NUCLEAR AND FUNDAMENTAL PARTICLE PHYSICS

AT the summer provincial meeting of the Physical Society, which took place in the Department of Natural Philosophy, University of Glasgow, during July 10–11, four main sessions were held and five main topics were considered from both the experimental and theoretical points of view. The president of the Society, Prof. R. Whiddington, was in the chair. The opening session dealt with the excited states of light nuclei, and in the afternoon the subject of π^0-mesons was discussed. On the morning of July 11 the chief topics were β-radioactivity and photo-disintegration, and in the afternoon a theoretical session on the S-matrix series was held. Discussion followed each session. The general opinion of all those participating was that the conference had proved very profitable indeed, and it had been a fitting occasion on which to use, for the first time, the new lecture theatre in the extension to the Department.

Excited States of Light Nuclei

Prof. P. I. Dee (Glasgow), in reviewing existing knowledge of excited states of nuclei, indicated the need for some principle correlating nuclear data. He illustrated in an original manner the severely limited field covered by most of the known methods for determining nuclear levels, which methods include neutron absorption, proton capture, β- and γ-activity, scattering, and the different particle reactions such as (d, p), (d, n), (d, α), (p, α) and (α, p). Detailed discussion of the measurement of γ-ray energy and the kinetic energy of particles was followed by consideration of resonance excitation. The absence of internal conversion has led to indirect methods of determining quantum energy; but accuracy is reduced ($\sim 0{\cdot}1$ MeV.) However, the situation is improving with the introduction of scintillation counters. For particle energies a large magnetic spectrometer is the most accurate (errors $\sim 0{\cdot}005$–$0{\cdot}01$ MeV.), but the low efficiency limits its application. Nuclear photo-emulsions offer a good solution, as shown by work at Bristol and Liverpool.

Regarding data on spin and parity, Prof. Dee considered that the methods are too tentative to be really satisfactory. The study of angular distributions is fruitful, and the method of internal pair creation, as used at Glasgow, seems to be of fairly wide application. It is his belief that as few as 10–20 states are known with complete certainty, and a brief review of the efforts to find regularities in the arrangement of levels leads to the conclusion that these are, at best, hopeful. A determined effort on the theoretical side, therefore, seems overdue.

Dr. J. G. Rutherglen (Glasgow) discussed mainly the resonances for the processes ^{27}Al (p, α) ^{24}Mg and ^{27}Al (p, γ) ^{28}Si, showing that three out of six observed are common, involving competition. In considering internal pair creation, as applied by Dr. E. R. Rae and himself to the study of γ-ray states, Dr. Rutherglen said that the low values of I, the internal pair coefficient ($\sim 10^{-3}$), necessitate considerable care in estimating the number of positrons emitted. The estimation can be made with the magnetic spectrograph or by measuring the annihilation quanta produced on stopping the positrons. Tests with sodium-24 are in agreement with other methods, which show the transitions are electric quadrupole. A new method of estimating the absolute number of γ-rays by measuring the area under the spectrum of Compton secondaries has been found useful when no β-rays are emitted, and the method has operated successfully for capture of γ-radiation (protons on fluorine)

The next speaker, Prof. H. W. B. Skinner (Liverpool), discussed stripping reactions using 8-MeV. deuterons, and showed how this has become a very powerful method, of wide applicability, for finding the spins and parities of nuclear states. Early work with photo-plates yielded valuable data but involved considerable labour in the analysis. More recently, differential ion chambers and proportional counters have operated successfully with (d, p) reactions, and moreover permit examination down to any small angle relative to the beam. Both (d, p) and (d, n) reactions have been assumed to proceed by way of a compound nucleus, but results, particularly at small angles, contradict the early theory and suggest a stripping mechanism. Comparison of angular distributions with the theoretical predictions (based on theoretical studies at Birmingham and Liverpool) show that spins and parities of states can be reliably deduced. Prof. Skinner illustrated the technique with many interesting examples, directing particular attention to the finding of a mixed state; the first excited state denoted ^{27}Al, p_1, which was mainly D and partly S ($S/D \sim 10$ per cent). A kind of anti-stripping, in which the bombarded nucleus 'seizes' a neutron, for example, ^{9}Be (d, t), and the capture and loss of neutrons as suggested by examination of magnesium-24, were discussed.

