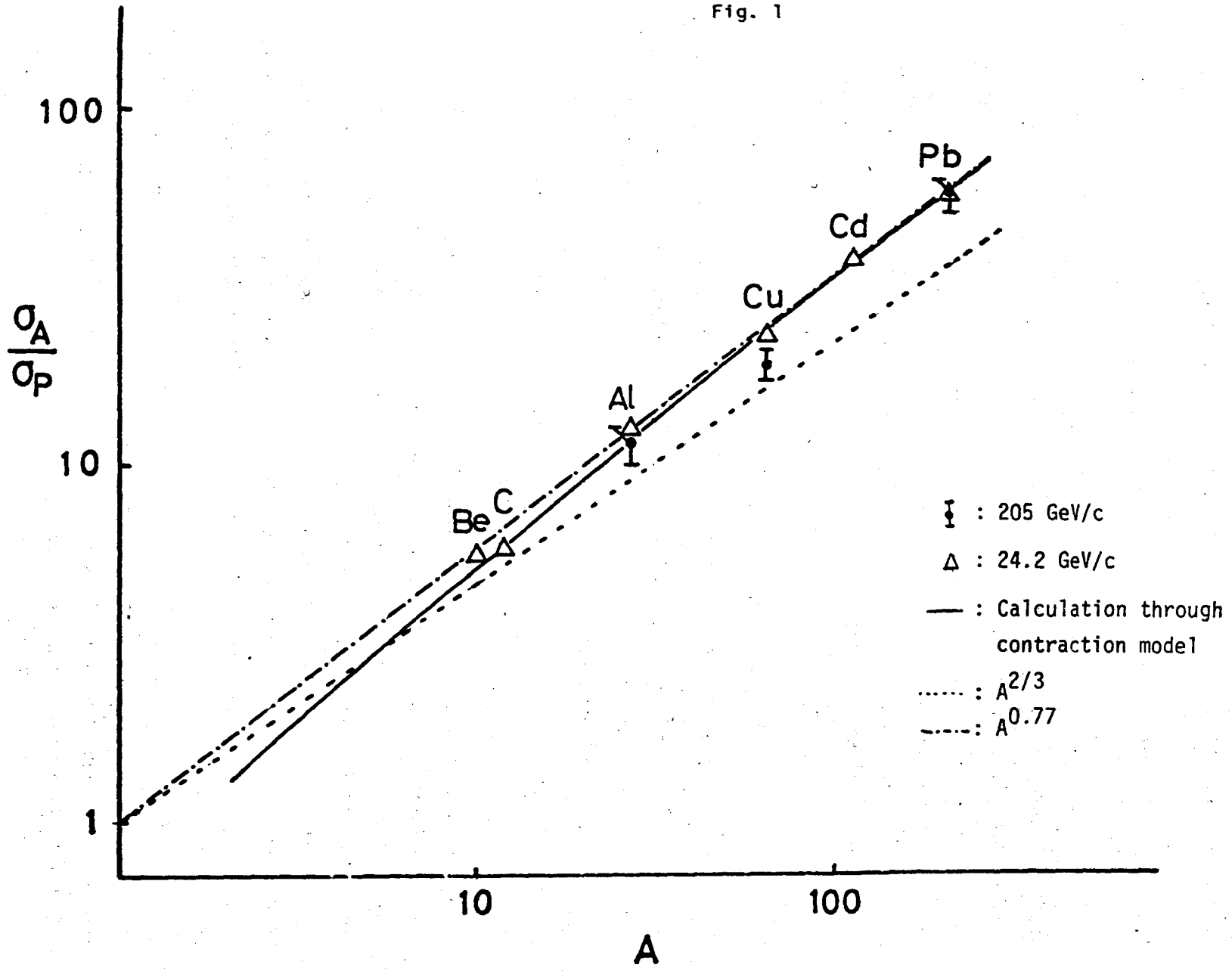
$(0.841)^2$. This means to be η^2 within the experimental error!
It is considered that this fact is by no means an accidental result.

The physical meaning should probably be given by the following interpretation: The conception of cross section should not be adapted to the collision of nucleon inside, because the cross section represents only the encountered area of two particles. Since one mean free path length is measured as $\frac{1}{\eta}$ in one nucleon size unit from the constancy of η, the expected value of the interaction length within nucleon in same unit is is given as $\eta^2 \times \frac{1}{\eta}$ $(=\eta)$. Namely, it is equivalent to the value of cross section in one ordinary nucleon size unit.
In this meaning, it can be said that the nucleon shows the self-consistency for the value of I.

If the hypothesis of contracting space is true, it might be necessary to reform the conception of absolute scale for the length of particle size besides the Lorentz contraction.

In the dual character of nature, photon has wave and particle properties, and both properties are imcompatible for the observation.
The diffractive and creative characters are shown in the inelastic interaction, and both characters are compatible for the observation. In order to seek the general physical law, it was necessary to obtain one constant(Planck's constant) for the former.
On the other hand, if the general law exist in the latter, it might be necessary to find the two constants.

Fig. 1


100
10
1
$\frac{\sigma_A}{\sigma_P}$
10
100
A
Be
C
Al
Cu
Cd
Pb
: 205 GeV/c
: 24.2 GeV/c
: Calculation through contraction model
: $A^{2/3}$
: $A^{0.77}$