Needs for the Thermonuclear Theory Program

Gerry Hale, T-16, LANL
(with lots of input from Thurman Talley)

- How TN reactions are usually analyzed (R-matrix theory)
- Example: the d+t reaction
- Types of data used
- Radiaoactive ions produced in TN environments
- A specific proposal
- Summary

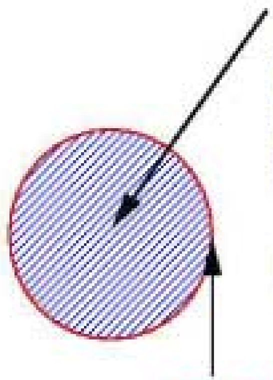
INTERIOR (Many-Body) REGION
(Microscopic Calculations)

ASYMPTOTIC REGION
(S-matrix, phase shifts, etc.)

$$\underbrace{H + \mathcal{L}_B}$$

compact, hermitian operator with real, discrete spectrum; eigenfunctions in Hilbert space

$$(r_c \,|\, \psi_c^+\rangle = -I_c\,(r_c\,)\delta_{c\,c} + O_c\,(r_c\,)S_{c\,c}$$



$$|\,\psi^+\,) = (H + \mathcal{L}_B - E)^{-1}\,\mathcal{L}_B|\,\psi^+\,)$$

Measurements

SURFACE

$$\mathcal{L}_B = \sum_c |c)(c|\left(\frac{\partial}{\partial r_c} r_c - B_c\right),$$

$$(\mathbf{r}_c|c) = \frac{\hbar}{\sqrt{2\mu_c a_c}}\frac{\delta(r_c - a_c)}{r_c}[(\phi_{s_1}^{\mu_1} \otimes \phi_{s_2}^{\mu_2})_s^{\mu} \otimes Y_l^m(\hat{\mathbf{r}}_c)]_J^M$$

$$R_{c\,c} = (c\,|\,(H + \mathcal{L}_B - E)^{-1}\,|\,c) = \sum \frac{(c\,|\,\lambda)(\lambda\,|\,c)}{\ldots}$$