For (d, n) reactions, negative Q reactions are preferred rather than high positive Q, as for (d, p). Observations with nuclear emulsions show that in some cases neither theory fits. Finally, Prof. Skinner showed that the excited states of some mirror nuclei (carbon- and nitrogen-13, oxygen- and fluorine-17, nitrogen- and oxygen-15, and sulphur- and chlorine-33) are well known, and he suggested that correspondence between spins and parities is perhaps more significant than that for energies.

Dr. C. A. Ramm spoke of his work at Birmingham, in collaboration with E. R. Collins and C. B. Mackenzie, in which precision measurements of the energy of particles produced with a Cockcroft-type magnet have yielded accurate Q values for reactions. He discussed the sources of error in such experiments, particularly for the reaction ^{6}Li (p, α) ^{3}He. Study of target deterioration has shown that some novel problems arise.

Prof. L. Rosenfeld (Manchester) brought the session to a close with an account of the theory of nuclear models and excited states. He began by stressing that, in attempting to explain the properties of nuclear states, we are still very far from the ideal set by the theory of atoms. In this the predominant influence of the Coulomb field introduces an element of simplicity entirely lacking in the nuclear case. Moreover, our knowledge of the interactions between nucleons lacks the definiteness of the law of electric interaction. We cannot hope to deduce the properties of nuclei from the mere knowledge of the number of constituent nucleons, and we must take over from experiment as basic assumptions the existence of closed shells as indicated by the magic numbers. This is the clue leading to the Jensen–Mayer shell model in which the additional assumption is made of a strong spin–orbit coupling with a sign such as to give rise to inverted doublets for the individual nucleon states. One may expect that some at least of the states of low excitation will correspond to the excitation of a single nucleon in an incomplete shell. The properties of such excited states are immediately predicted by the model. In experiments involving resonances, this type of excited state can be recognized by its having a larger width than those due to more complex modes of excitation.

Prof. Rosenfeld pointed out that direct experimental evidence supporting the assumption of large spin–orbit coupling is obtained in the scattering of nucleons by helium. Here the spin–orbit separation observed is ~ 5 MeV.

To improve the shell model it is necessary to investigate the result of the interactions of nucleons which are neglected in the first approximation. This problem has recently made great progress in two directions: the discussion of the mutual interactions in incomplete shells; and the interactions of these nucleons with the core formed by the closed shells. The first problem has been treated on the assumption of mainly central interaction between any two nucleons. The stationary states have been classified by methods of group theory, perfected by Racah, both for Russell–Saunders coupling (Jahn *et al.*) and for *jj*-coupling (Flowers, Flowers and Edmonds). Generally, the conclusions are found to be very sensitive to the assumptions made concerning the shape of the nuclear potential. The results of calculations by Talmi using a meson potential are completely different, as regards the order of succession of the excited states, from those obtained using a Gaussian potential.

The problem of interaction between the incomplete shells and the nuclear core has been most fruitfully attacked by Aage Bohr and Mottelson. The idea is that the interaction deforms the nucleus and excites oscillations on its surface. There appears to be a strong coupling between the angular momentum of the incomplete shell and that of the deformed nucleus. The predictions regarding the resultant angular momenta are then obtained by methods comparable to those used in molecular spectroscopy. In both cases, comparison with experiment reveals some discrepancies and shows the need for the next step, which should be to determine the combined effect of the two types of interaction described above.

In the discussion following the first session, Prof. R. Peierls (Birmingham) made a number of important points, and he deprecated the tendency to divide sharply between theory and experiment. He thought that at present the most important step is to ask the right question.

