EXCHANGE REACTIONS WITH DICK DALITZ

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1957 - first met, seminar on $K\bar{N}$

1959 - first publication

$\pi^+ \rightarrow p +$ Dalitz pair +

1961-62 Chicago

Fulbright scholar in Levi Sethi's emulsion group

$\rightarrow D^+$

$\rightarrow J(\psi\chi)$

$\rightarrow$ first hint of CSB in $^4H$, $^6He$ doublet
1962 Returned to London, rejoined European K- Emulsion Collaboration
1964 Dick returned to England briefly to Cambridge then permanently to Oxford to join Peierls

There followed a long and fruitful association between Dick and our Collaboration.

$\beta^-$ values (Dalitz, Gel, Soper)
$J^P_{\Lambda \bar{\Lambda}}$, $\Lambda \bar{\Lambda}$ (Dalitz, Zieminska)
$\pi^+$ decays (Dalitz, Rajasekharan, von Hippel)
C.S. $\beta$ (Dalitz, von Hippel)
Non-mesonic decays (Dalitz, Rayet)
I will concentrate on two sages in which Diek played a central role, double hypernuclei and substitutional states.

Double hypernuclei v H

1962 First double hypernucleus, Warsaw

$$\ ^{10}_{\Lambda}Be \rightarrow ^{9}_{\Lambda}Be + p + \pi^-$$

$$\rightarrow p + ^4He + ^4He + \pi^-$$

$$\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} (^{10}_{\Lambda}Be) - 2B_{\Lambda} (^{9}_{\Lambda}Be)$$

$$= + 4.8 \pm 0.4 \text{MeV}$$

1966 Second event, Prowse (Wyoming)

$$\Xi^- + ^{12}C \rightarrow ^{6}_{\Lambda}He + ^7Li$$

$$\rightarrow ^{5}_{\Lambda}He + p + \pi^-$$

$$\rightarrow ^4He + p + \pi^-$$

$$\Lambda R = + 4.7 \pm 0.5 \text{MeV}$$
Then nothing!

1971 Prowse dies
Puiewski casts doubt on Prowse event

1977 Jaffe's prediction of the H
H = (uuddds)

ie two well-bound Λs

Difficult to reconcile the H with existence of double hypernuclei

1989 Dick asks us to remeasure ¹⁰Be event to allely doubts.

Impossible, emulsion destroyed as a result of photographing event.

Unpublished pictures exist, as does independent measurement by P. Fowles et al.
Why was the emulsion destroyed

- schematic drawing

Three vertices \( \Xi \) capture

\(^{10}\Lambda^\Lambda\) Be decay
\(^{9}\Lambda^\Lambda\) Be decay

contained in cube, side length 3 \( \mu \)m.

Then emulsion shrinks by a factor a little more than 2 on processing.

Emulsion was swollen to twice its original thickness by saturating it in a saturated sugar solution (Tate and Lyle's Golden Syrup) to gain resolution for photographs.

Sugar solution subsequently crystallized \( \Rightarrow \) emulsion kaput.

Photographs + Fowler et al analysis published in Proc Roy Soc
Dick knew Prowse's widow, but a requested search among his old papers revealed nothing concerning the event.

However, one significant fact emerged.

The event published from Wyoming.

But

Prowse's emulsion work never moved from UCLA.

In 1966, Ticho, Schlein, and Slater were all in UCLA.

All were contacted in 1989, but none had any recollection of seeing a little.

I now believed Pniewski!
2004 NAQARA event
\[ \Xi^- + ^{12}C \rightarrow \Lambda ^{\Lambda}He + t + ^4He \]
\[ \rightarrow \Lambda ^{\Lambda}He + p + \pi^- \]

Two vertex fit gives
\[ \Delta B_{\Lambda\Lambda} = 1.0 \pm 0.2 \text{ MeV} \]
in direct contradiction to Prowse event.