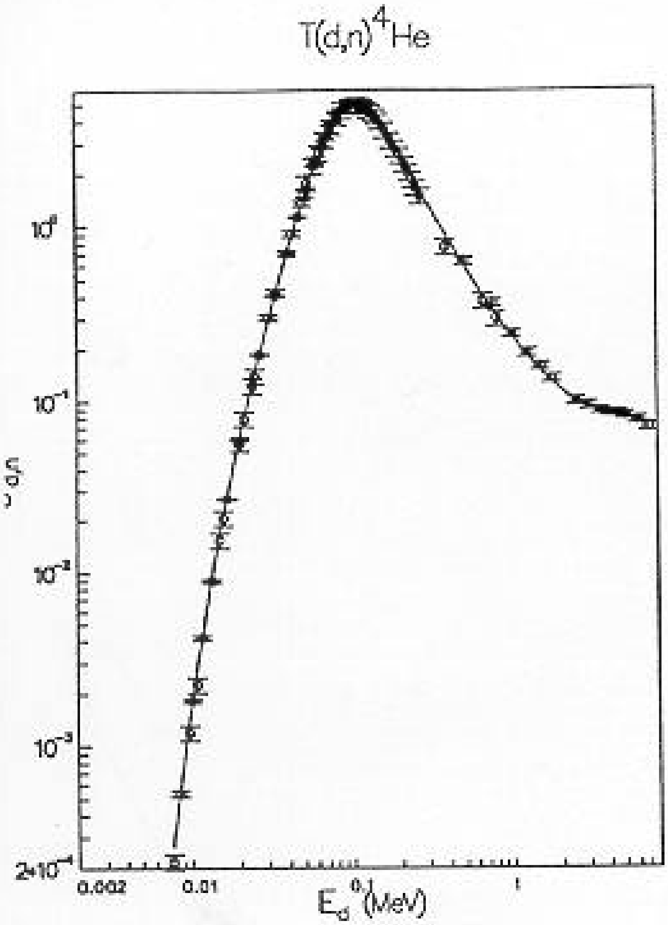
^{5}He System Analysis

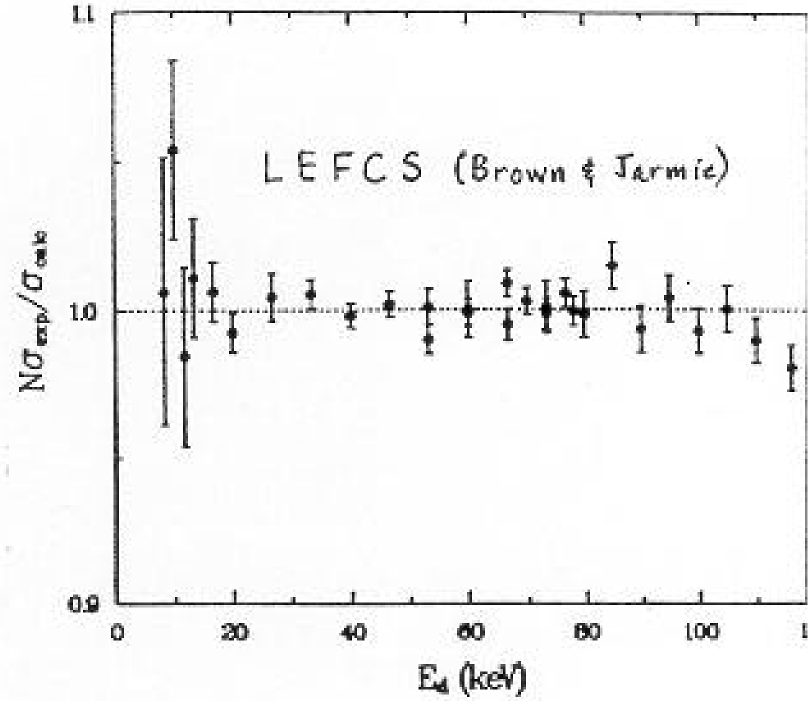
Channel	l_{max}	a_c (fm)
d-t	4	5.1
n-^{4}He	4	3.0
n-^{4}He*	1	5.0

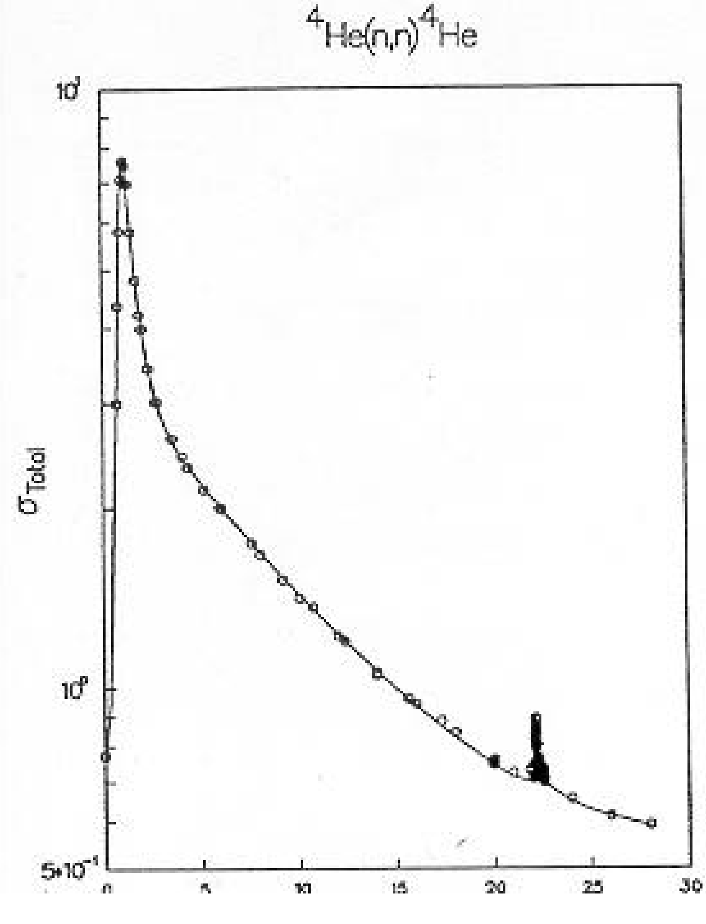
Reaction	Energy Range	# Observable Types	# Data Points	χ^2
T(d,d)T	E_d=0-8 MeV	6	704	1164
T(d,n)^{4}He	E_d=0-8 MeV	14	1121	1379
T(d,n)^{4}He*	E_d=4.8-8 MeV	1	10	26
^{4}He(n,n)^{4}He	E_n=0-28 MeV	2	793	1150
	Totals:	23	2628	3719

