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HISTORICAL

THE Institute of Nuclear Physics has grown out of the research laboratory of the Palit Professor of Physics of the Calcutta University and of the efforts of Prof. Meghnad Saha, Palit Professor of Physics (1938–55) who was its founder Director (1950–1956) till his death. The foundation stone of the main building of the Institute was laid on April 21, 1948, by the Hon'ble Dr. Syamaprasad Mukherjee, the then Minister of Industries and Supplies in the Central Government. The Institute was formally opened on January 11, 1950, by Prof. Madame Irene Juliot Curie (Nobel Laureate), Dr. K. N. Katju, the then Governor of West Bengal presiding in the presence of many eminent scientists of the world, viz., Prof. Frederick Joliot Curie, Lady and Sir Robert Robinson, Prof. J. D. Bernal, besides many Indian scientists.

The Institute is at present housed in two buildings having a total floor space of nearly 50,000 sq. ft., located within the compound of the University College of Science and Technology at 92, Acharya Prafulla Chandra Road, Calcutta-9. By mutual agreement between the Calcutta University and the Government of India, the Institute is managed by an autonomous Governing Body, composed of representatives of the Calcutta University, of various departments of the Government of India, of the Inter-University Board. and is presided over by the Vice-Chancellor of the Calcutta University. The Constitution of the Institute was originally framed and accepted by the Senate of the Calcutta University in 1951. The Constitution is given in subsequent pages.

The Institute of Nuclear Physics sustained a great loss in the death of Prof. Meghnad Saha, the Founder Director in 1956. The Calcutta University authorities, the Government of India and the Governing Body of the Institute decided to name the Institute after him. The present name was accepted and is in use since August, 1958.

The Saha Institute of Nuclear Physics is devoted to teaching and research in Nuclear Science and its applications. The Institute offers courses of instructions in Nuclear Physics and Biophysics to the students appearing for the M.Sc. degree in Pure Physics of the Calcutta University. It offers one-year Post-M.Sc. Associateship Diploma Course which imparts advanced training in theoretical and experimental nuclear science and also enrols students for the research degrees, such as D.Phil (Science) and D.Sc. Besides, it collaborates with the Departments of Applied Physics and Radio Physics and Electronics of the Calcutta University in teaching and research programmes. The Institute collaborates with other universities, organisations in various programmes of nuclear science, AZI., particle accelerators, beta and gamma ray spectroscopy, nuclear magnetic induction, neutron physics, mass spectroscopy, nuclear chemistry, instrumentation, theoretical nuclear physics etc.

This brochure gives a short account of the programme of the work under taken during 1951–60 by the different divisions of the Institute, the difficulties that hampered the progress of the work and the activities of the various divisions. This includes, apart from expansion, a proposal for a new accelerator in the 50 Mev energy range. The Institute now consists of the following divisions: Accelerator, Nuclear Physics, Theoretical Nuclear Physics, Nuclear Chemistry, Instrumentation, Post-M.Sc. Teaching and Biophysics. Besides these there are Workshop, Library, and Administration Sections.

During the period 1955–60, a five-year programme of work approved by the Department of Atomic Energy, Government of India, was taken up including a large expansion of the Institute's activities. The D.A.E. sanctioned a generous grant of Rupees 57 lakhs. One major item of this expansion—that of installing electron synchrotron—could not be carried out due to the foreign exchange stringency of the country. However, certain alternative programmes were undertaken during the period and carried out successfully and a part of the fund originally allotted for the electron synchrotron was spent on the alternative programmes.

The work of the Biophysics Division has expanded greatly in recent years. The Ministry of Scientific Research and Cultural Affairs sanctioned a five year development programme and gave a grant of about 6 lakhs of rupees for the period of 1955–60. This division started an advanced course of training in Biophysics to students appearing for the M. Sc. degree in pure physics of Calcutta University, since 1957.

RECENT DEVELOPMENT IN THE THEORY OF NUCLEAR STRUCTURE*

M. K. Banerjee

Since the introduction of the j—j coupling shell model in 1948 and the introduction of the collective model in the early fifties nothing much happened for quite a while in the theory of the nuclear structure, except for the advent of the ideas of the intermediate coupling in the shell model and of weak coupling in the collective model and their necessary corollaries. Quite recently two new complimentary approaches have been developed to attack the problem of predicting and explaining the nuclear level spacings and transition widths. Being quite new, these methods have not been applied as exhaustively as the older ones hence it will be inappropriate to pass judgment on their merits. But they are undoubtedly full of promise. The present talk describes the basic ideas behind the two methods without any critical assessment of their successes in actual application.

Let us first rapidly review the main considerations which led to the development of the new approaches. The works of Brueckner, Bethe and others in the field of nuclear many body problem have now given a more comfortable foundation of the shell model. We know that it should be possible to construct a self-consistent single particle spectrum and self-consistent single particle wave functions. With these single particle wave functions one should be able to construct a model wave function for the ground state and the expectation value of the reaction matrix in this ground state wave function should give us the ground state energy The reaction matrix is prescribed by the theory quite unambiguously. The model wave function is simply a determinant if the ground state is non-degenerate, or, better, not even near-degenerate with other levels of the same quantum-numbers. The situation where there are several configurations which are nearly degenerate with the ground state is of greater physical interest, since this is what one encounters for nuclei heavier than O^{16}. The procedure for this case, as suggested by Bethe, is as follows :

One should exclude the non-degenerate states from the summation over the intermediate states in the construction of the reaction matrix. The resultant self-consistent reaction matrix should be diagonalised within the space of the near degenerate configurations. In other words we are accounting for the effect of the short range correlation through the reaction matrix, while the long range

*This article is based on a talk given by the author at the 'Low-Energy Nuclear Physics Symposium', 1961, held in the Tata Institute of Fundamental Research, Bombay.

correlation will appear explicitly in the model wave function. Such a procedure should give us a wave function which is good for predicting not only energy but also other features which are not sensistive to short range fluctuations in the wave function. The multipole moments and gamma transition widths are examples of such features. Now I should make it quite explicit that these qualifications—long and short—refer to the radial distance. Pretty soon we shall start separating the long range radial corelation into long and short range angular correlations.

So the framework of the configuration mixed shell model is quite well defined. The trouble is that we do not have a precise knowledge of the reaction matrix and the single particle wave functions. The vagueness of our knowledge of the wave functions may not be terribly serious. The wave functions are determined to some extent by their angular momentum, number of nodes and the mean extent. About the two body interaction we know that it consists of a repulsive hard core of radius ~ 0.4 fermi, followed by a short ranged and deep attractive well. For energies with which the nucleons move inside a nucleus the nett force is attractive for at least all even relative angular momenta. The odd state force is very weak. For a pure configuration the matrix elements of such a force, which determine the level spacings, resemble those due to an attractive force of comparatively larger range. It may be presumed that this feature will be reflected in the reaction matrix and will be preserved when a few more configurations are added. Indeed, this has been found to be the case where people have tried to determine the effective potential in a shell model calculation by fitting the level spacing and assuming a simple and smooth radial dependence for the effective patential. To sum up, we may say that what were forced upon people doing shell model calculations, are now being given a more direct foundation.

To make our life simple let us therefore take a smooth form $v(|\vec{r_i}-\vec{r_j}|)$ for the effective potential and see what kind of correlation it is likely to bring about. This is best seen by following the very interesting approach developed by the Copenhagen group. Let us expand the two body potential in terms of the Legendre polynomials of the angle between the radius vectors $\vec{r_i}$ and $\vec{r_j}$.

$$v(|\vec{r_i}-\vec{r_j}|) = \sum_k F_k\,(r_i, r_j) P_k(\cos\theta_{ij})(2k+1)$$

For all smooth functions $v(r)$, which monotonically decrease with increasing r, the radial matrix elements of $F_k(r_i, r_j)$ decrease as k increases. The rate of decrease increases as the range of the force increases. For a zero range force the radial matrix elements are the same for all values of k. The Legendre polynomials determine the correlation in the angular space. For very high orders the Legendre polynomials are strongly peaked about $\theta_{ij} = 0$ and π. So the high terms tend to keep the orbits of the two particles either parallel or anti-parallel. A little thought will show that maximum coherence can be attained for the anti-parallel situation and this is obtained for the $J = 0$ state. In other words the high Legendre polynomials tend to produce a pair correlation—the pair being coupled to $J = 0$ state. A more general statement is that the high terms produce a short range correlation in angle. Now, from what has been said about the variation of the matrix elements of F_k with the range of the force it is obvious that these high terms and therefore the pairing correlation will be more important for the short range part of the force.

Let us now look at the low k terms. The $k = 0$ term does not mix different configurations and does not produce a splitting of the different J levels of the same configuration. The only effect it can have is in changing the spacings of the configuration. So its effect is comparable to a readjustment of the self-consistent field. Indeed, we may see that the main effect of the low terms will be to alter the Hartree field. Since the low k terms have a very large angular spread, very many orbits can be squeezed into its range without violating the exclusion principle. That is, one particle can interact with many particles simultaneously and, what is most important, *coherently*,, through the low k terms. This is the type of interaction which is responsible for the production of the Hartree field. Naturally a given k term will tend to produce a $P_k(\cos \theta_i)$ type term in the Hartree field. In other words, the low but non-zero k terms will tend to deform the Hartree field. It should be emphasised that the high terms cannot produce a coherent interaction of a large number of particles on a given particle. Since the angular range is small, it is not possible to accommodate more than two or three orbitals within the angular range without violating the exclusion principle. If the orbits which are being mixed have the same parity, which is the case for medium weight nuclei, the first non-vanishing k is equal to 2. The relative importance of the low k terms increases with increasing range of the force. Then the first non-zero k term is most important. This is why the quadrupole distortion plays such an important role in the theory of nuclear structure.

We summarise the situation as follows :

(1) The effective two-body interaction may be divided into two parts, viz.. the long range and the short range parts in the angular space.

(2) The most important effect of the long range part is to distort the Hartree field, while the most important effect of the short range part is to produce pair correlation.

(3) Since many pairs can interact simultaneously through the long range part its contribution is proportional to the number of pairs—$N(N-1)2$, where N is the number of particles outside the closed shell. The short range part will be proportional to N only. So the effect of the long range part will be most important as we approach the middle of the shell.

We shall now discuss the treatment of the short range part.

The part of the potential which is short ranged in the angular space has a large matrix element in the $J = 0$ state and very small matrix elements in the finite angular momentum states. A natural simplification will be to set the matrix elements in the other angular momentum states equal to zero.

$$(j^2J\,|\,v\,|\,j'^2J) = \delta_{JO} f(j, j')$$

The problem becomes remarkably pliable if we make the further assumption that $f(j, j') = (2j+1)^{\frac{1}{2}}(2j'+1)^{\frac{1}{2}}g$. Such a force is called a *Pairing Force* and g is called the strength of the pairing force. The matrix elements of such a force can be equivalently written as

$$(jm,\, \underline{j}\underline{m}\,|\,v\,|\,j'm',\, \underline{j}'\underline{m}') = \delta_{j\underline{j}}\delta_{j'\underline{j}'}\delta_{m,-\underline{m}}\delta_{m',-\underline{m}'},\ (i)^{j+\underline{j}+j'+\underline{j}'+m+\underline{m}+m+\underline{m}'}$$

The eigenvalues of such a potential are $(2j+1)g$ and zeros and the only non-degenerate eigenfunction is

$$\sum_j (2j+1)^{\frac{1}{2}}\,|\,j^2 0 >$$

I should point out at this stage that the δ-function potential is not strictly a pairing force. There are two main differences. The first is that the matrix elements in the finite angular momentum states are not zero but small finite numbers. This produces a significant difference in the level structure when one considers a large number of particles compared to the prediction for the same case due to a true pairing force. The second difference is that even for the $J = 0$ case the matrix element does not factorise so easily. g becomes proportional to the radial integral of the product of the four radial wave functions time the volume element. This is not entirely independent of j and j', neither is it factorisable. In any case the pairing force gives us a solvable problem and so we shall represent the short range part with it. For degenerate configurations the solution of the two body problem has already been mentioned. The many particle problem can also be exactly solved with equal ease. But the situation that is more interesting from the standpoint of physics is the case where the configurations are non-degenerate, principally because of the spacings of the single particle levels. Using the standard creation and annihilation operators the pairing force may be written as

$$g\,\Sigma a^*_{jm}a^*_{j-m}a_{j',-m'}a_{j'm'}$$

where $(1\,|\,a^*_{jm}\,|\,0) = \phi(j, m)$, for $m > 0$ and $(1\,|\,a^*_{j-m}\,|\,0) = (-)^{j-m}\phi(j, -m)$, for $m > 0$. Using e_j for the energy of the j orbital, the Hamiltonian that we have to solve is

$$H_0 = \sum_{jm} e_j a^*_{jm}a_{jm} + g\,\Sigma\, a^*_{jm}a^*_{j-m}a_{j',-m'}a_{j''m'}$$

The method of solving the problem was developed in connection with the problem of superconductivity by Bardeen, Cooper and Schriffer and by Bogoliubov. In fact it was the discovery of the profound role played by the pairing force (Cooper pairs) in the problem of super-conductivity which led nuclear physicists to look for the possibility of the existence of a similar situation in the problem of nuclear structure—and, of course, the fact that the mathematical tools needed to tackle the problem were already developed was also very encouraging. The credit line goes to the Copenhagen group. Particular mention should be made of Belyaev who was the first to apply the Bogoliubov method to the nuclear problem. One goes from the particle hole space to the quasi-particle and quasi-hole space through the Bogoliubov transformation

$$\alpha_{jm} = u_j a_{jm} + v_j a^{*}_{j-m}(-)^{j-m}$$
$$\alpha^{*}_{jm} = u_j\, a^{*}_{jm} + v_j a_{j-m}(-)^{j-m}$$

One notices that the quasi-particle is a mixture of the particle and hole state. The ideal situation would be if u's and v's could be found such that the transformed Hamiltonian contained only constants and the quasiparticle number operators. However in such an ideal situation the ordinary number operator would not be a constant of motion. In fact, starting from our original Hamiltonian we can never reach the proposed ideal situation as the original Hamiltonian commutes with the number operators. One may still hope to find such u's and v's which will lead us to the desired form after neglecting certain small terms. So in anticipation of that we should diagonalise not the original Hamiltonian H_0 but $H = H_0 - \lambda_n N_n - \lambda_p N_p$, where N_n and N_p are the number operators for the protons and the neutrons, respectively, with the condition that the expectation values of the two number operators are equal to the observed values. Upon transforming this new Hamiltonian we get

$$H = H_1 + H_2 + H_3 + H_4$$

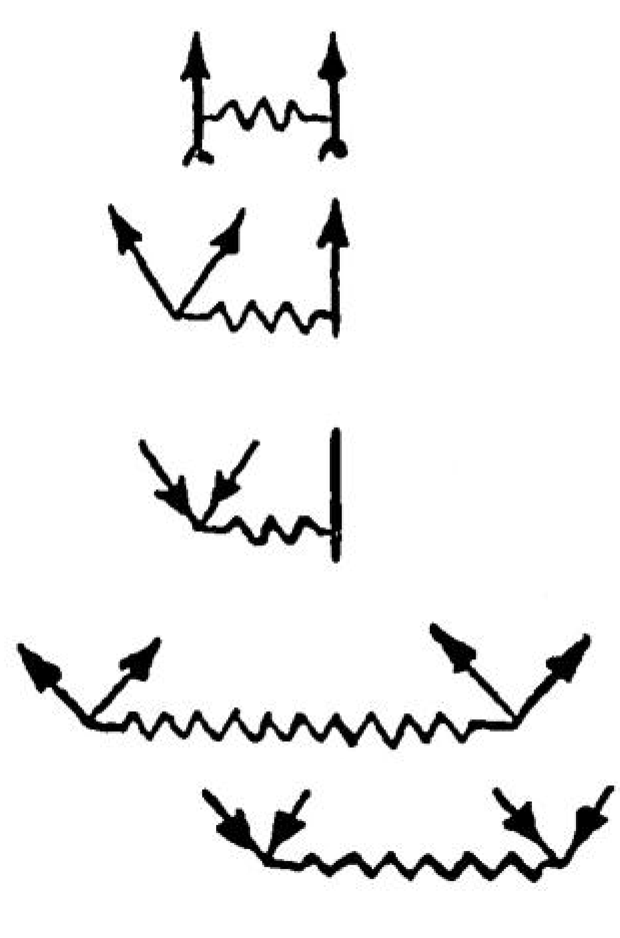
where
$$H_1 = \sum_{jm} [v_j^2(\eta_j + \tfrac{1}{2}\mu_j) - \tfrac{1}{2}u_j v_j \Delta_j]$$

$$H_2 = \sum_{jm} [u_j^2 - v_j^2)\eta_j + 2u_j v_j \Delta_j]\alpha^{*}_{jm}\alpha_{jm}$$

$$H_3 = \sum_{jm} (-)^{j-m}[u_j v_j \eta + \tfrac{1}{2}(v_j{}^2 - u_j{}^2)\Delta_j](\alpha^{*}_{jm}\alpha^{*}_{j-m} + \alpha_{j-m}\alpha_{jm})$$

$$H_4 = \sum_{(jm)} gN(a^{*}_{jm}a^{*}_{j-m}a_{j'-m'}a_{j'm'})$$

where N means the normal product.



