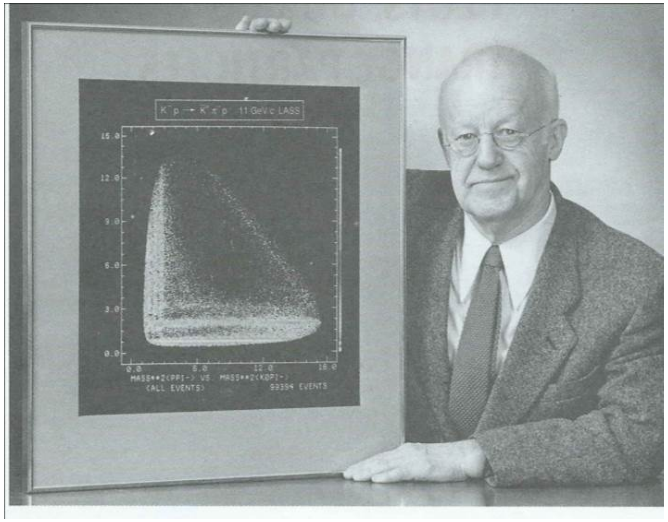
A Tribute to Dick Dalitz

28.2.1925 (Dimboola) – 13.1.2006 (Oxford)



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Dalitz student: 1964-67

Dalitz colleague: 1974-93

Draft Abstract of Royal Society Memoir

I Aitchison and C H Ll S

Richard (Dick) Henry Dalitz was a theoretical physicist whose principal contributions were intimately connected to some of the major breakthroughs of the twentieth century in particle and nuclear physics. His formulation of the '$\tau - \vartheta$' puzzle led to the discovery that parity is not a symmetry of nature - the first of the assumed space-time symmetries to fail. He pioneered the theoretical study of hypernuclei, of strange baryon resonances, and of baryon spectroscopy in the quark model (at a time when many considered it 'naive'), to all of which he made lasting contributions. The 'Dalitz Plot' and 'Dalitz Pairs' are part of the vocabulary of particle physics. He remained throughout his career in close touch with many experimentalists, and he had an encyclopaedic knowledge of the data. Many of his papers were stimulated by experimental results, and were concerned with their analysis and interpretation, work which often required the forging of new phenomenological tools; many also indicated what new experiments needed to be done. As a consequence, he was a theorist exceptionally valued by experimentalists. He served on a number of scientific Boards and Committees, including the CERN Scientific Policy Committee. He created and ran a strong and flourishing particle theory group at Oxford, which attracted many talented students and researchers.

What to choose from the extensive menu?

- Dalitz pairs
- The Dalitz Plot
- Hypernuclei
- KN Interactions, CDD Poles and the K Matrix
- Quarks – covered by Frank Close
- Reminiscences and reflections

Brief Biography of R H D

- 1944 BA Mathematics, Melbourne
- 1945 BSc Physics, Melbourne
- 1946-48 PhD student Cambridge (PhD awarded 1950)
- 1948-49 Research Assistant, Bristol
- 1949-53 Research Fellow then Lecturer, Birmingham
- 1953-55* Research Associate , Cornell
- 1956-63* Associate then full Professor, Chicago
- 1963-90 Royal Society Research Professor (Emeritus from 1990) Oxford

* with visiting periods at Stanford, Institute for Advanced Studies, Brookhaven, Lawrence Radiation Lab, Seattle,..

Context

- **1946:** Elementary particles = p, n, e and a cosmic ray 'meson'*
  (Yukawa?) mass ~ 200 m_e + neutrino? (a postulate)
  *1947 – actually two particles: π and μ

- **1963**: 'Elementary' particles

  Leptons: e, ν_e, μ, ν_μ

  Hadrons: baryons N, Λ , Σ, Ξ, Σ

  mesons: π, K

  + Small number of 'resonances' Δ (1952) ρ, ω, η, K* (all 1961)… many discovered using Dalitz plots

- **Theory in the 1960s**

  S matrix, bootstrap…

  G Chew: "Field theory like an old soldier will not die but simply fade away"

Dalitz Pairs (1)

- Dick's thesis on "Zero- zero transitions in nuclei" focused on

  $^{16}O^*(0+, 6.05\ MeV) \rightarrow {}^{16}O\ (0+,\ ground\ state)$

  He studied the decay via a virtual (longitudinal) photon → $e^+ + e^-$
  [emission of a single photon is forbidden]

- In 1951 members of Powell's group showed Dick some emulsion events, and said

  "Here are two peculiar pairs". In each of these cases, the outgoing pair of tracks were clearly identified as electronic. What was peculiar about them was that the origin of each pair could not be seen as separate from the centre of the cosmic ray star from which it emerged. What could give rise to these two pairs? On my way back to Birmingham, I suddenly realized that the π^0 itself could give rise to them by a direct decay to γe^+e^-, through the process of internal pair conversion of one of its product photons:

  $$\pi^0 \rightarrow \gamma + \text{"}\gamma\text{"} \rightarrow \gamma + e^+ + e^-$$

Dalitz Pairs (2)

- Recalling his thesis work Dick

  "calculated the rate for the internal conversion of one of the γ-rays in $\pi^0 \to \gamma\gamma$ decay for a free π^0" and found a branching ratio of 1.185%, later increased to 1.195% by radiative corrections

  Today's value is (1.198 ± 0.032)%

  With just 2 events, the Bristol group did not claim discovery of decays to Dalitz pairs, which were established a year later

- Dalitz pairs proved to be a useful, e.g.