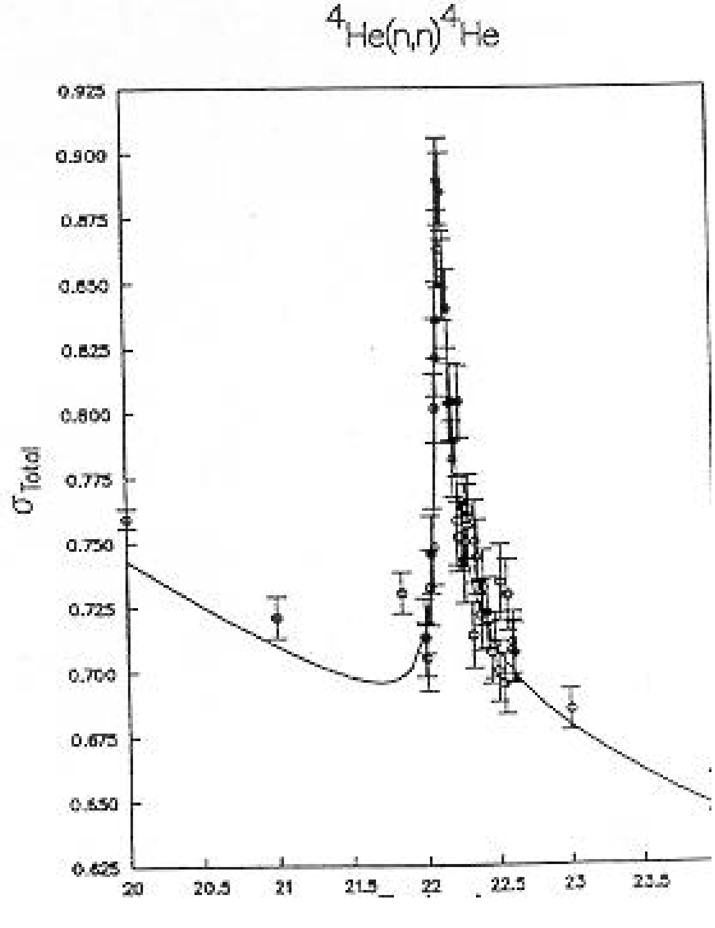
parameters = 108 $\Rightarrow$ χ^2 per degree of freedom = 1.48