The quantities η, μ and Δ are determined by the Hamiltonian H_0 and the Lagrange multipliers and the coefficients u's and v's. In particular

$$\eta_j = \epsilon_j - \mu_j - \lambda_j\,.$$

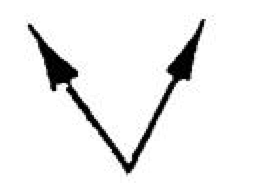
H_3 contains terms of the forms creation of two quasiparticles, and annihilation of two quasiparticles.

These diagrams are possible as the total number of the quasiparticles does not have to be preserved. H_4 contains terms of the form

scattering of two quasiparticles.

scattering of one quasiparticle with the simultaneous creation of two quasiparticles,

scattering of a quasiparticle with the simultaneous creation of two quasiholes,



creation of two pairs of quasiparticles and

creation of two pairs of quasiholes.

Now, with a truly pairing force H_4 is small and can be treated as a perturbation, if desired. So if one can find u's and v's such that H_3 is zero, H_2 will determine the spectrum. The condition for the vanishing of the coefficients of $(\alpha^*_{jm}$ $(\alpha^*_{j-m}\alpha^{t}{}_{m}\alpha_{jm})$ is

$$2u_j v_j = \frac{\Delta_j}{E_j} \; ; \; u_j^2 - v_j^2 = \eta_j / E_j$$

from which we get $E_j = \sqrt{\eta_j^2 + \Delta_j^2}$ and $H_2 = \sum_{jm} E_j \, \alpha^*_{jm} \, \alpha_{jm}$. Thus we see that even if there is a configuration which is infinitely close to the ground configuration in the absence of the pairing interaction, the energy needed to excite the ground configuration has a lower bound, which is equal to Δ_j. This is the energy gap. If the single particle spectrum is continuous the energy gap is volume-independent. In the case of discrete spectrum, the gap is volume-independent to the extent that the number of near-degenerate configurations which are being mixed up is proportional to the volume. Evidence of such an energy gap in finite nuclei is now established and it explains the odd-even dependence of the spacings of the band heads. This in itself is quite an achievement. But, of course, we are forgetting that the long range part had not been included at all. While the short range part determines the H_2 term, the long range part determines the H_4 term. The existence of large quadrupole moments etc. shows that an adequate treatment of H_4 is essential. The first attempts to evaluate the effect of the long range part, qualitatively by Beliaev and quantitatively by Kisslinger and Sorensen, was based on an intuitive approach rather than an effort to develop a better method of handling H_4. It was mentioned earlier that the most important long range, i.e., low k term, for the case of two or more particles outside the closed shell is the $k = 2$ term, which is basically

$$-\tfrac{1}{2}\chi \sum_{m} r_j^2 r_j^2 y_m^2(\Omega^*_i) \; y_m^2(\Omega_j)$$

If the motion induced by this term is very much slower than the motion induced by the pairing term, it is permissible to replace one of the factors by its average value, $Q\mu$, which is, of course, the intrinsic quadrupole operator. Upon doing that we get

$$-\chi Q \cdot q \; ; \; q = \Sigma r_i^2 y^2(\Omega_i)$$

where Q is the average of the quadrupole moment operator. Of course, the wave function of this Hamiltonian must reproduce Q as the average value. This self-consistency requirement is best dealt with by minimising the expectation value of the auxilliary Hamiltonian

$$H = H_0 + H_{pair} - \chi \, Q \cdot q - \mu q$$

where μ is the Lagrange multiplier. If the quadrupole moment is not too large and as a consequence the use of perturbation theory is justified, the wave function may be written as

$$\psi = \psi_o - (\tfrac{1}{2}\chi Q + \mu)\Sigma \frac{<f|q|0>}{E_f - E_0} \psi_f$$

Now μ may be determined by requiring that the expectation value of q in this wave function is equal to Q. Having determined the self-consistent wave function in this way we may calculate the ground state energy due to the Hamiltonian

$$H = H_{int} + H_{pairing} + H_q$$

and the result, to this approximation, is of the form,

$$E = E_0 + \tfrac{1}{2} C Q^2$$

where the spring constant C is determined by the quantities u, v, Δ and the single particle level spacings. An effective Hamiltonian of this form will give rise to a vibrational spectrum. The inertial parameter may be determined by the cranking formula. Clearly this approach is valid if the two approximations, viz, replacement of the quadrupole-quadrupole interaction by an interaction of the particles with the intrinsic quadrupole field and the use of the perturbation approach are justified. The first of these approximations requires that the states which are mixed up should have the same intrinsic quadrupole moment. The fluctuation in the intrinsic quadrupole moment should be small. The second requires that the quadrupole moment itself be small. This means that the excitation of the vibrational level should be small compared to the first quasiparticle level. In most nuclei, where the theory was appled by Kisslinger and Sorensen, the first 2^+ level is invariably below the quasiparticle level. But this is not necessarily true for the higher members of the vibrational band. Thus the prediction of the energies of the higher members may not be very dependable. However, the calculations made by these authors of the levels of the Pb, Sn and Ni isotopes, reproduced the qualitative features remarkably well.

The next step that one would naturally take is to develop a better method of treating H_4. This was done almost simultaneously by Bohr, Baranger, Kobayasi and Marumori and Arvieu and Veneroni. This is the first of the two new developments that I had in mind. The basic idea is as follows.

Let A^* $(abJM)$ be suitable linear combination of the quasiparticle creation operators $\alpha^*_{j_a m_a}$ and $\alpha^*_{j_b m_\beta}$ such that it has the angular momentum J. Let ψ_0 and ϕ_{BJ} be the true ground and first excited states of the total Hamiltonian H. We may introduce the amplitudes $\psi_{ab} = <\psi_0 \, | A(abJM) | \psi_{BJ}>$ and $\phi_{ab} = <\psi_0 | A^*(abJM) | \psi_{BJ}>$. Now $<\psi_0 | [A, H] | \psi_{BJ}> = \omega_B <\psi_0 | A | \psi_{BJ}> = = \omega_B \psi$ where ω_B is the energy of excitation of the state ψ_{BJ}. The commutator can be worked out and it will contain constants, number operators, two creation, two annihilation operators and more complicated ones. Now the new method consists of the following approximations.

(A) Let the ground state be described by the BCS type state, ie, a single determinant of the quasiparticle states. And

(B) let the excited state ψ_{BJ} be obtainable by operating on the ground state with a linear combination of A's and A^*'s. The coefficients of the linear combination are obviously the ψs and ϕs.

With these two approximations we get a set of secular equations connecting the ϕs and the ψs and ω_B is the eigenvalue to be determined from these equations. This procedure is clearly a generalisation of the shell model approach. But it has the advantage of predicting both the collective and non-collective type excited states. If the vibrational states exist then in this framework it should be possible to find a linear combination Q_{BM} of the As and A^*s such that it satisfies the commutation rule

$$[Q_{BM}, H] = \omega_B Q_{BM}; \; [Q^*_{BM}, H] = -\omega_B Q^*_{BM}$$

It should be noted that the operator relation is required to be satisfied, unlike in the previous case where the relation had to be satisfied among the matrix elements of the operators between the ground and an excited states. A consequence of this requirement is that Q_{BM} and Q^*_{CM} behave like Boson creation and annihilation operators and satisfy the commutation rule $[Q_{BM}, Q^*_{CM}] = \delta \;\; \delta_{MM}$ Operating on the ground state the commutator does satisfy the requirement. So the new approximation involved is that it be true for all states. Although it is not quite clear what is the relationship between this new approach and the old one, both yield the same result for the excitation of the first vibrational level, at least when the excitation is small. Whether the new approach will remain valid for higher excitations where the old method fails is still to be seen. However, the new method can be and has been very profitably applied to the situations where the excited state is obtained by exciting a particle out of the closed shell. It is believed that the giant dipole resonance states and the 3 states seen by Cohen and Goodman are of these types. To sum up we may say the approach based on the theory of superconductivity places the main emphasis on the short range part and treats the long range part in an approximate manner to get the collective level. The second development that I am going to discuss takes the opposite approach, that is, it emphasises the long range part of the potential and treats the short range part in an approximate manner.

It has been mentioned before that the main effect of the long range part is to produce a modification of the Hartree field and we have also seen that for nucleons outside of a closed shell the most important term is the quadrupole-quadrupole interaction. Such a term produces a quadrupole distortion of the Hartree field and the orbitals in this field tend to have the largest quadrupole moment. In other words, with an interaction like this the nucleus will try to have the largest quadrupole moment and a natural approach to the problem will be to look for a representation where the intrinsic quadrupole moment is a good quantum number. Such a representation was already developed by Elliott for oscillator wave functions. Three components of the orbital angular momentum operator and the five components of the second rank tensor

$$Q = \Sigma\, q_i = \sum_i \left\{ \frac{r_i^2}{b^2}\, y^2(\Omega_{r_i}) + \frac{b^2 p^2}{\hbar^2}\, y^2\,(\Omega_{p_i}) \right\} \sqrt{\frac{4\pi}{5}}$$

commute with the oscillator Hamiltonian $H_0 = \sum_i \left(\frac{p_i^2}{2m} + \frac{1}{2} m\omega^2 r_i^2 \right)$. The operator Q may be considered equal to twice the ordinary quadrupole moment operator if we are careful not to connect states of different major shells through this operator. The eight operators form the generators of the semi-simple group SU_3. A representation may be constructed by diagoalising Q_0 and L_0 simultaneously. The eigenvalues may be termed ϵ and K, respectively. It should be noted that the quantisation axis is a body fixed system. The Casimir operator of the group is

$$C = Q \cdot Q + 3L \cdot L$$

This commutes with every element of the group and can be diagonalised simultaneously with Q_0 and L_0. The complete set of eigen-functions having the same eigenvalue for the Casimir operator forms an irreducible representation of the group, labelled by the quantum numbers λ and μ, where the eigenvalue of the Casimir operator is given by the expression

$$C(\lambda\mu) = 4\{(\lambda+\mu)(\lambda+\mu+3) - \lambda\mu\}$$

The highest value of ϵ in a given (λ, μ) representation is $\epsilon = 2\lambda+\mu$ and the highest value of k permissible for a state with this value of ϵ is μ. Such a state is called the state of the highest weight. Physically this is the state with the highest quadrupole moment and its major axis is as close to being perpendicular to the quantisation axis as possible. The other six operators do not commute with both Q_0 and L_0. By suitably combining them linearly one can construct six step up, step down type operators which will change the values of ϵ by $\pm$ 3 and the value of k by $\pm$ 2.

Instead of labelling the states of an irreducible representation with ϵ and k, one could use the orbital angular momentum and its projection for the same purpose. Elliott has shown that all the linearly independent states of good orbital angular momentum states can be obtained by projecting them out of the state of the highest ϵ. Such states differ only in the value of k. which runs from μ to $-\mu$ decreasing in steps of two. From the invariance of the Hamiltonian under time reflection it is easy to show that the two states of the same L projected out intrinsic states of equal but opposite values of k must be the same, save and except for a possible phase factor. Thus the complete set of states of good orbital angular momentum can be obtained from the states of $\epsilon = 2\lambda+\mu$ and non-negative k. The range of values of L which can be projected out of an intrinsic state of $\epsilon = 2\lambda+\mu$ and k is

$$\begin{aligned} L &= k, k+1, k+2, \ldots k+(\max \lambda, \mu) \quad \text{for } k \neq 0 \\ &= 0, 2, 4, \ldots (\max \lambda, \mu). \end{aligned}$$

If the two body interaction were

$$\begin{aligned} \sum_{i>j} C_{ij} &= \Sigma(Q_i \quad Q_i + 3L_iL_j) \\ &= \tfrac{1}{2}\, C - \sum_i (Q_i^2 + 3L_i^2) \end{aligned}$$

then these L projected wave functions would be degenerate eigen functions. But the interaction which we want to diagonalise is not the sum of two body Casimir operators but it is

$$\sum_{>j} Q_i\, Q_j = \frac{1}{2} \; Q^2 - \Sigma\, Q_i^2 = \frac{1}{2} C - \frac{3}{2} L^2 + 3\Sigma\, L_i^2 - \Sigma C_i \,.$$

So apart from the $\Sigma\, L_i^2$ term, the Hamiltonian is still diagonal in the representation. We have exact rotational bands of constant moment of inertia. However, instead of an infinite sequence of rotational levels, we have bands of finite ranges of values of L. The group of states projected from the same value of K constitute a band. The principal effect of the ΣL_i^2 term is to split up these bands and make the moment of inertia dependent on the band quantum number. In principle, the ΣL_i^2 term can also mix different bands.

Recently, Levinson and I were able to develop a method of calculating matrix elements of two-body interaction between states of any number of particles outside a closed shell with configuration mixing. The method is based on a more general use of the properties of the SU_3 representation. So far it has been developed only for the *sd* shell and the method has been used to calculate the level spacings of *sd* shell nuclei by the two authors in collaboration with Pal and Meshkov.

