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COMMENTS ON THE INTERACTION BETWEEN THEORY AND EXPERIMENT IN HIGH ENERGY PHYSICS

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Setting the Tone

A central characteristic of the discipline of high energy physics has been, and still is, the close and fruitful interplay between theorists and experimentalists. Much of our success in establishing the Standard Model can be ascribed to such interactions. In this short and subjective talk, I illustrate this characteristic by the different ways in which I and my colleagues have benefitted from discussions with Dick Dalitz over the years.

The story starts in 1951 when I started as a physics student at the University of Birmingham. At that time, at least in Britain, experimental physicists worked in the tradition in which they were very much concerned with practical problems of apparatus design and experiment construction rather than focussing on the physics questions that the experiment was addressing.

Many of the physics courses were given by faculty of the Mathematical Physics Department whose head was Rudy Peierls. It was through our interactions with these theorists, including Dick Dalitz, that we, the experimental students, come to an understanding of the sweep of physics and why particular experiments were crucial. I call this "Setting the Tone", and the experience has stayed with me throughout my scientific career.

Today, of course, things are quite different. The Laboratories provide marvelous technical support for experiments and, on the other hand, a number

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DISCLAIMER

of theorists are lost in many dimensions. The scientific sophistication of a young experimental physicist of today would have been unimaginable forty years ago.

What is Going On; and Its Further Implications

One of Dick's earliest and best known pieces of work was the explanation of anomalous events seen in emulsion as the internal conversion decay of the $\pi^\circ \to \gamma e^+e^-$, known as the Dalitz decay.[1]

Such events were used in several experiments, including one done by a group at the Carnegie Tech cyclotron, to measure[2] the Panofsky ratio. This ratio, $R = \pi^- p \to \pi^0 n/\pi^- p \to \gamma n$, for pions absorbed at rest, is about 1.5. It is an important number as it connects low energy pion scattering with photoproduction.

The reason why the electromagnetic interaction can compete with the strong interaction at zero energy is because the pion is absorbed from S states of the mesonic atom, and the strength of the S wave πp interaction is much smaller than the P wave. The assumption of initial capture in high ℓ orbits with a subsequent cascade down to the 1S state, in a time of ~ 10^{-10} secs, was part of the scientific folklore of the time[3]. Our measurement[4] of the π^- cascade time of $\left(1.2 \begin{smallmatrix} +1.2 \\ -0.5 \end{smallmatrix}\right) 10^{-12}$sec together with the calculations of Day et al.[5], who showed that collisional Stark mixing populated the S orbits from the higher angular momentum states, led to the conclusion of capture from S orbits of higher n value.

By measuring the energy spectrum of internal pairs from π^- capture, shown in Fig. 1, and comparing with calculations[1,6] of the internal conversion rates, we measured $R = 1.51 \pm 0.10$.

We had planned to continue the experiment to collect a sample of double Dalitz decays $\pi^\circ \to e^+e^-e^+e^-$ which occurs with a rate of about one in 30,000 decays. Because of the relatively high mass of the virtual photon, there is a finite opening angle between the pairs, and so a decay plane can be determined. Kroll and Wada[6] had shown that by looking at the correlation between these planes, the parity of the π° can be determined. For a (scalar) pseudoscalar π°, the pairs tend to be in (parallel) perpendicular planes. The measurement was done, in a tour de force, by the Columbia group[7], so we at CIT did not pursue the experiment, particularly since the result was as expected!

How to Look at the Data

One of the earliest bubble chamber exposures made at the new CERN PS was of stopping antiprotons in the 80-cm hydrogen chamber built by Bernard Gregory and his group. Using this film, the Oxford-Padua collaboration studied the annihilation reaction $\bar{p}p \rightarrow \pi^+\pi^-\pi^\circ$.[8] Dick had shown us how to analyze such data with his famous study of the K meson decays to three pions.[9] The Dalitz plot for the $\bar{p}p$ annihilation of Fig. 2(a) shows strong ρ production, equally in ρ^+, ρ^-, and ρ°. In addition, the density of events along the ρ bands peaks in the center and is zero at the edges of the plot. Where the bands cross, there is a constructive enhancement, as seen in Figs. 2(b) and 2(c).