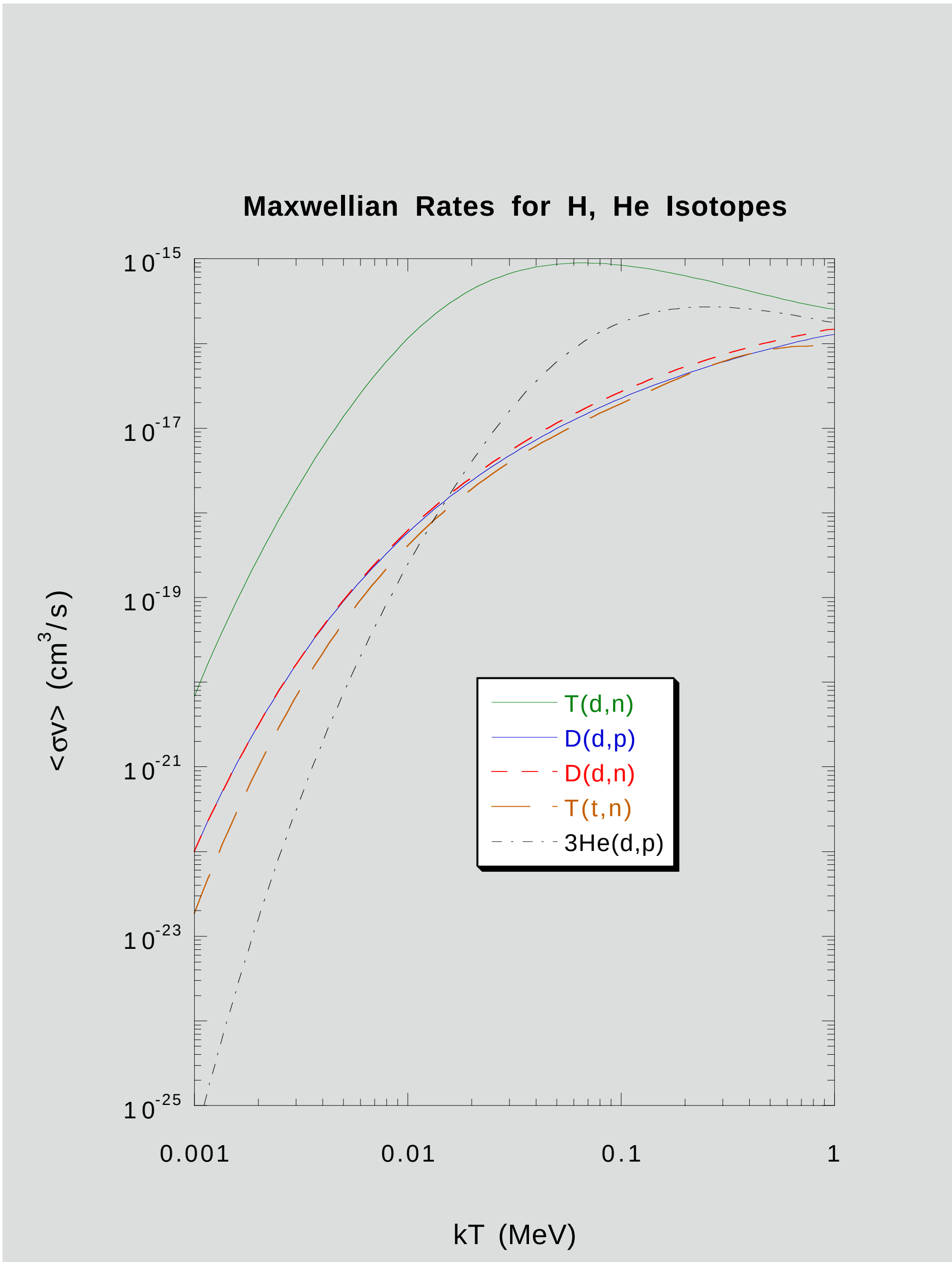
[89 phase parameters are necessary to describe the S matrix at a single energy]


T(d,n)4He
σd,n
Ed (MeV)
0.002
0.01
1
2×10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁰

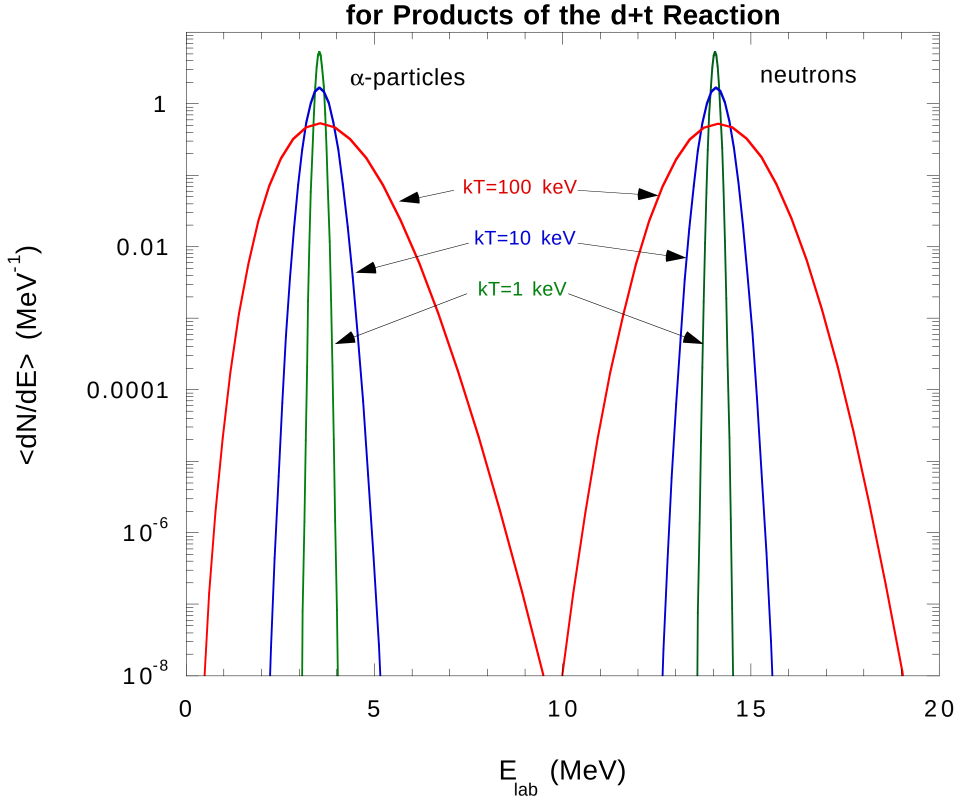

LEFCS (Brown & Jarmie)
Nσexp/σcalc
Ed (keV)
1.1
1.0
0.9
0
20
40
60
80
100


4He(n,n)4He
σTotal
10¹
10⁰
5×10⁻¹
0
5
10
15
20
25
30


4He(n,n)4He
σTotal
0.925
0.900
0.875
0.850
0.825
0.800
0.775
0.750
0.725
0.700
0.675
0.650
0.625
20
20.5
21
21.5
22
22.5
23
23.5


Maxwellian Rates for H, He Isotopes
<σv> (cm^3/s)
10^-15
10^-17
10^-19
10^-21
10^-23
10^-25
0.001
0.01
0.1
1
kT (MeV)
T(d,n)
D(d,p)
D(d,n)
T(t,n)
3He(d,p)

Maxwellian-Averaged Laboratory Energy Spectra for Products of the d+t Reaction



Radioactive Isotopes Produced in TN Reactions

^{6}He(806.7 ms):

Reaction	Q (MeV)
^{6}Li(n,p)^{6}He	-2.724
^{6}Li(t,^{3}He)^{6}He	-3.488
^{6}Li(d,2p)^{6}He	-4.949
^{7}Li(d,^{3}He)^{6}He	-4.481
^{7}Li(t,α)^{6}He	9.839
^{9}Be(n,α)^{6}He	-0.589

^{7}Be(53.29 d):

Reaction	Q (MeV)
^{4}He(^{3}He,γ)^{7}Be	1.5876
^{6}Li(p,γ)^{7}Be	5.606
^{6}Li(d,n)^{7}Be	3.381
^{6}Li(^{3}He,d)^{7}Be	0.112
^{7}Li(p,n)^{7}Be	-1.644
^{7}Li(^{3}He,t)^{7}Be	-0.881

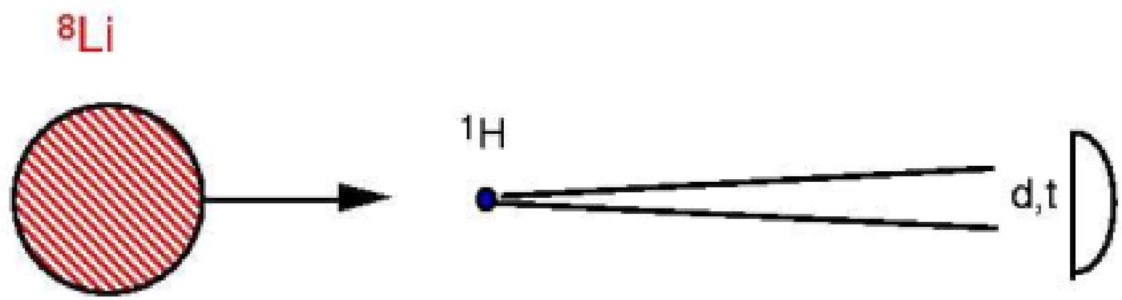
^{8}Li(838 ms):

Reaction	Q (MeV)
^{6}Li(t,p)^{8}Li	0.801
^{7}Li(n,γ)^{8}Li	2.033
^{7}Li(d,p)^{8}Li	-0.192

$\Rightarrow$ cross sections for reactions of ^{6}He, ^{7}Be, ^{8}Li, (and possibly ^{9}Li) with stable isotopes of H,He, and Li would be desirable.