Although one knows, in principle, how to construct N-particle configuration mixed wave functions and how to calculate matrix elements between such states through the use of the fractional parentage expansion, the procedure becomes unfeasible for more than three or four particles outside a closed shell. The number of states becomes enormously large and the calculation of fractional parentages involves prohibitive amount of labour. This is the reason why no configuration mixing calculation has so far been done for more than four particles outside a closed shell. Naturally people had to fall back on methods, such as described before, to get around this difficulty. These methods were excellent for predicting trends and general properties but were incapable of giving the specific features of a particular nucleus. The new method that we are going to discuss now allows us to calculate the matrix elements without the use of fractional parentages or Racah coefficients.

In the region of medium weight nuclei it is known that the levels which are strictly degenerate in the oscillator potential are nearly degenerate. Brueckner theory tells us to mix only these levels. So the advantage of using the SU3 representation is obvious. The fact that the wave functions are not truly oscillator wave functions presents little difficulty. It can be circumvented by replacing the old Q's by new Q's which have the same matrix elements between the actual single particle states as the old ones have between the oscillator wave functions. As a result the new Q is no longer the intrinsic quadrupole moment. But the difference is of the same order as the difference between the actual wave function and the oscillator wave function.

An analysis of the matrix elements of the usual shell model Hamiltonian showed that a very large part of it, 85% to be specific, can be written as a linear combination of 1_{ij}, P^{σ}_{ij} and the two-doby Casimir operator C_{ij}. This encouraged us to use the states $|[f], (\lambda\mu)\varepsilon kLSJM>$ as the basic representation. If may also be seen that if the two body potential is attractive, the C_{ij} term is also attractive. Thus the group of states belonging to the highest $(\lambda\mu)$ symmetry will be the lowest, In other words, the state projected out of the intrinsic wave functions of highest possible ϵ, i.e. highest possible intrinsic quadrupole moment, will be the lowest. This is why the method is useful when the long range part of the potential plays a more important role.

The fact that the lowest state has the maximum possible value of ε plays a very important role in the calculation of the matrix elements. The method of calculation of the matrix elements can be understood by considering the example of the matrix elements of a central force between states of the highest $(\lambda\mu)$ symmetry. The state $|[f]\ (\lambda\mu)\epsilon k\ LM > = \sum_{K'} \int d\Omega\ D^{L}_{MK'}(\Omega)^{*}\ R(\Omega)\,|[f](\lambda\mu)\ \epsilon k >$ where we may use the symbol P^{L}_{M} for the projection-rotation operator $\sum_{K'} \int d\Omega\ D^{L'}_{MK}(\Omega)$ $R(\Omega)$, $R(\Omega)$ being the rotation operator. Now $HP^{L}_{M}[f](\lambda\mu)\epsilon k > = P^{L}_{H}H\ [f]$ $(\lambda\mu)\epsilon k >$ because the Hamiltonian is a scalar and commutes with P^{L}_{M} which is a function of the components of the total angular momentum. Now $H\,|[f](\lambda\mu)\epsilon k >$ is a sum of states belonging to the highest $(\lambda\mu)$ symmetry and also of states belonging to other symmetries. The part of $H\,|[f](\lambda\mu)\epsilon k>$ which is in the highest $(\lambda\mu)$ symmetry may be written as

$$F_j\ (E)\,|[f](\lambda\mu)\epsilon k >$$

where $F_j\ (E)$ is a suitable function of the group operators E. A little thought would show that it is a linear of combination of eight linearly independent functions of the group operators. Let us call them F_is. So

$$H\,|[f](\lambda\mu)\epsilon k> = \Sigma a_i F_i(E)\,|[f](\lambda\mu)\epsilon k > + \text{other symmetries.}$$

The coefficients may be obtained from the eight equations that we get by evaluating the expectation values

$$<[f](\lambda\mu)\epsilon k\,|F^{*}_{j}(E)\,|H[f](\lambda\mu)\epsilon k > ;\ j = 1, \ldots 8$$

Clearly these will not have any contribution from the part of $H\,|[f](\lambda\mu)\epsilon k>$ which belongs to other symmetries. Actually the eight equations reduce to three sets of order 1, 3 and 5. So the problem of evaluation of the coefficients a_i is quite simple and they are functions of the quantum numbers λ, μ, and k. The F_is are functions of the six step up and step down operators. Two of these operators do not change ϵ but change k by ± 2. Of the other four two increase the value of ϵ by 3 and two decrease the value of ϵ by the same amount. Obviously by a judicious choice of the operators we can make them entirely free from the operators which step up ϵ. The two remaining step down operators are such that their effect on the state of the highest ϵ is the same as those of $L_{-} = L_x + iL_y$ and $L\ = L\ -iL_y$ on the same states. In other words, it is possible to write

$$HP^{L}_{M}|[f](\lambda\mu)\epsilon k > = P^{L}_{M}\sum_{K}\ a_i F_i(L_{+}, L_{-}k')\,|[f](\lambda\mu)\epsilon k' > + \ldots$$

and then ultimately as.,

$$= \sum_{K'} a_i(\lambda\mu k)\ F(L, k, k')P^{L}_{M}|[f](\lambda\mu)\epsilon k' > + \ldots$$

By using the relationship between the states projected out of $|[f](\lambda\mu)\epsilon k' >$ and those from $|[f(\lambda\mu)\ \epsilon, -k' >$ the summation above can be restricted to the nonnegative values of k' alone. Thus we are able to calculate the matrix elements as a function of the angular momentum, band quantum number and other quantum numbers. One can very easily extend the method to calculate the matrix elements between states of different symmetries and of spin-dependent and non-central forces. The matrix elements between the different bands are the band mixing terms. One also gets in the diagonal elements terms containing the factor $(-)^{J-\frac{1}{2}}(2J+1)$, which may be termed as the 'decoupling term' in keeping with the language of the collective model. The diagonal matrix element is of the form

$$a+bJ(J+1)+cJ^2(J+1)^2+d(-)^{J-\frac{1}{2}}(2J+1)$$

The coefficient of $J(J+1)$ may be identified as half of the reciprocal of the moment of inertia. Calculations in the *sd* shell have shown that the band mixing is very small—the mixing of different symmetries is small but not negligible. It is also seen that the matrix elements between two states of different ϵ decreases as the difference between the two ϵ increases. This is a very satisfactory result, for, it justifies the use of the representation which diagonalises the intrinsic quadrupole moment. Among the states of the highest particle symmetry the highest ϵ is invariably unique. This intrinsic state is naturally a single determinant of single particle states. We also see that this state is going to be the dominant part of the states of the lowest band. Thus, in an approximate way, we may say that the ground band of states can be obtained by putting the particles in a spheroidally distorted Hartree field—then projecting out the different angular momentum states out of the lowest independent particle state which is a single determinant, resulting from this distorted Hartree field. This is a confirmation of the view that the long range correlation can be largely eliminated by suitably distorting the Hartree field. However. in many cases there occurs in the second particle symmetry a state which has the same ϵ as the state of highest ϵ of the ground particle symmetry. These states will be fairly strongly mixed by the spin-orbit force. But the mixing is very weakly dependent on the angular momentum of the state. So even to this order we do get an intrinsic state from which the wave functions of the states of the ground band can be projected out—but the intrinsic state now contains correlations as it is no longer a single determinant but it is a linear combination of determinants.

If one ignores the mixing of other (λ, μ) one necessarily ends up with too large a value for the moment of inertia. Any admixture will necessarily reduce the moment of inertia. At the moment the effect of such admixtures has been estimated only through the ad hoc use of perturbation theory. Indications are that the use of perturbation theory is justifiable—but more work must go in before a definite statement can be made. In any case the perturbation results give very satisfactory predictions for the low-lying levels of Mg^{24}. The ground states of the *sd* shell nuclei are predicted without too much trouble. The only anomalous case is the ground state spin of Na^{22}, which is 3 instead of 1. But the spin orbit force of the usual strength brings down the spin 3 state without trouble.

Although this method makes calculation for many particles outside the closed shell feasible, it is still a time consuming work. One should also note that the states $P^{J}_{MI} | [f](\lambda\mu)\epsilon k\,\sigma >$ form a non-orthogonal, unnormalised basis. So long as not too many excited symmetries are mixed with appreciable amplitude, i.e., so long as the intrinsic quadrupole moment is large, this approach will pay dividends. But when one approaches the region where the vibration sets in, the present method may not be terribly useful.

OBJECTIVE OF THE SAHA INSTITUTE OF NUCLEAR PHYSICS: THE PROGRAMME OF WORK AND ITS LIMITATIONS

The Saha Institute of Nuclear Physics was founded with the dual objective of teaching and conducting research is Nuclear Science in its various aspects. As mentioned earlier, the teaching of Nuclear science had been fostered in the early years in the Palit Professor's laboratory since 1939. Nuclear Physics was introduced into the curricula in 1939 as a compulsory subject of study for the M.Sc. examination in Pure Physics. This course has been modified from time to time with the growth of the subject. An advanced course in Nuclear Physics and another in Biophysics as two of the optional papers for the M.Sc. course in Pure Physics were introduced in 1941 and 1957 respectively.

As already mentioned the Institute had intention of starting a Post-M.Sc. diploma course. The then Vice-Chancellor wrote to the Prime Minister stating the plan. In his reply to the Vice-Chancellor of the Calcutta University, the Prime Minister wrote: "Our resources in scientific talent as well as other matters are strictly limited although we hope to increase them. We have, therefore, to make the best use of them. That indeed requires co-ordination on an All-India basis. Because of these various things, certain suggestions were put forward on our behalf to give your Institute of Nuclear Physics more of an All India character. Of course, the running of it and the day to day control of it would naturally rest with the Director of the Institute and with the Chairman and the Secretary of the Governing Body. But in regard to wider policies it would be beneficial both to the Institute itself as well as to the development of Nuclear Physics and like subjects in India if an All-India character is maintained".

The University accepted the Prime Minister's suggestion and the Institute of Nuclear Physics was started in 1950 under the joint sponsorship of the Government of India and the Calcutta University with an All-India character. The authorities of the Institute drew up a scheme of advanced Post-M.Sc. training for one year in Nuclear Science open to students from all parts of India. The Post-M.Sc. one-year course open to 20 students from all over India, was started from 1953. In keeping with the All-India character as suggested by the Prime Minister ordinarily sixty-six per cent of the students admitted to the Post-M.Sc. course are from outside the State of West Bengal. The course leads to the Associateship diploma and is preparatory to research in the Institute or to technical or academic posts elsewhere.

The objectives and programme of the Institute are to follow closely of those in other countries for training and research in Nuclear science and its applications to other sciences, consistent, however, with the special conditions that pertain to India. Developmental research and production do not fall ordinarily within our category, although some developmental work is taken up from time to time when the need arises.

The Department of Atomic Energy has sanctioned the generous amount of approximately one crore of rupees for the five year period of 1960–65 for all the departments except Biophysics. This department is being financed by the Ministry of Scientific and Cultural Affairs separately from the last five years. The ministry has sanctioned a grant of thirteen lakhs of rupees for the development of the Biophysics Division during the next five years. There is also a major project of a new accelerator still under the consideration of the Department of Atomic Energy which the Institute is keen to undertake.

It is generally appreciated that inspite of the large amount of practical and theoretical work now being done we are far from understanding the laws of the nucleus and it may yet take long years before we come to a complete understanding of the problem.

It appears that our position with regard to the nucleus is much the same as was the position with respect to the atoms about the early years of the twentieth century or late in the 19th century. At present nuclear reactions and nuclear emissions of beta and gamma rays are being studied still with apparatus which subsequent generations may probably call "crude". But newer and more powerful techniques are being evolved, and more satisfactory data are being collected. It appears that as more comprehensive and accurate data are obtained we can hope to improve our understanding of the laws of the nucleus.

The Institute's research laboratories cannot compete with big undertakings of the American or European laboratories such as that at Berkeley, Brookhaven or Durham. The outlook in the laboratory is, therefore, to equip ourselves with as good techniques as possible. At the same time the Institute authorities feel that its organisation and equipment should be capable of adjusting quickly to newer techniques. The modest facilities at the Institute make it imperative that theoretical studies are not neglected, for, as Hamilton said long ago, experiments and mathematics are the two eyes of physical science, and to be able to make really good progress, one ought to be able to see with both eyes.

With these objectives in view the research programme follows more or less on the same pattern as drawn up five years ago and is divided in the following sections :

(a) Acceleration of particles to moderate energies and study of interactions with them.

(b) Study of nuclear reactions effected by these particles.

(c) β and γ spectroscopy of radioactive nuclei.

(d) Application of these techniques to other fields of physics and to other branches of knowledge, such as biophysics, chemistry, engineering, geology, etc.

(e) Study of theoretical physics.

The report of the progress of work of the individual divisions and sections together with the programme of work for the next five years are given in the next chapter.

During the last five years the work of the Institute has been strengthened by the appointment of Dr. A. K. Saha (1956). Dr. D. N. Kundu (1958) and Dr. M. K. Banerjee (1960) as professors, and other staff in various categories. It is hoped that with the increasing growth and expansion of our activities during the next five years one or two more senior appointments may be made.

A certain amount of extension of our space has been possibe by extending the hostel for the Post-M.Sc. students to 5 floors and converting two of these floors into laboratories. It is proposed if a suitable building is available to shift the hostel and to convert the entire building into laboratories.

A handsome gift of land from the Kolay family of Calcutta within a short distance from the present laboratories has made it possible to plan future extensions of the laboratoiy in the new site. The high intensity Cockroft Walton neutron generator will be one of the first installations in this new site.

The following pages narrate the work carried out in different departments in the last five years and future plans and programmes that will be undertaken during 1960-65.

DEPARTMENTAL REPORTS AND FUTURE EXPANSION

DIRECTOR'S RESEARCH SECTION

Under the Director two lines of work are being pursued :

1) *Low Level Tracer work :*

The primary aim of this research programme is to carry out radioactive tracer investigations in various branches of science using very small quantities of radioisotopes wherein the use and the development of various low level counting systems are required. A simple low level set-up for radioisotope tracer experiments was made by putting a gas flow counter in anticoincidence with a ring of cosmic ray counters with moderate shielding. This set-up was found very useful for counting small quantities of radioactive materials with high efficiency for beta detection even for low energy particles and better reproductibility for weak radioactive samples. The set-up has been applied mainly in physiological, zoological and medical investigations by Dr. Fazle Hosain and other co-workers. They have applied this technique recently in some chemical experiments.

The utilization of the low level counting device in biomedical tracer investigations has helped in the reduction of the radioisotope dose by 10 to 50 times compared to the conventional tracer doses in a number of experiments, such as thyroid function test, blood volume estimations, pancreatic insufficiency tests, plasma protein turnover studies and plasma iron utilization problems which were carried out extensively. This has therefore reduced the radiation dosage to human subjects delivered during a tracer study, consequently a person can be subjected to repeated tests. And babies and expectant mothers can also be tested with lesser risk if the situation so demands.

The future programme is to generalize the technique and modify for some special work at cellular levels.