The π^0-Meson

In opening the afternoon session on meson problems, Prof. J. C. Gunn (Glasgow) surveyed π-meson theory in relation to experiment, and described the general considerations from which the pseudoscalar character of the π-meson can be deduced. In particular, detailed balancing applied to the reactions $p + p \rightleftarrows \pi^+ + d$ shows that π-mesons have zero spin, while the observed process $\pi^- + d \to 2n$ shows that they have odd parity, provided, as is plausible, capture of the meson takes place from a K-orbit. More detailed methods of approach were then considered by Prof. Gunn for some basic meson problems. Combined phenomenological and weak-coupling calculations indicate that mesons should be produced isotropically in the reaction $p + p \to \pi^+ + d$ (corresponding to capture of S-wave mesons in deuterium). In fact, a $\cos^2 \theta$ distribution is found. It is difficult to explain this disagreement except by the breakdown of the weak-coupling approximation. The reaction $n + p \to \pi^0 + d$ is to be noted as a powerful test of the 'charge independence' hypothesis for meson coupling.

The weak-coupling treatment of quantum production of mesons, and of meson nucleon scattering, again shows little agreement with experiment. It has indeed proved most profitable to apply the methods of partial wave analysis to data on meson–proton scattering. This confirms the idea that these particles interact so strongly that they can no longer be regarded as simple structures. The two theoretical approaches which are clear at the present time are the *ad hoc* assumption of isobaric states to fit the experimental evidence or the use of the intermediate-coupling method.

Dr. R. G. Moorhouse (Glasgow) described his investigations using the intermediate-coupling method. The nucleon is represented as a superposition of states containing the bare particle, together with arbitrary numbers of mesons and nucleon pairs in given configurations. The variables are the amplitudes with which these states occur. Two cases have been considered: when the surrounding cloud contains only mesons; and when it includes nuclear pairs and no mesons other than those introduced in the pair creation. The first case gives wrong magnetic moments for the neutron and proton; but the second is more promising as the magnetic moments differ in absolute magnitude by a nuclear magneton.

Describing recent experiments on the decay of π^0-mesons, B. M. Anand (Bristol) said that examination of a large number of jets has shown that the life-time T is less than 5×10^{-14} sec. King at Bristol has observed electron pairs arising apparently in the second of the two decay processes: (*a*) $\pi^0 \to \gamma + \gamma$, and (*b*) $\pi^0 \to \gamma + e^+ + e^-$. Process (*b*) seems to be the more promising, for the evaluation of T and a method of time dilation applied to the photo-plates have given $T \simeq 1 \times 10^{-14}$ sec. A study of some fifteen hundred stars of low energy gives the ratio 80 for the probabilities of (*a*) to (*b*). The energy distribution of direct to related pairs is $\bar{E}_a/\bar{E}_b = 0{\cdot}86 \pm 0{\cdot}26$, which apparently confirms the theoretical value $1{\cdot}0$, so that the energy is shared equally between the two electrons and the γ-ray. Finally, Mr. Anand spoke of single electrons appearing to come from stars and the origin of which in some cases seems to raise interesting queries.

Dr. R. H. Dalitz (Bristol) discussed his theory of decay of π^0-mesons. In addition to (*a*) and (*b*) above, he considered: (*c*) $\pi^0 \to e^+ + e^-$, and (*d*) $\pi^0 \to 3\gamma$, noting that (*d*) is forbidden by charge conjugation. His theory gives for the ratio of probabilities $(a)/(b) = 80$, confirmed by experiment. He stressed the connexion with internal pair conversion, which has a low probability ($\sim 10^{-4}$) at energies ~ 1 MeV., as against 1/80 at the energies here involved.

The meetings for the first day of the conference closed with a discussion of the possible advantages of holding more conferences on nuclear physics. There seemed to be general agreement on the desirability of extra meetings, confined to specialized topics in the field.

