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Theoretical Overview: Pion and its Nuclear Interactions

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Abstract

Pion-nucleus interaction can be thought on the basis that pion is a particle that plays role of a mediator in the interaction between a pair of nucleons. This interaction is attractive. It pulls the nucleons together. In this paper, the use of pion nucleus scattering to explore the relative neutron proton distributions in nuclei is studied theoretically. This gives us a complete review of the advances and discusses open questions as well as issues related to current research. The field of research in the area of pion-nucleus interaction has been boosted in recent decades with the rise of meson factories.

Keywords: scattering, cross-section, absorption, mode of interaction.

Introduction

Some unique properties of the pion (π) play crucial roles in the developing description of the pion-nucleus interaction. Since pion is the lightest hadron it interacts strongly with nuclear matter and has been used as a nuclear probe, mostly its negatively charged variety. This pion –nucleus interactions is different from the nucleon (N) and light ion-nucleus interactions. Most of our knowledge of nuclear structure has come through analysis of nuclear reactions initiated by nuclear probes such as e, p, n, H^2, H^3, He^3 and He^4. The interaction of these ‘particles’ with nuclei is well-understood although this understanding has substantial phenomenological support. Nuclear structure studies have been done using also other probes such as μ, π, λ, k, $\bar{p}$, etc.

The basic reason for this study is to understand “how pion interacts with nucleus”. The study of “pionic properties” of nuclei is the primary motivation of pion-nucleus Physics. Once the pionic phenomena are understood, pions can be used in studies of nuclear structure, and in medical and technical areas.

For example (i) pion photoproduction and electroproduction attract increasing interest as powerful tools for studies of fundamental interactions and nuclear structure. (ii) Relativistic heavy ion collisions have been studied with the hope to observe new phenomena like high density nuclear matter, shock waves, hot spots etc.

Pion-Nucleus Reaction Cross-Section

The field of pion-nucleus interaction is very rich pions. The term inelastic is used to mean a scattering event that has a real pion in the final state but is not elastic scattering. The term reaction cross-section here refers to the sum of absorption and inelastic scattering, and total cross-section to reaction plus elastic scattering.

The total pion-nucleus interaction cross-section may be decomposed into major channel distributions.

$$\sigma_{tot} = \sigma_{el} + \sigma_{inel} + \sigma_{scx} + \sigma_{dcx} + \sigma_{abs} + \sigma_{\pi,\, 2\pi}$$

Apart from the elastic scattering (σ_{el}) all other major channel cross-sections are inclusive, and each consists of many partial channels according to the final state of the system. The inelastic scattering (σ_{inel}) includes population of low lying bound states, giant resonances, and knock-out scattering into the continuum. The single-charge exchange (σ_{scx}) and the double charge exchange (σ_{dcx}) reactions are composed of similar channels. The pion-absorption reaction (σ_{abs}) may also lead to many final states.

The partial cross-section on ^{12}C as a function of energy are shown in fig. 1(a) and as a function of A at 165 MeV in fig. 1(b); this later may be expressed as reaction power laws: σ~Aq where q=0.6 for σ_{tot}, q=0.7 for σ_{abs} and σ_{el}, and q=0.4 for $\sigma_{inel.}$

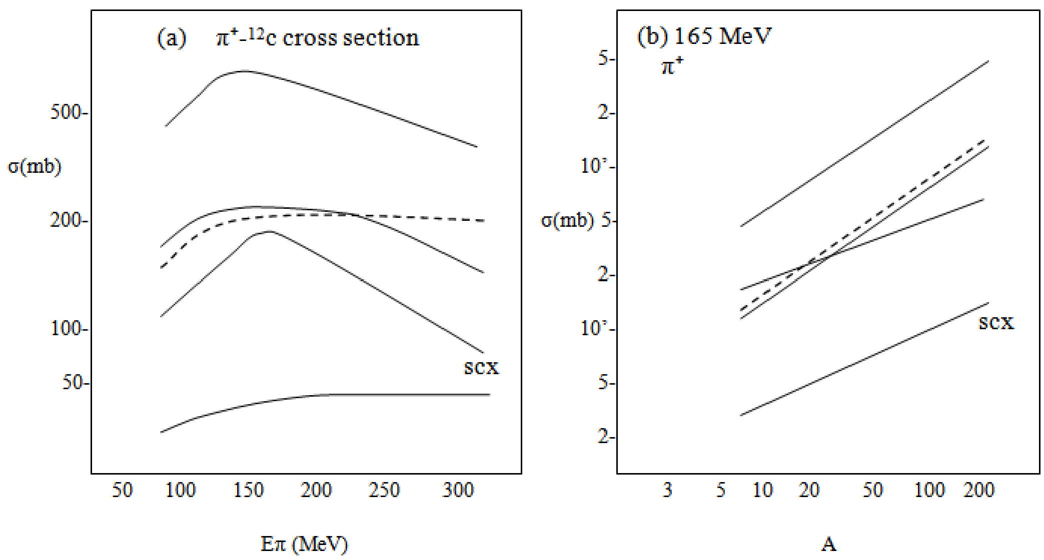

Figure 1 a & b.

Pion Reaction Modes on Nuclei

These are of two broad classes: inelastic scattering (including charge exchange) and absorption, where the pion disappears as an on-shell pion and its total energy including rest-mass is shared among nucleons.

The dependence of absorption on A has been parameterized to be

$$\sigma_{abs}/\sigma_{react} = (1/\pi R^2)\ {}_0\!\int^R (1-e^{-\alpha t})\ 2\pi r dr;$$
$$t = 2\ (R^2-r^2)^{1/2} \qquad (1)$$

Where t= thickness of the nucleus for a pion impinging with an impact parameter r.

The exponential represents the removal of pions from the inelastic pion flux. The value of parameter α is ~0.10 fm^{-1}.

The reaction cross-section can be represented by

$$\sigma_{react} = \pi R^2,\ R = (1.39\ A^{1/3} + 0.69\ )\ fm \qquad (2)$$

Equations (1) and (2) describe the different A dependences of the absorption, and inelastic fractions of the cross-sections.

Numerical constants are determined by least-squares fit.

Pion Absorption

In order to have a more substantial probability, pion-absorption should occur on at least two nucleons. In such cases, the nucleon momentum is only 363 MeV/c, which leads us to that short-range correlations between the two absorbing nucleons may be significant.

Actually, the role of pion-absorption is of much importance in pion-nucleus interaction. Pions have been used to study reactions and nuclear properties inaccessible or difficult to study with nucleon probes; e.g., double charge exchange, production of resonance, selectivity to neutron/proton interaction, and neutron radii, etc. interpretation of all these studies require understanding the process of pion absorption as it leads to the disappearance of the pion.

In heavy nuclei, pion-absorption is the major process responsible for attenuation of pion interacting with nuclei. This causes all reactions induced by pions in the resonance region to be limited to the outer surface of the nuclei. Further, this reaction couples to other reactions affecting them not only through attenuation of the incoming pion waves.

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