2) *The passage of fast charged particles through or in the neighbourhood of dielectric and permeable media :*

These investigations were started in 1955 with the aim of studying Cerenkov and Cerenkov-like phenomena in permeable and dielectric media. This work has recently been extended to plasma both in the case of field-free plasma and plasma under the influence of an uniform axial magnetic field. The coupling between plasma oscillations and the electromagnetic shock wave has also been investigated.

The possibility of generation of high frequency electromagnetic waves in a high permeability ferrite both theoretically and experimentally is under investgation.

Autocoincidence experiments with β rays passing through a transparent medium, a light pipe and phosphor with two photoelectron multipliers in fast coincidence between Cerenkov and Scintillation pulses were also carried out. The lower background of such counters was noted. The list of papers published, given in the appendix will illustrate the work carried out in the last few years.

ACCELERATOR DIVISION

I. Pre-1955 Period

The present Accelerator Division grew out of the former Cyclotron Division which together with the Biophysics Division and a few small sections carrying out researches on various branches of nuclear science constituted the Institute when it was first formed. Even before the beginning of the first five year programme in 1955, the plan of work of this Division was already sketched in bold outlines by late Professor M. N. Saha in close collaboration with the present Director of the Institute. The cyclotron was in a very advanced stage of construction with a number of ardent workers devising improvements for increasing the beam current.

The cyclotron magnet has a pole face diameter of 38 inches tapered from a 42 inch pole diameter according to a shape given by Rose. It is made of carbon free silicon iron and requires 300,000 ampere-turns for saturation, the designed operational maximum being set at 250,000 ampere-turns for which 35 KW are needed. The original self-excited push-pull oscillator has been replaced by a master-oscillator excited power-amplifier unit designed to give 80 KV between the Dees at 11 Mc/sec. and requiring a power of 85 KW. For the vacuum system, a CVD-8610 Kinney pump backs two 3-stage 10-inch oil diffusion pumps with freon cooled baffles. An arc type ion source which can be pulsed is fed with hydrogen and deuterium gas, the latter being generated from heavy water with an electrolysis unit provided with automatic switch-off and safety devices. Pro vision has been made for adequate cooling through heat exchanger units.

The division has already undertaken a variety of experiments cited below :—

a) Magnetic field and field gradient measurements.
b) Radio frequency power system and their delivery.
c) Magnetic field stabilization and control.
d) Scintillation counter technique.
e) Operation of diffusion pumps, back-diffusion and other problems of vacuum technology.
f) Design and operation of ion sources.
g) Neutron Spectrometry.

II. First Five-Year Programme 1955–59

In course of the first five-year development programme, the activities of the Division had been divided into three sections :

(1) Cyclotron,
(2) Mass Spectroscopy, and
(3) Electron Synchrotron.

For the Cyclotron Section it was proposed to extend and complete some of the work already started. In particular, R.F. ion source work, pulse height studies with scintillators, neutron time of flight measurements in the Kev range, high vacuum techniques, and the building of a 400 KV aradio frequency CW generator, high-lighted the programme. The Mass Spectroscopy Section was to undertake a critical study of different mass spectrometers and to construct suitable machines with the object of their use in physical researches. The Electron Synchrotron Section was to have an electron accelerator of about 50 Mev for photonuclear and electronuclear studies. The Neutron Physics group which originally was a Section in the Nuclear Physics Division, started its activities with a 450 mc Ra+Be source which yielded about 10^6 neutrons/second. Later this group aligned itself with the Cockcroft–Walton generator programme and was amalgamted with it.

III. Report of Work

The activities of the Division comprised in large measure developmental researches. The list of publications in the Appendix, therefore, shows a preponderance of papers on instrumentation and techniques. Work for the proposed Electron Synchrotron started out with design studies and, in particular, the problem of injection in detail. A comparative study was made on the conventional type of injection, namely, the Betatron injection and injection from an external injector at 1 or 2 Mev. It was found that the latter type of injection has several advantages as, for example, in greater beam current and in reduction of the size of the magnet gap which affects the cost of the machine. The programme, however had to be postponed indefinitely for lack of necessary foreign exchange and the already existing staff and resources were incorporated within the Cyclotron Section.

Cyclotron

In order to improve the beam current of the cyclotron, constructions and measurements of various kinds were effected. The previously existing single manifold twin line system of Dee stems was replaced by double manifolds and single co-axial lines with a consequent gain in Q-value by approximately a factor of two. This involved the construction of a new manifold of 24-inch diameter, modifications in the existing manifold, construction of the neck piece to join the manifold with the vacuum chamber, copper liners with adequate water cooling for heat removal, construction of a pair of dees with cut-away ends and cooling tubes on the internal surfaces and the fabrication of the retraction carriage. Structural changes in the building were made to accommodate the double manifold system and for better lay out of the various components. A new ion source assembly was constructed and modifications were made in the oscillator especially replacing the high Q grid line, in the water-cooling system, and in certain parts of the vacuum system. A new motor generator set was installed. Correction of some structural defects in the casting of the vacuum chamber and the installation of two liquid air traps resulted in improvement of the vacuum. Extra cooling on the chamber liners and two additional port-holes on the chamber walls for the introduction of the compensator were incorporated. The whole cyclotron room has been dehumidified. Extensive measurements of the magnetic field were made, adopting initially the nuclear magnetic resonance method and finally using Hall plates for proper shimming. The internal beam has been optimized up to the periphery of the dees with proton extraction in view and peak values of over a hundred microamperes of 4 Mev proton can be obtained on water cooled targets. To prevent common targets from melting away, the beam current is reduced by putting 50 cycle A.C. on the ion source. The machine is at present being used for making proton bombardments of numerous target nuclei and the radioactive disintegration characteristics of the product nuclei are being studied.

The combined report on the Cockcroft Walton Generator and the Neutron Physics group is given in a separate section.

During the period under review, work on the following additional developmental and research projects are :

1) A neutron velocity selector for total cross section studies has been constructed utilizing a ten channel milli-microsecond delay analyser. The apparatus is expected to provide new information in the neutron energy range of 2 to 50 Kev.

2) A low pressure cloud chamber with internal counter control and fully automatic photography and reset mechanism has been completed and tested. It is suitable for the study of fission fragments and also other low energy reaction products.

3) A high precision magnetometer based in part on the description of a similar instrument by Knoebel and Hahn was constructed and used to measure the cyclotron magnetic field and field gradient.

4) An elaborate and efficient scintillation counting outfit has been built up with several phosphors of different sizes, single channel and a twenty channel pulse height analysers and other necessary electronic circuits. The facilities developed are being used for studying the energy levels of nuclei from the cyclotron bombardments.

5) A method of simultaneous measurement of A.C. magnetic field and field gradients was developed. Using a test magnet, and a loud speaker search coil assembly, a signal was obtained incorporating the field and the field gradient at the same time. With the help of a reference coil also placed within the field, the field and field gradient signals were isolated, separately amplified and measured on electronic voltmeter.

C. W. Generaland Neutron Physic:

The work of this Section can briefly be summarised as follows :—

(1) A high flux neutron generator has been constructed and successfully run.

(2) Nuclear emulsion plate technique was developed. Applications were made of this technique in the measurement of neutron flux and energy. In general, fast neutron spectroscopy by means of emulsion plates was developed.

(3) Measurement of fast neutron flux by means of threshold detectors by measuring both the β and γ activity of the reaction products was made.

(4) A scattering chamber was designed and constructed.

High reaction cross section for D-T and D-D reactions was utilized to make a compact low voltage γ-free intense monoenergetic neutron source. A radio-frequency type Corkcroft-Walton voltage multiplier circuit was made use of to produce a D.C. voltage up to 400 KV at present. From consideration of economy and simplicity as also from the standpoint of getting a fairly ripple-free stable D.C. voltage, an r.f. type C-W multiplier was decided on. This type has a decided advantage over the commercial type of 400 c/s variety. A focussed ion beam up to $500\mu a$ was brought to bear on the target and ion beam up to 2.2 ma had been focussed on dummy target within an area of 1/8″ dia. However, restrictions of gas evolution of tritium targets have prevented the use of such high currents on the tritium targets. It seems feasible to increase this current up to 7 ma with some loss in the sharpness of focussing due to space charge effects. A neutron yield of the order of 10^{10} neutrons per sec. at the source has been obtained.

All constructional works on the generator have been completed up to the maximum performance ratings possible at the present site. With direct refrigerent cooling of the tritium target, operation with a beam current of more than 1 ma at 200 KV has been possible. Researches on cross sections on (n, p), (n, α), $(n, 2n)$ and (n, He^3) reactions have been made and values have been obtained for several nuclei in respect of which the cross sections measurements were either unavailable or involved larger errors. Neutron transmutation studies are also in progress.

Studies have been made of the energy of fast neutrons and of the proportion of scattered neutrons by means of recoil protons in nuclear emulsion plates. The recoil proton spectra due to the almost parallel beam of fast neutrons was measured. The spectra of neutrons from the following sources were measured :–

(a) a 200 ma Ra–Be Source,

(b) a 100 ma Po–Be Sources,

(c) neutrons issuing from the reaction $D(T, n)He^4$ collimated in iron and wax shield.

Ilford C2 emulsion plates of 200 microns and 400 microns thickness were used. These emulsions were exposed, at an angle of 6° to the plane of the plate, to a neutron beam for sufficient time to obtain an integrated flux of $10^9 n/cm^{12}$ as suggested by Rosen. The plates were developed according to the standard method. The plates were made ready for microscopic examination in a Leitz "Ortholux" microscope, with oil immersed objective of 20× magnification. Rosen's criteria for scanning was followed and all proton tracks within a solid angle subtended by a cone of half angle 10° were counted.

Studies of nuclear reactions with loaded emulsion are also being carried out. Phosphorus loaded emulsions have already been scanned and analysed obtaining information on the density of nuclear energy levels. Comparisons with data from other sources and with the expectations from the statistical model appear promising.

Mass Spectroscopy :

In the beginning of the first five-year period, the design studies for constructing a mass-spectrometer for heavy ions were undertaken. As a pilot instrument a small low resolution mass-spectrometer was constructed with a permanent magnet to test different types of ion-sources. Some types of surface ionisation and electron impact ion-sources were tested with it.

Later on, a two directional focussing mass-spectrometer with a radius of curvature of 28 cm. and magnetic field of 3800 gauss was designed and developed in this laboratory. The performance of the analyser has been tested with the conversion electron spectrum of Cs-137. A magnetic oscillation type ion source has also been constructed. Operation of the instrument as a mass-spectrometer with this ion source and accelerating voltage is found satisfactory. A duoplasmatron ion source after Von Ardenne has been procured for use with the above magnetic analyser for high intensity mass spectrometry work.

Theoretical studies on the collision of ions in gases have been made and some preliminary experiments on the measurement of cross sections of such collisions have been done.

A machine for the time-of-flight separation of ions has been constructed. In the preliminary runs for observing mass peaks on an oscilloscope screen the resolution was unsatisfactory. Centering round the equipment, theoretical studies were made on ion-bunching in space.

IV. The Second Five-Year Plan

The Development and Research programme for the Second Five-Year Plan Period is presented in four sections: (1) Cyclotron. (2) Cockcroft-Walton Generator and Neutron Physics, (3) Mass-Spectroscopy. and (4) A proposed new bigger accelerator viz. a Synchrocyclotron.

1. *Cyclotron*

The present use of the machine for making bombardments in the internal beam will be continued during the initial period. No major constructional developments for modernizing the cyclotron is contemplated and, therefore, no additional equipment was sought. Adaptations necessary for specific experiments would be effected. The proposed development programme is as follows :—

(1.1) Continuation and extension of existing work on the Cyclotron.

(1.2) Counting room with reaction chamber and reaction products analysis facilities.

(1.3) Continuation of current research projects :

- (a) Construction of a neutron velocity selector for intermediate energy range (2 Kev to 50 Kev) for total cross section study.
- (b) Construction of a pair spectrometer for study of high energy capture gamma rays.
- (c) Construction of a low pressure cloud chamber for further study on energy loss of ions e.g., fission fragments.
- (d) Design and construction of quadrupole focussing magnet.
- (e) Studies on simultaneous measurements of the field and the field gradient.
- (f) Other assorted problems.

(1.4) New research projects.

(1.5) Model studies of accelerator techniques.

In addition to the instrumental researches mentioned above, the following additional researches would be undertaken :

- (a) Stripping and other reaction studies with angular distribution of reaction products.
- (b) Nuclear transmutation studies.
- (c) Measurements of life times of excited states of nuclei by Döppler shift and other methods.
- (d) Fast Neutron Spectrometry (Energy range 0.5 Mev to 20 Mev). Time of flight arrangement is to be employed. Studies will include transmission and scattering, elastic and non-elastic.

2. *C–W Generator and Neutron Physics*

The C–W generator is being used for neutron irradiations for over a year. However, it is not possible to exploit its designed voltage of 400 KV and maximum current rating at its present first floor location because of shielding impracticabilities and space limitations. It is proposed, therefore, that researches be continued with the generator with its present performance figures and further developments be undertaken at a new site which may be available. The programme, therefore, is :

(2.1) Developments involving experimental equipments for neutron researches would be undertaken.

(2.2) Change of site of existing generator to exploit its full rated performance is proposed. Additional work would involve deflecting and analysing magnet for the generator, stabiliser for the magnet and high voltage, control desk, dehumidification, and other improvements.

(2.3) In order to generate neutrons from thick or gas targets and to obtain neutrons of different energies it is proposed to modify the existing generator to extend its voltage from 400 to 800 KV.

With the existing machine, the following researches, some already in progress, would be taken up :

(a) Measurements of the cross sections of nuclear (n, p), (n, α) and (n, He^3) reactions and study of angular distributions.

(b) Transmutation work involving the production of some unknown or partly explored radioactive nuclei.

(c) Study of $(n, 2n)$ reactions; several quantitative features of this reaction are to be investigated in conjunction with a large Mass Spectrograph proposed elsewhere.

(d) Study of nuclear energy levels from the angular distribution of scattered neutrons, with a low background collimated-neutron scattering chamber.

(e) Study of nuclear reactions with loaded emulsions.

With change of site of the generator, feasibility studies would be undertaken on :

(f) The production of polarised neutrons.

(g) Pulsing the ion source.

3. *Mass Spectroscopy*

The mass-spectrometer already constructed can with some developments be applied to the separation of isotopes of mass $\sim$ 100 and to measurement relative isotopic abundances of even the heaviest elements. The time-of-flight ion separator scheme will be continued for further developments only if the resolving power of the machine, already constructed, is found encouraging on test runs. The development programme is the following :

(3.1) Regarding the existing heavy ion mass spectrometer, the instrument is at present operated with a voltage supply for the magnets having a stabilization of $\sim 0.1\%$; this is to be improved to a stabilization of $\sim 0.005\%$, the accelerating voltage supply needing also to be stabilized to at least 0.01%.

(3.2) A high-intensity high-resolution mass spectrometer is to be purchased and installed.

(3.3) Model study of cycloidal type focussing in mass spectroscopy would be undertaken.

(3.4) The resolving power, transmission, and other performance characteristics of the time-of-flight ion separator would be tested and the instrument further developed, if promising, for isotope separation.