Beta Radioactivity

Dr. S. C. Curran reviewed the theory of β-decay and passed to discussion of the results of the Glasgow group with proportional and scintillation spectrometers. He listed the possibilities of disagreement with straightforward theory, which might show in the low-energy region of β-spectra. Here the proportional tube containing gaseous sources, particularly when supported with the scintillation spectrometer, is nearly ideal. Among the possibilities is readjustment of the atom consequent on the change of atomic number in the emission process. Assuming the adjustment energy goes entirely to the electron, a displacement of the spectrum along the energy axis follows, giving a 'hole' at the low-energy end. Tritium shows such a 'hole', but it is too extensive to be explained as readjustment. Work on radium-*D*, mercury-203 and nickel-63 does not support the view that the electron receives the whole energy.

The central problem of determining the mode of interaction (or combination of modes) has been attacked by investigating highly forbidden transitions. Study of rubidium-87 (half-life, 6×10^{10} yr.) shows that both C_{3T} and C_{3V} correction factors give excellent straight lines. This work with the proportional tube has been confirmed closely by G. M. Lewis using crystals of rubidium iodide (thallium) as their own spectrometers. Recent results for rhenium-187 give the transition energy as about 400 keV. and suggest the transition is probably at least third forbidden. This implies that stable osmium-187 has a spin of 11/2 or 13/2, an unusually high value possible, however, on the shell model. Dr. Curran stressed the possible close association of this model with the natural radioactive sources. For potassium-40, rubidium-87, lanthanum-138, lutecium-176 and rhenium-187, or the daughter elements, there seems to be a connexion with the important shell numbers 20, 50, 80, 106 and 112 respectively.

The curved crystal spectrometer used recently to examine the γ-rays of radium-*D* was described by Dr. G. T. Ewan (Edinburgh). A very sharp line at 46·52 keV. was observed, corresponding to the known excited state of radium-*E*. No line corresponding to a state at about 43 keV. was observed. In view of the absence of other apparently established γ-transitions, upper estimates to their possible intensities were given. The new results show that the mode of decay in some 20 per cent of the disintegrations of radium-*D* is still uncertain.

Dr. D. L. Pursey (King's College, London) spoke on his recent work on the theory of β-decay. This is concerned with the experimental determination of interaction in the theory of decay. The spectrum shapes of allowed and first forbidden transitions and the *ft* values of super-allowed transitions lead to the conclusion that the interaction contains either both the scalar and tensor or both the polar and axial vector invariants, the two interaction constants being roughly equal.

The decay of $^{228}MsTh_2$ was reported by Dr. C. G. Campbell (Edinburgh). A double β-spectrometer was used and the partial spectra separated; six such have been found with end-points and intensities as follows:

Energy limit	2·18	1·85	1·72	1·15	0·66	0·46
Intensity (per cent)	10	9	7	53	8	13

Photodisintegration

J. R. Atkinson (Glasgow) reviewed the field of photodisintegration in stimulating fashion. He divided the reactions into three categories—(i) γ, *p*; γ, *n*; (ii) γ, *p*, *n*; γ, *d*; γ, α; (iii) γ, stars—and he discussed for each the excitation curve, angular distribution, experimental methods and theoretical treatment. For (i) and (ii) the curves are about 5 MeV. wide for a large range of values of atomic number, but for (iii) there is resonance at discrete γ-ray energies. There appear to be anomalies in the form of the excitation curve and the angular distribution for the processes (γ, *pn*) and (γ, *d*). The stars appeared to be anisotropic. The theoretical models (Levinger/Bethe, Weisskopf, Goldhaber–Teller) leave much to be desired. The discussion of the work of the Glasgow team (with expansion chambers) centred on helium as target, and the criterion of selection was the close agreement of the quantum energy E_γ of the incident radiation as determined by two methods. Current work with the smaller Glasgow synchrotron on the disintegration of nitrogen promises to be fruitful.