The simplest interpretation of this data was annihilation from the $^3S_1$ protonium state. The S-wave was no surprise and agreed with measurements of the K_SK_L and K_SK_S final states made by Armenteros et al. using the same film.[10] The K_SK_S final state is forbidden by parity conservation from the $^1S_0$ initial state and by charge conjugation from the $^3S_1$ state. Why the $^1S_0$ state did not contribute to the 3π final state was a mystery to us and, indeed, is still an active subject of research at LEAR. The fact that P-wave annihilation does occur at some level in liquid hydrogen is proven by one event of the K_SK_S final state, shown in Fig. 3, that we found in Oxford.

Informal Interactions

Another time that I remember Dick helping was at a cocktail party in Chicago. The Oxford-Padua group had also been studying the reactions $K^+p \rightarrow K^\circ\Delta^{++}$ and $K^+p \rightarrow K^{*+}p$ at 1.5 GeV/c incident momentum.[11] Peter Jones had worked out the implications of the observed angular correlations in the decay of the Δ and K^* states for the spin parity of the exchanged particle. The data are shown in Fig. 4. To our surprise, the K^* final state seemed to be dominated by vector exchange, even though everyone knew that strong forces and peripheral reactions resulted from pion exchange. Indeed, the vector mesons were only just becoming established. Things became clear when Dick introduced me to John Sakurai at this party, who expounded on the importance of vector exchange in the scheme of the universe.

Guru

One of Dick's characteristics as a physicist is an intimate knowledge of the facts about a particular field. He has been the recognized authority - a guru - in a number of fields. One of them is hypernuclear physics in which we at Argonne, in collaboration with a group from Carnegie-Mellon made some contributions through an exposure of a 25 cm helium bubble chamber to a stopping K^- beam at the Argonne ZGS. At the time we started the experiment, there was an outstanding anomaly in that the Bologna-Northwestern-Syracuse collaboration(12) had reported a lifetime of the ${}_{\Lambda}H^3$ hypernucleus of $(0.95 \pm {}^{+\,0.19}_{-\,0.15})\ 10^{-10}$secs, two to three times smaller than the free Λ lifetime. Since the binding energy of ${}_{\Lambda}H^3$ hypernucleus is only a fraction of an MeV, this was an anomalous result that Dick tried hard to understand, but without success. This was not surprising, since the result is apparently wrong. Our measurement(13) of $(2.64\ {}^{+\,0.84}_{-\,0.52})\ 10^{-10}$ for the lifetime was completely consistent with Dick's prediction of 0.93 times the free Λ lifetime.

Another recent example from the same field of physics is Dick's demonstration(14) that recent counter measurements from KEK of the inclusive π^- spectrum from K^- absorption in helium does not show evidence for a ${}_{\Sigma}He^4$ hypernucleus in contradiction to the claims of the experimenters.(15) Figure 5 shows the high statistics, inclusive KEK data compared to the sums of individual channels measured in bubble chambers. The lines in (b) show the expectation for a ${}_{\Sigma}He^4$ bound state. It clearly does not agree with the data!

We held an international conference on hypernuclear physics at Argonne in 1969 at which Dick gave the summary talk. Following the observation by Dave Jackson that people working in such areas that fall between nuclear physics and elementary particle physics are neither fish nor fowl, our secretary decided to portray Dick in disguise, teaching us all about hypernuclei. Her interpretation is shown in Fig. 6.

Conclusions

My conclusions are obvious:

You can learn a lot from a good theorist.

Follow up the implications of new phenomena.

You can even learn physics with a drink in your hand.

Don't fool with a Guru.

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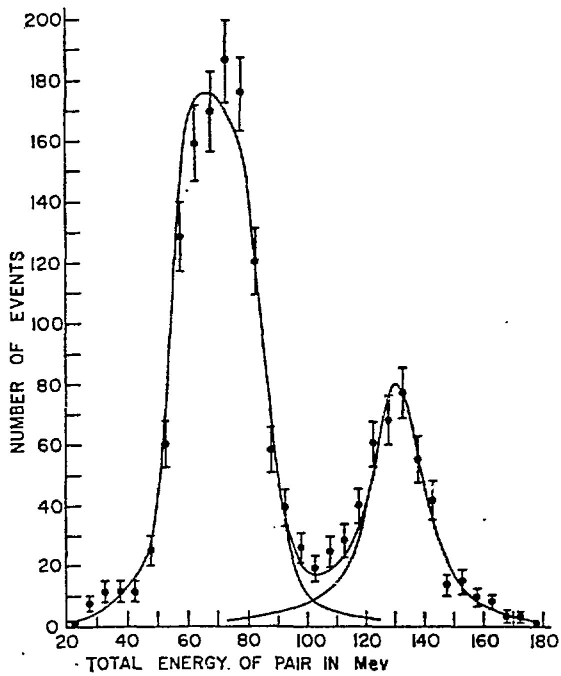

Fig. 1 Energy spectrum of internal pairs from π^- capture in liquid hydrogen.