With the heavy ion mass spectrometer the following researches would be undertaken :

(a) Elastic and inelastic collision of ions in gases.
(b) Range of ions of different energies in materials and studies of sputtering phenomena on surfaces.
(c) High intensity ion sources for isotope separation.
(d) Problem of collection of isotopes.
(e) Investigations on the process of ionization of solids in different types of ion sources.
(f) Problems of negative and metastable ions.

The commercially produced mass spectrometer will be used for :

(g) Preparation of thin sources for nuclear spectrometry.
(h) Separation of radioactive isotopes after irradiation by accelerators.
(i) Identification of mass after irradiation by accelerators.
(j) Enrichment of stable isotopes for determination of geological age, enrichment of radioisotopes for nuclear studies, trace analysis, etc., by isotope dilution method.

4. *The New Accelerator*

The need of a larger and fully operating accelerator is deeply felt by all the workers of the Institute. Without such an accelerator, researches remain restricted only to the low energy region of the available cyclotron. A bigger accelerator is therefore proposed which will not only provide such opportunities of active nuclear researches to-day but which will not, as far as can be foreseen, exhaust its usefulness within the next five or ten years. Such a machine will stimulate the present workers into fresh activities and create an inviting atmosphere for other able investigators from outside. There is a theoretical group at the Institute which has been doing excellent work on nuclear reactions and structure. There is a group of experimental physicists here with varied experience on nuclear researches and accelerator techniques. There is a nuclear spectroscopy laboratory equipped with modern precision instruments for various nuclear measurements; with the co-operation of these different groups, a larger accelerator will be just the major tool with which extensive researches may be planned.

The existing cyclotron with its low (4 Mev protons) energy is now quite outmoded by the introduction of several high energy Van de Graaff generators up to 12 Mev. In India precision work up to 10 Mev using a Tandem Van de Graaff machine is being planned. There remain in the energy region above 10 Mev, possibilities of new and interesting nuclear researches. In addition, a deuteron machine above this energy will be an isotope producing machine, complementary to a reactor in producing even those isotopes which cannot be made in the pile.

The proposed machine is to be a commercially produced one with a maximum particle energy greater than 20 Mev. Housing and part instrumentation are to be done locally.

Different positive ion accelerators have been considered from the following standpoints :

(a) Commercial availability;
(b) Energy of the ions, the maximum being set at 20 Mev;
(c) Nature of the accelerated particles (protons, deuterons and alpha particles);
(d) Energy variation possibilities;
(e) Versatility; and
(f) Cost.

The number of commercial organizations able to supply these machines is small. Two possibilities emerged :

(1) A 71-inch synchrocyclotron with internal beam, a machine similar to the one actually in operation at Amsterdam, providing 28-Mev deutrons and with prospects of beam extraction as an additional feature.

(2) A linear accelerator in which the first section would give an external beam of protons of continuously variable energy of 12 Mev which may be increased to 24 Mev by the addition of a second section.

Cost was the dominant factor for fixing the choice on the synchrocyclotron. In preliminary contacts with the manufacturers, approximate quotations have been obtained. It is also considered possible to have the proton energy increased to 50 Mev with the addition of an extra R.F. oscillator set-up.

Research Programme : The following are some of the many researches that may be undertaken with the help of the new machine :

(a) Nuclear transmutations with 28 Mev deuterons and 14-Mev protons, and later with 50-Mev protons, specially reactions with many particle emissions.

(b) Excitation function cross section, angular distribution in nuclear reactions with deuterons up to 28 Mev and protons up to 14 and then 50 Mev.

(c) Angular correlation in nuclear reactions of the type $(p, p' \gamma(\theta))$ for information on levels.

(d) Polarization studies with protons up to 50 Mev for information on the interactions.

(e) Stripping reactions with deuterons.

(f) High evergy and high intensity neutron irradiations.

(g) Direct interaction mechanism in nuclear reactions.

(h) Study of pick-up processes of the type (p, d) and (p, t) reactions; (p, n) and (p, r) reactions.

(i) Elastic and inelastic scattering studies, with different particles.

(j) Heavy ion bombardments.

Services : With the new accelerator it would be possible to help outside researchers, universities and other research institutes in their researches by service of the following types :

(a) Production of radioisotopes;

(b) Providing facilities with beam and counting room, for experimental research at site:

(c) Internal beam irradiation of safe targets.

V. Concluding Remarks

It may be observed that the new accelerator is the most important item of development envisaged in the second five year programme. This is an expensive machine and is still under consideration by the Department of Atomic Energy. Although many people are agreed on the desirability of such a machine at the Institute, the large foreign exchange involved in the project has delayed its realization so far. It may also be remarked that only half of the total funds expected to be required for the whole programme has been sanctioned. It would thus be necessary to reduce the size of the programme judiciously to practicable limits. The list of publications given in the Appendix conveys some idea of the types of activities undertaken by the members of the group.

NUCLEAR PHYSICS DIVISION

The Nuclear Physics Division grew out of research schemes supported by the Department of Atomic Energy. During the first 5-year plan period it was divided in three sections as follows :

(a) Theoretical Nuclear Physics Section

(b) Nuclear Spectroscopy Section

(c) Nuclear Magnetic Resonance Spectroscopy Section

An idea of the work done by the different sections will be found from the list of publications of the division attached to this report. We shall just give a brief sketch of the problems which engaged our attention in the first 5-year plan period. In the Theoretical Nuclear Physics Section we were interested in problems related to β-spectroscopy, nucleon-nucleon interaction, nuclear models, nuclear reactions, nuclear many-body problems, and high energy electron scattering from nuclei. In the Nuclear Spectroscopy Section we have set up a short lens β-spectrometer, a Siegbahn-Slätis β-spectrometer, well type γ-spectrometers, $\gamma-\gamma$ angular correlation spectrometers. We have also developed slow-fast coincidence circuits and a 10-channel pulse height analyser. Work is now in progress for the construction of a Gerholm type β-spectrometer and a γ-γ angular spectrometer with magnetic field. Precision measurements of a number of radioactive isotopes have been made and their energy levels investigated. We have also shown how the β-spectrometer can be used effectively for the measurement of internal conversion coefficients of γ-rays. We are setting up a chemical laboratory for isotope purification with the help of ion-exchange resins. In the Nuclear Magnetic Resonance Spectroscopy Section we have set up both the Bloch and the Purcell type of n.m.r. spectrometers, as well as a spin-echo spectrometer. Work is in progress for the construction of steady and transient electric quadrupole spectrometers. We have devised accurate methods for determining molecular self-diffusion coefficient and relaxation times by the spin-echo method. A wide line Varian n.m.r. spectrometer has also been set up in this laboratory. Line width studies with a number of interesting salts has been done with the wide line Varian n.m.r. Spectrometer. We have also studied theoretical aspects of the n.m.r. phenomenon, viz. the quantum theory of the formation of spin echoes by the density matrix formalism, the contribution of molecular self-diffusion to the formation of spin echoes, the effect of chemical shift and J-coupling in spin echoes, calculation of hyperfine interaction and chemical shielding in molecules etc. We are extending this laboratory to include a helium liquifier and a high resolution n.m.r. spectrometer. We shall supplement this laboratory in the next 5-year plan period by a Crystallography Laboratory with the usual X-ray equipments and instruments for growing crystals. In this connection mention may be made of the success obtained in growing sapphire crystals by the Vernouil's Oxy-hydrogen furnace and also of organic crystals from melts. We have also an extensive program to apply the n.m.r. method to study the solid state and to some biophysical problems. Towards the end of the first 5-year plan period we started work on the construction of a 3.2 cm electron spin resonance spectrometer.

The plans of the next 5-year plan period as accepted by the Department of Atomic Energy is given in the Annexure. The Theoretical Physics Section which has been responsible for some very fine original contributions under the leadership of Dr. Manoj Kanti Banerjee has been formed as a separate division under him. The most important equipment asked for his undoubtedly the helium liquifier which will be used both in the n.m.r. section for study of various properties of matter at low temperatures from the n.m.r. angle and also for studies of directional correlation of radiations from oriented nuclei. The high resolution n.m.r. spectro-meter will help us to start a broad program of study of chemical structures.

ANNEXURE 1

Research Program in the next 5-year plan Period

I Theoretical Physics Division
II Nuclear Physics Division

I *Theoretical Physics Division*
Study of nuclear structure,
nucleon-nucleon interaction,
shell structure theory of nucleus
synthesis of nuclear models
nuclear many body problem
nuclear reactions

applications of Researches on
Theoretical Studies of

II *Nuclear Physics Division*

(a) Theoretical Studies
Theoretical studies in nuclear spectrocopy and molecular and chemicals physics.

Nuclear Spectroscopy Section

Spectrometer :—

Sieghbahn-Slätis Absolute determination of internal conversion coefficient and effect of nuclear structure. Study of $n-\gamma$ reaction. Study of coincidence of nuclear radiations.

Scintillation Coincidence Spectrometer :—
Determination of Spectroscopy of short lived isotopes. Study of $\gamma-\gamma$, $\beta-\gamma$ coincidence for nuclear levels short half lives of excited states. Investigations based on Mösschbauer effect. Sum coincidence studies.

Angular Correlation Studies :—
Study of correlation of positron annihilation radiation. Study of the effect of extra nuclear field on $\gamma-\gamma$ correlation. Determination of nuclear gyromagnetic ratios and quadrupole moments in excited states. Multipole mixing ratios.

Coincidence pair β—spectrometer :—
Coincidence studies for nuclear level investigations.

High Resolution β—spectrometer :—
Precision determination of γ—ray energies.

c) *Solid State and Molecular Physics Division*

Magnetic Resonance Laboratory

Wide Line NMR Spectrometer :—

Study of solid Phase transformation of matter, hindered rotation. chemical bonds and imperfections in crystals.

Spin-echo N.M.R. Spectrometer :—

Diffusion and relaxation studies. Study of chemical association ion solvent reaction rate.

Electric Quadrupole Resonance Spectrometer :—

Quadrupole coupling constants and electronic structure of molecules and of solids investigation of imperfections in crystals.

High Resolution N.M.R. Spectrometer :—

Study of chemical shift and *J*-coupling in molecules. Study of Reaction rate and electronic structure of molecules.

Microwave Spectrometer (employing Stark modulation)

Studies of structure and electric moments of complex molecules. Cyclotron resonance determination of conduction band. Fermi surfaces in metals and conductors.

Electron Spin Resonance Spectrometer—at 3.2 cm and 1.25 cm.

Relaxation time at low temperature Free radicals produced by UV radiation, Study of Double resonance and its effect on relaxation times, Spectral analysis from "g" values and hyperfine interactions. Complex formation in liquids. Relaxation time measurements by pulsed techniques at 9KMc/s.

Crystallography Section

Study of crystal structures and structural changes by modern methods. Study of defects and dislocations. Effect of irradiation on solids and macromolecules. Study of free radicals and correlation with degree of radiation damage. Study of colour centers, Study of diffusion phenomenon, intermetallic compounds and semi-conductors. Study of optical, magnetic and electric properties of crystals as function of imperfections. Study of the structures and properties of molecules of biological origin.

ANNEXURE 2

List of important equipments in the Nuclear Physics Division

a) Short lens β-spectrometer :—fabricated
b) Siegbahn-Slätis β-spectrometer :—Imported
c) Gerholm-type coincidence pair spectrometer :—In course of fabrication.
d) γ—γ angular correlation spectrometer :—Assembled

e) $\gamma-\gamma$ angular correlation spectrometer with magnetic field :—In course of fabrication.

f) Well-type γ-spectrometer :—Assembled

g) Purcell and Bloch-type n.m.r. spectrometer—Fabricated

h) Spin-echo n.m.r. spectrometer—fabricated

i) Varian n.m.r. wide line spectrometer—Imported

j) E.Q.R. spectrometer :—In course of fabrication

k) E.Q.R. spin-echo spectrometer :In course of fabrication

l) 3.2 cm E.P.R. spectrometer :—In course of fabrication

m) Stark modulation spectrometer at 1.25 cm—In course of fabrication

n) X-ray diffraction units and necessary cameras :—Imported and fabricated.

THEORETICAL NUCLEAR PHYSICS DIVISION

On December 6, 1960, the Theoretical Physics Section of the Nuclear Physics Division was converted into the Theoretical Nuclear Physics Division. The programme of this division includes studies of all aspects of theoretical nuclear physics. However, at present, the emphasis is only on the low energy side.

A brief account of the activity of the group is already contained in the report of the Nuclear Physics Division. This may be supplemented by mentioning what has happened in the past few months. Miss Dipti Mitra, who was investigating the exchange effects in the inelastic scattering process, has submitted her thesis for the degree of D.Phil. (Science) of the Calcutta University. Mr. Hrishikesh Banerjee, who joined the division after its creation, started the study of excitation of closed shells in nuclei. He has completed the preliminary phase of the studies on dipole excitations. It has been possible to provide an explanation of the splitting of the giant dipole resonance by taking into account the spin exchange part of the nuclear interaction between holes and particles.

Studies have been undertaken in the following fields :

(A) Correlation between the nuclear shell model and the collective models.

(B) The question of continuation of the optical model wave function into the region where the interaction is present.

(C) Deuteron correlation in the independent particle model.

(D) Application of the theory of superconductivity to the problem of nuclear structure.

(E) Electric dipole and octupole excitation of the nucleus.

During the coming five years the activities of the group will be expanded to include studies in the fields of the elementary particles, field theory, dispersion relations, etc.

INSTRUMENTATION SECTION

The instrumentation division apart from developmental and constructional work described below undertakes teaching of students in electronics and instrumental techniques. Work is in progress for the construction of

(a) A fifty channel fast pulse height analyzer.
(b) Transistorized fast scalers.
(c) Transistorized counting systems.

Developmental research on fast scalers using transistors is being continued. A transistorized scale of sixteen thousand, using fast binaries and Dekatrons of half microsecond resolving time, has been constructed. A transistorized portable scintillation counting outfit is almost ready.

A fifteen channel fast pulse height analyser of Johnstone type has been completed.

The triggering delay of sweep circuits has been measured and calculated in connection with the design of fast oscilloscopes. Travel time of electrons, from cathode to deflection plates, of a cathode ray tube, forms an important fraction of the sweep triggering delay in fast oscilloscopes. This has been measured for several cathode ray tube types and lies in the range of seven to ten millimicroseconds. The response time of common types of Germanium diodes has been measured.

A step by step design procedure has been formulated for distributed amplifiers. Several wide band units (Bandwidth 350Mc/s) has been constructed.

High order harmonic generation has interesting possibilities in the design of Radio frequency systems and transmitters. The phenomenon of harmonic generation, however, has been found to be not quite simple. The subject is being studied theoretically and experimentally.

