Electromagnetic Dissociation Cross Sections for High LET Fragments

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2:15 - 2:30 pm (15 mins.)
INTRODUCTION

ELECTROMAGNETIC DISSOCIATION (EMD)

RESULTS

CONCLUSIONS
Introduction

Galactic cosmic rays (GCR) & solar particle events (SPE) are radiation hazards in space for humans & electronic components
- GCR contain all nuclei in periodic table
- Energies hundreds of GeV/nucleon (n) & beyond

Focus on GCR interactions
- Nuclei broken into lighter fragments upon interaction with target nuclei

Target nuclei represent nuclei making up
- Spacecraft shielding, human body, electronic components, etc.
- Example: $^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + n + \text{Al}$
**Introduction: Strong vs. Electromagnetic (EM)**

\[ ^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + \text{n} + \text{Al} \]

Short range strong interaction when projectile & target nuclei overlap.
\[ ^{56}\text{Fe} + \text{Al} \rightarrow ^{55}\text{Fe} + \text{n} + \text{Al} \]

Short range strong interaction when projectile & target nuclei overlap.

Long range EM interaction when projectile & target nuclei miss each other.
Electromagnetic Dissociation

\[ \sigma_{\text{EMD}} = \int dE_\gamma N(E_\gamma) \sigma(E_\gamma) \]

Photonuclear cross section \( \sigma(E_\gamma) \) shown by red curve, plotted against photon energy \( E_\gamma \).
Green & blue curves show virtual photon spectra \( N(E_\gamma) \) for low & high energy projectiles.
Previously, EMD models (e.g. within NUCFRG3) calculate single proton (p) production, single neutron (n) or light ion production:
- Light ion ≡ isotope of hydrogen (H) or helium (He)
- Deuteron (d ≡ ²H), triton (t ≡ ³H), helion (h ≡ ³He), alpha (α ≡ ⁴He)

New model EMDFRG accounts for multiple nucleon production:
- 2p, 2n, 1p1n, 2p1n, 3p1α, 2p2t, ... (in addition to single light ions)

Such processes important:
- Consider reaction $^{56}\text{Fe} + \text{Al} \rightarrow ^{52}\text{Cr} + X + \text{Al}$
  high LET $^{52}\text{Cr}$
- Most probable EMD particles representing X are 2p2n or $^4\text{He}$
- $^{56}\text{Fe} + \text{Al} \rightarrow ^{52}\text{Cr} + ^4\text{He} + \text{Al}$ EMDFRG & NUCFRG3
  $\rightarrow ^{52}\text{Cr} + 2p2n + \text{Al}$ EMDFRG
- $\sigma(^{52}\text{Cr}) = \sigma(2p2n) + \sigma(^4\text{He})$
- Production of high LET $^{52}\text{Cr}$, must include both multiple nucleon production of 2p2n plus light ion production of $^4\text{He}$
RESULTS

Compare:

EMDFRG ———— with photonuclear parameterization for \( \sigma(E_\gamma) \)
EMDFRG - - - - - with photonuclear data for \( \sigma(E_\gamma) \)
NUCFRG2 - - - - -
NUCFRG3 .........

Focus on  EMDFRG ———— and  NUCFRG3 .........
Excellent agreement for EMDFRG —— Poor agreement for NUCFRG3 • • • • •
Excellent agreement for EMDFRG —— Worse agreement for NUCFRG3
RESULTS - SINGLE NUCLEON

Similar agreement for EMDFRG —— and NUCFRG3 ● ● ● ●
RESULTS - SINGLE NUCLEON

Good agreement for EMDFRG

Poor agreement for NUCFRG3
Similar agreement for EMDFRG —— and NUCFRG3 • • • • •
Excellent agreement for EMDFRG
Large Hadron Collider (LHC)

4,056.44 TeV/n: \(^{208}\text{Pb} + \text{Target} \rightarrow 1\text{n}

Excellent agreement for EMDFRG
Results - Double Nucleon

Good agreement for EMDFRG

\[ \sigma_{\text{NUCFRG3}} = 0 \]
RESULTS - DOUBLE NUCLEON

EMDFRG —— DATA - - - MMM

Excellent agreement for EMDFRG ——

$\sigma_{\text{NUCFRG3}} = 0$

Poor agreement for EMDFRG ——

$\sigma_{\text{NUCFRG3}} = 0$

13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{26}\text{Al} + 1p1n$

13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{26}\text{Mg} + 2p$ (f=0.18)

13.7 GeV/n: $^{28}\text{Si} + \text{Target} \rightarrow ^{26}\text{Si} + 2n$ (f=0.05)

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RESULTS - DOUBLE NUCLEON EMDFRG —— DATA ——

Good agreement for EMDFRG

σ_{NUCFRG3} = 0
Results - Double Nucleon

EMDFRG — Data

Reasonable agreement for EMDFRG

$\sigma_{\text{NUCFRG}3} = 0$
**RESULTS - TRIPLE NUCLEON**

![Graph 1](13.7\text{ GeV}/n: \(^{28}\text{Si} + \text{Target} \rightarrow \^{25}\text{Mg} + 2p1n\))

![Graph 2](13.7\text{ GeV}/n: \(^{28}\text{Si} + \text{Target} \rightarrow \^{25}\text{Al} + 1p2n\))

**Excellent agreement for EMDFRG**  \(\sigma_{\text{NUCFRG3}} = 0\)

**Poor agreement for EMDFRG**  \(\sigma_{\text{NUCFRG3}} = 0\)

**RESULTS - TRIPLE NUCLEON**

**Mixed agreement for EMDFRG**

\[ \sigma_{\text{NUCFRG3}} = 0 \]
**RESULTS - MANY NUCLEON**

13.7 GeV/n: $^{28}$Si + Target $\rightarrow ^{24}$Mg + 2p2n

13.7 GeV/n: $^{28}$Si + Target $\rightarrow ^{23}$Na + 3p2n

Good agreement for EMDFRG --- $\sigma_{\text{NUCFRG3}} = 0$

Poor agreement for EMDFRG ---- (fit = - - -) $\sigma_{\text{NUCFRG3}} = 0$

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Excellent agreement for EMDFRG — Poor agreement for NUCFRG3
Results - Alpha & Multiple N

13.7 GeV/n: $^{28}$Si + Target $\rightarrow ^{27}$Al + $\alpha$ + 1p

Excellent agreement for EMDFRG ——– $\sigma_{\text{NUCFRG3}} = 0$
CONCLUSIONS

- New EMDFRG model for single & multiple nucleon & light ion
- Calculations are compared to *complete* set of experimental data
- Agreement with data is excellent for all cases relevant for space radiation
- Single, double & triple nucleon removal data agrees very well over the whole range of energies, projectiles and targets
- Alpha production data agrees very well for $^{28}$Si projectiles, including alpha production in coincidence with single nucleons
- Some discrepancies, but not important for space radiation, because cross sections are quite small
  - Exception is for double nucleon removal from $^{28}$Si
THE END

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