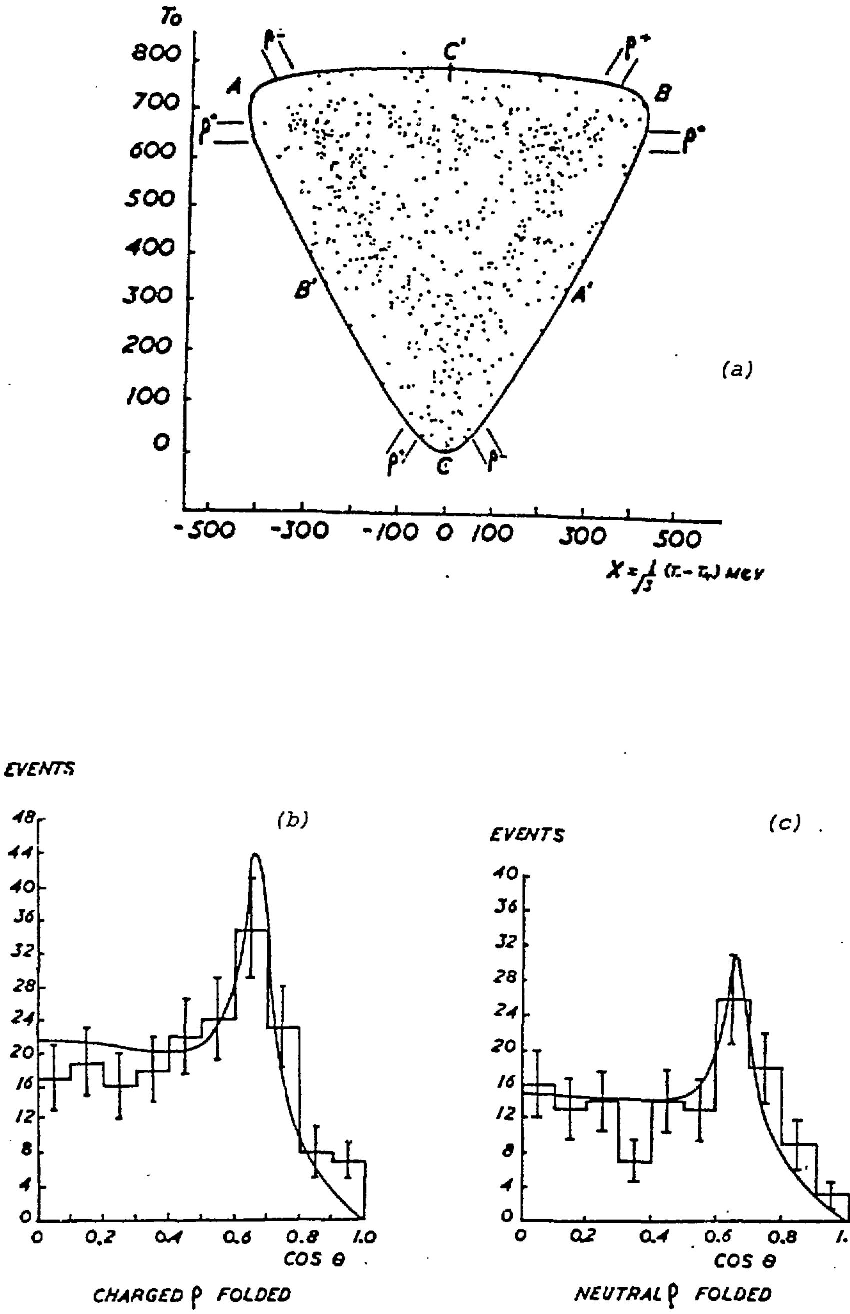

Fig. 2 (a) The Dalitz plot for the $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ reaction. The kinetic energy of the positive pion is zero at B and a maximum at B', and similarly for the negative pion at C and C'. The bands labelled ρ^+, ρ^-, and ρ^0 indicate the two-body processes $\bar{p}p \rightarrow \rho\pi$.