  - the decay $\Sigma^0 \to \Lambda^0 + \gamma$ (virtual) $\to \Lambda^0 + e^+ + e^-$ was used to establish that Σ^0 and Λ^0 have the same parity

  - Kroll and Wada extended Dick's work to the double-Dalitz process $\pi^0 \to e^+e^-e^+e^-$ which was used to determine the parity of the π^0

The τ-ϑ Puzzle and the Dalitz Plot

- **January 1953 Royal Society Discussion Meeting**

  11 events τ^+ (now called K^+) → $\pi^+\pi^+\pi^-$

  Dick later recalled "the time was ripe to give some serious consideration to their characteristics". He reported his considerations (in more detail in a paper already submitted) at the

- **July 1953 Bagnères-de-Bigorre conference**

  τ^+ well established, mass $(970 \pm 5)m_e$

  ϑ^0 (now called K^0)→ $\pi^+\pi^-$ reported, mass $(971 \pm 10)m_e$

  Question: given their similar masses, are τ^+ and ϑ^0 different states of the same particle? If so, they would have the same spin and parity

  Dick's analysis showed, when enough event had accumulated, that the $\pi^+\pi^-$ state from ϑ^0 decay and the $\pi^+\pi^+\pi^-$ state from τ+ decay have different party

  Either parity is not conserved (a revolutionary idea), or some unknown symmetry produces states with the same mass but opposite

The Dalitz Plot and the τ-ϑ Puzzle

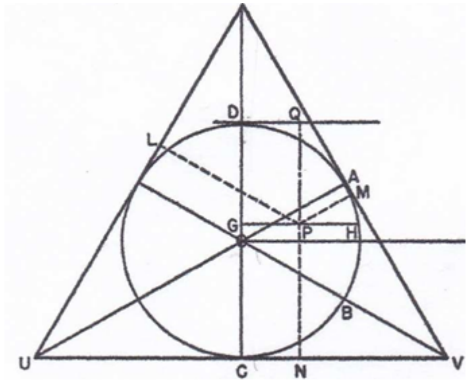
Dick later recalled:

It was my opinion that the amplitude for the decay mode $\tau^+ \to \pi^+\pi^+\pi^-$ should be largely calculable in form (although not in magnitude) in terms of angular momentum barrier considerations, apart from a few parameters necessary when the total angular momentum and parity could be apportioned to the internal orbital motions within the three-particle system in more than one comparable way. If so, it would then be possible to deduce the values of these internal angular momenta from the distribution of events and from them to reach some conclusions about the total spin-parity [of the τ-meson], at least to exclude some possibilities. First, a representation was needed to display the distribution of events pictorially……

The Dalitz Plot and the τ-ϑ Puzzle

- Dick's **'phase space plot'** is an ingenious way to display how the energy is shared between A, B and C in any decay X→ A + B + C ,which
i) treats A, B and C on an equal footing, and
ii) directly reflects physics (with kinematical factors removed)

- As they accumulated, the $\tau^+ \to \pi^+\pi^+\pi^-$ events populated the kinematically allowed domain (inside the circle) uniformly → no relative angular momenta→ parity opposite to that of ϑ !!



The original plot
Phys Rev 1954

- Dick (speaking in 1982) recalled the reaction:

"How was it possible that reflection invariance should not hold, people asked - was not left-right invariance inherent in our most fundamental conceptions about space-time? The only answer available was that the occurrence of both K → 2π and K → 3π decays actually did demonstrate this, but this answer did not have compelling force because it could not point to any *explicit* empirical demonstration of parity failure. . . . It required much less faith to suppose that . . . there existed two distinct K-meson charge doublets, labelled ϑ and τ , close in mass but with different spin-parities. . . . The mental obstacle [to accepting the parity violation explanation] arose from the fact that the $\tau - \vartheta$ puzzle did not provide an explicit demonstration of parity violation."