Studies are being made on some of the fundamental properties of semiconducting compounds, such as Bismuth Telluride. Experiment has been set up for measuring

(i) Resistivity variation with temperature
(ii) Hall coefficient and its variation with temperature
(iii) Thermoelectric power

NUCLEAR CHEMISTRY DIVISION

The Chemistry Division with the rest of the Institute received a grant from the D.A.E.. The grant of D.A.E. in 1955 enabled us to expand our activities to a considerable extent. Plans for research and developments were therefore taken up. Objects of the plan were to develop chemical techniques that find applications in nuclear science, work in nuclear chemistry and solve original problems in chemistry with the aid of radioactive tracers. In addition to teaching in post-M.Sc. and M.Sc. classes the following lines of research and developments were therefore thought of :

Section A : Inorganic Chemistry.

1) Original problems of inorganic chemistry with the help of radioactive tracers.

2) Target reactions and separations of active nuclei from the bulk of inactive material.

3) Study of heavy elements.

Section B : Analytical Chemistry.

1) Semi-micro, micro and ultra micro technology with special reference to study of nuclear science.

2) Application of radioactive nuclei to analytical chemistry.

3) Analysis of radioactive minerals and developments of techniques to improve upon the methods of recovery of uranium, thorium, rare-earths and rare elements that find applications in nuclear science.

Section C : Physical Chemistry.

1) Application of radioactive nuclei to the problems of physical chemistry.

2) Study of isotope separation with the help of radioactive indicators.

3) Problems related to radiation chemistry.

Some developments of all these sections require a bigger staff, more money and larger space, at least 2000 sq.ft. in addition to two thousand sq.ft. of floor space at our disposal. The policy followed here is to follow a course of steady progress and a slow continuous expansion.

Research activity of the Nuclear Chemistry Division is mainly concentrated on applications of radioactive nuclei to solutions of problems relating to analytical, inorganic and physical chemistry and development of radio-chemical technology.

Attempts have been made to improve upon radiometric methods of analysis. Silver up to 10^{-6}gm has been estimated with I^{131} as indicator. I^{131} has also been used for micro determination of aluminium, mercury, cadmium, bismuth and palladium. In case of silver and palladium it has been observed that a carrier like Zirconium phosphate under suitable experimental conditions takes up the corresponding iodide quantitatively. This observation has enabled us to estimate tracer amount of (10^{-6}gms) of silver and palladium. The details as regards the mechanism of this uptake requires further investigations. P^{32} has been used to find out a new method for the determination of scandium as pyro-phosphate.

Fluorimetric estimation of low uranium contents in natural substances has been developed. An easy and reliable method for the quantitative isolation of submicro gramme amount of uranium free from quenching material has been devised. It has enabled us to estimate even 10^{-7}gms of uranium present per liter of water in the hot springs of Bakreswar within an accuracy of $\pm$ 5%. Attempts are being made to develop simple and accurate methods for quantitative recovery of tracers of uranium present in natural substances like coal ash etc. which is ultimately estimated by a fluorimeter. It has been found that amongst rare earths, praseodymium and terbium are strongest quanchers of florescence emitted from uranium beads. It has been shown that praseodymium and terbium can be estimated from the study of degree of quenching. Method of determination of rare earth by isotopic dilution has been improved. An easy laboratory method for the decontamination of trace amount of rare earths and thorium from uranium, beryllium, zirconium and aluminium has been developed.

Mechanism of the uptake of tetravalent actinide by bismuth phosphate has been studied. UX_1 was taken as a representative of tetravalent actinides. Distribution studies using bismuth phosphate as a carrier and UX_1 as tracer indicate that Doerner-Hoskins distribution factor (γ) is a constant. But when freshly precipitated bismuth phosphate in contact with the mother liquor contaming the tracer was allowed to equilibrate, the homogeneous distribution factor (D) was not constant. This brings in an indication that freshly precipitated bismuth phosphate differs in morphology from aged samples. The constancy of γ is a strong evidence that freshly precipitated bismuth phosphate takes up tetravalent actinides through mixed crystal formation. Experimental conditions that give a clear cut separation of tetravalent actinides free from any rare earth and yttrium activity have been found out.

Study of mixed crystal formation with radioactive nuclei is under investigation. One of the objectives of the study is to get some insight into the nature of uptake through mixed crystal formation with special reference to uptakes which take place through anamolous mixed crystal formation as defined by Hahn. Uptake of rare earths and thorium by calcium compounds has been the subject matter of study in some details. It has been shown that out of three hydrates of calcium oxalate known to us it is only calcium oxalate dihydrate which takes up rare earths and thorium (UX_1) through mixed crystal formation. Uptake in case of mono and trihydrate takes place through adsorption. It has been shown that in case of UX_1 a very unstable species of the guest takes the role of uptake through mixed crystal formation. In case of calcium sulphate as host it has been found that an unstable form of gypsum (probably rhombic gypsum) is responsible for the uptakes of rare earths and thorium through mixed crystal formation.

The uptake through unstable phases has conveniently been studied with the help of the distribution laws (Berthelot-Nernst and Doerner-Hoskins). The importance of Doerner-Hoskins law in predicting the existence of an unstable phase of either of the host or of the guest has been demonstrated. Role of unstable hosts and unstable guests in this type of uptake may be of great help in expanding our knowledge in this branch of study. The observations in greater details may explain many of the phenomenon as regards the presence of trace constituents in minerals and rocks.

The nature of the guest species when incorporated in a host lattice has also been studied. It has been argued that the incorporation of rare earths and thorium takes place in both of calcium oxalate and calcium sulphate lattices through double salt formation. A strong indirect evidence has been placed in case of calcium sulphate system that the uptake takes place through double salt formation.

(b) The range and other aspects of these two systems have been studied in details.

Application of radioactive nuclei to the study of the chemistry of rare elements has been persued. It has been shown that ferric sulphate takes up scandium (Sc^{46}) through mixed crystal formation. In case of europium and yttrium uptake follows an adsorption isotherm. Violet chromium chloride ($CrCl_3 6H_2O$) and aluminium chloride ($AlCl_3 6H_2O$) takes up scandium through mixed crystal formation which put forth an evidence that probably $ScCl_3\ 6H_2O$ also does exist. Search for getting an evidence on the existence of scandium alum with Sc^{46} has been followed. It has been found that ammonium ferric alum takes up scandium through mixed crystal formation. Inferences can be derived that scandium alum also does exist. Similar study with Tl^{204} and In^{114} isotopes has set for the strong evidence on the existence of ammonium thallic alum and potassium indium alum. Details of this study and isolation of these interesting compounds require further study.

In addition to the extension of the work already started we shall give special stress on the following lines during 1960-65.

(a) Application of mixed crystal formation in problems of separation and analytical chemistry.

(b) Development of technology as regards measuring low level activity.

(c) Radio-activation analysis.

(d) Radiation chemistry.

(e) Target reactions with special reference to high energy projectiles (The successful operation of neutron generator and cyclotron has brought this field within our scope).

BIOPHYSICS DIVISION

The Biophysics Division undertakes teaching work in the M.Sc. and Post M.Sc. levels as well as research activities on the following lines.

1) Investigations with Electron Microscopic and Electron Diffraction techniques.

Under this topic (a) Myco-bacterium leprae obtained from patients under treatment were studied with electron microscope. The cell membrane of the bacillus was found to consist of a double layer. Bacilli were found in three types of association (i) parallel arrangement, (ii) star formation and (iii) connected by a constricted cell wall. Bacilli were present within the sensory end organ and were also found enclosed by the tip of nerve fibrile. Electron micrographs of Virchow cells containing one or more bacilli have been reproduced.

(b) The electron microscopic pictures of hydrolysed and early *E. Coli* Communior phage revealed the presence of internal organizations within their head. The shadow of the tail of phage particles shows periodicity due to distribution of alternate dense and light zones along its length.

The attachment of the bacteriophage to the host cell is random; i.e., they are found to be attached to the host cell by any part of their body. During the multiplication of the bacteriophage particles within the host cell, the bacterial cell matter shows alveolation. Some of the alveoli are found to contain dense bodies of various sizes. The alveolus is almost filled up with the dense structure and is found to lie detached from the host cell matter, as a free phage particle.

(c) Work on DNA molecules were also carried out to report the direct visualization of the intact DNA molecules, the effect of denaturation, and the individual strands of the twin stranded DNA molecules subject to storage in a buffer (*p*H 8.8) at 27°C for over two months with the help of improved electron microscopic method.

Ultraviolet absorption studies were made simultaneously for correlation with the electronmicroscopic results.

2) Tracer and autoradiographic studies with radioisotopes.

a) Beta particle sensitivity of Kodak autoradiographic stripping film, a photographic emulsion widely used in autoradiographic investigations has been studied in terms of the average member of grains developed per incident β-particle.

b) Several physical factors which influence an autoradiographic image produced by radioactive inclusions in the experimental specimens have been correlated through a semiempirical formula. The latter may be used to estimate the concentration of a radioisotope in a specimen from microscopic measurement of grain density.

d) Tracer doses of radioactive phosphorus were administered to patients with chronic myeloid and lymphatic leukemia and the growth of activity in the different fractions of blood and white cell phosphorus was studied. The life span of leukemic leukoytes was deduced from these studies.

3) Radiation Biology

a) Under this topic, the effect of *X*-radiation on the survival of yeast and in *E*-coli dry and wet conditions was studied.

b) And inhibition of colony forming abilities of *X*-irradiated *E*-coil was tested for both in the wet and in the dry condition.

4) Ultracentrifugal Analysis of Biomolecules.

a) Studies were made on undiluted sera of normal adults. Three major components albumin, globulin and fast sedimenting component (presumably a micro globulin) were identified and their respective S_0 values have been reported. The presence of a low density component (presumably a lipid aggregate) has been noted.

The Biophysics Division offers an advance course of teaching in both theoretical and practical Biophysics at the M.Sc. level of Calcutta University. It also offers facilities for Post-M.Sc. research in Biophysics leading to the Doctorate Degree of the same University. Another aspect of the work of the Division is co-operative research with different post-graduate research institutions.

The present fields of research activity of the Division are (1) Electron Microscopic Investigations on Micro-organisms and Macromolecules, (2) Tracer Research in Biology and Medicine, (3) Radiation Biology and (4) Ultracentrifugal Analysis of Biomolecules.

(1) *Electron Microscopic Investigations on Micro-organisms and Macromolecules :*

(a) The electron microscopic examinations of ultrathin sections of *Leishmania donovani*—the Kala-azar parasite revealed that the body of this protozoon is covered by a double walled pellicular membrane. The flagellum consists of ten fibrils which extend inside the body forming the kinetosome. The kinetoplast is a transversely banded structure surrounded by a double walled membrane. Inside the mitochondria small 'cristae' are clearly visible. The porous nature of the inner nuclear membrane and the different stages of mitotic division of this parasite have been studied for the first time.

(b) The electron microscopic study of the morphology of *mycobacterium leprae* revealed that the cell membrane of the bacillus consists of a double layer. Bacilli are found in three types of association *viz.*, (i) parallel arrangement, (ii) star formation and (iii) connected by a constricted cell wall. Bacilli were found to be present (i) within the sensory end organ, (ii) enclosed by a nerve fibril and also (iii) contained within Virchow cells.

(c) The electron microscopic pictures of hydrolysed and early *E. coli Communior phage* revealed the presence of internal organizations within their head. The shadow of the tail of phage particles shows periodicity due to distribution of alternate dense and light zones along its length.

The attachment of the bacteriophage to the host cell is random, i.e., they are found to be attached to the host cell by any part of their body. During the multiplication of the bacteriophage particles within the host cell, the bacterial cell matter shows alveolation. Some of the alveoli are found to contain dense bodies of various sizes. The alveolus is almost filled up with the dense structure and is found to lie detached from the host cell matter, as a free phage particle.

(d) By the high resolution electron microscopic technique individual human haemoglobin molecules have been visualised for the first time. Investigations on this biologically important macromolecules revealed that they were nearly spherical with a circumferential depression at the middle. Spectroscopic absorption studies of the haemoglobin solution were also made simultaneously to supplement the electron microscopic investigations.

(e) The high resolution electron microscopic studies were also made on the DNA molecules extracted from the *bacterium E. coli* and other cells. Evidence of the branching of the molecules and of the changes brought about by denaturation and alteration of *p*H has been obtained. Ultraviolet absorption studies were simultaneously made for correlation with the electron microscopic results.

(f) A technique of estimating dry mass thickness of biological specimens from their electron micrographs was developed. The method was successfully employed to determine the mass thickness of the cell membranes of human erythrocytes, *Bacterium coli* and the flagellate form of *Leishmania donovani* and of the yeast RNP particles.

(2) *Tracer Research in Biology and Medicine :*

(a) Beta particle sensitivity of Kodak autoradiographic stripping film, a photographic emulsion widely used in autoradiographic investigations has been studied in terms of the average number of grains developed per incident β-particle.

(b) Several physical factors which influence an autoradiographic image produced by radioactive inclusions in the experimental specimens have been correlated through a semi-empirical formula. The latter may be used to estimate the concentration of a radio-isotope in a specimen from microscopic measurement of grain density.

(c) After the application of the drug DDS tagged with S^{35} to several leprosy patients, the presence of radio-activity in tissues has been studied with autoradiographic technique. Evidence of the presence of the drugs within sections of blood vessels, peripheral nerves etc., have been obtained. From a counting of grains in the autoradiograph, a comparison could be made between the localisation of the drug in the normal and diseased tissues.

(d) Tracer doses of radioactive phosphorus have been administered to patients with chronic myeloid and lymphatic leukemia and the growth of activity in the different fractions of blood and white cell phosphorus studied. The life-span of leukemic leukocytes has been deduced from these studies.

(3) *Radiation Biology :*

(a) Inhibition of colony formation by the yeast and *E. coli* cells under the action of X-irradiation has been studied both in the dry and wet conditions.

It is found that the 37% survival dose is always less in the wet condition than in the dry state. From a comparison of the relative sensitivities in these two states, the mean diffusion distance of the radicals produced by the ionising rays inside the cell has been calculated.

(b) A new theory has been developed for the dependence of the diffusion distance on the shape of the target molecule. This theory has been applied successfully to explain the radiation inactivation of DNA molecules present in yeast and *E. coli* cells.

(4) *Ultracentrifugal Analysis of Biomolecules :*

(a) Studies were made on undiluted sera of normal adults. Three major components albumin, globulin and fast sedimenting component (presumably a micro globulin) were identified and their respective $S_{20 \cdot w}$ values have been reported. The presence of a low density component (presumably a lipid aggregate) has been noted.

(b) The ribosomes extracted from yeast cells has been analysed; the evidence of the presence of several size groups sedimenting at the rates 6-S, 20-S, 40-S, 60-S, 80-S and 100-S has been obtained. The size distribution of particles sedimenting with the rate 80-S (which are the most prominent) has been studied with electron microscope. It was found that the distribution obeyed Poisson's law with the number average size of 187 ± 46 Å.

(c) DNA molecules extracted from normal and irradiated *E. coli* cells have been analysed with ultracentrifuge, utilising Schliren optics at various concentrations ranging from .003%–.02%. No difference in the sedimentation constants as a result of irradiation in the ranges (18, 30, 40 Kr.) was observed. It was also found that the Schlieren optics can be useful for a concentration as low as .003% provided lower r.p.m. is used (40,000 or lower) in the ultracentrifuge.