(b) The angular distribution of $\rho^{\pm}$ decays in their barycentric system. The distributions have been folded about $\cos\theta = 0$. The curves show the distributions expected for a $J = 1$ particle produced from the $^3S_1$ state.

(c) The data for the neutral ρ.

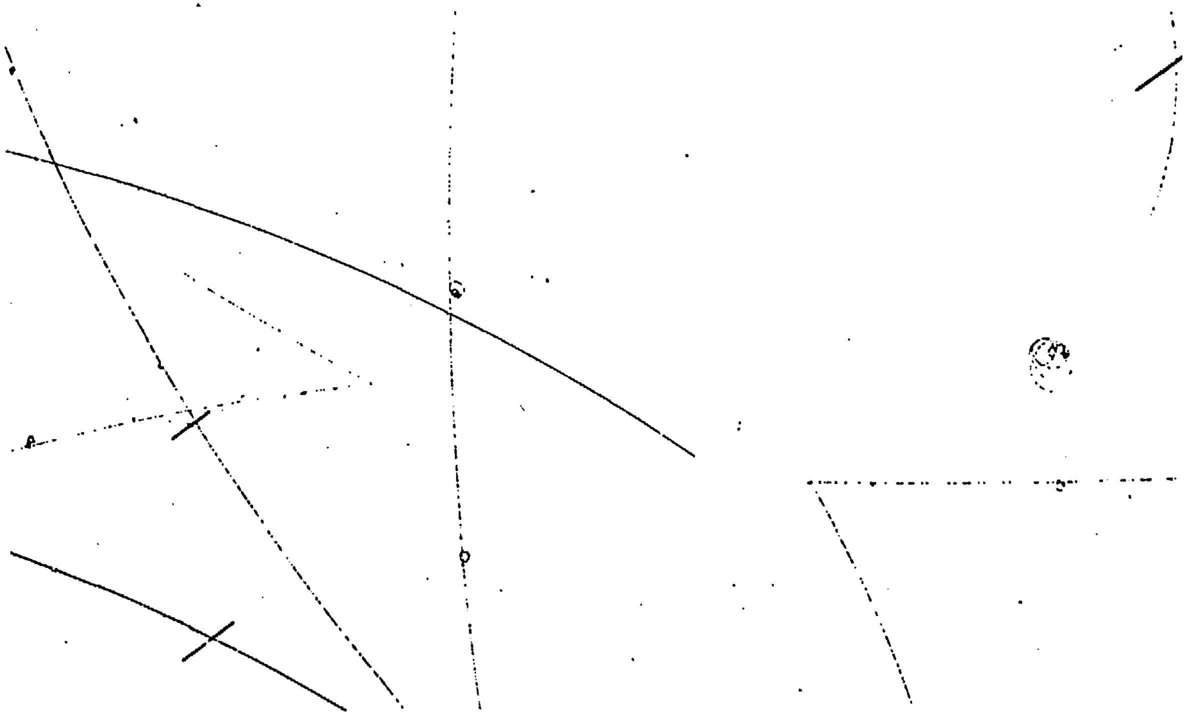

Fig. 3 Example of the reaction $\bar{p}p \rightarrow K_S K_S$ for a stopped antiproton in liquid hydrogen.

