ISABEL INC Model for High-Energy Hadron-Nucleus Reactions

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Eshed Toch Gar’ini
→ ETGAR
Etgar = Challenge
History

- R.Serber, Phys. Rev. 72, 1114 (1947)
- M.L.Goldberger, Phys. Rev. 74, 1269 (1948)
- N.Metropolis et al., Phys. Rev. 110, 185 (1958); Phys. Rev. 110, 204 (1958)
- ETGAR…
Nuclear Model

- Continuous charge distribution – Folded Yukawa. Nucleus divided into several regions of constant density. Ratio of proton to neutron density $Z/(A-Z)$

- Momentum distribution - degenerate Fermi Gas
  \[ E_{F_i} = \left( \frac{\hbar^2}{2m_i} \right) \left( 3\pi^2 \rho_i \right)^{2/3} \]
  
  $i = \text{proton, neutron}; m_i = \text{nucleon mass}; \rho_i = \text{density}$

- Potential depth (J.N. Ginocchio, Phys. Rev. C17, 195 (1978))
  \[ V_i = E_{F_i} + (\text{Separation Energy})_i \]
  \[ V_{\Delta^+} = V_p; V_{\Delta^0} = V_p + \frac{(V_p + V_n)}{3}; V_{\Delta^-} + \frac{(V_p + V_n)}{3} = V_n; V_{\Delta^-} = V_n \]
Hadron-Hadron Cross Sections (1)

\[ \sigma_{\text{tot}}, \sigma_{\text{inel}}, \sigma_{\text{el}} \]

Arndt phase shift analysis

\[ d\sigma_{\text{el}} / d\omega \]

P.C. Clements, L. Winsberg, UCRL 9043 (1960), unpublished
Hadron-Hadron Cross Sections (2)

N+N → N+Δ

Type of outgoing N, Δ determined by Isotopic Spin consideration
Z.Fraenkel, Phys. Rev. 130, 2407 (1963)

Mass of Δ is chosen from distribution:

\[ P(m_\Delta, E_{cm}^{N+N}) = \text{const.} \times \sigma_\text{tot}^\pi^+p (E_{cm}^{N+N}) \times F(m_\Delta, E_{cm}^{N+N}) \]

\[ m_\pi + m_N < m_\Delta < m_\pi + m_N + 500\text{MeV} \]

F = two body phase factor for the produced N+Δ
S.Lindenbaum and R. Sternheimer, Phys. Rev. 105, 1874 (1957); 109, 1723 (1958); 123, 333 (1961)

\[ P(\cos_{cm}) = .25 + .75(\cos_{cm})^2 \]
Hadron-Hadron Cross Sections (3)

Δ+N → N+N (π capture)

- Type of outgoing N, Δ determined by Isotopic Spin consideration
- σ, dσ/dω calculated from inverse process (Δ production) using the principle of “detailed balance”
- Δ production calculated using theoretical model (OPE)
Hadron-Hadron Cross Sections (4)

\[ \Delta + N \rightarrow \Delta' + N' \text{ (“exchange”)} \]

- Naively two step process:
  - Decay of initial Isobar, \( \Delta \rightarrow \pi + N' \)
  - Interaction of decay \( \pi \) with another Nucleon, \( \pi + N \rightarrow \Delta' \)

Z. Fraenkel, Nuovo Cimento 30, 512 (1963)
Z. Fraenkel, Phys. Rev. 130, 2407 (1963)
Hadron-Hadron Cross Sections (5)

\[ \pi^+ N \rightarrow \Delta \rightarrow \pi'^+ N' \]
(elastic & charge exchange)

- Experimental $d\sigma/d\omega$ + isospin considerations
  G.Giacomelli et al., CERN/HERA 69-1 (1969)

- For $\Delta$ decaying without interaction proper $\pi^+ N$ differential cross section

- Isotropic $\Delta$ decay after scattering or exchange
Hadron-Hadron Cross Sections (6)

◊ Δ → π+N

Energy dependant Δ width
Density depletion

After each interaction Fermi sea density, $\rho_i$, is depleted

Fast rearrangement: $\rho_i$ of the “partner type” Fermi sea is uniformly reduced for the whole nucleus

Slow rearrangement: “partner type” hole of radius $r$ is punched in the position of the interaction. No interactions are allowed in the hole with particles of “partner type”.
Pauli Blocking

◊ Options:

❖ Full Pauli Blocking: Interaction resulting in nucleon falling below Fermi sea is forbidden

❖ “Depleted” Pauli Blocking: Reaction resulting in nucleon falling below Fermi sea is allowed with probability of the relative depletion of the Fermi sea
High-Energy Fragments

- ISABEL was used without the additional coalescence model.
- No attempt was made to predict the production of high-energy “heavy” fragments.
Typical Results
ISABEL + GEMINI
$^{208}$Pb(p,X)n, 63 MeV
$^{208}\text{Pb}(p, X)p, \ 63 \text{ MeV}$
$^{208}\text{Pb}(p,X)n$, 256 MeV
$^{208}\text{Pb}(p,X)\pi^-$, 730 MeV
$^{208}$Pb$(p,X)\pi^+$, 730 MeV
$^{208}\text{Pb}(p,X)n$, 800 MeV
\(^{208}\text{Pb}(p,X)p, 800\text{ MeV}\)
$^{208}$Pb(p,X), 1000 MeV
$^{208}\text{Pb}(p,X)$, 1000 MeV
$^{208}\text{Pb}(p,X),\, 1000\, \text{MeV}$
\(^{208}\text{Pb}(p,X)n\), 1200 MeV
$^{208}\text{Pb}(p,X)n$, 1600 MeV
$^{208}\text{Pb}(p,X)n$, 3000 MeV
$^{63}\text{Cu}(p,X)\pi^+, 730\text{ MeV}$
$^{56}$Fe(n,X)n, 65 MeV
$^62\text{Fe}(p,X)p$, 62 MeV
$^{62}$Fe($p, X$), 300 MeV
$^{62}$Fe(p,X), 300 MeV

![Graph showing cross section vs. mass number for various elements in the context of $^{62}$Fe(p,X) reaction at 300 MeV.]
$^{62}\text{Fe}(p,X), \text{ 300 MeV}$
$^{62}\text{Fe}(p,X)n$, 800 MeV
$^{62}\text{Fe}(p,X), 1000 \text{ MeV}$
$^{62}\text{Fe}(p,X),\ 1000\ MeV$
$^{62}$Fe(p,X), 1000 MeV

![Graph showing cross-sections for different elements after reaction](image)
$^{62}$Fe$(p,X)n$, 1200 MeV
$^{62}\text{Fe}(p,X)n$, 1600 MeV
$^{62}\text{Fe}(p,X)n$, 3000 MeV
$^{238}\text{U}(p,X), 1000 \text{ MeV}$
$^{238}\text{U}(p,X), \, 1000 \text{ MeV}$
Thank You!

Questions, Remarks?