Some history of the (t,3He) reaction and why do we care about it.

Interest in charge exchange reactions started with (p,n) , first used to get masses for determining beta decay ft values then moved on with discovery of its use in finding analog states at Livermore and then to doing detailed spectroscopy for Gamow-Teller rates. Issue always was resolution with neutron detection.

3He beams came on the scene early 1970s so that one could do (3He,t) reactions and identify exact states populated especially with tandems but when you tried to use the DWBA reaction theory to describe the shape of the angular distributions the calculations and data were out of phase and so rules came about that if you were off by 6 degrees it was a J=6 state etc but totally unsatisfying. Also, magnitude was way off.

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IS (^{3}He,t) PRIMARILY A (^{3}He,α) (α,t) REACTION?*

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The reaction ^{48}Ca(^{3}He,t)^{48}Sc to the low-lying even spin states has been studied as a pure sequential (^{3}He,α) (α,t) process using an exact finite-range formalism. It is found that the strength of the cross-sections to these states is under-predicted by large factors. The consideration of second-order processes via the inelastic channels also fails to account for the strength of these states. The (^{3}He,t) discrepancy still exists.

^{3}He energy was 23 MeV

Recently there has been much interest in second rder reactions which are allowed to proceed through article transfer channels. Perhaps the most significant eported result from this work has been the apparent nderstanding of (^{3}He,t) reactions when they are analzed as (^{3}He,α)(α,t) [1,2]. In the case of ^{48}Ca(^{3}He,t) ^{8}Sc and similar reactions in other nuclei, it has been eported that including only the sequential transfer nechanism allows a consistent description of both the nagnitude and the shape for cross-sections leading to he natural parity states.

It is the purpose of this letter to report an addiional study for the reaction ^{48}Ca(^{3}He,t)^{48}Sc. This ase has been calculated as a pure two-step process roceeding through the ^{47}Ca ground state. It is found hat treating the reaction in a consistent way includng finite-range effects exactly (neglected in the above eferences) gives cross-sections with a magnitude about factor of 4–17 below the experimental data.

The Indiana Cyclotron with its ~100 MeV good resolution proton beam became a center of (p,n) reactions. Program was to do proton elastic and inelastic scattering and (p,n) and then combine it with electron scattering at MIT-Bates to have a complete data set for the nuclei understudy.

At the same time theory was being developed and here, I will get in trouble, because it seemed to me that the leaders were derived from Hugh McManus at Michigan State and Ray Satchler of Oak Ridge. Nucleon-nucleon interactions and structure were developed so that one began to have a microscopic description of the (p,n) cross sections. Some popular interactions were Love-Franey and Petrovich-Love. Gary Love was a student of Ray and Fred Petrovich was a student of Hugh. One of the leaders of the experimental program who moved from Oak Ridge to Indiana was Charles Goodman who won the Bonner prize for his work.

Of course there were many other interactions being developed along with the shell model led by Hobson Wildenthal also at Michigan State. His work focused on the s-d shell .

So let’s assume that the (p,n) reaction at energies of about 100 MeV are well understood and that information needed of astrophysical interest can be obtained or has been obtained. However, work at say 25 MeV where data was taken and theoretical work went on for many years with Petrovich, Frank Dietrich of Livermore and Love amongst many others is still not successful primarily because of not have stable nucleon-nucleon interaction.

What about (3He,t)? It seems that if you go high enough in energy ~100 MeV/amu you can get reasonable reproductions of the angular distributions and magnitudes of strong states if you have excellent structure theory to go along with an n-n interaction.

But what about (n,p) reactions?
How about (d,2He) work done at KVI or heavy ion transfer reactions?

Because Fred Petrovich had his office down the hall from me and Gary Love was a postdoc at FSU the same time as me and would visit from time to time this subject came up many times.

The main issue was getting an intense, high resolution neutron beam at 100 MeV where you could use the same theory apparatus that had been developed for (p,n). A proposal was put together to produce such a machine but it never went anywhere

So what about heavy ion reactions? We measured (7Li,7Be) and with Fred’s help did a reasonable job of describing it, but today we know that was a fluke, because multistep dominates this reaction through beam and ejectile excitation as well as transfer routes. Maybe at 100 MeV/amu you might do better but I still would be worried today even after all the progress we have made in understanding heavy ion reactions.