For $^6\Lambda Be$ (and also $^3\Lambda B$)

there is an escape clause
\[ ^{10}\Lambda Be \rightarrow ^9Be^*(3 \text{ MeV}) + p + \pi^- \]
\[ \rightarrow \gamma + ^9Be \]
\[ \rightarrow \pi^- p \rightarrow \alpha \]
\[ \Delta B_{\Lambda\Lambda} \text{ now } 4.5 - 3 = 1.5 \text{ MeV} \]

Incidentally, with $^{10}\Lambda Be$ now 3 MeV/c^2 heavier than originally thought, production now fits
\[ \Xi^- + ^{12}C \rightarrow ^{10}\Lambda Be + d + n \]
Double-hypenucleus Event "Nagara"

NOTE: This is the preliminary result of the analysis.

Event Description

The picture and schematic drawing of the event is shown in Figure 1. This event was found by Y. Iwata at Gifu University and named "Nagara". A Σ+ hyperon came to rest at point A, from which 3 charged particles (track#1, #3, #4) were emitted. One of them decayed to 3 charged particles (track#2, #5, #6) at point B. The particle of track#2 decayed again to 2 charged particles (track#7, #8) at point C.

The event was detected in the most downstream plate (#12) of the emulsion module. The particle of track#7 left the emulsion stack and entered the downstream SciFi-B inside detector (D-Block). Unfortunately, track#5 ended in the base (50 micron thick acrylic film). The particle of track#8 was scattered by about 90 degree in plate#10 and stopped in plate#11. The particle of track#6 was identified as π-.

Figure 1: Picture and schematic drawing of "Nagara" event.

u-7 plane  run 473  spill 5024  event 14

SciFi-Bundle
and still there is no H.

Strangeness Exchange States

Late Sixties — determining \( B_n \) values of \( p \) shell hypernuclei — need to confirm identities

Many possible examples of \( \Lambda^n B \rightarrow \pi^- C \)

but

\[ \begin{array}{cccc}
\Lambda^7 B & \rightarrow & \pi^- C & \text{Range/\( \mu \)m} \\
& & 20700 & 1.0 \\
\Lambda^{10} B & \rightarrow & \pi^0 B & \text{Range/\( \mu \)m} \\
& & 19800 & 1.1 \text{ (stable)} \\
\Lambda^7 L & \rightarrow & \pi^- Be & \text{Range/\( \mu \)m} \\
& & 21600 & 1.8 \text{ E.C} \\
\end{array} \]

\( \pi \) Range straggling \( \sim 3\% \)

These hypernuclei are inseparable from decay kinematics alone
I noted that many had $K^-$ production topologies $HF + \pi + 1$ baryonic track

\[ K^- \rightarrow \Lambda B + p + \pi^- + Q \]

(Q value known, $R_p \rightarrow T_p$ and $P_p$ known)

Use iteration procedure

Step 1, put $T_{\pi^-} = 0 \Rightarrow T_{\pi^-}' \rightarrow P_{\pi^-}$
\[ p' + p \rightarrow p_{HF}' \rightarrow T_{HF}' \]
\[ T_{HF}' \rightarrow T_{\pi}'' \rightarrow p'' \]
\[ p'' + p \rightarrow p_{HF}'' \rightarrow T_{HF}'' \]

and so on.

Procedure converges rapidly,
after 2 iterations \( T_{\pi} \) stable to 5 keV.

Compatibility with reaction \( \odot \) tested by comparing measured and computed range and direction of hypernucleus

\( \pi \) spectrum showed sharp spike

Suggested two body reaction
\[ K^0 + ^{12}C \rightarrow \lambda C^* + \pi^- \]
\[ \lambda \rightarrow p + \Lambda B \]

Sent to Nuclear Physics but rejected.
Returned with phase space and impulse model curves

Sent to second referee, success, first observation of highly excited state of a hypernucleus → PUBLISH

I saw Dick shortly afterwards and thanked him for overruling first referee

He was taken aback — N.P. no business to divulge his name.

They hadn't.

It was well before the coming of 'the Word'. Referee's reports were typed up by secretaries.

As many of you know, Dick was never satisfied
$\pi^-$ spectrum from $K^- C \rightarrow \pi^- p \Lambda \bar{B}$
and always modified text in his own, unmistakable handwriting.

We published a further paper with some more statistics, then left hypernuclei to go hunt for charm and beauty.