Hypernuclei = nulcei containing at least one strange baryon

- First observation (1952): a hyper-fragment event in a balloon-flown photographic emulsion (K + nucleus → π + hypernucleus with N replaced by Λ)
- In his first paper on hypernuclei (1955) Dick inferred that the nearly equality of the binding energies of ${}^4_\Lambda H$ and ${}^4_\Lambda He$ implies charge symmetry of the Λ-N interaction
- Soon after the discovery of parity violation, Dick realised that studies of the decays ${}^4_\Lambda H \rightarrow {}^4He + \pi^-$ and ${}^3_\Lambda H \rightarrow {}^3He + \pi^-$ could be used to determine the J^P of the parent hypernuclei
- He went on from simple s-shell cases to: p-shell and larger/more complex nuclei, including ΛΛ hypernuclei and Σ hypernuc;ei, and pioneered studies of non-mesonic weak decays in hypernuclei (ΛN→ NN) and γ decays of excited Λ hypernuclei
- Dick's work on light hypernuclei (in particular perhaps on ${}^3_\Lambda He$ and ${}^3_\Lambda H$, ${}^3_\Lambda N$)* honed expertise which he later used in his pioneering studies of three quark systems

*****$I= 0$ *${}^3_\Lambda H$ has small binding energy: Dick showed the iso-triplet state in not be bound*

KN Interactions, CDD Poles and the K Matrix

- **Pedagogical introduction:**

  Writing the scattering matrix $S = (1 - iK/2)/(1 + iK/2)$, then $SS^\dagger = 1 \rightarrow K^\dagger = K$, time reversal invariance → K real. Dick showed that parameterization of K is an excellent way to analyse data.

  With $S = 1 + iT$,setting $T = N/D$ where N [D] is analytic apart from a left-hand [right-hand] cut (N reflects particle exchanges = forces; D unitarity), was found in the 1950s to be a good way to solve model field theories, and formulate bootstrap models.

- **C**astillejo, **D**yson and **D**alitz (1956) pointed out that any solution of the N/D equation remains a solution if $D \rightarrow D + a/(s-s_0)$. Dick later pointed out that this leads to a resonance at $s \approx s_0 + a/ReD(s_0)$ if $a/ReD(s_0)$ is small.

- In a series of papers, with S F Tuan (later others) starting in 1959, Dick presented a masterly analysis of KN scattering, and developed the relativistic multi-channel K matrix formalism

Analysis of KN Scattering and the Λ (1405)

- **1st paper**: analysis of scattering lengths → one fit with pole below threshold in lower half (unphysical) complex plane (new idea phenomenology) "…the appearance of this maximum would correspond to the existence of a resonance . . . in pion-hyperon scattering [i.e. in $\pi\Sigma$] for a closely related energy value"

- Increasingly general/sophisticated K matrix analyses followed, while (following some bumps in the road) the predicted state – now known as the Λ (1405) – was confirmed (bump in $\Sigma\pi$ invariant mass distribution).

- Having predicted the state phenomenologically, Dick's attention then turned to its nature:
  - in the language of the time: elementary (CDD) or composite (dynamically generated by meson exchange)?
  - more recently: L = 1 three quark $½^-$ state? But why so much lighter than $3/2^-$ Λ(1520)?
  - Lattice QCD suggests KN molecule

Reminiscences and Reflections

- Scientific style
- Quarks
- Seen by students
- Hard work
- Professionalism

Dick's corrections to his own work

Autobiographical notes made by Richard Dalitz for Gerald Stone c. ~~1986~~ 1985–1990

My Childhood & Life in Australia

Dimboola, my birthplace, is a small town [(population 2000)] on the river Wimmera, which flows north from the Grampian mountains of western Victoria until it disappears in the sands of the semi-desert to the north. My grandfather Heinrich lived on the

in a district where there were many German settlers. A few years after Heinrich had married Anna Elizabeth Wuttke there, during which time my father Friedrich Wilhelm was born, Heinrich and his family left Robertstown to settle in the Wimmera district [of Victoria], which involved a journey of some 350 km, mostly across semi-

It is worth saying a little about the later history of this family. Of the girls, one died young by accident, while the other two married, one to a Schulze, the other to a Tepper, both being from German families. Of the other 9 boys, two became local farmers, having married into [German] families (Möller and Hirthe) owning farmland locally, two became grocer's assistants locally, one died in France in

the work of others (Ron Horgan's thesis)

by the usual symbols. In each case the SU(3) ⊗ $SU(2)_\sigma$ multiplet is ~~given~~ [indicated,] as well as the $SU(6)_\sigma$ ⊗ O(3) multiplet concerned. ~~N.B. where~~ [Note that, whenever] a matrix element is not tabulated, ~~then~~ it ~~is~~ [has value] zero.

A3(ii). [Appendix VI. The] ~~We give the~~ matrix elements for each of the [SU(3) singlet and SU(3) octet] operators [are tabulated in Appendix IV, taken] ~~listed above~~ between all the baryon states listed in Appendix I. ~~2(ii).~~

The matrix elements of the ~~spin-independent~~ [spin-scalar] operators ~~(i.e. transform as scalars under $SU(2)_\sigma$ rotations)~~ do not depend on the angular momenta [J] of the baryons concerned. Hence, for a given $SU(6)_\sigma$ multiplet, these matrix elements are the same irrespective of the orbital angular momentum involved. The listings for these particular operators are ~~accordingly~~ [therefore] only labelled by the $SU(6)_\sigma$ multiplet di-