F. K. Goward described the very interesting work which he and J. J. Wilkins are prosecuting at the Atomic Energy Research Establishment, Harwell, in which the photo-emulsion technique has been exploited fully in the study of stars; more recently, the gridded ion chamber has helped to improve the energy resolution of levels. The technique was admirably illustrated with slides of a variety of star-processes. For the reactions:

$$^{12}C + \gamma \rightarrow 3\alpha - 7{\cdot}3 \text{ MeV.} \quad (1)$$

$$^{16}O + \gamma \rightarrow 4\alpha - 14{\cdot}4 \text{ MeV.} \quad (2)$$

about 2,000 and 600 stars, respectively, have been measured. The quantum energy was deduced by adding the binding energy to the measured total energy release. The cross-section curve for (1) shows a doubly peaked curve, suggesting competition with (γ, *n*) and (γ, *p*) reactions and implying the formation of a compound nucleus. A series of narrowly spaced resonances ($\sim$ 1 MeV. apart) is probably superposed on a continuum, giving levels of carbon-12. Likewise, it seems that the levels of oxygen-16 are excited, and levels of intermediate nuclei—for example, beryllium-8—could be observed.

A paper on photodisintegration, by Mr. J. M. Reid (Glasgow), dealing with the application of counting techniques, was given at a special sectional meeting in the afternoon.

The S-Matrix

J. Hamilton (Cambridge) discussed the work of C. A. Hurst on the convergence of the renormalized *S*-matrix perturbation theory expansion (after Dyson), regarded as a power series in the coupling constant. The theory treated was a scalar meson field coupled scalarly to itself—the so-called 'φ^3' theory.

Estimation of the number of irreducible graphs of order *n* contributing to a chosen physical process gives $(n/k)!$ for large *n*, where *k* is a small integer, probably 2. The sign and magnitude of the contributions from these graphs are not easy to find, and Hurst limited his discussion to processes which do not relate to real particles, thus avoiding difficulties possibly arising from the creation of new particles. It is thought that the restriction can be thrown off by analytical continuation in the energy plane. For a particular process the series of contributions from the irreducible graphs diverges in an oscillatory manner with great rapidity. When the coupling constant is small, say 1/137, successive terms decrease rapidly at first, but ultimately the enormous number of graphs becomes the predominant factor. In pseudoscalar π-meson theory the coupling constant may be in the range 4–40, and at no stage does the series even appear to converge.

During the discussion, Prof. Peierls pointed out that a weakness of the work is the lack of any estimate of the finite contributions from the self-energy and vertex parts occurring in the graphs.

The work of B. F. X. Touschek and of Dr. W. K. Burton on field equations and commutation rules was then described by the latter. Dr. Burton referred to a recent paper by J. Schwinger[1] which gives an account of a comprehensive scheme for the quantum mechanics of localizable fields based on an operator Lagrangian. The theory makes no appeal to the correspondence principle or an underlying classical theory, and all the results are derived from a single fundamental principle analogous to Hamilton's principle in classical theory. This theory has been shown by Burton[2] to lead to a particularly simple derivation of the S-matrix series in terms of the interaction Lagrangian. Schwinger describes how the commutation relations are to be obtained from the fundamental postulate; and, by studying examples from particle mechanics, Burton and Touschek found that the Schwinger method gives a unique prescription for the determination of the commutation rules for systems free from anholonomic constraints. If such constraints are present, the method may—in special cases—no longer apply as it stands. Equations of the Dirac type belong to this category, since the number of degrees of freedom is just half the number of co-ordinates appearing in the Lagrangian.

