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Multiplicities in Nuclear Interaction of Negative Pions with Heavy Nuclei

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Abstract

During the last four decades, nuclear interactions of negative pions have been studied by many workers. At high energy, many reaction channels are open when an energetic pion interacts with a nucleus. Such channels are not open for a low energy pion. Here; we have studied nuclear interaction of –ve pion confined to absorption only. The values of multiplicities are calculated in case of neutron and proton emission. The experimental work is performed with some calculating parameters following simulation. So here we discuss the variation of results among themselves and the variation is appreciably large.

Keywords: Reaction channels, multiplicity and absorption.

Introduction

A great deal of work in the field of nuclear interactions of negative pions initiated with the availability of meson beams at laboratories like LAMPF, SIN, KEK, TRIUMF, CERN etc. However; most of the studies have been done at high energy. In this work, the study of nuclear interactions of negative pions is confined to absorption only. On the basis of some past illustrative examples, these facts are observed that the pion-nucleon interaction is very strong from 30 to 250 MeV. At low energies, meaning below 80 MeV, experimental results are mainly of elastic scattering.at say 40 MeV, the nucleus is rather transparent to pions and at 14 MeV, the coulomb interaction becomes pronounced and begins to affect the scattering characteristics. Thus it is the absorption of –ve pions, which is extensively studied.

Difference between π^+ and π^- Reaction

One difference between the reactions involving π^+ and π^- has to be kept in mind. The π^+ reactions cannot be performed with zero pion momentum as in the case of π^- which get captured in orbits, form pionic atom, undergo transition from higher orbit to lower orbit, and eventually reach the nuclear periphery where they get absorbed after having lost all the kinetic energy and momentum, the π^+s do not form pionic atom and are able to reach the nucleus with kinetic energy and momentum having lost some energy in interactions with atomic electrons only. Thus, the π^+ loses its kinetic energy and momentum through nuclear interactions involving nucleons of the nucleus with which the π^+interacts.

Calculation

All the calculations are done for absorption in nine nuclei ^{12}C, ^{16}O, ^{27}Al, ^{28}Si, ^{40}Ca, ^{56}Fe, ^{58}Ni, ^{64}Cu and ^{80}Br. In this aspect, the pion is assumed to be absorbed on a pair of nucleons (pp or np pair). The only difference is that π^- decreases the nuclear charge by one unit, and consequently more neutron than protons are emitted following its absorption. This difference has also impact on energy distributions of protons and neutrons. In this calculation, the two nucleons are followed one by one, as they move inside the nucleus, colliding with other nucleons. This sets up a nuclear cascade. Each nucleon involved in the cascade is followed till it goes out of the nucleus or is again absorbed within the nucleus. When the cascade stage is over, the nucleus having got excitation energy from the nucleons unable to be emitted during the cascade stage, de-excites through evaporation. And this evaporation comes to an end when the excitation energy is reduced so low that no more particles can be emitted.

Neutron Emission

Multiplicity

The values of neutron multiplicity are presented in table 4.1. As seen from the columns 2, 3 and 4 of the table, it is worth noting that while the multiplicity of direct neutrons (i.e., the ones emitted during the cascade stage) is almost the same for all the nuclei, whereas the multiplicity of evaporated neutrons increases as the nuclear mass increases.

Table 4.1: Neutron Multiplicity Following π^- Absorption.

Nucleus	Cascade	Evaporation	Total
^{12}C	1.69	0.26	1.95
^{16}0	1.64	0.46	2.10
^{27}Al	1.64	1.94	2.58
^{28}Si	1.62	1.29	2.93
^{40}Ca	1.65	1.89	3.54

^{56}Fe	1.59	2.36	3.95
^{58}Ni	1.59	2.42	4.01
^{64}Cu	1.59	2.92	4.52
^{80}Br	1.55	4.97	6.52

Conclusion

This suggests that heavier the nucleus the more effective is the process of its evaporation leading to the emission of more neutrons. This means that more excitation energy is imparted to the nucleus during the cascade stage and a lesser number of particles including neutrons are able to go out of the nucleus. There are likely to be more secondary collisions in a heavy nucleus, resulting in energy being shared among more nucleons and consequently lesser of them acquire energy to enable them to be emitted. This explains also why the multiplicity of direct neutrons tends to decrease, even if slightly, as the nuclear mass increases.

Proton Emission

Multiplicity

The proton multiplicity for all the nuclei is presented in table 5.1. As seen from column 2, the multiplicity of direct protons is small, nearly 25% of the multiplicity of direct neutrons. The multiplicity of evap protons is still smaller, and more so as compared to that of evaporated neutrons (column 3). Thus the number of direct as well as that of evaporated protons, emitted from the nuclei being studied is very small, much smaller than that of neutrons.

Table 5.1: Proton Multiplicity Following π^- Absorption.

Nucleus	Cascade	Evaporation	Total
^{12}C	0.37	0.05	0.42
^{16}0	0.39	0.09	0.48
^{27}Al	0.36	0.17	0.53
^{28}Si	0.38	0.15	0.53
^{40}Ca	0.37	0.20	0.57
^{56}Fe	O.35	0.19	0.54
^{58}Ni	0.34	0.20	0.54
^{64}Cu	0.36	0.17	0.53
^{80}Br	0.39	0.09	0.48

Conclusion

The neutrons take away most of the energy during the INC, and whatever small energy is left is shared between the direct protons, and the evaporated neutrons, evaporated protons, and other heavier charged particles emitted during evaporation. Thus, the number of protons emitted, direct as well as evaporated, is small, much smaller as compared to that of neutrons.

Neutrons take away most of the energy released after the pion is absorbed.

The neutron multiplicity is larger than proton multiplicity.

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