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Correlations in nuclear interactions between $E_{\text{CM}}/u$ and unexplained experimental observables

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Abstract: A new concept is introduced for the classification of “unresolved problems” in the understanding of interactions in thick targets irradiated with relativistic ions: The centre-of-mass energy per nucleon of a hypothetical compound nucleus from a primary interaction, $E_{\text{CM}}/u$, is calculated and correlated with several experimental observations in thick target irradiations. One observes in various reactions of relativistic primary ions with thick targets that there appears to be a threshold for reactions leading to “unresolved problems” which lies around $E_{\text{CM}}/u \sim 150$ MeV where $E$ is the kinetic energy of the beam. A thick target is defined so that products from the first nuclear interaction will make secondary nuclear interactions. All “unresolved problems” are exclusively observed above this threshold, whereas below this threshold no “unresolved problems” are found. Another (the same?) threshold exists at a nuclear temperature of 158±3 MeV as a threshold for massive pion production in nuclear interactions. Hagedorn had proposed this threshold decades ago and it is known as the Hagedorn limit. In this paper we will only mention, but not elaborate on Hagedorn’s theoretical concept any further. Some considerations will be presented and further studies in this field will be suggested.

1. Introduction

Spallation mass-yield curves in nuclear interactions with thin targets were systematically studied in many nuclear chemistry laboratories for decades around the world. These observed spallation mass-yield curves strictly obey well-known concepts of “limiting fragmentation” and “factorisation” (see section 2.2) and are thus well understood within current theoretical models. This applies for nuclear reaction studies induced by ions from $E_{\text{total}} < 1$ GeV and is extending up to 80 GeV $^{40}$Ar irradiations. Limited studies extend up to proton induced reactions with $E_{\text{kinetic}} = 300$ GeV (see Ref. [1] for details).

Several articles have recently appeared describing “unresolved problems” in the study of nuclear interactions in thick targets induced by relativistic ions and their secondary reaction products$^{[1, 2]}$. Product yield distributions in thick copper targets from irradiations with 72 GeV $^{40}$Ar (at the LBNL, Berkeley), 44 GeV $^{12}$C (at the JINR, Dubna), and 48 GeV $^4$He (at CERN, Geneva)$^{[3]}$ cannot be understood with well-established theoretical concepts, thus constituting “unresolved problems”. Moreover, exceedingly large neutron emission during the irradiation of thick copper, lead and uranium targets with high energy heavy ion beams having $E_{\text{total}} > 30$ GeV have been observed in several laboratories; an exceedingly large neutron multiplicity is also considered to be an “unresolved problem”.

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All attempts to characterise unresolved problems in thick-target nuclear reactions since about 1954 [4] have borne no fruit; the problem being that there are no defined ion energy, projectile mass, and target mass where these unresolved problems systematically occur.

In this paper the following approach will be introduced:
One calculates on a purely hypothetical basis the centre-of-mass energy $E_{CM}$ per nucleon in the entrance channel of the nuclear interaction. This entrance channel is defined by the kinetic energy $E_p$ of the primary ion (projectile) with mass $A_P$ and the target mass $A_T$. The value of $E_{CM}/u$ in units of MeV is calculated as:

$$E_{CM}/u = E_p * A_T / (A_P + A_T) / (A_P + A_T) \quad (1)$$

Experimental phenomena are produced in thick targets by primary ions (primaries) up to the end of their range and, in addition, by secondary fragments (secondaries) making nuclear interactions in the thick target. The relative importance of nuclear reactions in thick targets due to secondaries compared to primaries increases with the thickness of the target. One correlates the value $E_{CM}/u$ - which might be taken as the hypothetical average excitation energy of each nucleon in the entrance channel of the reaction - with experimentally observed phenomena.

Some correlations are presented in Section 2 for increasing $E_{CM}/u$. Obviously any observed correlation between $E_{CM}/u$ of the entrance channel and interactions of secondary fragments in thick targets will not explain the reason for unresolved problems, but one does find a systematic dependence. In section 3 we will present some considerations which may be helpful as a start to understanding the observed order presented in Section 2. Section 4 contains our conclusions on the subject and new experiments are suggested which may help to shed light onto this rather old and complex set of unresolved problems.

References
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As the length of this contribution exceeds space limitation we present only Abstract and Introduction. The full paper can be requested at:

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