A Specific Proposal:

Do measurements with a ^{8}Li beam ($E_{beam} \leq 100$ MeV) on a ^{1}H target, detecting the deuterium and tritium that are produced. Tritium will be observed only at beam energies above 7.2 MeV. Due to inverse kinematics (heavy particle on the light one), the reaction products are limited to a narrow cone in the lab.



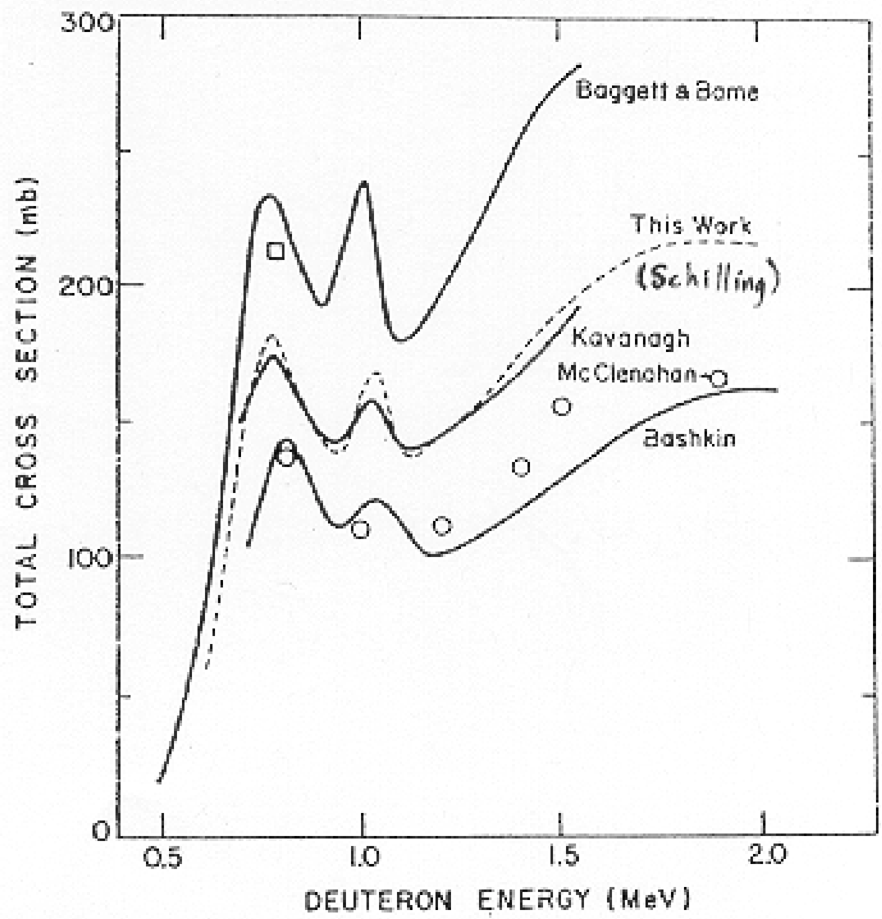


Fig. 1. A comparison of cross-section data for the reaction $^{7}Li(d, p)^{8}Li$. Data were obtained fr[illegible] following sources: Baggett and Bame [13]), Kavanagh [4]), McClenahan and Segel [11]) (open [illegible] Bashkin [10]) and Parker [6]) (open squares).

Summary

- Radioactive ions (^{6}He, ^{7}Be, ^{8}Li) are produced in a TN environment
- Some of the production cross sections have been measured, but in the few cases that multiple data sets exist, they are usually discrepant.
- Need cross sections for the reactions of radioactive light ions with stable isotopes of H, He, and Li.
- A specific case that would be useful is a ^{8}Li beam on a ^{1}H target. Detecting the d's and t's from this reaction would check the results of earlier measurements that have been done as $^{7}Li(d,p)$ or $^{6}Li(t,p)$.