WORKSHOP SECTION

The Workshop has altogether got twentyfour machine tools of which four are of a heavy duty type, all of them being effectively utilized. The shop occupies a floor space of about 2000 sq.ft. There is no room for installing any more machine. At least another three thousand square feet of floor space are required, where some new machine tools can be installed and where it is proposed to start a small moulding shop, a machanized carpentry shop and arc welding.

Most of the components of the research machines are constructed in the Institute workshop such as the remodelled cyclotron, the two directional mass spectroscope and the neutron generator. With larger machine tools workshop can help construction of larger research machines. The following are the important jobs done in the Workshop.

1) Vacuum valves and gates, rotary seals.

2) Carriage, supporting the Cyclotron manifolds. Cyclotron Dees and the stems supporting the Dees.
3) Ion sources—for the cyclotron and for the mass spectrometer.
4) Lens system and Target assembly of the neutron generator.
5) Proton resonance probes and nuclear induction heads.
6) Microwave plumbing—waveguides, different types of cavity resonators.
7) Electromagnets.
8) Glass to metal graded seals.
9) X-ray cameras and slits.
10) One angular correlation table with a rotational motion of 1/5 r.p.m.
11) One biological cell disintegrator with an amplitude of 3/4" and 500 vibrations per second.
12) One jig for drilling wooden spheres at different angles for making crystallographic models.
13) Shakers for chemical liquids.

A high speed rotor with 50,000 r.p.m., one ion source, a beta ray pair spectrometer and one magnet are under construction. A machine for winding helical coils of 3/4"O.D. copper tube has been designed and is being constructed.

The number of mechanics, both junior and senior, is twelve. Besides, there is a glass blower, an electrician, a draftsman and a carpenter. There is an apprenticeship training scheme and the number of boys getting such training at present six.

LIBRARY SECTION

No.	*Periodicals available at the Library*
1	Abstracts (compiled by Dept. of Atomic Energy, Bombay)
2	Acta Crystallographica
3	Advances in Biological and Medical Physics
4	Advances in Chemical Physics
5	Advances in Electronics and Electron Physics
6	Advances in Inorganic Chemistry and Radiochemistry
7	Advances in Mass Spectrometry
8	Advances in Physics
9	Advances in Virus Research
10	A. E. I. Engineering News
11	American Journal of Physics
12	American Journal of Science
13	American Scientist
14	Analytical Chemistry
15	Annals of Physics

16 Annales de Radioelectricite
17 Annual Review of Nuclear Sciences
18 Annual Review of Physical Chemistry
19 Archive of Biochemistry & Biophysics
20 Arkiv Fur Physik
21 Aslib Book List
22 Aslib Proceedings
23 Atom
24 Basic Radio Propagation Predictions
25 Bell System Technical Journal
26 Biographical Memories of Fellows of the Royal Society, London
27 Biological Abstracts (Subject Index)
28 Biological Abstracts Section A
29 Biological Abstracts Section B
30 Biological Abstracts Section C
31 Biological Abstracts Section E
32 Biophysics (Russian Translation Journal)
33 Biochemica et Biophysica Acta
34 Bollettino Della Souita Italiana Li Fisica
35 British Book News
36 British Journal of Radiology
37 Brookhaven National Laboratory : Quarterly Progress Report
38 Brown Boveri Review
39 B. T. H. Activities
40 Bulletin of the All India IMDA
41 Bulletin of the American Physical Society
42 Bulletin of the American Meteorological Society
43 Bulletin of the Institute for the Study of the U.S.S.R.
44 Bulletin de L'Academia Polonaise des Sciences
45 Bulletin of the Atomic Scientists
46 Bulletin of the Calcutta Mathematical Society
47 Bulletin of the Department of Anthropology
48 Bulletin of the Institute of Nuclear Science
49 Bulletin of Mathematical Biophysics
50 Bulletinual Instituterlui Politehnic Bucuresti
51 Bulletin of the Netherlands Universities Foundation for International Co-operation
52 Canadian Journal of Chemistry
53 Candian Journal of Physics
54 Canada, Atomic Energy Ltd. : Annual Report
55 Chemical Abstracts
56 Chemical Age

57 Chemical and Engineering News
58 Civil Defence : International Bulletin
59 Comptes Rendus (Paris)
60 Control Engineering
61 Current Documents and Papers on International Problem Relating to Peace
62 Current Radiological Literature
63 Current Science
64 Danske Mathematisk Fysik Meddelelser
65 Danske Mathematisk Fysik Skrifter
66 Doctoral Dissertations accepted by American Universities
67 Die Naturwissenchaften
68 Electrical Engineering
69 Electronics
70 Electronic Application Bulletin
71 Electronic Engineering
72 Electronic Technology
73 Electro Technology
74 Endeavour
75 Experimental Cell Research
76 G. E. C. Atomic Energy Review
77 General Radio Experimenter
78 Helvetica Physica Acta
79 Hewlett-Packard Journal
80 Hilger Journal
81 Hindusthan Year Book & Who's Who
82 Iaslic Bulletin
83 II Nuovo Cimento
84 Index to thesis accepted for Higher Degrees in the Universities of Great Britain & Ireland
85 Indian Ephemeris and Nautical Almanac
86 Indian Journal of Mathematics
87 Indian Journal of Medical Research
88 Indian Journal of Physics
89 India : A Reference Annual
90 Indian Medical Journal
91 Indian Minerals
92 Information Bulletin (German Democratic Republic : Trade Representation)
93 Informations News F. I. D.
94 Instruments and Control Systems
95 International Atomic Energy Agency Bulletin

96 International Electronics
97 International Journal of Applied Radiation & Isotopes
98 International Journal of Molecular Physics
99 International Journal of Radiation Biology
100 International Review of Cytology
101 Ionospheric Data (All India Radio)
102 Ionospheric Data (Radio Resh. Committee)
103 Ionoszfera Jelentes
104 I. R. E. Transactions on Electron Device
105 I. R. E. Transactions on Electronic Computers
106 I. R. E. Transactions on Nuclear Science
107 Jena Review
108 Joint Establishment for Nuclear Energy Research : Annual Report
109 Journal de Physique et la Radium
110 Journal of the American Academy of Arts & Sciences
111 Journal of the American Chemical Society
112 Journal of Applied Physics
113 Journal of the Association of Applied Physics
114 Journal of Biochemical & Biophysical Cytology
115 Journal of Chemical Education
116 Journal of Chemical Physics
117 Journal of Documentation
118 Journal of the Franklin Institute
119 Journal of the Indian Medical Association
120 Journal of Inorganic and Nuclear Chemistry
121 Journal of Mathematical Physics
122 Journal of Mathematics and Physics
123 Journal of Molecular Biology
124 Journal of Molecular Spectroscopy
125 Journal of Nuclear Energy Part A—Reactor Science
126 Journal of Nuclear Energy Part B—Reactor Technology
127 Journal of Nuclear Energy Part C—Plasma Physics, Accelerator and Thermonuclear Research
128 Journal of Nuclear Materials
129 Journal of the Physical Society of Japan
130 Journal of Research of N. B. S. Section A
131 Journal of Research of N. B. S. Section B
132 Journal of Research of N. B. S. Section C
133 Journal of Scientific Instruments
134 Journal of Science and Engineering Research
135 Journal of Ultrastructure Research
136 L'Astronomie

137 Lex Prix Nobel
138 Massachusetts Institute of Technology, Laboratory for Electronics: Quarterly Progress Report
139 Massachusetts Institute of Technology : Laboratory for Nuclear Science : Progress Report
140 Massachusetts Institute of Technology : Solid State and Molecular Theory Group : Quarterly Progress Report
141 Methods Biochemical Analysis
142 Methods in Medical Research
143 Metropolitan—Vickers Garette
144 National Bureau of Standards : Technical News Bulletin
145 Nature
146 Nautical Almanac and Astronomical Ephemeris
147 New Scientist
148 No More Hirosimas
149 Notiziario (Comitato Nazionale per be Ricerche Nucleari)
150 Nuclear Data Sheets
151 Nuclear Engineering
152 Nuclear Fusion
153 Nuclear Instruments & Methods
154 Nuclear Physics
155 Nuclear Power
156 Nuclear Science Abstracts
157 Nuclear Science and Engineering
158 Nuclear Theory Index Cards
159 Nucleonics
160 Nukleonik
161 Observatory
162 ONGC News Letter
163 Philips Industrial and Electronic Bulletin
164 Philips Matronics
165 Philips Research Reports
166 Philips Serving Science, and Industry
167 Philips Technical Review
168 Philips Telecommunication Review
169 Philosophical Magazine
170 Physica
171 Physical Review
172 Physical Reivew Letters
173 Physics & Chemistry of Solids: An International Journal
174 Physics of Fluids
175 Physics in Medicine and Biology

176 Physics To-day
177 Plastics To-day
178 Platinum Metals Review
179 Proceedings of the Institution of Electrical Engineers—Sec. B
180 Proceedings of the Institution of Electrical Engineers—Sec. C
181 Proceedings of the I. R. E.
182 Proceedings of the National Academy of Science U.S.A.
183 Proceedings of the National Institute of Sciences for India—Part A
184 Proceedings of the National Institute of Sciences of India—Part B
185 Proceedings of the Physical Society of London
186 Proceedings of the Royal Society, London Section A
187 Proceedings of the Royal Society, London Section B
188 Proceedings of the Society of Experimental Biology and Medicine
189 Progress in Biophysics & Biophysical Chemistry
190 Progress in Metal Physics
191 Progress in Nuclear Physics
192 Progress in Elementary Particles & Cosmic Ray Physics
193 Progress in Low Temperature Physics
194 Progress in Semi-Conductors
195 Progress of Theoretical Physics
196 Progress of Theoretical Physics: Quarterly Supplement
197 Publications of the Astronomical Society of the Pacific
198 Radiation Research
199 Reports on Progress in Physics
200 Reports of the Chemical Society, London
201 Research and Industry
202 Report of the Ionosphere & Research in Japan
203 Review of Documentation
204 Reviews of Modern Physics
205 Review of Scientific Instruments
206 Rochester Conference on High Energy Nuclear Physics
207 Rockfeller Institute Quarterly
208 Royal Society Year Book
209 School Science Review
210 Science
211 Science Abstract Section A—Physics Abstracts
212 Science Abstracts Section B—Electrical Engineering Abstracts
213 Science and Culture
214 Science et Vie
215 Scientific American
216 Simens Review
217 Sky and Telescope

218 Solid State Physics : Advances in Research and Application
219 Soviet Physics (JETP)
220 Soviet Physics (Technical Physics)
221 Soviet Physics (Doklady)
222 Soviet Physics (USPEKHI)
223 Study Abroad
224 Symposium on Electron Microscopy
225 Technology Review
216 Time
227 Times Science Review
228 Transactions of the American Nuclear Society
229 Title Service (Compiled) by Dept. of Atomic Energy. Bombay
230 Transactions of the Faraday Society
231 Transactions of the National Institute of Science of India
232 U. K. Atomic Energy Authority : Annual Report
233 UNESCO Bulletin for Libraries
234 U. S. Atomic Energy Commission : Semi Annual Report
235 Vacuum
236 Wireless World
237 Zeitschrift fur Naturforschung : Section A
238 Zeitschrift fur Naturforschung : Section B
239 Zeitschrift fur Physik

CONSTITUTION AND RULES OF THE SAHA INSTITUTE OF NUCLEAR PHYSICS, CALCUTTA, AS FRAMED IN 1951 AND CHANGES MADE SUBSE UEN LY. (ACCEPTED BY SENATE FIRST ON 12-5-51 AND AMENDED FROM TIME TO TIME BY THE SENATE OF THE CALCUTTA UNIVERSITY UP TO 19-9-1959)

Name

1. The name of the Institute shall be "Saha Institute of Nuclear Physics" hereinafter called the "Institute" (C.U. Senate dated 21-7-1958).

Object

2. The Institute shall provide facilities for and offer courses of instruction in both Elementary and Advanced Nuclear Physics to students appearing for the M.Sc. degree in Physics. It will also offer facilities to post M.Sc. students for research and training, both theoretical and technical, including training in atomic energy, nuclear science and biophysics and carry on scientific and technical investigations and other experiments for the purpose aforesaid. (C.U. Senate dated 12-5-1951).

Relationship with the Calcutta University and the Government of India

3. Subject to the Institute being administered in accordance with the provisions of this Scheme, it will provide for post-graduate teaching and research as an integral part of the University. Not more than one third of the students shall, ordinarily, be from among persons belonging to West Bengal, the rest being from other States. (C.U. Senate dated 22-3-1958).

Governing Body

4. There shall be a Governing Body for the Institute composed of the following members :—

(i) The Vice-Chancellor of the Calcutta University, Chairman (Ex-officio).
(C.U. Senate dated 12-5-1951).

(ii) The Director, Saha Institute of Nuclear Physics.
(C.U. Senate dated 22-3-1958).

(iii) One Professor or Emeritus Professor of Physics or Applied Physics of the Calcutta University (to be

nominated by the Syndicate of the Calcutta University for a period of three years).
(C. U. Senate dated 19. 9. 1959)

(iv) One of the Donors to the Saha Institute of Nuclear Physics (to be nominated by the Syndicate of the Calcutta University for a period of three years) (C.U. Senate dated 12-5-1951).

(v) Two representatives of the Department of Atomic Energy of the Government of India.
(C.U. Senate dated 21-7-1958 and 19-9-1959).

(vi) One representative of the Ministry of Education, Government of India (to be nominated for a period of three years).
(C.U. Senate at 12-5-1951).

(vii) The Accountant General. Government of West Bengal (Ex-officio).
(C.U. Senate dated 12-5-1951).

(viii) One Science representative of the Inter-University Board of India (to be nominated for a period of three years).
(C.U. Senate dated 12-5-1951).

(ix) One representative of the Ministry of Finance of the Government of India.
(C.U. Senate dated 21-7-1958).

(x) The Palit Professor of Physics of the Calcutta University (if he is not a member otherwise), as long as his services and those of his Staff and facilities offered by the Palit Governing Body are permitted by the Calcutta University to be utilised by the Institute.
(C.U. Senate dated 22-3-1958).

Proceedings of the Governing Body

5. The Governing Body shall keep an intimate touch with the Calcutta University as also with the Government of India and will report to them all its proceedings and decisions. (C.U. Senate dated 12-5-1951).

Powers of the Governining Body

6. The Governing Body shall have full powers of administration, finance and appointments, except in the case of Director, the manner of whose appointment is provided

in clause 9. Posts maintained out of any Trust Fund will be made subject to the rules of the respective Trust by the appropriate body con-cerned. (C.U. Senate dated 22-3-1958).

Standing Orders

7. The Governing Body shall have the power to make standing orders regulating its own procedure, the procedure of Committees appointed by it and the duties of the officers, teachers, and other employees of the Institute.
(C.U. Senate dated 12-5-1951).

Director

8. There shall be a Director of the Institute who will be in charge of the Institute and will be responsible for the admission of the students into the Institute, but the number of students to be admitted in each session should be determined by the Governing Body.
(C.U. Senate dated 19-9-1959).

