

The Physics of Spallation Processes Theory and Experiments

Frank Goldenbaum

- > What is spallation?
- > Why are spallation reactions of interest? (applications, fund. physics)
- > Theoretical models describing spallation reactions (INC and evap. model)
 - Limits and constraints
 - validation
- > Experimental investigations (here: PISA & NESSI at COSY)
- Comparison between models and experiments
- Conclusion

PISA @ COSY Proton Induced SpAllation



>measurement of double differential spectra of emitted pre-equilibrium and evaporation ejectiles for pinduced reactions up to 2.5 GeV

>syst. investigation of production cross sections in spallation reactions

> benchmark data bank for validation/ improvement and development of computer-simulation models and codes

- 2 arms equipped with 2 Multichannel plates, Bragg curve detector, 3 silicons detectors and phoswich (15° & 120°)
- Cooled silicon detector telescopes (35°, 50°, 65° & 100°)
- Phoswich det.: all 8 arms

Atomic number identification with BCD p (1.9 Gev)+Ni



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Double differential cross sections ($Z_{projectile}, \Theta_{lab}$)

for He-isotopes



Reasonable agreement with INCL+ GEM Model in the Evaporation part
INCL+GEM can not describe the high energy part of the spectra





Fit of two Maxwell-like functions (two moving sources model) to experimental data p (2.5 GeV)+ ¹⁹⁷Au









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Particle	κ ₀	T_1	σ _l	βı	T_2	σ_2	β ₂	σ _{GEM}
type		[MeV]	[mb]		[MeV]	[m b]		[mb]
³ He	0.25	8.3	240	0.0036	26.9	510	0.064	166.72
⁴ He	0.45	8.6±0.3	1830±80	0.0036	26.7±1.2	350±30	$0.059 {\pm} 0.004$	1725.36
⁶ He	0.23	-	_	-	15.8±0.6	30.2 ± 1.8	0.028 ± 0.002	29.59
⁶ Li	0.60	9.6±0.7	32.4±2.3	0.0036	29.5±1.8	9.9±1.4	$0.048 {\pm} 0.006$	54.67
⁷ Li	0.65	9.6±0.6	48.5±3.0	0.0036	27.3±2.0	10.7 ± 2.0	$0.029 {\pm} 0.005$	43.86
⁸ Li	0.74	11.3 ± 0.8	10.7±0.6	0.0036	-	-	-	13.58
⁷ Be	0.5	8.0	2.9	0.0036	18.6	8.3	0.023	5.69
⁹ Be	0.53	8.0	4.2	0.0036	15.6	9.4	0.0175	9.37
¹⁰ Be	0.53	8.0	2.2	0.0036	15.0	9.5	0.017	10.57
¹⁰ B	0.53	8.0	1.5	0.0036	16.5	4.2	0.018	5.78
¹¹ B	0.65	8.0	4.5	0.0036	12.8	11.2	0.016	4.48
¹² B	0.72		-	-	12.8	3.5	0.010	2.64
C	0.71	-	-	-	13.1±0.8	16.2 ± 1.3	0.012 ± 0.002	4.6
N	0.76	. –	-	-	12.6±0.9	8.2±0.8	0.012±0.002	1.95
0	0.84		-	-	11.8 ± 1	3.8±0.4	0.012 ± 0.002	0.84
total			2187			957		2080





Summary

- PISA provides precise measurement of double differential cross section for ^{3,4,6} He, ^{6,7,8,9} Li, ^{7,9,10} Be, ^{10,11,12} B and C, N, and O ejectiles (for Si.det.)
- isotope (up to N) and element (up to Mg) identification (BCD)
- Important benchmark data for model improvement and development in particular for the emission of composite particles during the pre-equilibrium processes(emission of p,n during INC and evaporation phase is essentially understood)
- Two contributions were observed in the spectra: evaporation from the compound nucleus and isotropic emission from fast, hot source using the moving source method