While we were struggling with (3He,t) reactions at 9 MeV per nucleon at many tandem labs, Los Alamos was developing a 24 MeV (8 MeV per nucleon) triton beam to determine some masses in the late 1960 and 1970s.

For example, *A Study of* ^{64}*Cu,* ^{66}*Cu,* ^{68}*Cu and* ^{70}*Cu by (t,* ^{3}*He) Reactions* Phys.Lett. 67B, 275 (1977)

J.D.Sherman, E.R.Flynn, O.Hansen, N.Stein, J.W.Sunier

In this work the triton beam energy was 24 MeV they found the masses of ^{68,70}Cu and found energy levels in ^{64,66}Cu. The point was that they didn't have to worry about DWBA since these were spectroscopy measurements.

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Experimental location of Gamow-Teller strength for astrophysical calculations in the region of $A=54$—58

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The (t,^{3}He) charge exchange reaction has been used to locate Gamow-Teller states with T_0+1 isospin in the region of $A=54$—58. These data were obtained at $E_t=25$ MeV on targets of ^{54,56,58}Fe and ^{58}Ni.

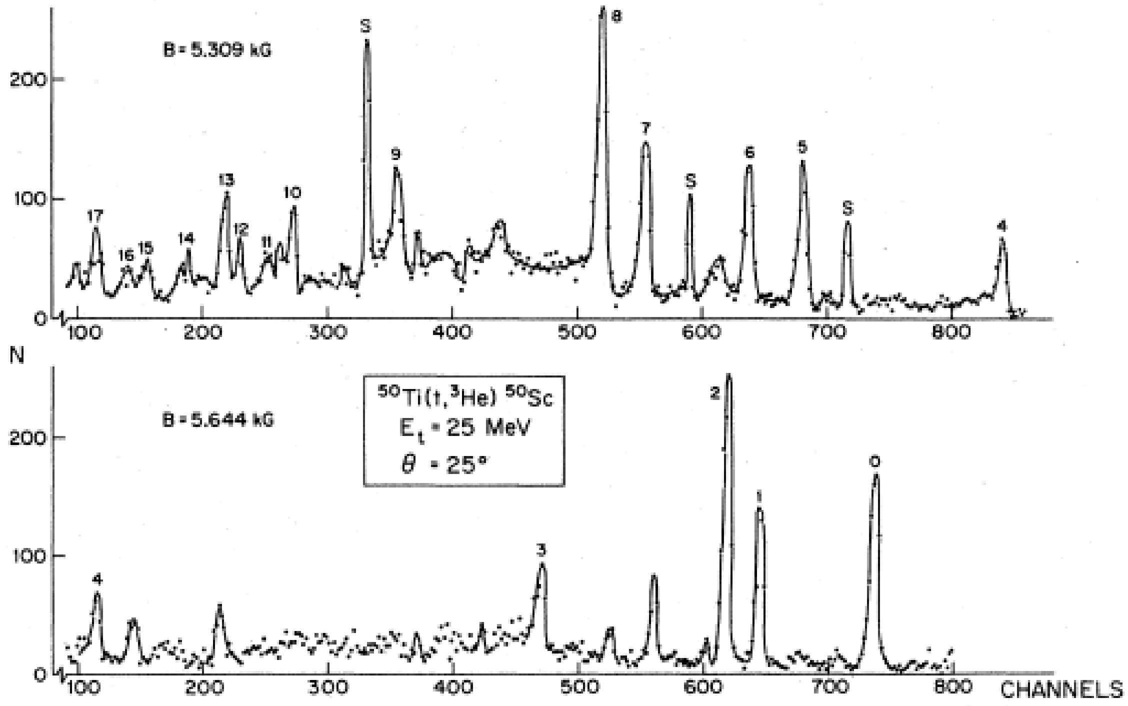

FIG. 11. Spectrum of the $^{50}Ti(t,^{3}He)^{50}Sc$ reaction at θ(lab) = 25°. The groups labeled *S* are spurious. See also the comments in the text.