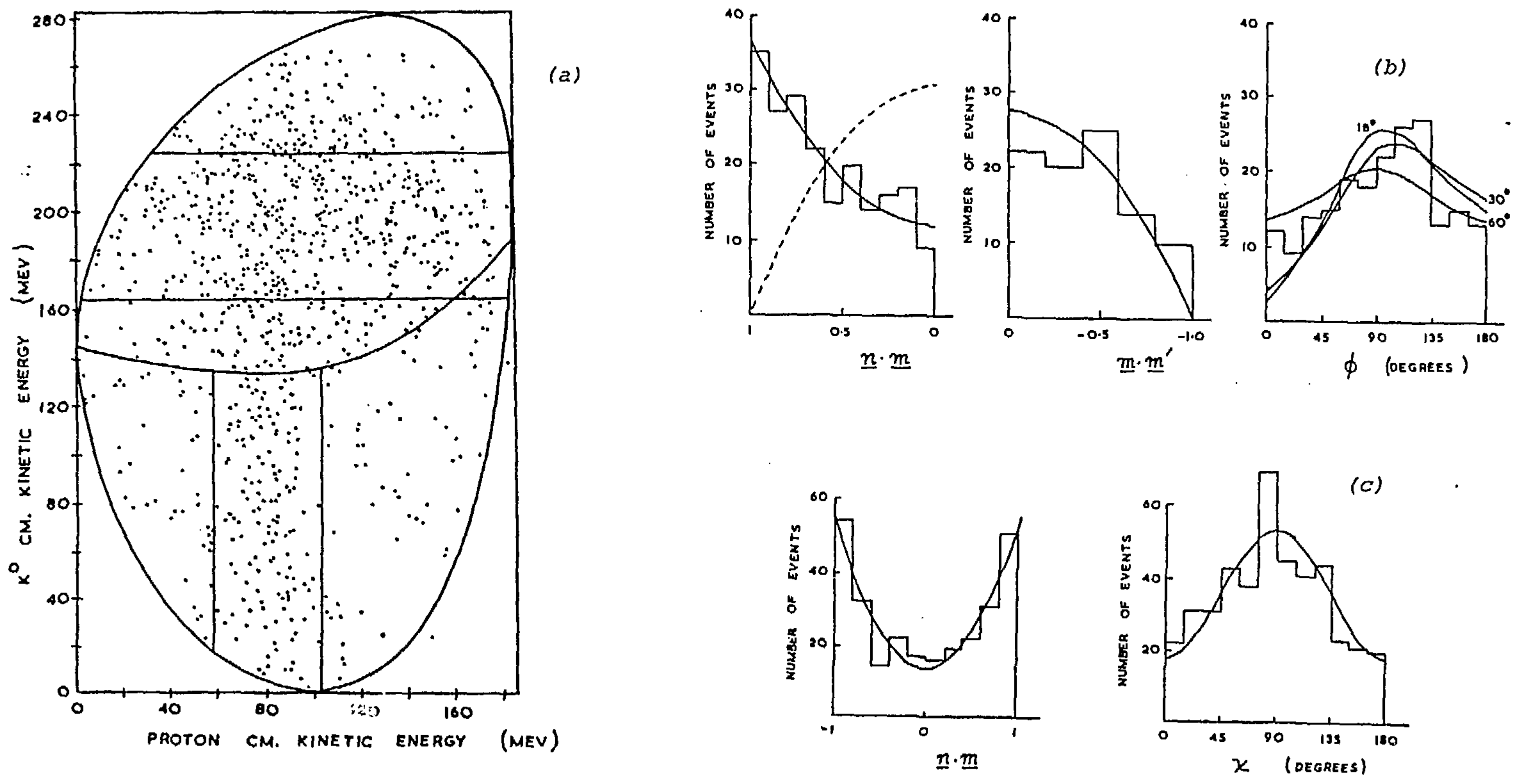

Fig. 4 (a) Dalitz plot for the reaction $K^+p \rightarrow K^0\pi^+p$. Production of the K^{*+} and Δ^{++} intermediate states can be seen in the marked vertical and horizontal bands.
(b) Angular distributions in the decay of the K^* state. The dashed line shows the expectation from pion exchange. The best fit (full lines) corresponds to a mixture of 1^- and 0^- exchanges with a ratio of 1.5:1.
(c) Angular distributions in the decay of the Δ^{++}. The line shows the expectation of ρ exchange model of Stodolski and Sakurai.