Appointment of the Director

9. The Director shall be appointed by the Governing Body of the Institute, subject to the approval of the Government of India in the Department of Atomic Energy, on the recommendation of a Selection Committee of five to be composed as follows :—

(a) The Vice-Chancellor of the Calcutta University —Chairman.
(b) Two experts to be nominated by the Department of Atomic Energy of the Government of India.
(c) One expert to be nominated by the Calcutta University.
(d) One expert to be nominated by the Governing Body of the Saha Institute of Nuclear Physics.

N.B. The emoluments, terms and conditions of service of the Director to be fixed by the Governing Body of the Institute and approved by the Department of Atomic Energy of the Government of India.
(C.U. Senate dated 19-9-1959).

Appointment of Officiating or Temporary Director

10. In case of a temporary vacancy in the post of the Director, the Vice-Chancellor shall nominate one of the senior officers of the Saha Institute of Nuclear Physics to

be the officiating Director for a period not exceeding three months and report the matter to the Governing Body at a meeting to be held within three months for confirmation or extension of the period if the vacancy is likely to extend over three months.

In the event of a permanent vacancy, and pending the appointment of the Director under Clause 9, the Vice-Chancellor may nominate one of the senior officers of the Institute to act as the Officiating Director and report the same to the Governing Body and take action for the appointment of a permanent Director under Clause 9. (C.U. Senate dated 22-3-1958).

Existing Staff of the Institute of Nuclear Physics

11. The existing employees of the Institute will continue in their service, and all new and subsequent appointments will be made by the Governing Body.
(C.U. Senate dated 12-5-1951).

Delegation of Power to the Director

12. The Governing Body may delegate such of its powers to the Director as it may think will be in the interests of the Institute.

(C.U. Senate dated 22-3-1958).

13. (i) The Governing Body shall be reconstituted every three years provided that members nominated or elected shall continue as such after the expiry of the term until fresh nominations are made by the bodies concerned.

(C.U. Senate dated 22-3-1958).

(ii) If any casual vacancy is caused in the Governing Body by death, resignation or for any other cause, the body concerned shall be requested to nominate a new member for the rest of the period of three years for which the original members had been nominated.
(C.U. Senate dated 22-3-1958).

Meeting of the Governing Body

14. (a) Meetings of the Governing Body shall be held at least twice a year as such time and as such place as may be fixed by the Chairman at the request of the Director or at the discretion of the Chairman.
(C.U. Senate dated 12-5-1951).

(b) *Budget :* At an ordinary meeting to be held in the first quarter of the calendar year the annual budget of the Institute for the next financial year shall be passed. The financial year will be from the 1st April of a year to the 31st March of the next year.

(C.U. Senate dated 22-3-1958).

(c) *Notice of Meeting :* Fourteen clear days' notice of any ordinary meeting of the Governing Body specifying place, date and hour of the meeting and the general nature of the business to be transacted therein shall be given to every member of the Governing Body by notice sent by post, provided that accidental omission to give such notice to any of the members shall not invalidate any resolution passed at such meeting.

(C.U. Senate dated 12-5-1951).

(d) *Quorum :* In each meeting of the Governing Body five members shall form a quorum.

(C.U. Senate dated 22-3-1958).

(e) *Vote :* Every member of the Governing Body shall have one vote. In the event of equality of votes at any meeting the Chairman shall have a second or casting vote.

(C.U. Senate dated 12-5-1951).

(f) *Requisition meeting :* Upon a requisition in writing made by any three members of the Governing Body, the Chairman shall call a special meeting.

(C.U. Senate dated 12-5-1951).

STAFF LIST

Prof. B. D. Nagchaudhuri—*Director*
Shri H. K. Basu—*Registrar*
Shri G. N. Sarkar—*Workshop Superintendent*
Sm. P. Hosain—*Librarian*
Shri A. K. Chatterjee—*S.T.A.* (*Library*)
Shri N. K. Moorthy—*Accountant*

Shri K. S. Manian
Shri A. N. Banerjea
Shri B. K. Chakravarty
} *Administration Section*

Shri O. N. Kaul
Shri S. C. Chaudhuri
Shri S. C. Majumdar
} *Director's Research Section*

Prof. D. N. Kundu—*Head, Accelerator Division*

Shri A. P. Patro
Shri S. K. Mukherjee
Shri M. N. Viswesvariah
Dr. A. Chatterjee
Shri B. Basu
Shri S. B. Karmohapatro
Shri P. K. Dutta
Shri M. Rama Rao
Shri S. K. Majumdar
Shri A. N. Saxena
Shri B. B. Baliga
Sm. Bani Sen
Shri D. N. Basu Mallick
Shri N. K. Mazumdar
Shri A. V. Narasinham

Prof. A. K. Saha—*Head, Nuclear Physics Division*

Dr. N. N. Saha
Dr. R. N. Roy
Dr. Monisha Bose
Dr. D. K. Roy
Shri S. K. Ghosh Roy
Sm. Tuhina Ray
Shri P. N. Mukherjee
Sm. Ila Dutta
Shri S. K. Sinha
Shri S. Shastri
Shri A. K. Roy Chaudhuri

Prof. M. K. Banerjee—*Head, Theoretical Physics Division*

Dr. M. K. Pal
Shri S. Mukherjee
Shri A. K. Bhattacharyya
Sm. Dipti Mitra
Shri Hrishikesh Banerjee
Shri S. N. Tewari
Shri P. Das Gupta
Shri Anand Kumar
Shri Amit Goswami

Dr. S. Chatterjee—*Head, Post M.Sc. Teaching Section*

Shri R. L. Bhattacharyya
Dr. R. K. Das
Shri S. Das

Shri B. M. Banerjee—*Head, Instrumentation Seciton*

Dr. J. K. Das Verma
Dr. S. C. Nath
Shri K. S. Patel
Sm. Sneha Chowdhuri

Shri B. C. Purkayastha—*Head Nuclear Chemistry Division*

Shri S. N. Bhattacharyya
Shri H. B. Das
Shri K. N. Dutta
Sm. Shymali Sen
Shri D. K. Bhattacharjee

Prof. N. N. Das Gupta—*Head, Biophysics Division*

Dr. B. B. Sen
Shri M. L. De
Dr. R. K. Poddar
Shri C. K. Pyne
Sm. J. Chakravorti
Shri P. Sadhukhan
Sm. Sheela Mukherji
Sm. Anjali Mukherji

Sm. Jayanti Lahiri, D.A.E. Fellow (Nuclear Physics Division)

Sm. Amala Chatterji
Shri D. N. Misra
Shri A. L. Bhattacharya
Sm. Madhuri Sarkar
} *R. T. Scholar Biophysics Division*

Shri P. K Ganguly, C.S.I.R. Scholar (Biophysics Division)
Shri S. B. Bhattacharyya, C.S.I.R. Scholar (Biophysics Division)
Dr. Fazle Hosain, National Institute Research Fellow

APPENDIX I

SYLLABUS OF THE POST-M.Sc. ASSOCIATESHIP COURSE

1. *Course of Studies :* There will be five basic courses, to be taken by all students. In addition, each student will have to select one of the four groups of elective courses.

The basic courses are as follows :—

(i) *Nuclear Physics I :* A phenomenological study of the properties of nuclei, radioactivity, nuclear fission, nuclear structure and nuclear reaction and the instruments and techniques.

(ii) *Quantum Mechanics I :* A complete study of the non-relativistic quantum mechanics and Dirac's theory of electron, emphasizing the applications, such as the use of perturbation theory, two body problem, collision problem etc.

(iii) *Basic Mathematics :* Elements of Vector and Tensor Analysis. Curvilinear coordinates. Ordinary differential equation. Theory of Complex variables and Complex integration. Theory of orthogonal functions. Partial differential equations. Linear algebraic equations. Eigen values and Eigen functions. Elementary theory of groups. Elements of statistics and theory of errors. Calculus of finite differences.

(iv) *Classical Mechanics :* (a) Calculus of variations, (b) Lagrange's Principle, (c) Lagrange Equations of Dynamics, (d) Hamiltonian and Hamilton's canonical Equations, (e) Contact transformation and Hamilton-Jacobi differential equations, angular momentum, top motion, transformation theory, (f) Poisson-bracket, (g) Lagrange and Hamiltonian formulation for a continuous system of field.

(v) *Slow neutron physics :* Slow down and diffusion of neutron, coherent scattering and diffraction phenomena, magnetic scattering and polarization phenomena.

(vi) *Radiation hazard and Health Physics :* (a) Units of radiation dosage and methods of measuring dosage, (b) Biological effect of radiation, (c) Common radiation hazards, (d) Occupational safe dosage rate, maximum permissible dosage and lethal dose, (e) Personnel monitoring.

The elective groups will be taught at a higher standard and generally after the completion of basic courses the general syallbi will depend on the teachers who will take up classes and will announce the details of the courses. Only the names of the subjects are given below :

The elective groups :

I. Electronics, Nuclear Chemistry, Nuclear Spectroscopy, Accelerators, Advanced Experiments on Nuclear Physics*, Nuclear Physics II.

II. Electronics, Uses of X-ray, N. M. R., Microwave, etc., in the study of solids and molecules, Advanced experiments on Solid State and Molecular Physics, Solid State and Molecular Physics.

III. (A) Advanced Quatum Mechanics. (B) Selected topics in theoretical physics and (C) Nuclear Physics.

IV. (A) Advanced Quantum Mechanics, (B) Selected topics in theoretical Physics and (C) Solid State and Molecular Physics.

Laboratory work : Basic experiments :

(1) Determination of absorption coefficient of gamma rays from Co-60 in Lead.
(2) Measurement of Gamma rays energy by scintillation spectrometer.
(3) Determination of range and end energy of beta rays in Aluminium.
(4) Measurement of alpha ray energy of Thorium stars in nuclear emulsion.
(5) Determination of the half life of some radioactive source.
(6) Mean life of neutron in water.

Advanced experiments :

(1) To study the Beta spectrum of Co^{60} and to determine the end energy by drawing the Kurie Plot.
(2) To determine the Relative absorption of fast neutron from Ra-Be source in plastic and iron.
(3) To determine the photofraction for gamma rays of different energies.
(4) To produce N^{12} by the reaction C^{13} (d,n)N^{13} with the help of cyclotron and to determine the half life of N^{13}.
(5) To determine the back-scattering co-efficient of Lead, Aluminium etc., for beta rays from Pm^{147}.
(6) Association with research or development work of any one group of the Institute.

Appendix 2

List of Receipients of D.Phil. (Science) degree :—

1. M. K. Banerjee
2. S. Biswas
3. S. Chatterjee
4. S. N. Chatterjee
5. R. K. Das
6. T. P. Das
7. S. Dhar
8. S. K. Ghosh
9. A. Guha
10. F. Hosain
11. S. Nath
12. M. K. Pal
13. R. K. Poddar
14. D. K. Roy
15. R. N. Roy
16. S. K. Sen
17. J. K. D. Verma

List of Receipients of Premchand Roychand Studentship

1. S. Chatterjee (1951)
2. M. L. De (1953)
3. S. Dhar (1953)
4. S. B. Karmahapatro (1955)
5. M. K. Pal (1957)
6. D. K. Roy (1955)

LIST OF A.S.I.N.P.

1954

1. Sm. Uma Banerjee
2. Shri Rangalal Bhattacharyya
3. Shri Anil Chandra Chatterjee
4. Shri P. N. Ganju
5. Shri S. K. Ghosh Roy
6. Sm. V. M. Menon
7. Shri R. K. Poddar
8. Shri P. K. S. Raja
9. Shri D. K. Roy

1955

1. Shri B. B. Baliga
2. Shri Udaysankar Ghosh
3. Shri Fazle Hosain
4. Shri P. Mahapatra
5. Shri M. K. Pal
6. Sm. Padala Parvati
7. Shri V. R. Paivernekar
8. Shri M. Rama Rao
9. Shri K. Nageswara Rao
10. Shri B. P. Rastogi
11. Shri A. N. Saxena
12. Shri B. N. Srivastava

1956

1. Shri P. N. Mukherjee
2. Shri M. N. Viswesvariah
3. Shri A. K. Sen Gupta
4. Shri P. V. Sastry
5. Shri E. V. Krishnamurty
6. Shri B. K. Chatterjee
7. Shri S. Mukherjee
8. Sm. Bani Sen
9. Shri S. K. Mazumdar
10. Shri P. J. Ouseph
11. Shri R. N. Indra
12. Shri K. S. Patel
13. Shri M. K. Chakravarty
14. Shri R. K. Banerjee
15. Shri B. N. Paria

1957

1. Shri G. K. Mehta
2. Shri S. N. Srivastava
3. Shri Arunaditya Mukherjee
4. Sm. Ila Dutta
5. Shri M. A. Nagarajan
6. Shri N. C. Rastogi
7. Sm. Arundhati Ghosh
8. Shri B. Dutta Roy
9. Shri M. G. Shahni
10. Shri A. K. Bhattacharyya

11. Shri S. K. Srivastava
12. Shri M. R. Setty
13. Shri D. Basu

1958

1. Shri D. K. Bhadra
2. Sm. J. Lahiri
3. Sm. D. Mitra
4. Sm. G. C. Pramila
5. Shri V. S. Rao
6. Shri B. S. Rao
7. Shri S. K. Sinha

1959

1. Shri S. C. Nayar
2. Shri K. Rama Reddy
3. Sm. Sunanda Dutta
4. Shri M. Divadeenam
5. Shri S. K. Shah
6. Shri Ashish Palit
7. Shri R. B. Ram Chander
8. Shri B. R. Avasthi
9. Shri A. K. Bhattacharyya
10. Shri A. K. Mitra
11. Sm. Krishna Pal
12. Shri H. N. Bhattacharyya

1960

1. Shri A. K. Bhattacharyya
2. Shri R. Muthukrishnan
3. Shri Nityaranjan Nath
4. Shri P. N. Tandon
5. Shri H. Banerjee
6. Shri Rohitashva
7. Shri V. P. Gupta
8. Shri N. Dwarkanath
9. Shri Ashok Jain
10. Shri V. Shadagopan
11. Shri A. V. Narasimhan
12. Shri A. Srinivas Rao

1961

1. Shri C. K. Mazumdar
2. Shri S. C. Moitra
3. Shri Amit Goswami
4. Shri K. J. Cleetus
5. Shri B. I. Seth
6. Shri Anand Kumar
7. Shri P. Das Gupta
8. Shri S. N. Tewari
9. Shri S. N. Mukherjee
10. Shri A. K. Tamuli
11. Shri Hasaram Bhakru
12. Shri Sitaram Shastry

Appendix 3

List of Papers Published from the Institute

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9. Das, T. P., Saha, A. K. and Roy, D. K.: Quantum-Mechanical Analysis of Spin-Echo Phenomena. (*Proc. Roy. Soc., A.*, **227**, 407, 1955).
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14. Karmahapatro, S. B.: A Low Resolution Mass Spectrometer. (*Proc. Indian Science Congress, Agra*, 1955).
15. Poddar, R. K.: On the Quantitative Relation Between Isotopic Beta Radiation and its Photographic Response. (*Ind. J. Phys.*, **29**, 189, 1955).
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