You see selective population of states with some strong.

TABLE VII. Energy levels of ^{50}Sc.

Present results				Previous work[a]	
Group No.[b]	E_x (keV)	L[c]	$J^{\pi d}$	E_x (keV)	J^π
0	0[e]	4+6	5^+	0	5^+
1	257±5	2+4	3^{+d}	256.9	$2^+,3^+$
2	331±8	2+4	3^+	328.5	
3	764±10	4	4^+	756±8	
4	1852±10	0+2	1^+	1847.8	1^+
5	2225±10	2+4	3^+	2226±5	
6	2327±10	2+4	3^+	2331±8	
7	2527±10		1		
8	2614±10	0+2	1^+		
9	3028±15				
	f			3089±5	
10	3250±20[g]			3259±7	
11	3300±20[g]			3287±5	
12	3355±15			3380±20	
13	3388±15				
14	3475±20[g]			3510±20	
15	3556±15[g]				
16	3598±15[g]			3617±15	
17	f			3682±5	

[a]D. E. Alburger, Nucl. Data Sheets **42**, 369 (1984).
[b]See Fig. 11.
[c]L transfers assumed in the CCBA curves shown in Fig. 12: see the text and footnote c of Table II for additional comments.
[d]See also the text.
[e]$Q_0 = -6878 \pm 20$ keV: see also Table I.
[f]Observed at several angles: groups are weak.
[g]The width of this group indicates that it is due to unresolved states.

According to latest NNDC compilation of levels in 50Sc, done April 2019, once you get above the 2614 MeV level Jpis are in brackets or unknown.

So if you are interested in understanding the structure of odd-odd nuclei around in the upper fp shells then (t,3He) coupled to a gamma ray system will be an excellent system moving forward. However, a word of warning, the cross sections are small.

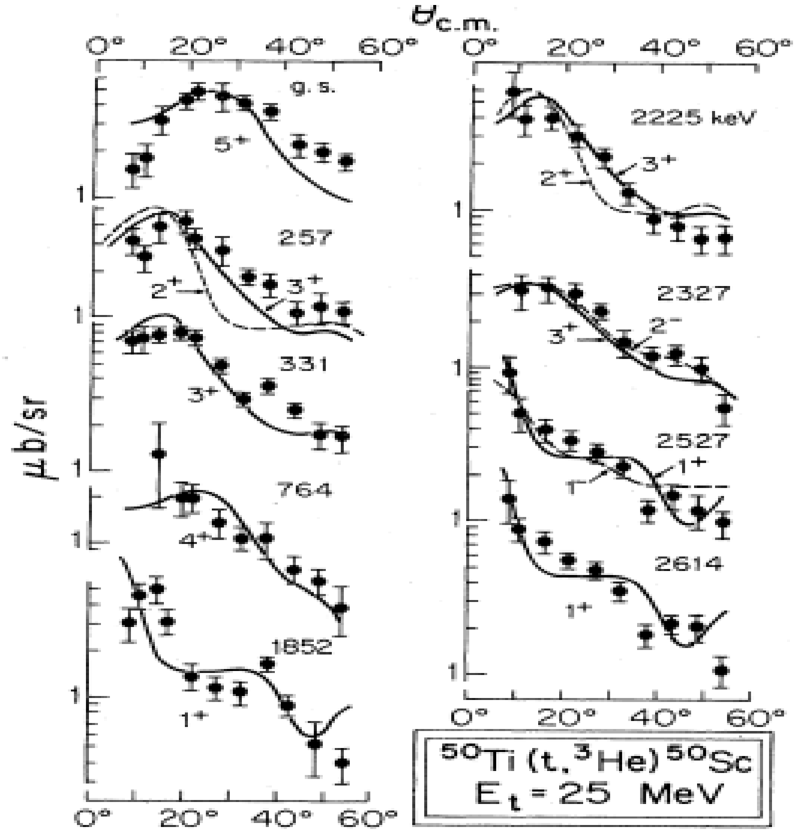

FIG. 12. Angular distributions of the ^3He groups from the $^{50}Ti(t,^3He)^{50}Sc$ reaction. See also the caption of Fig. 2.