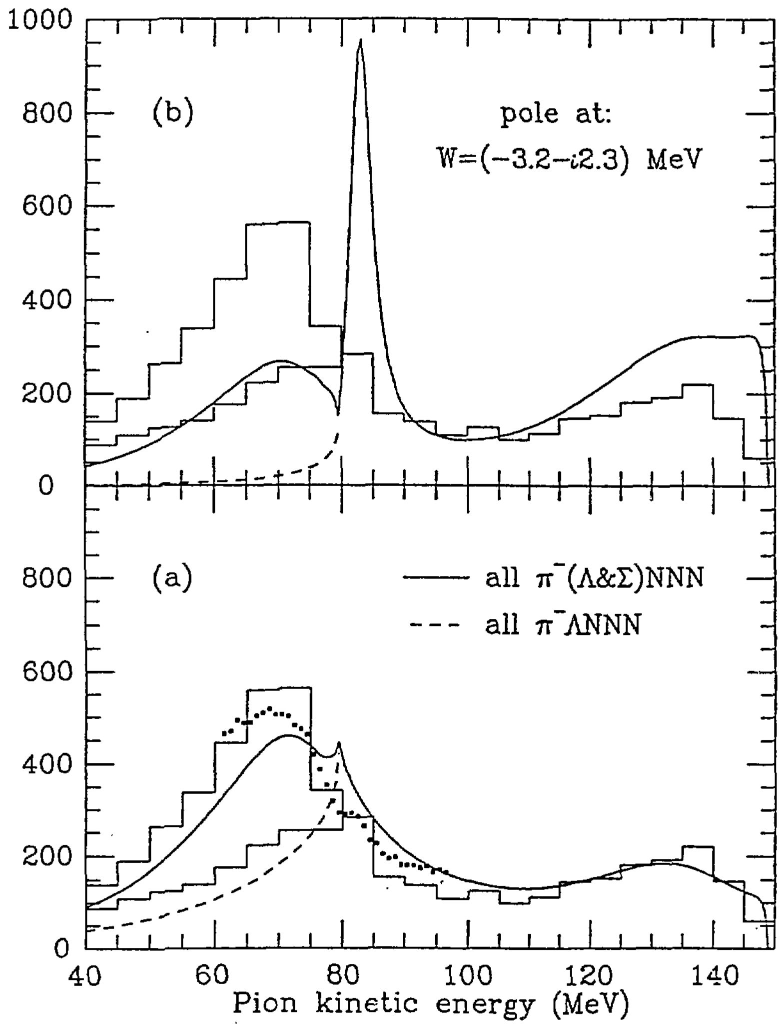

Fig. 5 (a) Pion energy spectrum from K^-He absorptions at rest. The histograms show the bubble chamber data; the dots the high statistics KEK counter data. The shoulder near 80 MeV in the latter could represent production of a $_\Sigma He^4$ hypernucleus.
(b) The line, which clearly disagrees with the data, gives the rates predicted for an unstable bound state pole with the parameters shown.

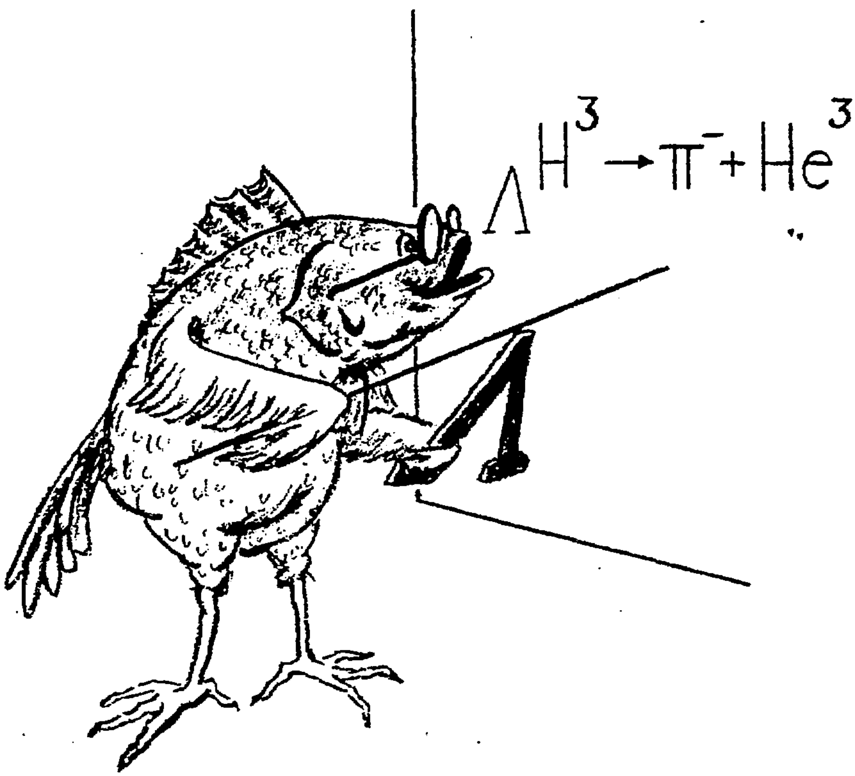

Fig. 6 Dick in mufti.