Subject was taken up by \((K\pi), (\pi K)\) counter spectroscopy groups at CERN, BNL and more recently KEK.

1982 I was brought back to the subject by Dick at the Heidelberg Conference.

He had a problem

'Was the \(\Lambda\) in \(\Lambda^C\) bound or unbound?'

Theoreticians worry about such things.

BNL had 2 values for \(B_\Lambda (\Lambda^C)\)
\[ \theta_{KN} = 0^\circ \quad B_\nu = +0.033 \pm 0.130 \text{ MeV} \]

\[ \theta_{KN} = 15^\circ \quad B_\nu = -0.027 \pm 0.160 \text{ MeV} \]

Moreover he had checked both of our papers, \( B_\nu \) was positive in both, but they didn't agree!

Cause of discrepancy — during early 70s PDG mass values, especially that of kaon, changed by considerably more than quoted error.

Dave Tovee and I reanalysed all our old data, including a large sample of events obtained using resonance peak to identify \( \pi^B \) events

\[ \Rightarrow \quad \Theta = \text{non-mesonic} \]

\[ \Rightarrow \quad n/p \text{ etimulation ratio} \]
These data were presented at BNL 1985.

\[ \Rightarrow \pi^- \text{ spectrum} \]

\[ \Rightarrow \mathcal{Q} (\Lambda^c \rightarrow p \Lambda^B) \]

A good fit to the \( \mathcal{Q} \) spectrum below 2 MeV essentially purely \( \pi^c \), requires 3 Breit-Wigners.

One stands alone, but need two, centred around \( \mathcal{Q} \approx 1.4 \text{ MeV} \), a 'fat' and a 'thin' one to fit.

What do we expect?

States formed by \((P_{3/2})_\Lambda\) hole and a \((P_{1/2})_\Lambda\) or \((P_{3/2})_\Lambda\)

\[
(P_{3/2})_\Lambda^{-1} (P_{1/2})_\Lambda \Rightarrow 1^+, 2^+ \\
(P_{3/2})_\Lambda^{-1} (P_{3/2})_\Lambda \Rightarrow 0^+, 1^+, 2^+, 3^+
\]
Fig. 1. The $T_{min}$ distribution for all events interpreted as $K^- + \Lambda \rightarrow \pi^- + p + \Lambda$. For $K^- \rightarrow \pi^- + p$ stopping in nuclear emulsion.

$T_{min}$ distribution for all events interpreted as $K^- + \Lambda \rightarrow \pi^- + p + \Lambda$.
Q value distribution
\[ ^{12}C^* \rightarrow p \, ^{11}B \]
Low energy \( ^3\text{He}N \) is s wave, no spin flip, so expect only \( 0^+ \), and \( 2^+ \) states.

Since \( J^A_B = 5/2^+ \)

- \( p \) decay from \( 2^+ \) states may be s wave
- \( p \) decay from \( 0^+ \) state needs d wave.

\( Q \) values are small, \( \leq 1.5 \text{ MeV} \)

so expect strong inhibition of d wave

ie natural to assume narrow state is \( 0^+ \)

With this assignment we have

<table>
<thead>
<tr>
<th>State</th>
<th>#</th>
<th>( T/\text{keV} )</th>
<th>( B_n/\text{MeV} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 0^+ )</td>
<td>64</td>
<td>( \leq 100 )</td>
<td>( +0.14 \pm 0.05 )</td>
</tr>
<tr>
<td>( 2^+ )</td>
<td>193</td>
<td>( \sim 600 )</td>
<td>( +0.20 \pm 0.05 )</td>
</tr>
<tr>
<td>( 2^+ )</td>
<td>49</td>
<td>( \sim 150 )</td>
<td>( +0.95 \pm 0.05 )</td>
</tr>
</tbody>
</table>
In conclusion
3 states located, determined real widths of 2, an upper limit for the third.

Answer to Dick's original question,
the Λ is bound in all three.

It is right to say that neither of these two works would have been undertaken without Dick's encyclopaedic knowledge of past results and his nagging persistence to obtain solutions to puzzling situations.