The final lecture, by Dr. J. S. R. Chisholm (Glasgow), dealt with the calculation of higher order S-matrix elements. Dr. Chisholm demonstrated explicitly automatic procedures for carrying out the calculations according to a prearranged programme. Previous efforts in this field appear as special cases of the general method which he detailed. Dr. Chisholm brought out clearly the principles described at length in his published work[3]. S. C. CURRAN

[1] *Phys. Rev.*, **82**, 914 (1951).
[2] *Phys. Rev.*, **84**, 158 (1951).
[3] *Proc. Camb. Phil. Soc.*, **48**, 2, 300 (1951); and *Proc. Roy. Soc.* (in the press).

PROGRESS OF CANCER RESEARCH

THE reviewer of a production like the Annual Report of the British Empire Cancer Campaign*, which covers a wide field of research, will naturally tend to limit his choice of investigations for description to those with which he feels at home, or which seem to him to be especially interesting, original or promising. The subjective element in selection is unavoidable and, in fact, will become more pronounced as cancer research extends, since the range of studies as a whole is beyond the scope of any one reviewer.

Carr, in experiments on the virus of Rous sarcoma, has found that it is recoverable from the leg of a chick when the muscle is extracted a few hours after injection; after 6 hr. it can no longer be detected in any quantity, but at 66 hr. it can again be separated in amount greater than was injected. It is believed that the infective virus disintegrates into smaller components inside the cell, that these multiply and recombine to give the infective virus. "All these considerations lead to the suggestion that infective virus is present in the cell for only a very short proportion of the mitotic cycle. It therefore seems probable that the malignant condition is caused by some earlier stage of the virus multiplication cycle, and this leads to the possibility that a tumour may sometimes result from a non-infective virus."

Investigations at the Chester Beatty Institute on chromosome abnormalities induced in *Drosophila* by chemical mutagens (nitrogen mustards, diepoxides, ethyleneimines, dimesyloxyalkanes) have shown that these changes are observed as partial deficiencies. This fact has been used in support of a theory of malignancy, the outline of which can be sketched in as follows: (1) Many carcinogens are also potent inducers of mutations in *Drosophila*. (2) There must therefore be some fundamental relation between carcinogenesis and mutation (hence the somatic mutation theory of cancer). (3) Mutagens acting on *Drosophila* induce chromosomal abnormalities, namely, deficiencies and minute deletions. (4) It is possible, therefore, that cancerous transformation also is an expression of a chromosomal deficiency, that is, an interference with the reproduction of the gene pattern. (5) Hence the cancer cell is a normal cell which has irretrievably lost something clearly it has lost its growth-controlling mechanism. (6) The specific hormones control the growth of their target organs and xanthopterin brings about renal hypertrophy; therefore an obvious aim of cancer research must be to find a chemical compound or an enzyme which can replace the lost growth-controlling material of the malignant cell.

There exist some different types of chromosomal aberrations which are not permanent features of tumour tissue. In an account of the work of Koller and associates, it is stated: "From continued study of cytological abnormalities frequently observed in the cells of tumours induced by the aromatic nitrogen mustards it is clear that these are of 2 classes, those which gradually disappear in the course of serial transplantation, and those which continue to be transmitted to the descendant transplant generations, apparently indefinitely. Even these permanent abnormalities are, however, still regarded only as associated changes, and not in themselves the cause of the malignant alteration, which can clearly occur in their absence. They are nevertheless of great interest as suggesting a likely site of action of these carcinogens, and it is probable that the malignant transformation itself involves a much less tangible or even 'invisible' effect on the chromosome or gene".

Ludford, who has been studying variations in size and structure of the malignant cells of transplantable tumours in inbred strains of mice, says: "On the basis of these observations it seems justifiable to conclude that cellular polymorphism correlated with variations in chromosome numbers and aberrations of the process of mitosis are not specific features of malignancy but occur, although to a lesser extent, in normal tissues. This suggests the probability that after cells have become differentiated the full chromosome complement is no longer essential for their continued life and functional activity".

* British Empire Cancer Campaign 29th Report (1951). Edited by Sir Heneage Ogilvie (11 Grosvenor Crescent, London, S.W.1).